PLEA STGO 2022

November 22 - 25, 2022

WILL CITIES SURVIVE?

The future of sustainable buildings and urbanism in the age of emergency.

BOOK OF PROCEEDINGS VOL 2 ONSITE SESSIONS

PLEA STGO 2022: WILL CITIES SURVIVE?

Conference Chairman
Waldo Bustamante

Co-Chair
Felipe Encinas
Magdalena Vicuña

Editorial Team
Waldo Bustamante
Mariana Andrade
Pablo Ortiz E.

Hosting Organization
Pontificia Universidad Católica de Chile
Avenida Libertador Bernardo O'higgins 340

Graphic Design Project
Nicolás Gutierrez

November 22 - 25, 2022
Santiago de Chile

ISBN
978-956-14-3069-3

PLEA STGO 2022

November 22 - 25, 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

ORGANISED BY

Passive and Low Energy Architecture (PLEA) — plea-arch.org

Centro de Desarrollo Urbano Sustentable — cedeus.cl

Facultad de Arquiectura, Diseño y Estudios Urbanos UC — fadeu.uc.cl

Universidad de Concepción — udec.cl

Agencia Nacional de Investigación y Desarrollo — anid.cl

ABOUT

PLEA Association is an organization engaged in a worldwide discourse on sustainable architecture and urban design through annual international conferences, workshops and publications. It has created a community of several thousand professionals, academics and students from over 40 countries. Participation in PLEA activities is open to all whose work deals with architecture and the built environment, who share our objectives and who attend PLEA events.

PLEA stands for "Passive and Low Energy Architecture", a commitment to the development, documentation and diffusion of the principles of bioclimatic design and the application of natural and innovative techniques for sustainable architecture and urban design.

PLEA serves as an open, international, interdisciplinary forum to promote high quality research, practice and education in environmentally sustainable design.

PLEA is an autonomous, non-profit association of individuals sharing the art, science, planning and design of the built environment.

PLEA pursues its objectives through international conferences and workshops; expert group meetings and consultancies; scientific and technical publications; and architectural competitions and exhibitions.

Since 1982 PLEA has been organizing highly ranked conferences that attract both academia and practicing architects. Past Conferences have taken place in the United States, Europe, South America, Asia, Africa and Australia.

After almost a decade the PLEA conference is coming back to South America, Santiago (Chile), to be organized by the Pontifical Catholic University of Chile (PUC). Inevitably, the theme of PLEA 2022 is inspired by the current pandemic which has put the whole world on alert and makes us rethink our built environment in terms of health and safety. Whereas due to its current social unrest and significant social divide Santiago and South America in general provides a great ground to talk about inequalities and revisit social movements, that spanned around the globe from Lebanon, France to Chile and other countries just before the pandemic hit.

The aim of the PLEA 2022 is to question the whole idea of a city, the way we inhabit and use them generating the definitive inflection point that a sustainable city requires.

GOAL AND THEME

PLEA STGO 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

For decades, the climate crisis has been demanding our action and commitment. Numerous efforts to reach an international consensus via climate summits, such as COP25, and Paris Agreement have not had any expected results yet. However, even though the COVID-19 pandemic has intensified the sense of urgency, many talks about climate change were put on hold during 2020, when the new virus put the world on alert.

In no time it has become a global issue and provoked various reactions from political leaders around the world—from absolute denial to the harshest restrictions—adjusting and learning in the process by trial and error.

This process has not been easy as COVID-19 highlighted critical deficiencies in our built environment and urban design. Even though infections battered affluent areas too, the pandemic hit the hardest when the virus reached sectors with high rates of poverty. Dense neighborhoods and overcrowded buildings could facilitate the rapid spread of infections due to the difficulty of generating social distancing and the application of extensive quarantines.

Yet, various changes have been adopted rapidly. Hygiene protocols, wearing masks, social distancing and other strategies has become part of our ordinary life. On top of that, the use of public spaces, streets, parks, homes and all buildings had to be adjusted to control the spread of the virus transforming our habits and conception of them. Numerous studies showed great variations in the use of transportation during the pandemic too. But the questions are: are those changes here to stay? What does the future hold for our built environments?

Some even go as far as to question: Will cities survive? While many intellectuals and academics call for the end of cities (at least as we know them), some stakeholders urge to return to normality, or so-called status quo.

Is this the last opportunity to effectively build a healthy, livable and equitable city? It is clear that cities can no longer be conceived as before and it is time to question the way we inhabit and use them. What are the standards, mechanisms and criteria to define a sustainable city and building? Do they respond to the problems and deficiencies in the age of emergency? History shows us how cities reacted to and changed after health crises similar to COVID-19; this is the time to question everything around us and strive for environmentally sustainable and socially just cities.

The aim of PLEA 2022 is to be a relevant part of the discussion and bring about proposals to the developing and developed world. It is a great chance to talk about the changes that affected cities around the globe since the start of the pandemic and bring the scientific knowledge generated in this short time to the discussion.

Social inequality should also be a part of the debate as both health and climate emergencies may further increase the injustice and, at the same time, the inequality may make such crises worse. Latin America, as the most unequal region, and Chilean case might serve as a great example of such issues and could become a source of inspiration to find the definitive inflection point that a truly sustainable city requires.

WELCOME TO SANTIAGO DE CHILE

Dynamic and cosmopolitan Santiago is a vital and versatile city. Home to many events showcasing the very best of Chilean culture, it also hosts superb international festivals of sound, flavor and color. The Chilean capital breathes new life into all its visitors!

The city's diversity shines through in its many contrasting neighborhoods. Set out to explore the city streets and you'll discover beautiful and original art galleries, design shops and handicraft markets, as well as a great selection of restaurants, bars and cafes. Night owls can enjoy a taste of lively Latino nightlife in hip Bellavista!

Visit downtown Santiago to get a real feel for the city. Learn more about the country in its many fine museums, or wander around the famous Central Market – a gourmet's delight.

Fans of the great outdoors can head for the hills that surround the city and marvel at panoramic views of Santiago with the magnificent Andes as a backdrop. Take the opportunity to grab a picnic and visit one of the city´s many parks.

In Chile there are places that have not seen a drop of rain in decades, while there are others where the rain brings out the green in the millenial forests.

This diversity captivates and surprises its visitors. Because, as a consequence of its geography, Chile has all the climates of the planet and the four seasons are well differentiated. The warmest season is between October and April and the coldest, from May to September.
The temperature in Chile drops down as you travel south. In the north, the heat of the day remains during the day while the nights are quite cold. The central area has more of a Mediterranean climate and the south has lower temperatures and recurring rainfall throughout the year.

The conference will be held at the Centro de Extensión de la Pontificia Universidad Católica de Chile, located at Avenida Libertador Bernardo O'Higgins 390, Santiago, Metropolitan Region. Universidad Católica subway station, Line 1

The Center is located in the center of the city of Santiago, with excellent connectivity to the rest of the city and the most characteristic neighborhoods of the capital, either through the Metro network (Line 1) or other means of public transport such as Transantiago (Santiago's public bus network).

To make your hotel reservations, we recommend looking in the Providencia or Las Condes districts, close to Metro Line 1. We also have some suggestions for accommodation close to the conference venue.

WILL CITIES SURVIVE?: TRACKS

1. Sustainable Urban Development
– Regenerative Design for Healthy and Resilient Cities
– Sustainable Communities, Culture and Society
– Low Carbon Neutral Neighbourhoods, Districts and Cities
– Urban Climate and Outdoor Comfort
– Green Infrastructure
– Urban Design and Adaptation to Climate Change

2. Sustainable Architectural Design
– Resources and Passive Strategies
– Regenerative Design
– Energy Efficient Buildings
– Net-zero Energy and Carbon-neutrality in New and Existing Buildings
– Vernacular and Heritage Retrofit
– Building Design and Adaptation to Climate Change

3. Architecture for Health and Well-being
– Comfort, IAQ & Delight
– Thermal Comfort in Extreme Climates
– IAQ and Health in Times of Covid-19
– Comfort in Public Spaces

4. Sustainable Buildings and Technology
– Renewable Energy Technologies
– Energy Efficient Heating and Cooling Systems
– Low Embodied Carbon Materials
– Circular Economy
– Nature-based Material Solutions
– Water Resource Management and Efficiency

5. Analysis and Methods
– Simulation and Design Tools
– Building Performance Evaluation
– Surveying and Monitoring Methods
– User-building Interaction and Post-occupancy Evaluation

6. Education and Training
– Architectural Training for Sustainability & Research
– Professional Development
– Sustainable Initiatives and Environmental Activism
– Methods and Educational Practices
– Strategies and Tools

7. Challenges for Developing countries
– Energy poverty
– The Informal City
– Climate Change Adaptation
– Affordable Construction and Architecture Strategies
– Urban Planning and Urban Design Policies for Sustainable Development
– Housing and urban Vulnerability

CRISTINA DORADOR

Keynote speaker
CHILE

Between July 2022 and July 2022 she served as a member of Chile's constitutional convention. She is currently back to teaching at the Universidad de Antofagasta.

Chilean scientist, doctor and politician who conducts research in microbiology, microbial ecology, limnology and geomicrobiology. She is also an associate professor in the Department of Biotechnology of the Faculty of Marine Sciences and Natural Resources at the University of Antofagasta. From July 2021 to July 2022 she served as a member of the Constitutional Convention representing District No. 3, which represents the Antofagasta Region.

Her achievements include the coordination in Chile of the Extreme Environments Network for the study of ecosystems in the geographic extremes of Chile and having developed biotechnological tools to value the unique properties of some altiplanic

microbial communities such as resistance to ultraviolet radiation to elaborate cosmetic creams, joining the field of cosmetic Biotechnology. She has also led application projects such as the development of textile material using the photoprotective properties of altiplanic bacteria.

She was a member of the transition council of the National Commission for Scientific and Technological Research in 2019 that gave rise to the National Agency for Research and Development of Chile, and has been recognized nationally and internationally as one of the most relevant researchers in Chile.

ADRIANA ALLEN

Keynote Speaker
ARGENTINA

Professor of Urban Sustainability and Development Planning at The Bartlett Development Planning Unit (DPU), University College London and President of Habitat International Coalition (HIC).

Adriana has over 30 years of international experience in research, graduate teaching, advocacy and consulting in over 25 countries in the global South, she has specialized in the fields of development planning, socio-environmental justice and feminist political ecology.

She is currently President of Habitat International Coalition (HIC), as well as a regular advisor to UN agencies, positions from which she is actively engaged in promoting urban justice through advocacy and policy evidence, social learning and fostering international collaboration both within UCL and globally.Through the lens of risk, water and sanitation, land and housing, food and health, her work examines the interface between everyday city-making practices and planned interventions and their capacity to generate transformative social and environmental relations.

Adopting a feminist political ecology perspective, her work combines qualitative, digital/mapping, and visual research methods to decolonize urban planning practices and elucidate the "cracks" in which transformative planning can be reinvented, nurtured, and pursued. Her work focuses on three interrelated themes: urban justice, everyday city-making, and transformative planning.
Over the years, she has worked at the interface between insurgent practices and planned interventions and their capacity to generate socio-environmentally just cities.

This work stems from her engagement with the analysis of governance approaches to address structural deficits at the interface between "policy-driven" and "needs-driven" approaches and emerging improvements at scale – in water and sanitation, as well as in other areas such as food security, land, housing and health. Since 2008, she has explored the intersection of urbanization and climate change, with a particular focus on the generation and distribution of risks, vulnerabilities and capacities for action in southern cities. A third strand of her research focuses on urban planning as a field of networked governance and pedagogical strategies to decolonize planning education and shape pathways for urban equality.

PLEA STGO 2022
PLEA STGO 2022: WILL CITIES SURVIVE?

ANACLAUDIA ROSSBACH

Keynote speaker
BRAZIL

Economist with a track record of more than 20 years working on the issues of slums, social housing and urban policy.

She is currently Director for Latin America and the Caribbean at the Lincoln Land Institute of Policy. She also serves as a member of the editorial board of Vivienda magazine of INFONAVIT – México. And previously she worked as a consultant on housing and urban development issues for the IDB (Inter-American Development Bank).

She worked in the Prefecture of São Paulo, supporting the Brazilian Ministry of Cities in the design and implementation of the Brazilian housing policy. She founded and served on the board of directors of the NGO INTERAÇÃO, which supported the development of high-impact projects in communities in the state of São Paulo and Recife.

As a senior consultant to the World Bank, she provided technical assistance for the development and implementation of Brazilian housing policy and slum upgrading for 10 years, including two major programs: the "PAC Favelas" slum upgrading and the "Minha Casa, Minha Vida" housing subsidy.

She acted as a senior specialist in social housing for the World Bank and other research and project organizations in Brazil and several countries around the world such as the Philippines, China, India, South Africa and Mozambique, among others.

She was Regional Manager for Latin America and the Caribbean for the Cities of Alliance Global Informality Program where the exchange of experiences and knowledge through different networks was consolidated and structured.

The main achievements in Latin America are the Urban Housing Practitioners Hub (UHPH), which brings together practitioners and networks working in the field of social housing. In the global south, multi-sectoral and disciplinary communities of practice on the theme of slum upgrading in the global south with emphasis on the countries: Mexico, Guatemala, El Salvador, Paraguay, Brazil, South Africa and India.

PLEA STGO 2022
PLEA STGO 2022: WILL CITIES SURVIVE?

GIANCARLO MAZZANTI

Keynote Speaker
ARGENTINA

Born in Barranquilla, a port city in northern Colombia, Giancarlo Mazzanti is an architect graduated from Pontificia Universidad Javeriana with postgraduate studies in industrial design and architecture in Florence, Italy.

He has been a visiting professor at several Colombian universities, as well as at world-renowned academic institutions such as Harvard, Columbia and Princeton, and is the first Colombian architect to have his works in the permanent collection of the Museum of Modern Art in New York (MoMA) and the Centre Pompidou in Paris.

Giancarlo has more than 30 years of professional experience and his studio, El Equipo Mazzanti has gained notoriety due to its design philosophy based on modules and systems, which generate flexible elements capable of growing and adapting over time, seeking an architecture that is closer to the idea of strategy than to a finite and closed composition. The idea of architecture as an operation was born from exploring the different forms of material and spatial organization, considering concepts such as repetition, the indeterminate, the unfinished, instability, arrangement and patterns.

Equipo Mazzanti also stands out for its research on play and its link to the world of architecture. It is precisely this interest in the play-architecture relationship that has led it to seek new collaborations with professionals from different areas of knowledge, finding new opportunities for cooperation and developing projects and exhibitions that have been presented throughout the world under the We play You play brand.

Social values are at the core of Mazzanti's architecture, who seeks to realize projects that give value to social transformations and build communities. He has dedicated his professional life to improving the quality of life through environmental design and to the idea of social equality.

His work has become a reflection of the current social changes occurring in Latin America and Colombia, demonstrating that good architecture manages to build new identities for cities, towns and inhabitants, transcending reputations of crime and poverty.

CHAIR COMMITTEE

Waldo Bustamante
Mechanical Civil Engineer from the University of Chile. Master in Urban Development from the Pontifical Catholic University of Chile and PhD in Applied Sciences from Catholic University of Louvain, Belgium. Professor at the Faculty of Architecture, Design and Urban Studies from the Pontifical Catholic University of Chile. Director of the Centre for Sustainable Urban Development (CEDEUS).

Felipe Encinas
Architect from the Pontifical Catholic University of Chile. Master of Science from the University of Nottingham in the United Kingdom and a PhD in Architecture and Urbanism from the Catholic University of Louvain, Belgium. Academic Secretary at the Faculty of Architecture, Design and Urban Studies (FADEU). Researcher at the Centre for Sustainable Urban Development (CEDEUS) and Associate Professor at the School of Architecture in the Pontifical Catholic University of Chile.

Magdalena Vicuña
Architect from the Pontifical Catholic University of Chile. Master in Community Planning from the University of Maryland in the United States and PhD in Architecture and Urban Studies from the Pontifical Catholic University of Chile. Director of Research and Postgraduate Studies at the Faculty of Architecture, Design and Urban Studies (FADEU). Associate Professor at the Institute of Urban and Territorial Studies and Associate Researcher at CIGIDEN.

INTERNATIONAL ADVISORY COMMITTEE

Alessandra R. Prata Shimomura
Universidade de São Paulo. BRASIL.

Carlos Javier Esparza López
Universidad de Colima. MÉXICO.

Edward Ng
Chinese University of Hong Kong. HONG KONG.

Heide Schuster
BLAUSTUDIO. GERMANY.

Jadille Baza
Presidenta del Colegio de Arquitectos de Chile. CHILE.

Joana Carla Soares Goncalves
Architectural Association School of Architecture, UK. University of Westminster, UK. Bartlet School of Architecture, UCL, UK.

Jorge Rodríguez Álvarez
Universidade da Coruña, ESPAÑA.

Juan Carlos Muñoz
Ministro de Transporte y Telecomunicaciones. CHILE.

Luis Edo Bresciani Lecannelier
Pontificia Universidad Católica de Chile. CHILE.

Luis Fuentes Arce
Pontificia Universidad Católica de Chile. CHILE.

Mario Ubilla Sanz
Pontificia Universidad Católica de Chile. CHILE.

Pablo La Roche
Cal. Poly Pomona / CallisonRTKL Inc. USA.

Paula Cadima
Architectural Association Graduate School. UNITED KINGDOM.

Rajat Gupta
Oxford Brookes University. UNITED KINGDOM.

Rodrigo Ramirez
Pontificia Universidad Católica de Chile. CHILE.

Sanda Lenzholzer
Wageningen University. THE NETHERLANDS.

Sergio Baeriswyl
Presidente del Consejo Nacional de Desarrollo Urbano. CHILE.

Simos Yannas
Architectural Association Graduate School. UNITED KINGDOM.

Susana Biondi Antúnez de Mayolo
Pontificia Universidad Católica de Perú. PERÚ.

Ulrike Passe
Iowa State University. USA.

LOCAL ORGANISING COMMITTEE

María José Molina
Commercial Engineer from the Pontifical Catholic University of Chile. Master in Local and Regional Development from the Institute of Social Studies of Erasmus University Rotterdam, The Netherlands. Executive Director of the Centre for Sustainable Urban Development (CEDEUS).

José Guerra
Architect from the Catholic University of the North. PhD in Architecture, Energy and Environment from the Polytechnic University of Catalonia. Director of the School of Architecture from the Catholic University of the North. Director of the Research Center for Architecture, Energy and Sustainability (CIAES) at the Catholic University of the North.

Sergio Vera
Civil Engineer from the Pontifical Catholic University of Chile. PhD from Concordia University and Master of Science, Pontifical Catholic University of Chile. Director of the Interdisciplinary Center for the Productivity and Sustainable Construction (CIPYCS). Assistant Professor and Director of the Department of Engineering and Construction Management at the Pontifical Catholic University of Chile.

María Isabel Rivera
Architect from the University of Concepcion. Master of Architecture from the University of Washington, USA. PhD in Architecture from the University of Oregon. Researcher of the Centre for Sustainable Urban Development (CEDEUS) and Assistant Professor of the Department of Architecture, University of Concepcion.

Maureen Trebilcock
Architect from the University of Bio Bio. Master of Arts in Green Architecture and PhD from the University of Nottingham. Director of the PhD program in Architecture and Urbanism at the University of Bio Bio.

Nina Hormazábal
Architect from the University of Washington. Master of Architecture from the University of California, Berkeley. PhD in POE and Energy Efficiency in Housing from the University of Nottingham. Professor and Researcher of the Laboratory of the Bioclimatic Area in the Department of Architecture of the Federico Santa María Technical University.

PLEA STGO 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

M. Beatriz Piderit
Architect from the University of Bio-Bio. Master in Applied Sciences and PhD from the Catholic University of Louvain, Belgium. Associate Professor and researcher at the Faculty of Architecture of the University of Bio-Bio. Researcher of the research group in "Environmental Comfort and Energy Poverty" of the University of Bio-Bio.

Claudio Carrasco
Architect from the Universidad de Valparaiso. PhD in Architecture, Energy and Environment from the Polytechnic University of Catalonia. Master in Geographical Information Systems from MappingGIS. Professor at the Department of Architecture of the Federico Santa María Technical University. Professor and Researcher of the Civil Construction School and the City Science Laboratory (CSLab) at the Faculty of Engineering of the Universidad de Valparaiso, Chile. Associate Research of the Climate Action Center (CAC) of the Pontifical Catholic University of Valparaíso, Chile.

Massimo Palme
Materials Engineer from the University of Trieste. Master in Geographical Information Systems from MappingGIS. PhD in Architecture, Energy and Environment from the Polytechnic University of Catalonia. Professor at the Department of Architecture of the Federico Santa María Technical University.

SCIENTIFIC COMMITTEE

Khandaker Shabbir Ahmed
Bangladesh University of Engineering & Technology. BANGLADESH.

Noelia Alchapar
CONICET Mendoza. ARGENTINA.

Fazia Ali-Toudert
Ecole Nationale d'Architecture Paris Val de Seine. FRANCE.

Hector Altamirano
University College of London. UNITED KINGDOM

Sergio Altomonte
Université Catholique de Louvain. BELGIUM.

Servando Álvarez
Universidad de Sevilla. SPAIN.

Mohammad Arif Kamal
Aligarh Muslim University. INDIA.

Shady Attia
University of Liege. BELGIUM.

Julieta Balter
CONICET Mendoza. ARGENTINA.

Gustavo Barea Paci
CONICET Mendoza. ARGENTINA.

Jonathan Bean
University of Arizona. USA.

Susana Biondi
Pontificia Universidad Católica del Perú. PERÚ.

Philomena Bluyssen
TU Delft. HOLLAND.

Denis Bruneau
ENSAP Bordeaux. FRANCE.

Vincent Buhagiar
University of Malta. MALTA.

Victor Bunster
Monash University. AUSTRALIA.

Waldo Bustamante
Pontificia Universidad Católica de Chile. CHILE.

Paula Cadima
Architectural Association. UNITED KINGDOM

Isaac Guedi Capeluto
Technion — Israel Institute of Technology. ISRAEL.

Alexandre Carbonnel
Escuela Arquitectura. Universidad de Santiago. CHILE

Claudio Carrasco
Universidad Técnica Federico Santa María — Universidad de Valparaíso. CHILE

Giacomo Chiesa
Politecnico di Torino. ITALY.

Helena Coch
Universitat Politècnica de Catalunya. SPAIN.

Florencia Collo
Atmos Lab. ARGENTINA.

Erica Correa Cantaloube
CONICET Mendoza. ARGENTINA.

Manuel Correia Guedes
University of Lisbon. PORTUGAL.

Robert Crawford
University of Melbourne. AUSTRALIA.

Marwa Dabaieh
Malmö University. SWEDEN.

Richard De Dear
University of Sydney. AUSTRALIA.

Silvia De Schiller
Universidad de Buenos Aires. ARGENTINA.

Claude Demers
Laval University, Québec. CANADA.

Samuel Domínguez
Universidad de Sevilla. SPAIN.

Denise Duarte
Universidade de São Paulo. BRAZIL.

Felipe Encinas
Pontificia Universidad Católica de Chile. CHILE

Evyatar Erell
Ben Gurion University of the Negev. ISRAEL.

Carlos Esparza
University of Colima. MEXICO

Juan Carlos Etulain
Universidad Nacional de la Plata. ARGENTINA.

Arnaud Evrard
Université Catholique de Louvain. BELGIUM.

Lone Feifer
Active House Alliance. CANADA.

Jesica Fernández-Agüera
Universidad de Sevilla. SPAIN.

Gilles Flamant
Centro de Desarrollo Urbano Sustentable. CHILE.

Brian Ford
Natural Cooling Ltd. UNITED KINGDOM.

Miguel Ángel Gálvez Huerta
Universidad Técnica Federico Santamaría. CHILE.

Carolina Ganem
CONICET Mendoza. ARGENTINA.

Rodrigo García
Universidad del Bío-Bío. CHILE.

José Roberto García Chávez
Universidad Autónoma Metropolitana. MÉXICO.

Aritra Ghosh
University of Exeter. UNITED KINGDOM.

Mark Gilliott
University of Nottingham. UNITED KINGDOM.

Jorge Gironás
Pontificia Universidad Católica de Chile. CHILE.

Vanessa Gomes Silva
University of Campinas. BRAZIL.

Margarita Greene
Pontificia Universidad Católica de Chile. CHILE.

José Guerra
Universidad Católica del Norte. CHILE.

Rajat Gupta
Oxford Brookes University. UNITED KINGDOM.

Rafael Herrera-Limones
Universidad de Sevilla. SPAIN.

Marcos Hongn
Universidad de Salta. ARGENTINA.

Cecilia Jiménez
Pontificia Universidad Católica del Perú. PERÚ.

Nina Hormazábal
Universidad Técnica Federico Santa María. CHILE.

Cecilia Jiménez
CJD Arquitectos. PERÚ.

Alison Kwok
University of Oregon. USA.

Mauricio Lama
Pontificia Universidad Católica de Chile. CHILE

J. Owen Lewis
International Development Ireland. IRELAND.

Florian Lichtblau
Lichtblau Architects. GERMANY.

María Lopez de Asiain
Universidad de Las Palmas de Gran Canaria. SPAIN.

Sanyogita Manu
CEPT University. INDIA.

Leonardo Marques Monteiro
Universidade de São Paulo. BRAZIL.

Andrea Martinez
Universidad de Concepción. CHILE.

Juan Manuel Medina
Universidad de Los Andes. CHILE.

María del Pilar Mercader-Moyano
Universidad de Sevilla. SPAIN.

Ranny Michalski
Universidade de Sao Paulo. BRAZIL.

Aurora Monge-Barrio
Universidad de Navarra. SPAIN.

Michele Morganti
Universitá di Roma La Sapienza. ITALY.

Rafael Moya
Universidad de Concepción. CHILE.

Julia Mundo-Hernandez
Benemérita Universidad Autónoma de Puebla. MEXICO.

Emanuele Naboni
The Royal Danish Academy of Fine Arts. DENMARK.

Edward NG
The Chinese University of Hong Kong. HONG KONG – CHINA.

PLEA STGO 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

Diego Palma
Pontificia Universidad Católica de Chile. CHILE.

Massimo Palme
Universidad Técnica Federico Santa María. CHILE.

Ulrike Passe
Iowa State University. USA.

Pablo Pastén
Pontificia Universidad Católica de Chile. CHILE.

Andrea Pattini
CONICET Mendoza. ARGENTINA.

Alexis Perez-Fargallo
Universidad del Bío-Bío. CHILE.

Marco Perino
Politecnico di Torino. ITALY.

María Beatriz Piderit Moreno
Universidad del Bío-Bío. CHILE.

Eduardo Pimentel Pizarro
Universidade São Judas Tadeu. BRAZIL.

Adrian Pitts
University of Huddersfield. UNITED KINGDOM.

André Potvin
Laval University, Québec. CANADA.

Alessandra Prata Shimomura
FAUUSP. BRAZIL

Jesús Pulido
University of Tokyo. JAPAN.

Rajan Rawal
CEPT University. INDIA.

Dana Raydan
Raydan Watkins Architects. UNITED KINGDOM.

Alexandra Rempel
University of Oregon. USA.

María Isabel Rivera
Universidad de Concepción. CHILE.

Susan Roaf
Heriot-Watt University. SCOTLAND.

Lucelia Rodrigues
University of Nottingham. UNITED KINGDOM.

Carolina Rodriguez
Universidad Piloto de Colombia. COLOMBIA.

Jorge Rodriguez
Universidade de A Coruna. SPAIN.

Jean-François Roger-France
Université Catholique de Louvain. BELGIUM.

Jeannette Roldán Rojas
Facultad de Arquitectura y Urbanismo. Universidad de Chile. CHILE

Carlos Rubio
Universidad de Sevilla. SPAIN.

Khaled Saleh Pascha
University of Applied Sciences Upper Austria, AUSTRIA.

Agnese Salvati
Universidad Politécnica de Cataluña. SPAIN.

Mattheos Santamouris
University of Athens. GREECE.

Marc E Schiler
University of Southern California. USA.

Heide Schuster
BLAUSTUDIO – Sustainability in Architecture and Urban Design. GERMANY.

Valentina Serra
Politecnico di Torino. ITALY.

Denise Silva Duarte
University of Sao Paulo. BRAZIL

Masanori Shukuya
Tokyo City University. JAPAN.

Joana Soares Goncalves
Architectural Association School of Architecture. UNITED KINGDOM.

Victoria Soto Magan
Swiss Federal Institute of Technology. SWITZERLAND.

Thanos Stasinopoulos
Izmir University of Economics. TURKEY.

Tomás Swett
Universidad del Desarrollo. CHILE

Kheira Anissa Tabet Aoul
United Arab Emirates University. UNITED ARAB EMIRATES.

Hideki Takebayashi
Kobe University. JAPAN.

Maureen Trebilcock
Universidad del Bío-Bío. CHILE.

Leena E. Thomas
University of Technology. AUSTRALIA.

Ola Uduku
Manchester Metropolitan University. UNITED KINGDOM.

Juan Vallejo
University of Westminster – Natural Cooling Ltd. UNITED KINGDOM.

Sergio Vera
Pontificia Universidad Católica de Chile. CHILE

Magdalena Vicuña
Pontificia Universidad Católica de Chile. CHILE.

Rufei Wang
Atelier Ten USA LLC. UNITED STATES.

Paulina Wegertseder
Universidad del Bío-Bío. CHILE.

Barbara Widera
Wroclaw University of Technology. POLAND.

Jan Wienold
École Polytechnique Fédérale de Lausanne. SWITZERLAND.

Feng Yang
Tongji University. CHINA.

Simos Yannas
Architectural Association. UNITED KINGDOM.

Aram Yeretzian
American University of Beirut. LEBANON.

Gabriela Zapata-Lancaster
Cardiff University. UNITED KINGDOM.

Daniel Zepeda
University of A Coruña. SPAIN.

Antonio Zumelzu
Universidad Austral de Chile. CHILE.

S01 SESSION 01

page 43

Sustainable Urban Development (1) | ANDES HALL | Chair Agnese Salvati

1669	Modelling Resilient Construction through a Mixed-Use Development within an Urban Environment	Murray, Martin; Colclough, Shane; Griffiths, Philip
1329	Water Sensitive Urban Design Systems Thermal Behavior II: Thermal Analysis of WUD's Which Do Not Retain Water	Pérez Cambra, María del Mar; Martínez Santafé, María Dolors; Roca Cladera, Josep
1430	Cooling Cities. Innovative Water-Based Cooling Systems in the Era of Urban Heat: Solutions For Outdoor Climate Adaptation	Moredia Valek, Adrian; Dessi, Valentina
1458	Sky View Factor And Urban Heat Island Mapping. Applications In Barcelona	Salvati, Agnese; Casals, Jordi; Lopez Besora, Judit; Coch, Helena

S02 SESSION 02

page 69

Education and Training (1) | ANTARCTICA HALL | Chair Jonathan Bean

1535	Climate Positive Innovation and Design: Graduate Education to Drive Change in the Built Environment	Bean, Jonathan Yorke
1351	The Use of BIM Tools in E-learning for Architecture During the Covid-19 Pandemic. A Case Study at the University of Brasilia	Blumenschein, Raquel Naves; Muza, Pedro Henrique
1482	The Mini Wind Lab Project: An interactive, numerical, physical wind simulation platform concept for teaching	Moya Castro, Rafael
1627	A Shared Curriculum For Daylighting Education To Meet The Educational Needs Of Society	Gentile, Niko; Giuliani, Federica; Sarey Khanie, Mandana; Sokół, Natalia; Lo Verso, Valerio Roberto Maria; Caffaro, Federica; Kofod Pedersen, Mikkel; Pompili, Federica; Mattsson, Pimkamol
1655	New Demand for Training In Energy Efficiency In The Built Environment - The Development Of New Postgraduate Programs In Latin America	Dub, Angela; de Schiller, Silvia; Evans, Jobn Martin; Guillén Gutiérrez, Guido
1142	Sustainable Attitudes Project: The University Acting in the Education and Popularization of News Energy-saving Lamp Technologies	Brandao, Helena Camara Lace

S03 SESSION 03

page 103

Sustainable Architectural Design (1) | ATACAMA HALL | Chair Ulrike Passe

1392	Adequacy of Weather Data Standards to Assess Building Passive Performance During Summer: An Application to French Buildings	Piñas Moya, Mc Joshua Miguel; Gobert, Robin; Alessandrini, Jean-Marie; Sabre, Maeva; Kraiem, Samy; Lefebvre, Gilles; Liu, Wei; Pelé, Charles
1243	Optimization-based Design Of Insulating Cementitious Foams Combined With Phase Change Materials For NZEBs	Bre, Facundo; Caggiano, Antonio; Koenders, Eduardus A. B.
1469	Catalogue of Urban Surface Finish Materials. Optimizing Solar Energy Management in Latin American Cities Located in Different Climatic Zones	Perez, Gloria; Medina-Lagrange, Orisell; Martin-Consuegra, Fernando; Alchapar, Noelia; Flores Sasso, Virginia; Martinez, Patricia; Pezzuto, Claudia; Prado, Luis; Alonso, Carmen; Arnsdorff, Max; Frutos, Borja; Guerrero, Ana; Martinez-Ramirez, Sagrario; Ojeda, Juan; Ruiz-Valero, Letzai
1414	Automatic Mesh Generator For Urban Computational Fluid Dynamics Simulations	Gimenez, Juan Marcelo; Bre, Facundo

S04 SESSION 04

page 129

Architecture for Health and Well-being (1) | RAPA NUI HALL | Chair Maureen Trebilcock

1346	Lighting Planning For A Resilient Urban Environment: Visual Comfort And Well-being In The City During The Night	Vital, Rebeka; Peretz, Hanan
1407	Effect Of Window Glazing Colour And Transmittance On Human Visual Comfort	Jain, Sneha; Wienold, Jan; Andersen, Marilyne
1145	Folk Memories And Temperature Measurements For Thermal Comfort in Vernacular Courtyard Houses Of Saudi Arabia´s Hot Arid Climate: Resident´s Memories Of Living In Al-Khabra Vernacular Mud Brick Houses	Alghafis, Mohammed Fahad; Sibley, Magda; Latif, Eshrar
1652	Well-being In Office Spaces From The Occupants' Perspective. A Qualitative Approach	Trebilcock-Kelly, Maureen; Soto-Muñoz, Jaime; Wegertseder-Martínez, Paulina; Ramírez-Vielma, Raúl

PLEA STGO 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

S05 SESSION 05 page 155

Sustainable Architectural Design (2) | PATAGONIA HALL | Chair Felipe Encinas

1640	How Much Does Your Building Weigh? An Exploration Into Different Early Design Stage LCA Workflows	Newmarch, Emily Ruth; Donn, Michael; Dowdell, David; Twose, Simon; Short, Fiona
1417	Courtyard As A Microclimate Modifier Of Buildings In Hot Climates. A parametric Study	Alqadi, Shireen Bader; Elnokaly, Amira; Kafafi, Ahmad; Irfayieh, Wala
1608	Daylight Discomfort Glare In Home Workspaces: Influencing Factors And Adaptation	Buhagiar, Vincent; Psaila Diacono, Kimberley
1507	Bioclimatic Residential Buildings Strategies for Tropical Savanna Climate, Brazil: Examples of Heritage Modernist Houses in Goiania	Abreu-Harbich, Loyde Vieira de; Araújo, Larissa Rodrigues; Hora, Karla Emmanuela Ribeiro
1107	A Technical and Energy Performance Approach for the Construction and Operation of the Zero-energy Renovation of a Residential Building in the Netherlands	Konstantinou, Thaleia; Boess, Stella

S06 SESSION 06 page 187

Sustainable Urban Development (2) | ANDES HALL | Chair Margarita Greene

1609	Vegetation as a Mitigation Strategy on Mediterranean Context: Outdoor Thermal Comfort From Simulated Data	Arriaga Osuna, Maria Fernanda; Martínez-Torres, Karen Estrella; Rincón-Martínez, Julio Cesar; González-Trevizo, Marcos Eduardo
1476	Urban Materials For Thermally Liveable Madrid. A Digital Twin Strategy To Characterize Developments	Giancola, Emanuela; López, Helena; Soutullo, Silvia; Sánchez, Nuria; Gamarra, Ana; Herrera, Israel; Zarzalejo, Luis; Naboni, Emanuele
1556	Evaluation of Thermal Performance of Urban Asphalt Pavements with Rubber Incorporation	Kowalski, Luiz Fernando; Amancio, Daiane Coragem; Viana, Juliana Fernandes; Silva, Felipe Pereira da; Teixeira, Ivonei; Masiero, Érico
1550	Can different vegetation influence on outdoor thermal comfort by cycling routes in tropical savanna climates?	Abreu-Harbich, Loyde Vieira de; Roriz, Júlia Wilson de Sá; Hora, Karala Emmanuela Ribeiro
1357	Evaluation of radiant Temperatures of Tree Canopies and their Effects on Close Surfaces	Garcia, Thiago dos Santos, Labaki, Lucila Chebel

S07 SESSION 07 page 217

Sustainable Buildings and Technology (1) | ANTARCTICA HALL | Chair Susel Biondi

1397	Integration Of Sustainability Tools And Building Information Modelling In The Early Stages Of Design	Berges Alvarez, Ileana; Muñoz Fierro, Jorge; Giraldi, Sebastian; Marín-Restrepo, Laura
1390	Development of an Artificial Neural Network Prediction Model for Reducing Particulate Matter (pm2.5) in School Facility	Kim, Tae Won; Choi, Young Jae; Byun, Jae Yoon; Moon, Jin Woo
1166	A Dynamic Feedforward Control Strategy for Energy-efficient Building System Operation	Chen, Xia; Cai, Xiaoye; Kümpel, Alexander; Müller, Dirk; Geyer, Philipp
1638	Energy Renovation Towards Net-Zero Carbon Emission Buildings: a case study in Sweden	Bernardo, Ricardo; Pizarro, Rafael

S08 SESSION 08 page 241

Sustainable Architectural Design (3) | ATACAMA HALL | Chair Carolina Ganem

1306	Potentials of Passive Housing Design in Emerging Countries with Mediterranean Climate: Latest Results and Design Recommendations for Central Chile	Mueller, Ernst
1493	Passive Design Optimization Towards Nearly Zero Energy Buildings Requirements. Operational Performance of a Low Energy Office Building in Continental Semi-arid Climate.	D Amanzo, Micaela; Andreoni Trentacoste, Soledad Elisa; Montiel Zamorano, Virginia Gloria; Betman, Alicia; Ganem Karlen, Carolina
1356	Net Zero Energy Buildings: Analysis of passive strategies for buildings retrofits in central-southern Chile	Valenzuela, Andrea Belen; Guiñez, Roxana Andrea; Bedoya, Daniel; Toledo, Romina Valentina
1260	An Innovative Environmental Test Chamber for Testing Passive Cooling Prototypes: A New Methodology for Research and Pedagogical Applications	Al-Hassawi, Omar Dhia; Drake, David
1323	The Complex Challenge of Sustainable Architectural Design. Assessing Climate Change Impact on Passive Strategies and Buildings' Opportunities for Adaptation. A case study.	Ganem Karlen, Carolina; Barea Paci, Gustavo Javier

S09 SESSION 09 page 275

Architecture for Health and Well-being (2) | RAPA NUI HALL | Chair Isabel Rivera

1665	Humanizing Social Housing: A Case Study of Indoor Environmental Quality in San Pedro de la Costa, Chile	Rivera, Maria Isabel; de la Barrera, Francisco; Barraza, Camila; Durán, Carla; Pavez, Jorge; Martínez, Andrea
1471	I Lived in a Passive House Building: Here's What I Learned. A Post-occupancy Evaluation Comparing Indoor Environmental Quality And Performance Between One Residential Unit Built To Passive House Standards And Another Residential Unit Built To Conventional Standards	Shemesh, Sigal
1110	Analysis Of Urban Thermal Behaviour In Hot Dry Climate In Relation To Its Vegetation Before And After The COVID-19 Pandemic	Grajeda-Rosado, Ruth Maria; Vazquez-Torres, Claudia Erendira; Sotelo-Salas, Cristina
1663	Neurourbanism: Analysis of Public Space of Small Town Peruíbe -SP	Oliveira, Halana Duart; Morelli, Denise Damas de Oliveira
1416	Co-producing Healthy Communities: A Methodological Approach to Prevent Arbovirus Epidemics in a Brazilian Social Housing Neighbourhood	Garrefa, Fernando; Villa, Simone Barbosa; Bortoli, Karen Carrer Ruman de; Stevenson, Fionn; Vasconcellos, Paula Barcelos; Carvalho, Nathalia Lya de Melo

S10 SESSION 10 page 307

Analysis and Methods (1) | PATAGONIA HALL | Chair Vincent Buhagiar

1172	Urban Vulnerability Assessment And Urban Planning Management To Urban Heat Islands in France: A Multicriteria Analysis	Techer, Magalie; Ait Haddou, Hassan; Aguejdad, Rahim
1585	The microclimate effects of urban green infrastructure under RCP 8.5 projection and plant vitality. Will plants be enough?	Yoshida, Daniel Felipe Outa; Shinzato, Paula; Duarte, Denise Helena Silva
1199	Analysing the Effect of Cool and Green Roof Design Scenarios on Building Energy Loads and Air Temperature at Pedestrian Level in Hot Arid Climate	Elnabawi, Mohamed; Hamza, Neveen; Sedki, Ali
1468	Fos Gis to Support Regenerative Design Processes in Urban Areas	Clementi, Matteo; Romano, Manuela; Rogora, Alessandro
1213	Aerodynamic Analysis of Urban Blocks: Case Study in Open, Row and Vertical Block	Girotti, Carolina; Nazareth, Samuel Bertrand Melo; Shimomura, Alessandra R. Prata

S11 SESSION 11 page 339

Sustainable Urban Development (3) | ANTARCTICA HALL | Chair Magdalena Vicuña

1673	Mind the Gap: Bridging the Void between Energy Policy as Business and Social Policy as Equality.	Murray, Martin; Colclough, Shane; Griffiths, Philip
1434	Hygrothermal Characterization Of Water-absorbing Granules: A Preliminary Experimental Study For The Development Of An Evaporative Cooling Façade Module	Görgen, Fabian; Rossi-Schwarzenbeck, Monica
1300	Impact-Based Project Ideas for Sustainable Cities: The Case Of Digital Planning Tools In Piura, Peru	Fernandez, Trinidad; Schroeder, Stella
1305	Where Public Space Meets Climate Change. Linking Urban Projects With Lisbon's Metropolitan Adaptation Plan	Santos, João Rafael
1309	Targeting the Most Energy Vulnerable. Deprived Neighbourhoods at Risk of Winter Fuel Poverty and High Summer Urban Heat Island Intensity. A Study Case in Madrid (Spain)	Martin-Consuegra, Fernando; Núñez Peiró, Miguel; Alonso, Carmen; Sánchez-Guevara, Carmen; Pérez, Gloria; Arranz, Beatriz

S12 SESSION 12 page 371

Challenges for Developing Countries (1) | RAPA NUI HALL | Chair Joana Goncalves

1543	Symptomatic Urbanism: Analysing The Relationships Between Motorway Traffic And Health And Food	da Rocha, Emanuela Alves; Drach, Patricia Regina Chaves
1318	Improving The Environmental Conditions Of Favela Homes Through A Participatory Process: With Reference to Case-studies In São Paulo And Rio De Janeiro	Soares Goncalves, Joana Carla; Paixao, Patricia; Shimomura, Alessandra R. P.; Pizarro, Eduardo P.; Curcio, Gustavo; Diegues, Gustavo
1363	Microclimate Evaluation Method for Urban Planning in Legal Amazon Region	Sanches, João Carlos Machado; Domingos, Renata Mansuelo Alves; Guarda, Emeli Lalesca Aparecida; Assis, Eleonora Sad
1149	Optimization Of A Social Housing Model In Brazil: The EPS Application To Reduce The Impact Of Climate Change On Buildings' Thermal-Energy Performance	Cruz, Alexandre Santana; Bastos, Leopoldo Eurico Gonçalves; Besson, Axel
1513	City Lab: Support Infrastructure	Cardona Betancourt, Manuela; Aguirre Arango, Juan Camilo; Monroy Arango, Santiago; Velasquez Loaiza, Juanita Carolina; Gonzales Ceballos, Juan Carlos; Correa Vanegas, Gustavo
1433	Daylight Priority In Apartment Room-Layout Design When Daylight Access Is Limited Due To Dense Urban Surroundings: A Case From Dhaka City	Islam, Saiful; Uddin, Mohammed

S13 SESSION 13 page 409
Sustainable Buildings and Technology (2) | ANDES HALL | Chair Nina Hormazabal

1221	Comparative Study Of Two Passive Cooling Systems: Indirect Evaporative Cooling Vs. Radiant-Capacitive Cooling	Gonzalez-Cruz, Eduardo Manuel; Krüger, Eduardo
1561	Thermal Performance Of Ceramic Coatings Used On Vertical And Horizontal Surfaces	Castello, Ana Julia Pilon; Carvalho, Marcius Fabius Henriques; Pezzuto, Claudia Cotrim
1421	Reversible Building Design: Viewing A Building As A Material Bank	Ossio, Felipe; D'Alençon, Renato; Rücker, Moritz; Ahumada, Matías
1661	Characterization Of Native Macroalgae: "Pelillo" (Agaro-phyton Chilense) And "Lamilla" (Ulva Lactuca) For The Development Of A Prototype Thermal Insulating Material	Rojas Herrera, Carlos Javier; Uribe De La Cruz, Claudio Marcelo; Cárdenas Ramírez, Juan Pablo

S14 SESSION 14 page 435
Sustainable Architectural Design (4) | ATACAMA HALL | Chair Chris Whitman

1156	Adaptation of Passive Heating Strategies in the Peruvian Mesoandean Zone: Thermal Improvement In Social Housing	Pari Quispe, Diana Karen; Cronemberger Ribeiro Silva, Joára; Frederico e Silva, Caio
1224	Thermal Performance of Traditional Courtyard Houses in Warm Humid climate. Case Study of Colima, Mexico.	Toris Guitron, Maria Gabriela; Esparza López, Carlos J.; Escobar del Pozo, Carlos
1534	Hygrothermal Comfort In School Yard. A Case Study Leed In Rio De Janeiro	Pereira da Silva, Rita de Cassia; Nogueira de Vasconcellos, Virginia Maria
1496	Hygrothermal Evaluation of an Indigenous Dwelling on the Andean Highlands: Evidence Of How Atacameño Architecture Can Achive Better Indor Thermal Standards Than Those Set By The Chilean Regulation And The Average Chilean Dwellings	Escobar Doren, Irene Paulina
1165	Replacement Infill Panels for Historic Timber-Framed Buildings: Measured and Simulated Hygrothermal Behaviour	Whitman, Christopher J.; Prizeman, Oriel; Walker, Pete; Rhee-Duverne, Soki; McCaig, Iain; Gervis, Nigel

S15 SESSION 15 page 467
Sustainable Architectural Design (5) | PATAGONIA HALL | Chair Florencia Collo

1352	Innovative Transparent and Translucent Materials on Facades: Non-Visual Effects of Light	Walter Costa, Joao Francisco; David Amorim, Claudia Naves
1112	Performance Analysis Of Side Lighting Systems In Commercial Buildings In Southern Brazil	Gabriel, Elaise; Zambonato, Bruna; Meller, Gabriela; Grigoletti, Giane
1633	Green Facades and Its Shading Potential: the solar radiation attenuation promoted Promoted by Climber Species	Munoz, Luiza Sobhie; Fontes, Maria Solange Gurgel de Castro
1139	Building-integrated Solar Technology: Learning From More Than 30 Years Of Experience With Solar Buildings (Examples From International Competitions)	Krippner, Roland; Flade, Fabian
1111	Application Case of a Bioinspired Approach: Ideation, Prototyping and Assessment of a Novel Thermo-responsive and Deployable Building Skin	Hubert, Tessa; Durand-Estebe, Baptiste; Dugué, Antoine; Vogt Wu, Tingting; Aujard, Fabienne; Bruneau, Denis

S16 SESSION 16

page 499

Challenges for Developing Countries (2) | RAPA NUI HALL | Chair Susel Biondi

1136	Roadmap Towards Energy-Efficient Buildings at a City Perspective: Case Of Study Of Florianopolis, Brazil	Triana, Maria Andrea; Geraldi, Matheus Soares; Melo, Ana Paula; Lamberts, Roberto
1345	Participatory learning methods to improve energy efficiency in Chilean residential sector: Public programs to support self-management	Schueftan, Alejandra; Reyes, René; Aguilera, Florencia
1211	Design Research Role in Supporting Net-Zero Buildings	Moreno-Rangel, Alejandro; Tsekleves, Emmanuel; Young, Paul; Huenchuñir, Marcelo; Vazquez, Juan Manuel
1677	Factors That Promote the Offer of Green Financing for Real Estate Projects of High Energy Efficiency Housing	Palominos Gajardo, Paola Andrea; Marmolejo Duarte, Carlos Ramiro
1245	The Cost Of Rehabilitating A Historical Building: Application Of Roof Materials Alternatives Towards Thermal Comfort	Moon, Beatriz Se Keng; Gonçalves, Sara Breia; Barbosa, Sabrina Andrade

S17 SESSION 17

page 531

Sustainable Urban Development (4) | ANTARCTICA HALL | Chair Denise Duarte

1672	Analysis of Isolated Shrubby-Arborean Species as a Barrier to Winds for Urban Thermal Comfort: Methods to Obtain the Leaf Area Index	Padovani Zanlorenzi, Helena Cristina; Marques Monteiro, Leonardo
1223	How hot is your city design? Surface temperature portrait of São Paulo Metropolitan Region	Ferreira, Luciana Schwandner; Duarte, Denise Helena Silva
1457	Urban Oasis For Adaptation To Climate Change: Analysis Of Climate Adaptation Plans (CAP) Around The World	Sousa, Bruna Dallaverde; Yoshida, Daniel Felipe Outa; Duarte, Denise Helena Silva
1250	CityPlan Water Neutrality Framework for New Urban Developments	Puchol-Salort, Pepe; Mijic, Ana; Van Reeuwijk, Maarten; Boskovic, Stanislava; Dobson, Barnaby
1621	Exploring the Association Between Satellite Indices and Local Climate Zones in Brasília, Brazil	Werneck, Daniela; Romero, Marta

S18 SESSION 18

page 563

Sustainable Architectural Design (6) | ATACAMA HALL | Chair Joana Goncalves

1606	Wladimiro Acosta And The Helios System: 3 Case Studies. Comparative Analysis And Critical Review	Collo, Florencia
1331	2000 Meters Above Sea Level: Climate Adapted Urban Development Strategies In The Highlands Of Oman	Kader, Alexander; Kamal Ritu, Nusrat
1322	Lessons Learnt From The Brazilian Bioclimatic Modernism: The Case-Study Of The Sul American Bank Building (1966)	Soares Goncalves, Joana Carla; C. Kronka Mulfarth, Roberta; Loureiro Xavier Nascimento Michalski, Ranny; R. Prata Shimomura, Alessandra; Nascimento e Souza, Beatriz; Reis Muri Cunha, Guilherme; Pereira Marcondes-Cavaleri, Monica; Regina Sara, Sheila
1530	Exploring The Thermal Quality Of The Modernism Legacy's Architecture: Analytical Studies Of Acayaba's Single-Family Houses In São Paulo	Lima, Eduardo Gasparelo; Gonçalves, Joana Carla Soares; Michalski, Ranny Loureiro Xavier Nascimento

S19 SESSION 19

page 591

Architecture for Health and Well-being (3) | ANDES HALL | Chair Nina Hormazabal

1622	Engaging School Facilities: a literature review	Kwok, Alison G.; Coronado Cabrera, Maria Camila; Lee, Jean K.L.; Fretz, Mark; Van Den Wymelenberg, Kevin; Seely, John
1515	Thermal Performance In Educational Environments From The Consideration Of Climate Change In Medellín, Colombia	Patino Vasquez, Carolina; Palacio Zapata, David
1298	Overheating risk in naturally ventilated and conditioned elementary schools from the perspective of climate change	Gnecco, Veronica Martins; da Guarda, Emeli Lalesca Aparedida; Mizgier, Martin Órdenes; Lamberts, Roberto
1642	Acoustic Design in Open-plan Learning Environments: Dealing With Sound Intrusion For Speech Intelligibility	Ipinza Olatte, Constanza; Trebilcock Kelly, Maureen; Piderit Moreno, María Beatriz

PLEA STGO 2022
PLEA STGO 2022: WILL CITIES SURVIVE?

S20 SESSION 20

Sustainable Architectural Design (7) | PATAGONIA HALL | Chair Ulrike Passe

S21 SESSION 21

Analysis and Methods (2) | PATAGONIA HALL | Chair Massimo Palme

S22 SESSION 22

Sustainable Urban Development (5) | ANTARCTICA HALL | Chair Magdalena Vicuña

S23 SESSION 23

Sustainable Architectural Design (8) | ANDES HALL | Chair Alejandra Schueftan

PLEA STGO 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

S31 SESSION 31 page 961

Sustainable Architectural Design (12) | PATAGONIA HALL | Chair Héctor Altamirano

1441	What Interior Temperatures Can Be Expected In Irish Nzeb Dwellings? An Analysis Of Recorded Interior Temperatures In A Scheme Of Irish Nzeb Dwellings Built To The Passive House Standard	Colclough, Shane; OHegarty, Richard; Leblanc, Mathieu; Desbertrand, Tom; Hewitt, Neil; Kinnane, Oliver
1280	Rethinking the Work Environment: An analytical design applicability to office buildings in Santiago, Chile	Swett, Tomas; Soares Goncalves, Joana Carla; Bode, Klaus
1366	Influence of Cost-benefit of Different Construction Systems for Envelopment on Energy Consumption in a Housing of Social Interest	Domingos, Renata Mansuelo Alves; Pereira, Fernando Oscar Ruttkay
1646	One-Stop-Shops as a Model to Manage Housing Energy Retrofit. A General Approach to Europe and Spain	Marmolejo-Duarte, Carlos; Biere-Arenas, Rolando; Spairani-Berrio, Silvia; Spairani-Berrio, Yolanda; Pérez-Lamas, Carlos
1546	Assessment of a Retrofit Proposal for Workspace in a Brazilian Public University	Castro, Adriana Petito de Almeida Silva; Barbosa, Elisabeti; Albertin, Camila de Freitas; Labaki, Lucila Chebel

S32 SESSION 32 page 993

Sustainable Architectural Design (6) | ANTARCTICA HALL | Chair Carlos Esparza

1364	How Climate Trends With Urban Morphology Impact The Thermal Performance of Buildings	Guarda, Emeli Lalesca Aparecida; Domingos, Renata Mansuelo Alves; Machado, Rayner Maurício e Silva; Mizgier, Martin Ordenes; Pereira, Fernando Oscar Ruttkay
1196	Understanding Informal Production Of Public Spaces For A New, Sustainable Urban Planning Strategy. Case Study Of Community Gardens In Piura, Peru	Schroeder, Stella
1267	Brazilian Coastal Cities: A Case Study Related To The Impact Of Rising Sea Level	Bussolotti, Victor Moura; Pellegrini, Izabela Uliana; Alvarez, Cristina Engel de
1670	Urban Climate Model For Valparaiso, Chile. Adaptation Of The Urban Climate Model Of The Eixample Area Of Barcelona City	Carrasco, Claudio; Palme, Massimo; Isalgué, Antonio
1269	Climate Change and Megacities: South Asian Mega-cities are in Extreme Heat Stress	Debnath, Kumar Biswajit; Jenkins, David; Patidar, Sandhya; Peacock, Andrew D; Bridgens, Ben; Mitrani, Helen

S33 SESSION 33 page 1025

Sustainable Architectural Design (13) | ATACAMA HALL | Chair Felipe Victorero

1271	Recycling Waste and its Applications in Building Construction: Aseptic Packaging as a Thermal Insulator for Emergency Housing	López-Guerrero, Rafael Eduardo; Nalbandian, Kevork Micael; Caamaño, Leonardo; Beller, Scott; Carpio, Manuel
1348	The Potential Of Wall Thermosyphon To Reduce Heat Generated By Internal Charge Density In Residential Bedrooms	Almeida, Fernando da Silva; Brandalise, Mariane Pinto; Cisterna, Luis Hernán Rodríguez; Mantelli, Marcia Barbosa Henriques; Mizgier, Martin Ordenes
1361	Development of Accessibility Evaluation Checklists for Public Sports Facilities	Baek, Si-Yeon; Bae, Yoong-Ho; Kim, Jin-Cheol; Kim, Sung-Wan; Lee, Kyung-Hoi
1659	The Effects Of An Airtightness Prescriptive Regulation Code In A Developing Country: The Chilean New Housing Airtightness Requirements And Its Effects On The Timber Construction Quality	Victorero, Felipe; Mendez, Daniela
1184	¿Innovation or Effectiveness? Using a Competition as a Teaching Tool	Herrera-Limones, Rafael; LopezDeAsiain, Maria; Borrallo- Jiménez, Milagrosa; Roa-Fernández, Jorge; Hernández-Valencia, Miguel

S34 SESSION 34 page 1057

Sustainable Buildings and Technology (4) | ANDES HALL | Chair Barbara Widera

1615	Photocatalytic Wall Shingles from Recycled High-Density Polyethylene. An Environmental Solution to Remove Atmospheric Gaseous Pollutants in Urban Areas	Carbonnel, Alexandre; Perez, Hugo; Gavilanes, Dayana; Loyola, Mauricio; Moreno, Cristobal; Escobar, Daniel; Jiménez, Maria Paz; Murillo, Herman; Chacón, Carla; Formandoy, Yanara; Masferrer, Roxana
1599	Calculating Algorithm to Estimate the Hygrothermal Performance of Vegetation for Green Screen Façades	Vásquez, Claudio; Da Rocha, Camila; De La Barra, Pedro Pablo
1559	Thermal Insulation Using Sheep Wool: Social, Environmental And Economic Impact Of Large-Scale Use In Social Housing	Nunez Berte, Alejandra Elena; Evans, John Martin; Fernandez Luco, Luis
1158	Analysis and Assessment of the Global Warming Potential of Solid Wood and Timber Frame Construction Based on a Life Cycle Assessment Including Forestry Production and Transport Options	Stanger, Nico Frank; Findeisen, Erik; Steinbach, Sven
1344	Vacuum-glazed Windows: A Review on Recent Projects' Methods, Results, and Conclusions.	Pont, Ulrich; Schober, Peter; Wölzl, Magdalena; Schuss, Matthias; Haberl, Jakob

S35 SESSION 35

page 1087

Challenges for Developing Countries (3) | RAPA NUI HALL | Chair Alessandra Prata

PLEA STGO 2022

PLEA STGO 2022: WILL CITIES SURVIVE?

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE URBAN DEVELOPMENT

DAY 01
11:15 — 12:45

CHAIR
AGNESE SALVATI

PAPERS
1669 / 1329 / 1430 /1458

1ST PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Modelling resilient construction through a mixed-use development within an urban environment

MARTIN MURRAY[1], SHANE COLCLOUGH[1], PHILIP GRIFFITHS[1]

[1] Department of Computing, Engineering, and the Built Environment, Ulster University, Shore Road, Jordanstown, Belfast, Co Antrim, BT37 0QB. Corresponding author: Murray-M46@ulster.ac.uk

ABSTRACT: The study is an investigation into what constitutes resilient construction in 2022, understood through the metrics of a mixed-use development within an urban environment. The context is the climate change emergency and the pressing need to successfully implement the 'nearly' Zero Energy Buildings (nZEB) policy across the EU construction industry. This policy in Ireland is still evolving however significant issues of performance definition and procurement have already been identified. The paper identifies a performance bonus to be achieved by expanding the nZEB Policy Platform to encompass an energy standard for urban areas which for new buildings is at least 'energy-plus'. The benefits accruing include long life buildings, with an inbuilt flexibility of use and a demand side support for our power grids. To progress, energy use needs to be perceived as part of a larger system. The metrics of success need to change from calibrations of individual assets through a 'Building Energy Rating', (BER) to a more expansive focus on reducing 'Greenhouse Gas Emissions', (GHG) at a neighbourhood and community level. This will require integration of our communities into an energy system reflecting 'minimal entropy', 'closed loop resource allocation' and clearly defined criteria for measuring same.

KEYWORDS: nZEB, EU Policy, Resilient Construction, Community Energy, Energy-plus

1. INTRODUCTION

It is an undoubtable fact that significant change will be required if we are to successfully transition our energy system and reduce carbon emissions to zero between now and 2050.

Transitions by their nature can be either distressing or energising, depending both on preparedness and establishing a clarity of response. This paper is concerned with both these necessities, through a consideration of how we need to build to express preparedness, and how we might bring community value to what we do, in order to clarify our response to both the energy transition and energy change. The paper is framed within the context of a mixed-use case study project, located in an Irish market town, which is currently in design development. The purpose of the case study is to establish a template development which through deliberate design, can be long serving, flexible in use and resilient to the coming energy use transformation.

Resilience is commonly characterised by a robustness to deal with change or recover quickly from difficult circumstances. The premise of the case study is that resilience in energy terms, within Northern European countries starts with fabric, air tightness and controlled ventilation [1]. Resilience is also infectious, as an energy optimised development allows for a reduction in local energy use, can help to support local microgrids, expand and optimise energy boundaries and promote a culture of energy understanding which can encourage low carbon urban lifestyles. The energy-plus project therefore aligns to a central theme of the PLEA 2022 conference which is consideration of the whole idea of a city, and the way by which we might inhabit and use them, thus generating an increased understanding of the need to live within the confines of planet earth, protect social equalities and reduce carbon emissions. In such a way the definitive inflection-point of what constitutes a sustainable city or urban environment might well emerge.

The theme of the project is also one of urban regeneration. In Ireland, like towns and villages throughout Europe, the traditional 'main' street and the multitude of buildings and uses that had evolved there, have slowly dissipated online or have been transplanted to car-friendly suburban locations. This commercial transformation made sense in the context of cheap and readily accessible fossil fuels, however as all activities now become reliant on renewable sources of energy, as we begin to consider our broader carbon budgets, both public and private, then this pattern of land use is open to reconsideration. The project therefore also endeavours to model resilience construction from the point of view of the built heritage of our towns and villages and a revaluation of the embodied or 'up-front' carbon intensity which they represent

2. PROJECT DESCRIPTION

The development case study consists of a mixed-use, low-rise development of three campus-style buildings (492m^2) located on a 600m^2 back-lands urban site, located within an Irish country town. The research highlights the importance of such sites in the revitalisation of our towns and villages and as operational fulcrums around which the patterns of a low carbon lifestyle will mature.

Figure 1*: Aerial view of proposed case study.*

The site is located within an architectural conservation area (ACA) and has all the restrictions and challenges emblematic of such locations, including a strong architectural context, close proximity of adjacent structures, and restrictive town planning criteria. The three buildings have been designed to be flexible in both plan and section to facilitate research into the implications for fabric and building services of a long-life, loose fit design strategy, and the energy profiles and energy demands which such alternative future uses, (either as retail, offices or residential), might give rise to, (Fig 1).

The research aims to answer one specific overriding question however which is, to assess whether across a range of metrics, (such as primary energy use, IAQ, PV use, resource allocation, and utilizing materials of low embodied carbon, reflecting a circularity of supply), the current nearly zero energy standard (nZEB) as practiced in Ireland, is an adequately resilient methodology for modelling buildings required through to 2050.

The alternate is a significant step change in nZEB performance to reduce our GHG emissions in transition and reach zero emissions as soon as possible. The validity of the question and the context for its consideration lies within the myriad of challenges which the climate emergency has given rise to, such as impending time constraints, priority of resource allocation, potential social inequalities, and associated fuel poverty. All allied within the capacity limitations of our electrical power grid.

The context of a specific case study is useful in understanding such complex scenarios as it provides a useful fixed data set for understanding the wide variety of interdependence and criticality of relationship between the project variables. In such a way also the case study links academic research to project implementation, and the particularities of construction to an understanding of the power grid. The case study frames the data to be analysed.

3. LITERATURE REVIEW AND CONTEXT

There is an emerging body of academic literature which acknowledges that for a mild maritime temperate climate area such as Ireland, the availability of low carbon operational energy has been effectively solved by the approaching adequacy of decarbonised grid electricity. The academic literature increasingly identifies however that the parameter of constrain is no longer the low carbon operational energy itself, but rather the use of resources which embody carbon emissions and therefore need to reflect a circularity of use and reuse [2].

Figure 2: *Ratios of operation energy (carbon emissions) vs. whole life embodied carbon emissions. (Hone Energy))*

The reason for this is the obvious inverse relationship between low operational energy and the high volume of materials required to achieve that performance. Across a range of building types, it is noted that the operational emissions have begun to be dwarfed by the whole life embodied carbon emissions necessary to achieve such performance, (Fig 2). Concerns have always been expressed against the temptation to use high embodied carbon solutions to achieve low operational energy, driven by cost optimality and short term pay back criteria [3].

Obviously, such an approach is not optimal and defeats the very purpose of achieving long-term sustainable emission reductions. The long-term view requires high embodied carbon insulating materials to be substituted by bio-based solutions which can be regeneratively grown. We do however need time to allow for a circularity of material supply to emerge not just for insulation but across all building materials. Therefore, the new buildings constructed now, need to create an 'operational energy space' within which these product supply lines can be established. Energy-plus projects are therefore of critical benefit within urban areas to support and supplement local grid capacity and support local micro grids as they might emerge. The case study project will analyse how energy use across a campus of buildings can combine not just an optimality of operational use with resource use but rather a resilience level of performance.

4. RESILIENT CONSTRUCTION

The research intended is focused on achieving a net-zero energy campus. The research data will emanate from using a variety of energy standards principally, the 'Domestic Energy Assessment Procedure' (DEAP) and the 'Non-Domestic Energy Assessment Procedure' (NEAP) which are the national predictive performance softwares for nZEB, and the Passive House (PH), Planning Package (PHPP) analysis software. The intention is to compare the predictive and operational effectiveness of these standards.

All geographical locations are climatically unique and therefore the energy strategies for particular countries are unique. As the literatures make clear the rolling out of nZEB as an EU standard has had to overcome significant climate disparity across member states. [4] What is common to all countries, however, is the political distaste for bringing forward radical changes and therefore countries have been allowed to set their own standards based on cost optimality criteria within each member state. By aligning in this way with market values, it is inevitable that a policy intervention such as nZEB, becomes a captive victim of the prevailing economic and political culture that legislates downward. In turn this allows the marketplace to verify the validity of policy direction and determine the limited breath of its vision.

This is regrettable and it is in this respect that the nZEB legislation in Ireland is in 2022, questionable as to its fitness for purpose. It establishes no more than an asset value for buildings and creates a technological 'solution' for low energy buildings derived from what the market can sustain. However, as the literatures also indicate the resulting energy use within nZEB buildings has proven difficult to predict, data has been misleading and buildings represent potentially a greater use of resources, beyond any acceptable notion of optimality [5]. It thus creates an ideal scenario for widening inequalities as resources are loss and finances eroded.

It is clear from the literatures also, that a market driven economy by its nature can only define a problem by the parameters of its own value system. In the context of an 'emergency', a market dominated response which is focused on access to energy, cost, technology, and a lack of perceived value in community and manual labour, will inevitably fail to define the emergency cogently. This realisation also sets in place the question posed by De Masi et al (2021): *Is the most energy efficient solution also the best one in term of environmental sustainability* [6].

Figure 3: *Ground floor plan of development.*

4.1 Beyond nZEB

That there is an urgent need to proceed beyond the current nZEB cost-optimality metrics and the limiting energy boundaries, to a more socially equitable solution is also emphasised by the definition established by the Institute for Sustainable Communities, for what the hallmarks of a sustainable community might be. Effectively: - *"A sustainable community is one that is economically, environmentally, and socially healthy and resilient. It meets challenges through integrated solutions rather than through fragmented approaches that meet one of those goals at the expense of the others"*, [7]. Sustainability through this lens is one of community, shared resources and enlarged energy boundaries.

The case study sits within these aspirations of balance, just as it sits also within the policy limitations of the nZEB strategy, as currently formulated and legislated for. However, the intention of the case study data is to indicate how a broader leadership nZEB standard would create a greater equality and optimality of energy use between supplier and user. In one sense this relationship between supplier and user is already happening through the roll out of smart metering which allows real time engagement between the energy user and the local supply grids.

A danger of course is that, just as happened previously with another Irish utility, (water), metering can be seen as a retrograde step, reflective of a strictly technological solution (with nefarious undertones of control), against what is first and foremost, a green transition. Whether such a green transition is directly solvable, by the technological attitude to energy management prevalent in neo-liberal societies, is fundamentally what is now under debate.

4.2 Beyond technological solutions only.

Clarke and Sahin-Dikmen, (2020) [8] take up this theme in their consideration of an alternative labour-centred strategy as an antidote to a technical-driven green transition. Their research investigates trade union response to the green transition across four countries. Their research recognises and tabulates the vocational educational training (VET) required within the construction industry which would constitute a major transformation. Referencing Clarke et al (2019), Clarke and Sahin-Dikmen identify the fact that the construction industry across Europe, and in particular, in Anglo-Saxon countries, is burdened with long standing problems of vocational, educational and training expressed as skill shortages, insecure employment and fragmentation of the construction process, all prevalent aspects of the industry in Ireland.

Clarke and Sahin-Dikmen (2020) also identify the irony that exists between the social potential of a just green transition and the ecological modernising of an industry without concern for the quality of labour and employment involved nor for worker agency in shaping this transition. It is ironic that while UN climate change declarations are linked to inequality, the probability of this not translating into national programmes is as identified by Sweeney (2015) deeply problematic [9]. In this regard Clarke references Biernacki (1995), who within a deeply historic study usefully differentiated between 'labour power' and 'embodied power'. To contemporise the distinction. The former is offered to be reflective of labour's potential, while the latter is simply defined by cost optimality. The former requires social relationships and organising structures, the latter seems to reflect the (EU) vision of a change, instigated primarily through renewable technologies and energy efficiency measures only, lacking in an ambition to exploit the opportunity for vocational training and careers. It is an open question now, as to whether ecological ambition within the existing neo-liberal economic order can flourish; the physics of sustainability may add up, but if the political mood fails to capture the societal vision, little progress will be made other than progress that facilitates neo-liberal value extraction.

5.0 RESILIENT CONSTRUCTION

The resilience of the proposed development is derived from an underlying belief in the certainty of the law of subsidiarity, commonly known as 'small is beautiful' [10]. Ironically it is also an underlying principle permeating through all EU laws. It is based on the principle of facilitating decision making and therefore independence at the lowest appropriate level of authority. In energy terms this reflects localised energy independence, derived in the first instance from renewable energy generation on site.

5.1 Energy independence

The development has been designed to combine roof mounted PV use with optimal orientation. The electricity generated will be used to maximise self-absorption. This takes the form of battery storage, a shared electrical car scheme, heat pump operation and thermal stores. However, the key to energy independence is optimising generation benefits by controlling waste at source. In this regard the construction utilises PH standards of fabric and air tightness to minimise heat loss.

Table 1:
Predictive annual solar array (160m^2) output (kWh/yr)

Month	(kWh)	Month	(kWh)
JAN	560	JULY	2,055
FEB	935	AUG	2,616
MAR	1,682	SEPT	1,682
APR	2,429	OCT	934
MAY	2,803	NOV	374
JUN	2,429	DEC	187

Note*: Monthly comparison of the case study 160m2 of PV array output, across the year (reflecting optimum orientation and inclination resulting in an average output of 117 kWh/yr/m^2).*

5.2 Use independence

The improved fabric performance creates a reduced variability of energy use within all the buildings, regardless of end use, all of which allows a more accurate understanding of overall energy use on the site. More importantly, such 'energy loose fit' will allow a variety of different uses to occur within the buildings in the years ahead.

In this context the research wishes to identify if an operational energy 'sweet spot' exists which could underpin an *Urban Energy Metric (UEM)*. Such an optimality would facilitate the optimal development of inner town and village sites; would help to define our future understanding of primary energy, its primary energy factor and what use profile it reflects. Not only is primary energy not defined rigorously across standards, (PH for example includes plug loads while nZEB does not, PH allows for 24-hour temperature comfort while nZEB is defined by specified periods of occupancy only and internal temperatures), it also requires redefining now as the primary energy factor of the electrical grid reduces toward 'one', to reflect 100% renewables.

Table 2: *A comparison of the predictive energy use across a range of different end uses, set against yearly PV energy production. The energy use is derived from benchmarks only and are based on common energy use estimates for different building types derived from overheating criteria.*

	Predictive annual primary energy use (kWh/yr) measured across a range of standards nZEB & Passive House. (Operational benchmarks only used)				Solar Array 160 m²	Min. Yearly Shortfall (kWh/yr) and %	Max. Yearly Shortfall (kWh/yr)
Unit No.	nZEB Dwellings (BER: A2) (50kWh/m2/yr	nZEB Non dwelling¹ (Offices) 150kWh/m2/yr	PH* (Classic) (120** kWh/m2/yr)	PH* (PER)² (60 kWh/m2/yr)	(Area & Output)	(% reflected of total)	
492m2 Total (Units 1 to 6)	24,600 (kWh/yr)	73,800 (kWh/yr)	59,040 (kWh/yr)	29,520 (kWh/yr)	Total Output 18,686 kWh	5,914 kWh	55,114 kWh

Note: *(*PH = Passivehouse) (**120kWh/m2/yr = Pre-2015 'Classic' PH Primary Energy Use Definition. 1: - Reflecting office use at 150kWh/m2. 2: - PER: Reflecting altered Post-2015 Primary Energy Renewable calculation as per PH. 3: - PV % per unit generated, indicating units 3, 5 and 6 would qualify as PH premium standard unit, (subject to full modelling).*

In Table 2 above, in order to maintain definition alignment in a general way between nZEB and PH, the old primary energy for the pre-2015 'Classic' PH is referenced, which is 120kWh/m2/yr. This has, since 2015, been revised into a PER metric which equates to an energy use of 60kWh/m2/yr. This is the Primary Energy Renewable (PER) definition of Primary Energy now used by PH, to reflect changing primary energy factors and the transitioning of the power grid to becoming carbon neutral [11].

In the circumstances of a carbon neutral power grid, no cost optimality assessment could justify any renewable energy interventions, unless the criteria were altered, and the demand side of the grid is modelled to reflect the benefit it can bring. The functional (comfort and economic) criteria for Passive House are a very good starting point for a completely renewable worldwide energy supply.

5.3 The building use profile

Buildings designed and constructed now must meet the energy performance needs of 2050 regarding zero carbon. A response to resource depletion would require that buildings be capable of easy transformation to different uses over their lives thus maximising their ongoing utility. New design therefore needs to deliver buildings with an inbuilt flexibility of use and reuse, to ensure long life and access to sustainable energy. Where such design strategies are grafted unto urban areas, including our existing towns and villages, then these buildings take on the added potentiality of an urban energy leader, compensating in some situations for heritage buildings that may never achieve a viable energy standard to facilitate either comfort or economic use. This necessitates that the planning process itself recognises these design needs within its development plans, to promote buildings with energy credentials that have the potential to support the effective and balanced operation of community energy, either through the local power grid or district heating.

With the nZEB strategy in Ireland focused on individual buildings achieving energy labels in a cost optimal way, (with accompanying performance gaps), then our towns and cities will become submerged in power hungry heat pumps, an exponential growth in EV charging, and an increasing internet driven plug load; all matters not yet extrapolated through to their impending effect on our power grid environment and the cash strapped occupants of these nZEB buildings.

New developments such as the case study may, if designed with energy in mind, facilitate solutions to these emerging energy realities. Despite significant climatic variation across the European Union (EU), the nZEB implementation has helped in promoting a unified approach to tackling a reduction in operational energy. However, the increased central role of resource utilisation suggests that our new nZEB buildings must be geared toward the creation of optimal performing flexible buildings both to justify their use of resources and ensure that their future carbon profiles will meet 2050 standards directly or be intrinsically ready to do so without significant modification.

Table 3 below indicates a variety of energy use profiles across the six units using nZEB benchmark energy profiles to reflect the operational energy. It is notable that the nZEB profile allows a 600% differential across the site with the lowest energy use reflecting residential use. It is notable also that in the UK there is an active reconsideration of commercial uses (as defined by planning), to a more explicit definition of building types, according to their energy need for space and water heating. Undoubtably this strategy brings closer the concept of a shared typology between dwellings and small non-dwelling buildings and suggests that in line with this research the energy line of differentiation between such buildings in an urban setting is becoming increasingly vague. It is noted also that since the emergence of Covid, IAQ as a building metric now transcends building use. Commonly used in regard to commercial buildings only, it is now considered critical in domestic settings, and so our buildings of the future will require careful, ventilation in accordance with more advanced energy standards beyond nZEB, such as Passivhaus.

Table 3:
A comparison of the predictive energy use across all units reflecting a two potential end uses. The monthly energy use can vary by over 500% depending of end uses.

Table 3: Primary energy profile per unit across different uses – nZEB Profiles (Benchmark energy use estimates only)							
Use	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Totals
	(105m2)	(79m2)	(110m2)	(42m2)	(78m2)	(78m2)	(492m2)
Residential (BER:A2 50kWh/m2/yr)	5,250	3,950	5,500 €880.00	2,100	3,900	3,900	24,600
Retail (338 kWh/m2/yr)	35,490	26,702 €4,272.32	37,180 €5,948.80	14,196	26,364	26,364	166,296 (€26,607.36)
Annual PV² (kWh/yr)	1,121	3,363	5,980	zero	4,111	4,111	18,686
Highlighted units	Grey colour indicates the probable optimal usage in regard to rental income and mixed use which equates to 66,936 kWh/yr (5,578 per month).						

6. CONCLUSION

Given the uncertainties emerging in regard to embodied carbon costs as raised by Rovers (2019) [12], the potential of 'business as usual' (BAU) solutions to create technologies and materials masquerading as positive contributions to energy conservation whilst creating negative emissions is not to be overlooked. BAU always reflects the priorities of big business as noted by Morningstar, (2019). To invest in BAU technologies and energy generation might well be perceived as 'value-added' by definition, but could be more accurately defined as 'value-extraction', in the context of carbon use.

These are all important considerations given the global nature of climate change. Smil (2017), (Pg. 386), [13] identifies how commodities have become absolute identities dominated by a small number of controlling companies. Therefore, by delaying our response to climate change we have in fact created the ideal scenarios for 'rent-taking' as defined by Christophers (2020) [14]. Any problem that if tackled early, and with long term aims would have been one of value creation, in the hands of private agencies with time constraints, it unfortunately becomes an opportunity of value extraction. The case study proposed and analysed, wishes to set a standard that can be both equitable in energy use and reflective of energy use as a 'commons' good.

By addressing whether this changed relationship is conducive to aligning energy and social policy, the project also reflects a central theme of the PLEA 2022 conference, which is to question whether energy-equality and social-equality can be aligned in a world of diminishing resources, commercial imbalances, and technological driven solutions. The emerging analysis is as yet lacking in such detail as to render it fit for interpretation. However, the overwhelming impetus shows that a campus of buildings sharing energy has the potential to significantly minimise general demand through improved fabric, thus reducing peak demand, heat pump combined with optimised PV generation and **battery storage** allowing a meaningful sharing of surplus energy generation across campus buildings and electrical vehicle (EV) usage.

Such developments can in urban design terms be 'greater than the sum of their parts', supporting localised electrical power grids, and localised low carbon lifestyles, and creating energy resilience as our towns and villages transition to a zero emissions future.

ACKNOWLEDGEMENTS
This paper is supportive of ongoing Ph D research at the Ulster University, Jordanstown. I am grateful to the University for their academic sponsorship and to my supervisors, Dr. Shane Colclough, and Prof. Philip Griffiths, for their ongoing support.

REFERENCES
1. International Passive House Association. https://passivehouse international.org./
2. Sturgis Carbon Profile and RICS (2017).
3. Moran, P., Goggins, J. Hajdukiewicz, M., (2017). *Super-insulate or use renewable technology?* Energy and Buildings, 139(2017), pp.590–607. Available://dx.doi.org/10.1016/j.enbuild.2017.01.029.
4. EPRS Review, (2016) *Implementation of the Energy Efficiency Directive.* (2012/27/EU), *579.327, April.*
5. Colclough, S., O Hegarty, R., Murray, M., Lennon, D., Rieux, E., Colclough, M., Kinnane O., (2021). *Post Occupancy Evaluation of 12 Retrofit nZEB dwellings. Results from the Irish nZEB101 project. (TBP).*
6. De Masi, R., F., Gigante, A., Vanoli, G., P., (2021) *Are nZEB design solutions environmentally sustainable? Sensitive analysis for building envelope configurations and photovoltaic integration in different climates. Journal of Building Engineering Volume 39, July 2021, 102292.*
7. Blueprint for a Sustainable Economy. By D. W. PEARCE and E. B. BARBIER London: Earthscan, 2000, 273 pp. L12.95 (pbk) ISBN 1 85383 515 3
8. Clarke, L., Sahin-Dikmen, M., (2020). Unions and the green transition in construction in Europe: Contrasting visions. *European Journal of Industrial Relations. https://doi.org/10.117/0959680120951705*.
9. Sweeney, S., (2015). Green Capitalism Won't Work. *New Labor Forum. 2015;24(2):12-17. doi:10.1177/1095796015579693*
10. Schumacher, E. F., Small Is Beautiful: A Study of Economics as If People Mattered. (1973) Harper Collins.
11.https://passipedia.org/basics/energy_and_ecology/primary_energy_renewable_per
12. Rovers, R. (2019). People vs Resources. *(Eburon, Utrecht).*
13 Smil, V., (2017). Energy and Civilisation: A History. *Cambridge, MA: MIT Press*
14. Christophers, B., (2020), Rentier Capitalism. Who owns the economy and who pays for it? *Verso.*

PLEA SANTIAGO 2022
Will Cities Survive?

Water Sensitive Urban Design systems thermal behavior II

Thermal analysis of WSUDs which do not retain water

MAR PÉREZ CAMBRA [1] DOLORS MARTÍNEZ SANTAFÉ[1] JOSEP ROCA CLADERA[1]

[1] Technical University of Catalonia (UPC) Barcelona School of Architecture. Department of Architectural Technology I (TA), Centre of Land Policy and Valuations (CPSV).

ABSTRACT: There is a global trend to urbanize with Water Sensitive Urban Design systems. WSUDs try to integrate the urban water cycle in the urban design to improve the environmental behavior in the urbanization of the cities. Focusing on thermal behaviour and climate change effects mitigation, the question is: can WSUDs improve the environmental behavior of the cities while water cycle recovering through WSUDs? Some conclusions were exposed in CTV'18 related to thermal behavior of WSUDs with a high specific heat due to their water retention; however, this is not always the case. There are other parameters which explain thermal behavior for those WSUDs without the possibility to retain water where a high specific heat doesn't exist. New measurements have been done during 2021 to go deeper into the parameters that affect thermal behavior of that second group of WSUDs such as: green and building shades, albedo, granulometry, and calculations related to thermal inertia have been done to compare those parameters and see how they can affect to WSUDs thermal behavior. Thus, this communication will expose these results and stablish a conclusion on how these parameters can improve thermal behavior to reduce surface temperatures and mitigate this effect of climate change.
KEYWORDS: WSUDs, thermal surface, climate change, thermal comfort, landscape.

1. INTRODUCTION

Population growth is increasing in urban areas and traditional drainage and supply systems fall short for this new situation. Besides, climate change brings floods and water scarcity worldwide. In this context WSUDs are implemented to mitigate these climate change effects.

However, when we use WSUDs we might be increasing surface temperatures if we don't stablish selection criteria regarding climate comfort.

The subject matter of this paper is "sustainable urban development" and its aim is to stablish the parameters which can mostly affect surface temperature materials.

This communication is part of a broader research which first part was published in a previous congress: CTV'18 (International Conference Virtual City and Territory). [1].

Data exposed in CTV'18, which were collected during two years and a half (from July 2016 to December 2018) was focused on WSUDs which could retain water. The cause is that while researching we could check that thermal surfaces which could retain water usually had a lower temperature in the hottest hours of the day than the environmental temperatures.

What happens then with surface temperatures amongst all WSUDs which could not retain water? I.e.: all those which need a moderate or fast percolation of rainwater runoff and its granulometry has a permeability coefficient above 10^{-9} m/s according to the FAO permeability coefficients table[2]. Systems with these materials are efficient in decreasing runoff and floods; however, as they infiltrate water with a certain speed there are other parameters different from specific heat which influence in thermal comfort.

In 2018 research a lot of questions arose and remained up today. Thus, how can influence other parameters such as: thermal inertia, shades effect, granulometry or albedo in surface temperatures?

2. METHODOLOGY AND MATERIALS:

To answer to these questions this communication brings new measurements and calculations.

The methodology has been in situ measurements of five different parameters of construction systems which are part of an existing WSUD in Barcelona or materials that can take part of WSUDs (such as infiltration basins, french drains, retention basins, etc…). These parameters are: surface temperatures with a thermal camera, wind speed with an anemometer, relative humidity with a hygrometer and the albedo with a lux meter. Thermal inertia will be derived through calculations.

Data were collected in Barcelona in three different sites and two days without 24-hour previous rain (named as "dry days"), as water retention is not part of this research. Barcelona is a Csa area according to the Köppen-Geiger Climate Classification map.

The first two sites are two parks built by Bagursa, and were measured in the same day:

1.Can Cortada: 41°26'04.0"N 2°09'04.7"E

2.Cristóbal de Moura:41°24'34.3"N 2°12'15.9"E

The third site is in a terrace of Architecture School of Barcelona (ETSAB, UPC, 41°23'03"N 2°06'50"E). It consists of 340 kg of gravels divided in 17 bags of 20 kg and composed by three different types of gravels and three different granulometries per each type (except for one of them for which a third type of granulometry was not available). Gravel is a material often used for different types of WSUDs. The types of gravels are: volcanic, sedimentary and metamorphic stones.

The analysis of the behavior of these different types will lead us to conclusions about which parameters have larger influence in surface temperatures.

3.Architecture School of Barcelona (ETSAB, UPC): 41°23'03"N 2°06'50"E

The two parks were measured on October 1st 2021 and the gravels in November 19th 2021. The optimum dates for the measurements would have been during the summer season; however, it was impossible to have nor the machines nor the permissions in one of the sites to measure before. In any case, the trend obtained is similar to 2016-2018 measurements so that conclusions about the influence of some parameters for the surface temperatures can be stablished.

In 2016 and 2018 we could see that systems which retain water or are in direct or indirect contact with water have a surface temperature in summer which is always lower than the environmental temperature in the hottest hours of the day. The main examples analyzed then were the vegetated surfaces of the infiltration basins of the WSUDs built in Can Cortada and an existing blue roof and a blue roof prototype (in "La Fábrica del Sol", Barcelona), when there was water in the blue roof. The difference measured, for the Can Cortada greened infiltration basin area, between surface and environmental temperature (Ts and Te) on August 28th, 2016 was 15.0°(being Ts always lower than Ts) and a similar difference between environmental and surface temperatures was measured 15 days later, on August 12th.

In the case of "La Fábrica del Sol" blue roof, with an open joint artificial stone surface, showed Ts up to 16.4°C lower than Te and for the blue roof vegetated Ts was up to 15.0°C lower than Te on September 14th 2016. Therefore, water arose as a first parameter to consider in order to lower WSUDs surface temperatures, due to its specific heat (4.1813J·kg^{-1}·K^{-1}). This effect didn't happen for the systems which couldn't retain but percolate water in a moderated or fast way.

Which other parameters can we analyze which can mitigate surface temperatures?

2.1 Building shade effect:

To see the building shade effect, two WSUDs shave been chosen: draining concrete and a soil pit tree (Figure 1 and Figure 2, left and right side pictures respectively).

Figure 1: *Sunny (left side picture) and building shaded (right side picture points #1' and #2') soil pit tree and draining concrete of Can Cortada (right side point# 1 and point #2)*

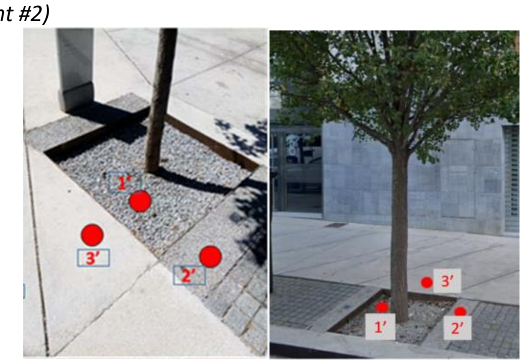


Figure2: *Sunny soil pit tree of Can Cortada (point# 1')*

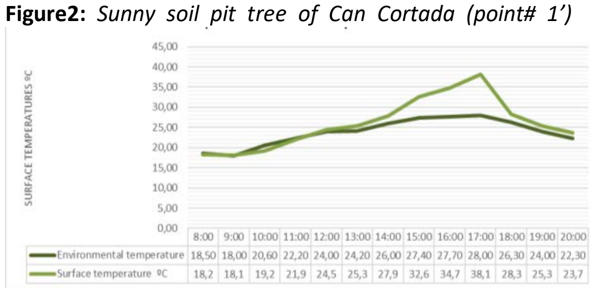
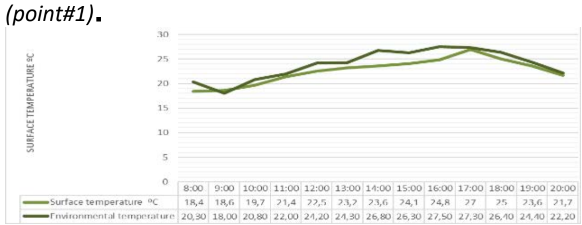


Figure 2 shows the difference between Ts and Te in the whole day sunny soil pit tree. In the hottest hours of the day surface temperatures are 10.1°C above Te in October 1st 2021.

On the contrary, the whole day, for the shaded soil pit tree (Figure 3), Ts was always below Te with a maximum difference of 3.2°C at 13:00h during the same day.

Figure3: *building shaded soil pit tree of Can Cortada (point#1)*.



It's remarkable that this difference is higher in summer. During the summer of 2016, Ts (15.7°C) was 17.1°C lower than Te (32,8°C) in the shaded area on August, 24th 2016 (hotter date than October 1st) while, in this case the same sunny soil pit tree had a Ts (48.8°C) 12.3°C higher than the Te (36.5°C) at 17:00h.

Draining concrete shows a similar thermal behavior than the soil pit tree in the same day (Figure 4): in the hottest hours of the day Ts are 8.0°C above environmental temperature while shaded draining concrete on October 1st 2021 is 4.0°C underneath Te (Figure 5).

Figure4: *Sunny draining concrete of Can Cortada (point # 2'of figure1)*

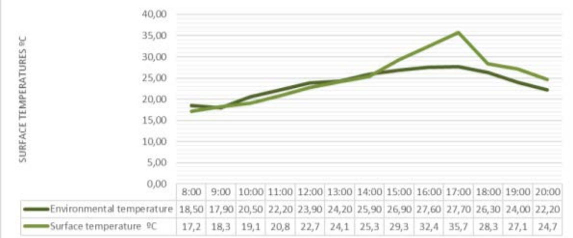
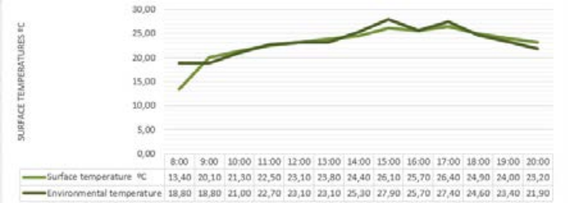


Figure5: *Building shaded draining concrete of Can Cortada (point # 2 of figure1)*



During the summer the trend is the same but, as it happens with the soil pit tree, the difference of the building shaded draining concrete and the sunny draining concrete measured in August 24th of 2016 is higher.

Ts (14.8°C) was 18.0°C lower than the Te (32.8°C) in the building shade while Ts (45.3°C) was 9.3°C higher than the Te (36.0°C) in sunny conditions.

2.2 Green shade effect:

In this case non-infiltration basins of both parks were under building shades but some of the WSUDs were in the shade and green shade effects for infiltration basins with gravels and sand could be measured.

Figure 6: *Sunny infiltration basin of Can Cortada*

Figure 7: *Gravels in sunny infiltration basin (point#1)*

This similar pattern in a sunny situation in October 1st 2021, during the hottest hours of the day, shows that for gravels (#1 of the infiltration basin), Ts is 9.5°C higher than Te.

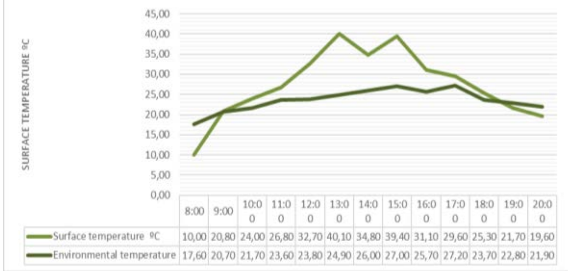
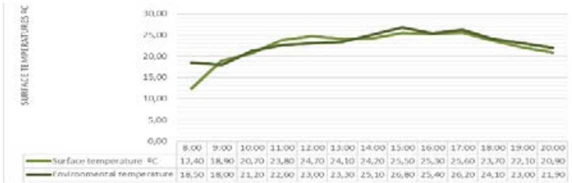
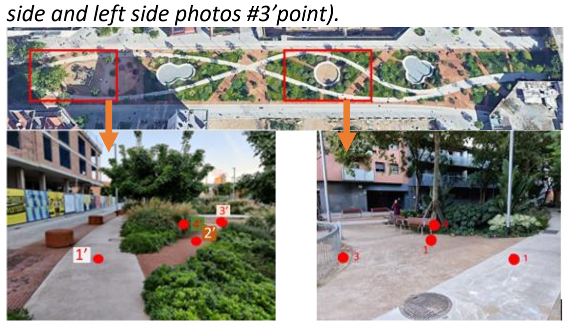


Figure 8: *Green shaded infiltration basin (point#1' Upper photo in right side of Figure 9).Cristóbal de Moura.*



In the shaded situation, Ts is similar to Te and not so high as in the sunny situation during the same day as in Figure5.

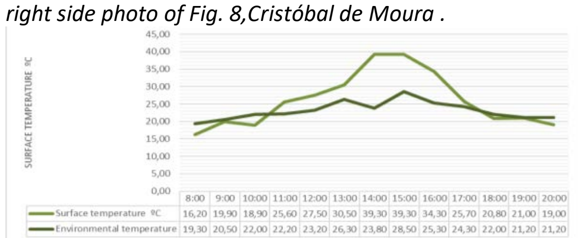
Figure 9: *Cristóbal de Moura Park (green shaded sand pervious surface in lower right and left side photos and #3point and sand sunny infiltration basin in upper right side and left side photos #3'point).*



This sand pervious surface is shaded by a big platanus hispanica which shade lasted during the measurements.

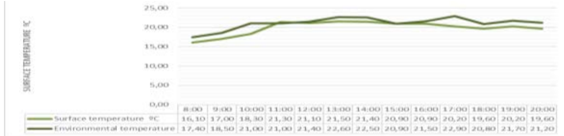
In this park other construction systems were measured such as a sunny and a shaded gravel infiltration basin and also the sunny and shaded brown draining concrete (points #1 and #1').

Figure 10:*Sunny sand pervious surface (point #3'). Upper right side photo of Fig. 8,Cristóbal de Moura .*



Again, for the sunny situation, Ts (39.3°C, maximum) is up to 15.5°C higher than Te (23.8°C) also in August 10th 2021.

Figure 11: *Green shade in sand infiltration basin (lower right side Figure 9 photo, point #3) Green shaded sand pervious surface (point#3).Cristóbal de Moura.*



In this case Ts is 2.70°C (maximum) underneath Te showing the same pattern seen before.

Although gravel infiltration basins in sunny and green shade conditions were also measured, results in the shaded situation are not very reliable due to the fact that the shade was moving from the same area because of the discrete canopy.

The comparison between grey and brown draining concrete will be shown in next section.

2.3. Granulometry and albedo.

Figure 12: *Volcanic, sedimentary and metamorphic gravels with different granulometries.*

These measurements were taken in November 5th 2021. They couldn't be taken in summer for different reasons: in August the Architecture School is closed and during the rest of summer months nor the tools to measure, nor the gravels nor the weather conditions were gotten. Nevertheless, a trend related with albedo and granulometry has been detected.

2.3.1. Volcanic stones:

In this case we have two type of volcanic stones: the natural volcanic stone and the red volcanic stone. Both of them show a similar albedo: natural volcanic stone has an albedo of 12,87% and red volcanic stone has an albedo of 12,15%. It was measured with the luximeter the same November 5th 2021. In both cases thermal intertia is also similar due to its origin and it's 3158,32 J m^{-2} K^{-1} $s^{-1/2}$. Thus, the parameter which can affect surface temperature is Granulometry. In this case, granulometries are 5-10 mm, 10-25 mm and 25-50 mm for both types of stones. In both cases stones of 5-10 mm are the ones that get higher surface temperatures once relative humidity of the stones is in its lower point. Gravels are in the sunniest terrace of the Architecture School but there were some hours of shade which can be identified in the graphics which are until 10:00 h and some shades from 16:00 h-17:00 h. The pattern is similar in both cases and depending on the granulometry, once are under the sun. In both cases, and as in the whole analysed cases, Ts of gravels are above Te in the hottest hours of the day. The difference in both stones between the 5-10 mm granulometry and the 25-50 mm stone is 12.50°C.

Figure 13: *Natural volcanic stone: Ts (surfaces temperatures and Te (environmental temperatures).*

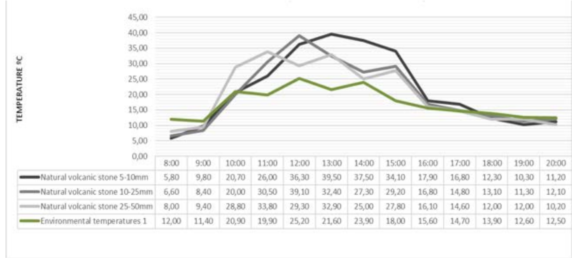
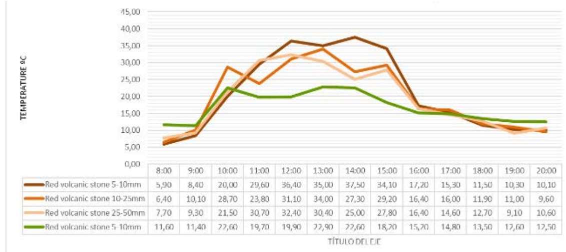


Figure 14: *Natural volcanic stone: Ts and Te.*



2.3.2. Sedimentary stones:

We could obtain two types of sedimentary stones, with granulometries of 6-12 mm and 12-18 mm for the yellow sedimentary limestone and 6-12 mm, 12-24 mm and 24-40 mm for the black sedimentary stone.

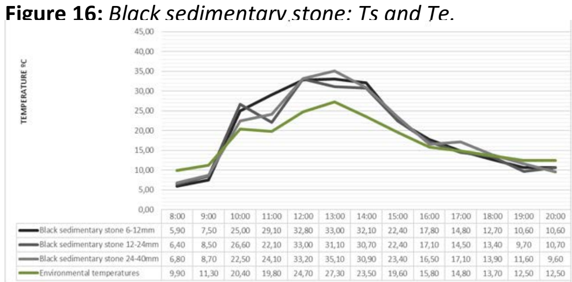
In this case albedo is different: 18,75% for the yellow sedimentary stone and 13,50% for the black sedimentary stone. These values are coherent with a lower maximum Ts measured for the yellow stone (27.60°C) than the maximum Ts (33.0°C) for the black sedimentary stone (without taking into account the 24-40 mm granulometry which couldn't be obtained for the yellow stone).

Again, once both types of stones get the lowest relative humidity they get the maximum temperatures. This fact happens one hour later in yellow sedimentary stone probably due to higher albedo.

According to the parameters obtained from the CTE WEB http://cte-web.iccl.es/ (Código Técnico de la Edificación web about construction solutions) [3] thermal inertia for sedimentary stones is 1628,80 J m^{-2} K^{-1} $s^{-1/2}$ This is surely why maximum Ts for black sedimentary stone is about 4.0°C lower than for the black volcanic stone, for the stones with the most similar granulometries (10-25 and 12-24 mm).

Figure 15: *Yellow sedimentary limestone: Ts and Te.*

Figure 16: *Black sedimentary stone: Ts and Te.*



About granulometry, while the yellow limestone shows a similar trend to the volcanic stone (the one with the smallest granulometry has maximum Ts around 4.1°C higher than the bigger granulometry one), black sedimentary stone doesn't show such a clear trend. If 24-40 mm sample was removed, the intermediate granulometry would show a Ts a bit lower than the 6-12 mm. Unexpectedly, the biggest granulometry for black sedimentary stone is not following the same trend.

2.3.3. Metamorphic stones:

We have two types of metamorphic stones: the pink metamorphic stone, with an albedo average of 19,95% and the red marble metamorphic stone with an albedo of 16,79% measured with the luximeter. This lower albedo must affect the higher temperatures for red metamorphic stones different from pink metamorphic stones (as it happens with sedimentary gravels). Maximum Ts for red marble metamorphic stones is 35.1°C and 24.2°C for pink metamorphic stone.

Both of them show the same behaviour seen up to now: Ts is higher than Te in the hottest hours of the day; however, for pink metamorphic stone, the difference is very similar (which may be due to the higher albedo, a 19,94%).

For metamorphic stones thermal inertia is a bit higher (1944,22 $m^{-2}\,K^{-1}\,s^{-1/2}$) than for sedimentary stones (1628,80 J $m^{-2}\,K^{-1}\,s^{-1/2}$); however, Ts are similar between both stone families. It's remarkable that Ts for pink metamorphic stone are even a bit lower than for yellow sedimentary stones, in spite of thermal inertia values, probably due to the slightly higher albedo of metamorphic stones.

Figure 17:*Pink metamorphic stone stone: Ts and Te.*

Figure 18:*Red marble metamorphic stone stone:Ts and Te*

Again, the smallest granulometry is linked to the highest maximum temperatures in the hottest hours of the day, in both cases. Granulometry, for the intermediate types couldn't be the same for both types of stones (it couldn't be found in the market); thus, the lowest granulometry Ts for the red marble gravel coincides with the intermediate granulometry Ts. It's probably modifying the trend but, the biggest granulometry of this stone is changing the trend. In the black sedimentary stone Ts of the highest granulometry (24-40 mm) is similar to the intermediate granulometry (12-24 mm) Ts. As a last case, we can compare grey and brown draining concrete. These measures were taken in Cristóbal de Moura and Can Cortada Park the same day, on October 1st 2021. Although grey draining concrete albedo average is 17% and brown draining concrete average is 19% they have both a similar thermal behaviour. During the same day, with Te for both of them between 20.0°C and 25.0°C, both of them reach a maximum Ts of 35.0°C ; however, it's true that Ts are higher for brown draining concrete than for grey draining concrete.

2.4. Thermal inertia:

Thermal inertia is the degree of slowness with which the temperature of a body approaches that of its surroundings and which is dependent upon its absorptivity, its specific heat, its thermal conductivity, its dimensions, and other factors [4].

The formula and units are: $I=\sqrt{(k\rho c)}$ [J $m^{-2}\,K^{-1}\,s^{-1/2}$]. [5].

According to this formula and the parameters found in CTE web (http://cte-web.iccl.es/)

[3] thermal inertia for the three groups of stones are:

Figure 22: *Thermal inertia calculations.*

		Thermal Inertia	Density (Kg*m-3)	Conductivity(W/m·K)	Specific heat(J/Kg·K)
Natural volcanic stone	I=	3158,32234	2850	3,5	1000
Sedimentary limestone gravel	I=	1628,80324	1895	1,4	1000
Metamorphic stone	I=	1944,22221	2700	1,4	1400

(Measured in J $m^{-2}\,K^{-1}\,s^{-1/2}$)

3. CONCLUSIONS

There are different parameters which determine surface temperatures. In this study, through measurements taken during three years and a half, we have inferred the parameters most contributing to mitigate climate change by decreasing surface temperatures. The parameters analysed are: the effect of water, the effect of building shades and of green shades, albedo, granulometry and thermal inertia.

Firstly, the effect of water was analysed in CTV'18 Congress. As it has been remembered, systems which retain water in direct or indirect contact with water have a surface temperature in summer which is always lower than the environmental temperature in the hottest hours of the day. The difference between Te and Ts reaches 15.0°C for green surfaces of an infiltration basin (Can Cortada), 16.4°C for La Fábrica del Sol blue roof and 15.0°C for its blue-green-roof. The difference for building shades in soil pit trees is 3.2°C (in October 1st 2021) and 17.1°C (in summer, August 24th 2016). In the case of draining concrete, a similar pattern is obtained: Ts is below Te, 3.2°C in October 1st 2021 and 17.1°C in summer (in August 24th 2016).

Thus, building shade is very effective (the reduction of Ts is similar to that of water retention systems) in case it's required to use soil pit tree or draining concrete, no matter if the color is grey or brown because they have similar albedo.

About gravels of WSUDs, like an infiltration basin, Ts can be underneath Te if it's under a tree shade or ~~if~~ it has a big canopy wich projects a constant shade during the hottest hours of the day, up to 1.20°C in October 1st (Figure 8) and probably higher during the summer. Sand of an infiltration basin behaves a bit better having a Ts 2.7°C lower than Te (probably because of its water retention) in October 1st 2021. The different would probably be higher in summer as it its for the other WSUDs.

In relation to gravels of a WSUDs, granulometry determines a higher Ts under the same thermal inertia and similar albedo as it happens with volcanic stones. Volcanic ones have the highest Ts. Their maximum Ts are double of sedimentary Ts or a third more than the metamorphic Ts. They also have the lowest albedos (12,87% and 12,15% for natural volcanic stone and red volcanic stone respectively while the rest go from 13,5%-19,94%) in relation to the other gravels (Figure 19).

About the sedimentary and metamorphic stones thermal inertia is very similar (1628 J $m^{-2}\,K^{-1}\,s^{-1/2}$ nad 1944,22 J $m^{-2}\,K^{-1}\,s^{-1/2}$) while volcanic stones have 3158 $m^{-2}\,K^{-1}\,s^{-1/2}$ .They also have similar albedos between yellow sedimentary stone (18,75%) and pink metamorphic stone(19,94%) and black sedimentary stone (13,5%) and red marble metamorphic stone (16,79%) while albedos of volcanic stones are 12,87% and 12,15%. Thus, thermal behaviour of yellow sedimentary stone (Fig.15) and pink metamorphic stone (Fig.16) and black sedimentary stone (Fig 17) and red marble metamorphic stone (Fig.18) are similar although they belong to different types of stones. Surprisingly in these three last groups where 24-40 mm gravels were obtained, this granulometry behaves worse than the smaller one achieving Ts higher than the other granulometries Ts in November 5th.

Then, by order of surface temperature decrease, according to the measurements taken in summer and during the beginning of autumn (from 2016-1018 and 2021 respectively) the parameters are: water retention (direct or indirect), building shade, green shade with a dense and big canopy, thermal inertia, albedo and granulometry when it's very different.

ACKNOWLEDGEMENTS

This paper is part of the project PID2019-105976RB-I00 (Extreme Spatial and Urban Planning Tool for Episodes of Heat Waves and Flash Floods. Building resilience for cities and regions), supported by the Ministry of Science and Innovation of Spain."

Thanks to Dr. Josep Roca and Dr. Maria Dolors Martínez for all the support during this research. Thanks also to all the persons who made possible to measure the WSUDs and the gravels: Sara Martín Elboj and Laura Rubiralta, both architects by ETSAB, UPC, Fatima-Zahra Moumni, and Juan Orellana, both architects finishing MBLandArch Master at UPC and special thanks to my family.

REFERENCES

1. Pérez Cambra, M. and Roca, J. WSUDs (Water Sensitive Urban Design Systems) thermal behavior. En: Libro de proceedings, XII CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. Ciudades y Territorios Inteligentes. UNCuyo, Mendoza, 5-septiembre 2018. Barcelona: CPSV, 2018, p. 401-416. DOI http://dx.doi.org/10.5821/ctv.8254
2. FAO char about soil permeability: https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e09.htm
3. Instituto de Ciencias de la Construcción Eduardo Torroja y el ICCL, Instituto de la Construcción de Castilla y León. Copyright 2007:http://cte-web.iccl.es/
4. Thermal inertia formula: Planetary Sience Institute Thermal Inertia Web Site: https://se.psi.edu/~than/inertia/

Cooling Cities. Innovative Water-Based Cooling Systems in the Era of Urban Heat

Solutions for Outdoor Climate Adaptation

ADRIAN MOREDIA VALEK[1] [2], VALENTINA DESSI[1]

[1] Politecnico di Milano, Italy
[2] Arcadis Nederland B.V.

ABSTRACT: The Climate Change phenomenon continues to affect urban areas and their populations, the Urban Heat Island Effect (UHI) related impacts, such as heatwaves, are known to affect the climatic conditions of cities and increase the thermal stress of citizens. This research investigates the implications of heat stress on citizens' thermal comfort by analysing the Universal Thermal Climate Index (UTCI); and, based on well-known urban cooling principles and techniques, proposes an innovative water-based cooling system design specifically to reduce peak temperatures during heatwaves in outdoor areas, promoting enhanced spaces (urban oasis) that improve citizens' thermal comfort during heat stress conditions. Applying a research through design approach to optimise and document results in a series of iterative design-test-optimisation processes. The cooling potential of the "downdraft-evaporative-windcatcher" (DEW) Cooling Façade is simulated in a testbed combining four variables into twenty different configurations, the best-performing configuration (in the UTCI values) is later applied to a case study in the city of Milan, Italy.
KEYWORDS: Research Through Design, Urban Heat Island Effect, Human Thermal Comfort, Climate Sensitive Design, Downdraft Cooling, Evaporative Cooling

1. INTRODUCTION

The global warming we are experiencing more critically every year in urban areas is a combination of factors, phenomena, and occurrences. The so-called urban heat island (UHI) effect refers to the difference in temperature between rural and urban areas, mainly due to the cities' absorption, creation, and retention of heat. It primarily occurs due to substituting the natural landscape with an urban layout, retaining heat during the day, and releasing it back into the atmosphere above the city at night (1). Directly impacting human physical health through exposure to high temperatures during heatwaves, thus increasing the risk of thermal discomfort, dehydration, and cardiovascular diseases such as heat strokes (5).

Various factors impact citizens' thermal comfort; the urban morphology and the local climate are among the most relevant. The urban morphology consists mainly of public spaces (parks, streets, squares, and water bodies, among others), buildings shape and scale, street geometry, vegetation cover, and the typology of materials used to build them. Such unique configurations determine the city's diverse microclimates (1) according to their orientation and exposure to solar radiation and natural ventilation.

Research on cooling outdoor microclimates has gained much attention in the last decades due to the continuous increase in global temperature and the increasing intensity of heatwaves that strike cities worldwide. Extensive research has demonstrated water systems' relevance and applicability to reducing air temperature due to the cooling potential of water evaporation and heat transfer principles (1, 2, 3, 4).

This research investigates evaporative cooling principles and techniques by designing an innovative Water-Based Cooling System (WBCS) to a prototype level, aiming to reduce peak temperatures during heatwaves in urban areas. The "downdraft-evaporative-windcatcher" (DEW) Cooling Façade is introduced into the urban fabric to promote enhanced spaces (urban oasis) and improve the thermal comfort of citizens during heat stress conditions.

During the research, we analyse microclimatic parameters (at the local scale) to estimate people's heat stress levels, such as air temperature (Ta), relative humidity (RH), wind speed (ws) and the mean radiant temperature (MRT). Finally, we use the Universal Thermal Climate Index (UTCI) to determine heat stress conditions as a comprehensive heat budget model.

2. METHODOLOGY

The research initiates by studying water-based cooling principles and other compatible cooling techniques to identify the most suitable combination of variables to develop effective wbcs.

In this research paper, two (digital) scenarios are analysed: a testbed and a case study. Both have variations A and B. The first (A) represents the business as usual of the location named in the research reference case. The latter (B) tests the wbcs performance.

The wbcs efficiency is analysed through simulations that evaluate the thermal behaviour of the model, imputing and changing four variables one at a time—facilitating the evaluation of each variable's importance at the moment of choosing the most effective combination for the final prototype.

Both simulations were analysed in the climate region of Milan, Italy, in the year 2015; selected for its heat stress characteristics and data availability within the epw[1] database - the preferred method for running the climatic simulations with the software ENVI-met-. The month of July presented the mean maximum Dry Bulb Temperature (DBT) and is being chosen for running the simulations on the first day of the month, from 12 hrs. to 19 hrs.

The data extracted from the simulations is always at a selected grid 'x', measured at 1.5 m from the street level, at precisely 16 hrs., and at one meter from the building façade.

The methodology is based on three steps to design, test and analyse the innovative wbcs.

Step one: analysis and selection of suitable urban cooling principles; step two: data-driven spatial analysis (identifying the intervention areas); and step three: prototyping responsive and adaptive solutions for outdoor thermal comfort.

2.1 Step One: Urban cooling principles.

The fundaments of thermodynamics have been applied for centuries as a cultural representation of architectural design seeking to cool down indoor and outdoor spaces.

In current days, spatial planning principles and techniques are typically used for cooling outdoor urban environments. The essential principles for cooling outdoor environments are natural ventilation, blocking solar radiation, improving albedo properties of materials, ground heat exchange, water evaporation, and evapotranspiration from green areas (1, 2, 3).

In this case, where a water-based solution has been developed, the principle taken into consideration are the downdraft effect and natural ventilation, relying on water evaporation as a cooling technique where surface-area to volume-ratio indicates the speed at which water changes from liquid to gas. Considering that water requires high amounts of energy to evaporate and that the higher the surface area exposure is, the higher the energy transfer due to heat exchange may be.

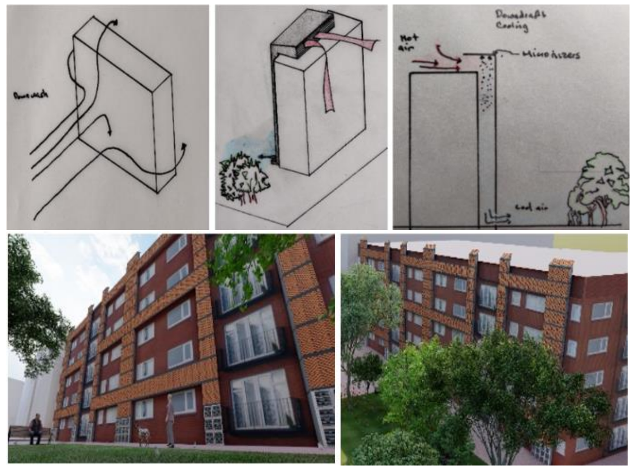
2.1.1 DEW Cooling Facade.

The downdraft-evaporative-windcatcher cooling facade (DEW Cooling Facade) presented in this paper is a digital prototype; designed as a self-support modular system and installed on a building facade as a second skin. Regardless of the building's new or existing conditions, the system's first benefit is reducing the incident solar radiation and, thus, the overall heat load and energy consumption of the building.

Following the design of a windcatcher, the air intake is built 1.5 m above the building's roof level to capture natural ventilation, equipped to close and open according to the desired needs.

The top of the system is equipped with a water nebulisation system at variable heights (15-20 m), according to the building. It creates a cloud of micronised water that evaporates when climate conditions are adequate (hot, semi-humid/dry), thus creating a downdraft current directed to the pedestrian level. Image 1 shows the system's conceptual drawings and rendered images of its attachment to the façade of a building.

Figure 1: DEW Cooling Façade. Conceptual drawings & rendered images of the top & lateral views of the system. Source: Author, 2022



The system uses front panels made from porous and water absorbent materials (aired baked clay) in identical built-in modules of 60x120 cm. The lateral and back panels are of aluminium, forming a confined space for the improved air - similar to an A/C ducting system- with a shaft approximately of 50x60 cm wide. Image 2 shows the air intake and the nebulisation system installed.

Figure 2: DEW Cooling Facade. Air intake and nebulisation system views. Source: Author, 2022

Beyond the specific contributions of the downdraft cooling effect, other contributions are possible; the panels' are designed

[1] Extensions of epw files are data files associated to specific software, in this case they are used for ENVI-met to input climate data.

with symmetric concave areas to support local flora and fauna proliferation, as plants may be installed in the concave areas. They absorb water from the porous, wet panels, sprayed from the inside, a point at which this system may be considered a green wall.

The panels can absorb and retain rainwater during heavy storms (20% to 35% absorption); the water retained in the panels slowly evaporates, infiltrates the storage unit or the soil, reducing runoffs to sewage systems. Thus, becoming a responsive and adaptive building skin designed to improve the outdoor thermal comfort of citizens and provide a series of co-benefits to outdoor climate adaptation.

Other specific elements could improve the system, such as installing solar panels, mechanical ventilation, and water filtration systems.

2.2 Step Two: Data-driven spatial analysis. Identifying the intervention areas.

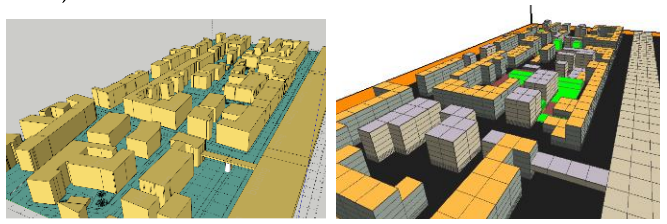
Providing data to decision-makers supports them in better understanding where solutions will have the most impact. The methodology for selecting the intervention areas considers crossing local microclimate data with the urban morphology, showing priority areas to assess.

The analysis uses multiple software, starting by opening and modifying municipality blueprints with software such as Revit or AutoCAD. These files are not directly compatible with the software ENVI-met; thus, other software is needed for transferring the information to ENVI-met. (e.g., Sketch-Up with the ENVI-met plugin installed).

ENVI-met version 5.02 is a three-dimensional modelling system designed to simulate microclimate conditions in the urban environment based on the fundaments of fluid and thermodynamics (3).

Image 3 shows the software (sketch-up & ENVI-met spaces) used to build the model's urban morphology; later, microclimatic data inputs are added to the model. When preparing the simulation, it is opted to use epw files to input the local climate variables using the full forcing option in ENVI-guide.

Figure 3: Data-driven analysis. The image on the left is realised with the software Sketch-Up; the image on the right is with ENVI-met Spaces. Source: Author, 2022



3.3 Step Three: Prototyping innovative water-based systems for outdoor thermal comfort. The DEW Cooling Facade Prototype.

The DEW Cooling Facade prototype has been designed and analysed, considering its cooling potential and efficiency. The first aspect analyses the extent of the prototype to reduce heat stress by considering the thermal comfort conditions (UTCI, °C). The second aspect analyses the cooling potential (Ta, °C), its total water (l/h) and energy (w/h) consumption.

Twenty configurations are simulated in the ENVI-met software, representing the combination of four variables v1,v2, v3, and v4 (v1-v4).

v.1= refers to the nebulisation output regarding the number of nozzles, water nebulised per nozzle, and total water/energy consumption. Six systems are tested in this paper. The first nebulisation system (s.1) was tested with a total consumption of 432 l/h and 1250 w/h. This nebulization system was simulated in virtual prototypes: 1a, 1ab, 2a, 2ab, 3a, 3ab, 4a, 4ab, 5a and 5ab. The second nebulisation system (s.2) was tested with a total consumption of 144 l/h and 680 w/h in the virtual prototypes 5a, 5ab, 6a, 6ab, 7a, 7ab, 8a and 8ab. Table 1 shows values for both nebulisation systems, underlining the two systems used as v.1 during the simulations.

Table 1: The DEW Cooling Façade Prototype. Variable, v.1 (Nebulization System Configurations), considers the number of nozzles and the water/energy consumption. Source: Author, 2022

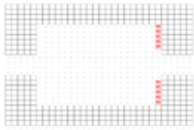
system type	*total nozzles (pzs)*	*output per nozzle (l/h)*	*output (µg/s)*	*water consumption (l/h)*	*energy consumption (w/h)*
s.1	20	62	347	1249	3250
s.2	20	21	115	414	1250

v.2= refers to the width of confinement used to channel the improved air. Two options were tested: one represents a single wall of 30 cm wide, and the other represents a normal wall of 45 cm wide which is commonly used in the ENVI-met software.

v.3= refers to the materials used to build the system. Two different materials are included in the simulations: the first is aerated brick with a solar absorptance of 0.6 frac, and the second material is aluminium with a solar absorptance of 0.1 frac. The terminology frac refers to the fraction of solar radiation absorbed by a given material.

v.4= refers to the installation height of the nebulisation system. Two heights are used during the simulations, 15m and 20m. Table 2 shows the four different variables and the twenty combinations (Prot. 1a to 8ab); the results are shown in Figure 4.

Table 2: Twenty configurations of the DEW prototype, combining four variables: nebulisation output (v.1), width (v.2), materials (v.3), and the system's height (v.4). Source: Author, 2022.



	Neb.1	Neb. 2	Neb.3	Neb. 4
	347µg/s	347µg/s	115µg/s	115µg/s
	15 mt	20 mt	15 mt	20 mt

	Prot. 1a	Prot. 1ab	Prot. 2a	Prot. 2ab
v.1	347µg/s	347µg/s	347µg/s	347µg/s
v.2	single wall	single wall	single wall	single wall
v.3	brick	brick	alluminium	alluminium
v.4	15 mt	20 mt	15 mt	20 mt

	Prot. 3a	Prot. 3ab	Prot. 4a	Prot. 4ab
v.1	347µg/s	347µg/s	347µg/s	347µg/s
v.2	normal wall	normal wall	normal wall	normal wall
v.3	brick	brick	alluminium	alluminium
v.4	15 mt	20 mt	15 mt	20 mt

	Prot. 5a	Prot. 5ab	Prot. 6a	Prot. 6ab
v.1	115µg/s	115µg/s	115µg/s	115µg/s
v.2	single wall	single wall	single wall	single wall
v.3	brick	brick	alluminium	alluminium
v.4	15 mt	20 mt	15 mt	20 mt

	Prot. 7a	Prot. 7ab	Prot. 8a	Prot. 8ab
v.1	115µg/s	115µg/s	115µg/s	115µg/s
v.2	normal wall	normal wall	normal wall	normal wall
v.3	brick	brick	alluminium	alluminium
v.4	15 mt	20 mt	15 mt	20 mt

4. RESULTS

The first scenario to be analysed is the testbed. The reference case (A) is without a prototype. The data was collected at a 1.5 m high and 1 m distance from the building's façade. Six parameters are collected for data: Wind direction (deg), flow w (m/s)[2], wind speed (m/s), air temperature (°C), RH (%), MRT (°C), and the UTCI (°C), as presented in Tables 3 & 4.

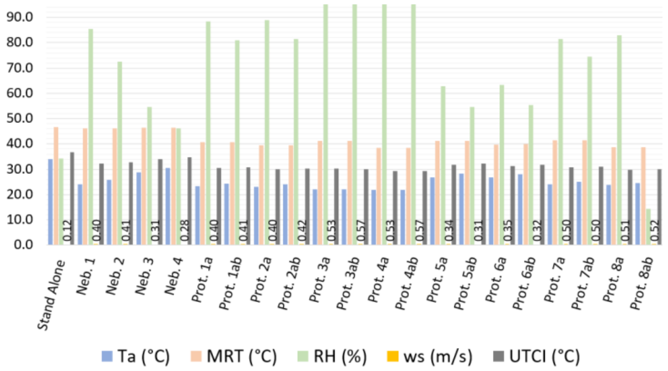
Table 3: Testbed Scenario - A: Reference case. Results of the model without any wbcs. Source: Author, 2022

Reference Case (A)							
Date	Time	Flow w (m/s)	ws (m/s)	Ta (°C)	RH (%)	MRT (°C)	UTCI (°C)
01.07.2015	12.00.00	0.01	0.0	30.3	44.7	39.6	32.6
01.07.2015	13.00.00	0.02	0.1	32.7	36.2	45.3	35.4
01.07.2015	14.00.00	0.02	0.1	33.8	32.9	47.3	36.5
01.07.2015	15.00.00	0.03	0.1	34.4	33.6	47.9	37.3
01.07.2015	16.00.00	0.03	0.1	35.0	35.0	47.5	37.9
01.07.2015	17.00.00	0.03	0.2	34.9	34.1	45.3	37.1
01.07.2015	18.00.00	0.03	0.2	34.1	38.8	42.4	36.2
01.07.2015	19.00.00	0.03	0.2	32.5	43.0	34.2	33.0
		0.03	**0.12**	**34.1**	**34.4**	**46.6**	**36.9**

After extracting the data, an average during operational hours is calculated (13 hrs to 17 hrs) as a comparative value between the twenty different simulations. We can observe that the average Ta is 34.1 °C, and the UTCI is 36.9 °C (the range of no thermal stress conditions is between 9°C and 26°C).

After acquiring the data from the simulation without the prototype, twenty simulations are performed using the same microclimate parameters and urban morphology. The only difference is introducing the different variables (v.1 to v.4). Figure 4 presents the results of the parameters collected in the twenty simulations.

Figure 4: Results of the twenty configurations of the DEW prototype. Data collected are Ta, MRT, RH, ws and UTCI. Prototype 4a, 4ab and 8a perform best in terms of UTCI. Source: Author, 2022



When comparing the UTCI data from all the simulations, it is possible to determine that the best performing is Prototype 4a with the configurations v.1=347 µg/s, v.2=normal wall (45cm wide), aluminium shafts at 15 m high.

Table 4 presents the values of Prot. 4a. The prototype shows the best results in all parameters except for the RH, which shows high humidity levels inside the shaft. This prototype is selected to apply in the case study.

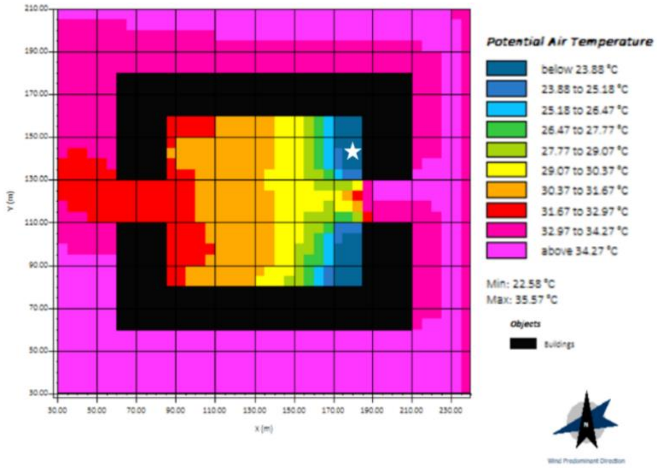
Table 4. Testbed Scenario - B: WBCS case. Results of the model with Prot. 4a. Source: Author, 2022.

WBCS Case (B) with prot. 4.a_normal wall_alluminium_15mts_347µg/s							
Date	Time	Flow w (m/s)	ws (m/s)	Ta (°C)	RH (%)	MRT (°C)	UTCI (°C)
01.07.2015	12.00.00	-0.05	0.1	29.2	45.3	34.9	30.5
01.07.2015	13.00.00	-0.23	0.4	21.4	98.9	40.5	29.5
01.07.2015	14.00.00	-0.24	0.5	21.3	98.8	39.0	29.0
01.07.2015	15.00.00	-0.29	0.6	21.8	98.7	38.9	29.2
01.07.2015	16.00.00	-0.29	0.6	22.5	99.7	38.0	29.6
01.07.2015	17.00.00	-0.29	0.6	22.2	99.4	35.9	28.8
01.07.2015	18.00.00	-0.29	0.6	27.7	62.6	33.7	30.2
01.07.2015	19.00.00	-0.10	0.2	31.4	43.2	29.8	30.9
		-0.27	0.53	21.9	99.1	38.5	29.2

The Prot. 4.a presents an average Ta of 21.9 °C and a UTCI of 29.2 °C. Figure 5 shows the cooling potential of the prototype in a floor plan at 16.00 hrs, where the cooling effect is of 12. 5 °C in the first 15 m away from the façade and reduces its effect drastically to 7°C after 35 m distance.

Figure 5. Testbed Scenario – B: wbcs simulation: Analysis of the Ta for Prot.4a in a floor plan. The location where the data was collected for the simulation is represented with a star. Source: Author, 2022.

[2] Flow w represent the wind speed inside the shaft, thus, the downdraft effect.



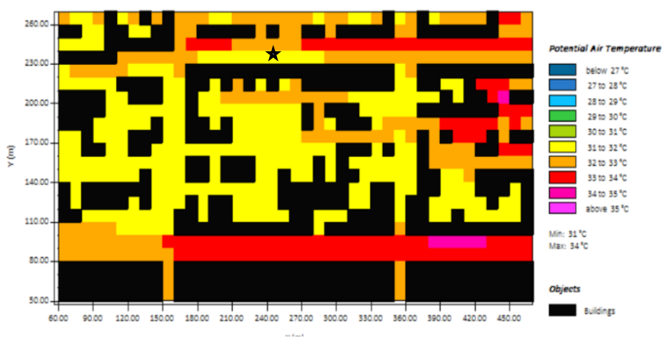
4.1 Case Study. Sammartini, Milano

The second scenario to be analysed is the case study developed in the City of Milan, Italy. Confined by the roads Via Giovanni Battista Sammartini (1) and Via Cristoforo Gluck (2). It has an approximate perimeter of 250x470 m and a total area of 117,500 m2. Figure 6 shows the location of the streets where the scenario is analysed.

Figure 6. The aerial photo of the city of Milan. Via G.B. Sammartini (1) & Via C. Gluck (2). Source: Google Earth Pro, 2022.

As before, the reference case (A) is analysed without a prototype, and the wbcs case (B) is simulated with prototype 4a. Figure 7 shows a map representing the reference case (A), with Ta ranging from 31.5 °C to 34.3 °C. It is possible to observe that both streets present the highest Ta ranges, making them ideal testing sites for the DEW Cooling Facade prototype.

Figure 6. Case Study Scenario - A: Reference case. Results of the model without any wbcs. The location where the data was collected for the simulation is represented with a star. Source: Author, 2022.

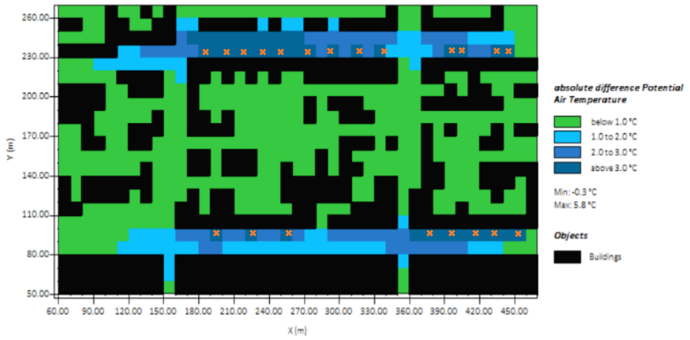


To simulate the wbcs case (B), locating the prototype in the software grids with source points is necessary. Twenty-one source points were located (represented with an orange cross); each represents a DEW Cooling Façade System configured by the Prot. 4a, their approximate total consumption is 9,072 l/h and 26,250 w/h.

Figure 7 shows the location and distribution of all the point sources by street. In Via Cristoforo Gluck, 13-point sources were placed with a total consumption of 5,616 l/h and 16,250 w/h. Meanwhile, in the street Via Giovanni Battista Sammartini, 8-point sources were placed with a consumption of 3,456 l/h and 10,000 w/h.

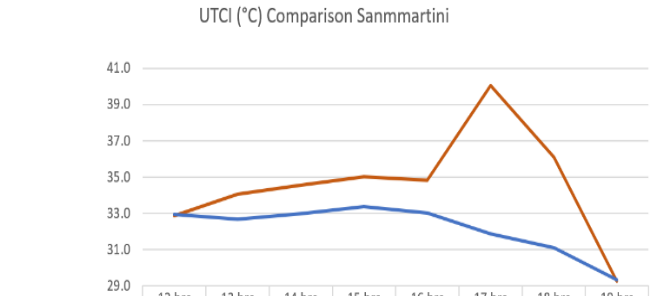
The map also presents the areas of improved Ta, with maximum values of 5.8 °C, showing the cooling potential of the DEW Façade System.

Figure 7. Case Study Scenario - B: WBCS case. Map showing the location and distribution of all the 21-point sources by street, each represents one Prot. 4a, marked in orange crosses. Source: Author, 2022.



The UTCI data from cases A and B are compared in Figure 8. We can appreciate a temperature drop when the prototype is operational from 12 hrs, keeping the temperature below 33.5 °C at the hottest moment of the day, thus, preventing very strong heat stress from occurring. Providing moderate conditions alongside the streets throughout the day (the range of strong and very strong thermal stress conditions are between 32-37 °C and 38-46 °C, respectively).

Figure 8. UTCI comparison between A & B in the case study. The two configurations have differences in temperature of about 8.9 °C. Source: Author, 2022.



	12 hrs	13 hrs	14 hrs	15 hrs	16 hrs	17 hrs	18 hrs	19 hrs
Reference Case (A)	32.9	34.1	34.6	35.0	34.8	40.0	36.1	29.3
WBCS Case (B)	32.9	32.7	33.0	33.4	33.0	31.9	31.1	29.3

5. DISCUSSION

This research explores the efficiency of the DEW Cooling Facade prototype using the downdraft cooling principle in the climate region of Milan, Italy. Focusing on reducing Ta in urban areas and promoting enhanced spaces (urban oasis) that improve citizens' thermal comfort during heat stress conditions.

Twenty simulations are tested in a digital testbed combining four different variables (v.1. output of the nebulisation system, v.2. width of the confinement, v.3. materials used in the outer panels and v.4. installation height of the nebulisation system). The four variables analysed and combined among each other have different levels of relevance.

V.1. Nebulisation Output. In all the tests performed, the most relevant variable was the water output, all the combinations using higher outputs of nebulisation had a better cooling effect, regardless of the other variables. The testbed presented Ta reductions up to 12.5 °C up to 35 m from the prototype. The system that performed best was Prot. 4a using a total consumption of 432 l/h and 1250 w/h (from 12 to 17 hrs) see table 4.

Reductions in water consumption may be achieved by lowering the µg/s used per nozzle, reducing the amounts of nozzles in the system, or the total operational time.

V.2. Width of Confinement. The confinement greatly impacted the RH inside the shafts, increasing the original value from 35 % to 99 %. Substantial reductions on the RH were documented in relation to further distances from the prototype.

Another interesting result was the value documented for the flow w inside the shaft, related to the downdraft effect from the evaporated water. It shows that it increased its original value up to 9.6 times, from 0.03 m/s to 0.29 m/s. It proves that the downdraft effect is calculated by ENVI-met, regardless of using a single wall or a normal wall as confinement (terminology commonly used in the software). To our knowledge, such a finding has not been revealed.

V.3. Materials: Two materials were used (aluminium panels and baked clay). The prototypes built with aluminium layers had better performance on average. This situation may have multiple explanations as the aluminium absorbs and retains less heat during the day than clay, the air flows faster in such material, or the hot metal supports faster evaporation of the nebulised water.

V.4. Height of the Nebulisation System: The least influential variable was the nebulisation's height; a range of 5 m was insufficient to detect a significant difference between the two distances analysed (15 m and 20 m). In general terms, the cooling potential was higher at 15 m height. However, when testing only the nebulisation systems without the confinement provided by the prototype, the improved air dissipated fast, barely providing any cooling potential at pedestrian levels (1.5 m).

The UTCI analysis in the testbed revealed a maximum temperature reduction of 9.1 °C with a range of improvement from 37.9 °C (strong heat stress) to 28.8 °C (moderate heat stress).

During the case study, Prot. 4a was tested. It reduced the air temperature up to 5.8 °C. In the case of Via Cristoforo Gluck, those conditions were perceived at about 330 m along the street following predominant wind directions. The UTCI analysis showed improvements of 8.9 °C, providing moderate heat conditions during the day and avoiding very strong heat stress conditions that would be otherwise above 40 °C.

6. CONCLUSION

This paper provides insight into the direct impacts on thermal comfort by reducing exposure to high temperatures during heat stress conditions. Moreover, it uses different principles and techniques to develop innovative water-based cooling solutions.

The downdraft-evaporative-windcatcher cooling facade (DEW Cooling Façade) is presented and analysed in this paper, demonstrating the potential of downdraft cooling. Two digital scenarios are analysed, one as a testbed and the second in a case study in Milan. In the testbed, we analysed twenty prototypes combining four variables, providing results of their cooling effect; we then selected the best performing prototype and used it to analyse the case study. Regarding the UTCI analysis, the values presented temperature reductions of 9.1 °C; meanwhile, the case study showed reductions of 8.9 °C, avoiding the strongest impacts of heat stress in surrounding areas of the prototype.

The prototype provides the possibility of higher comfort levels, where users can find a place to cool and relax in outdoor spaces avoiding strong and very strong heat stress conditions. Such improvements are directly reflected in livelihoods and may promote outdoor activities, better health among citizens and thus, fewer heat-related deaths.

Decision-makers and practitioners interested in improving citizens' thermal comfort may use the procedures and results presented as part of the tools to tackle heat stress in cities. For example, by selecting the most suitable intervention areas where such a typology of wbcs may have the most impact, promoting at the same time enhanced urban spaces (urban oasis) that improve citizens' thermal comfort during heat stress conditions. This approach integrates resilient public spaces, urban design practices, academic research, and climate policies.

ACKNOWLEDGEMENTS

Our extensive gratitude to all members of the SOLOCLIM consortium involved in this research, especially the members from Arcadis who contributed with valuable content during the process. Marjan, Verali, Luc and the rest of the contributors, thank you for your valuable inputs.

REFERENCES

1. Oke, T.R. (1978). Boundary-Layer Climates: Halsted Press, New York.
2. Santamouris, M. et al. (2002). Energy and Climate in the Urban Built Environment. James and James, London, pp: 1-399.
3. Guiseppe, et al., 2020. Numerical Modelling and Experimental Validation of the Microclimatic Impacts of Water Mist Cooling in Urban Areas. Energy & Buildings 231 (2021) 110638, Elsevier, pp: 1-17.
4. Domínguez, S. and Sánchez, F., 2016. The Effect of Evaporative Cooling Techniques on Reducing Urban Heat. Urban Climate Mitigation Techniques, pp:113-130.
5. WHO, (2018). Health and Climate Change. COP24 Special Report. World Health Organization (2018), ISBN 978-92-4-151497-2, pp: 1-73.

Sky View Factor and Urban Heat Island Mapping
Applications in Barcelona

AGNESE SALVATI[1] JORDI CASALS[1] JUDIT LOPEZ BESORA[1] HELENA COCH[1]

[1] Barcelona School of Architecture, Polytechnic University of Catalonia

ABSTRACT: This study proposes a methodology to map urban heat island intensity based on sky view factor (SVF) data, using Barcelona as a case study. We used LiDAR data to generate the SVF map of the city and empirical and simulation data to obtain the relationship between nighttime urban heat island intensity and canyon SVF in Barcelona. The data were processed and interpolated in a GIS software to obtain the micro-scale and local-scale urban heat island map of the city. The methodology proved effective in showing hot and cold spots across the city. Some unexpected results were used to discuss the validity and limitation of the urban canyon model approach for those urban fabrics with more heterogeneous morphology.
KEYWORDS: Sky View Factor, Urban heat Island, Urban microclimate, Urban form, GIS

1. INTRODUCTION

The rise in global and urban temperature has become a serious risk for urban health [1]. The risk is amplified in cities due to the presence of the Urban Heat Island (UHI), increasing air temperature compared to the surrounding rural areas, especially during the night [2]. The UHI exacerbates heat-related health impacts by increasing heat stress during the day and reducing cooling potential and relief at night. The UHI also significantly increase the cooling energy demand of buildings in summer [3-4]. For these reasons, improving the microclimate conditions of urban spaces would play a pivotal role to improve health and wellbeing of urban population and to reduce energy consumption at the urban scale, increasing urban resilience to climate change.

The UHI intensity varies across the city depending on the characteristics of the urban fabric [5-6]. Mapping the spatial distribution of the UHI intensity is not an easy task, due to the heterogeneity of the urban fabric in terms of form, anthopogenic heat generation and vegetation cover. However, studies have shown that urban form takes a dominant role on the local-scale UHI intensity because it is correlated to several causes of the UHI [7]. The complex three-dimensional geometry of the urban surface produces multiple reflections of the incident solar radiation, increasing solar absorption [8]. It also reduces the long-wave radiation loss at night, due to reduced openness to the sky. Furthermore, the roughness of the urban surface reduces the turbulent heat transfer out of the urban canopy, due to the reduced wind speed between buildings [9]. All these effects are related to the percentage of sky "seen" by urban surfaces, which is expressed by the parameter Sky View factor (SVF), ranging between 0 and 1 for totally obstructed and completely open spaces, respectively. This explains the relationship between the night-time UHI intensity and the SVF of street canyons identified by Oke for various cities of the world [9]. A negative correlation between UHI intensity and SVF was confirmed also by more recent studies [10–12]. Based on these assumptions, this study presents a methodology to map the UHI intensity of Barcelona based on the SVF of urban spaces.

2. METHODS

The methodology is based on consecutive steps:

1) Generation of a high-resolution map of the SVF of the urban fabric of Barcelona using LiDAR data

2) Identification of the relationship between canyon SVF and UHI intensity in Barcelona using simulations and measurements

3) Generation of a continuous map of UHI intensity at local scale using spatial interpolation.

2.1 Generation of the SVF map of Barcelona

The open-source GIS software QGIS was used to generate the Digital Surface Model (DSM) of Barcelona and to calculate the SVF in each cell. The DSM was created from the LiDAR 3-D point clouds file (0.5 points/m²) provided by the Catalonia Cartographic and Geologic Institute (ICGC), corresponding to a 2016 flight. The accuracy of the original DSM was increased by applying a semi-automatic method (VisionLidar 30.0.01.116.40) to improve the classification of land, building and vegetation. A Digital Terrain Model (DTM) was created from the reclassified data by including only the ground points. The detailed building data available from CartoBCN (http://w20.bcn.cat/cartobcn/) were then added to the optimised DTM to generate a new, more accurate, DSM at 2m resolution. The new DSM was used to calculate the SVF of each cell using the module "Sky View Factor" of the SAGA-GIS Module Library (v2.2.0). The resolution of the SVF map was set at 1x1 m.

2.2 Relationship between SVF and nocturnal UHI intensity in Barcelona

We used air temperature measurements in urban canyons and simulation results by the Urban Weather Generator (UWG) model to identify the relationship between canyon SVF and nighttime UHI intensity in Barcelona.

The measurements were taken at the street level (1.2m height) at 1AM during three nights of July 2014 in eight urban canyons of the neighbourhoods of Raval and Gracia. The canyons' SVF varied between 0.18 and 0.88. More details on the characteristics of the canyons can be found in a previous publication [3]. The UHI intensity was calculated as the temperature difference between each canyon and the airport weather station. Linear regression analysis was performed to identify the relationship between the canyon SVF and the night-time UHI intensity.

The relationship between the canyon SVF and the UHI intensity was investigated also using the urban canopy model UWG [13]. The UHI intensity at 1 AM over one week of July was simulated for five urban textures. The results were correlated to the SVF of the urban canyon used in UWG calculation [14]. More information about the textures can be found in a previous study [5]. Linear regression analysis was used to identify the relationship between the nighttime UHI intensity and the canyon SVF according to UWG results.

2.3 Mapping the local-scale UHI intensity across the city of Barcelona

The last step of the methodology was aimed at generating a continuous map of the nighttime UHI intensity at the local scale in Barcelona.

The SVF map generated from the previous steps is continuous and has a spatial resolution of 1mx1m. This means that there are different SVF values along the section of each urban canyon. The SVF is highest at the central point of the canyon - the point equidistant from the buildings - and lowest at points close to the façade of the buildings.

According to Oke [9], the relationship between SVF and canyon geometry applies to the central point of the canyon. For this reason, the SVF of the centre point of all open spaces was extracted from the detailed SVF map. This was done using the QGIS tool 'Euclidean distance', which identifies points in urban spaces that are equally distant from any buildings. This resulted in a new type of SVF map, represented as a network of lines running through the midpoints of all open spaces: each point on these lines has a SVF value that depends on the distance to surrounding buildings. This map was used to establish the expected value of the nighttime UHI intensity based on the SVF of the urban canyons, applying the relationship previously derived for Barcelona.

The last step of the methodology was the spatial interpolation of the UHI values of the canyon network. This was done to up-scale the calculated point-by-point UHI values into a local-scale atmospheric UHI intensity, which is the result of the spatially averaged energy balance over a larger urban area. For this purpose, the inverse distance weighted (IDW) technique was applied to interpolate the UHI values, considering a radius of 50 meters. The output map represents the expected spatial distribution of the nighttime UHI intensity at the local scale in Barcelona.

3. RESULTS

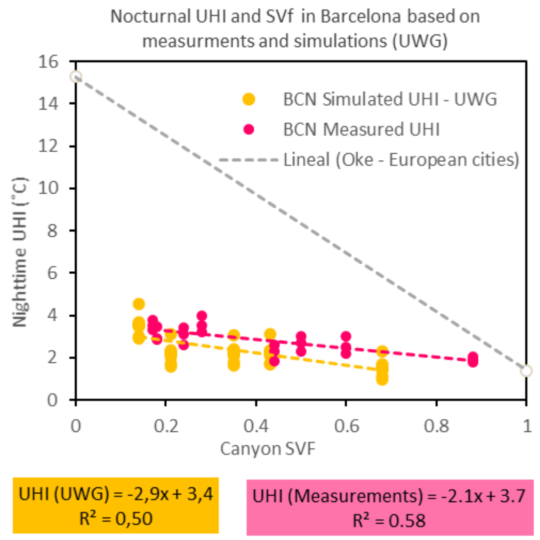
3.1 SVF and UHI intensity in Barcelona

Equation 1 reports the relationship between the nighttime UHI intensity and the canyons' SVF based on measurements:

$$UHI_{Night} = 3.7 - 2.1\ SVF \quad (R^2=0.58) \qquad (1)$$

The comparison with the relationship obtained from simulation results and the one reported by Oke [9] for European cities is reported in figure 1.

Figure 1:
Relationship between SVF and nocturnal UHI intensity in Barcelona based on measurement and simulation results.



The graph shows that the UHI intensity measured in Barcelona is lower compared to the one according to Oke's relationship, for the same canyon SVF. However, this was expected because Oke's correlation is based on the maximum nighttime UHI intensity, while the data used in this study correspond to the UHI intensity over some days of July, at 1AM.

The comparison between measurements and simulation results reported in Figure 1 shows that the UHI intensity estimated by UWG is lower than the one measured in the eight urban canyons. The robustness of the relationship expressed by the coefficient of determination R^2 is also lower for simulation-based results (R^2=0.50) than measurement-based data (R^2=0.58). For this reason, we used the measurement-based relationship to generate the UHI map.

More data would be needed to validate the robustness of such relationship. However, this is out of the scope of this paper, whose main aim is to develop a methodology to generate an urban-scale map of the UHI intensity based on the spatial distribution of the SVF of the open spaces.

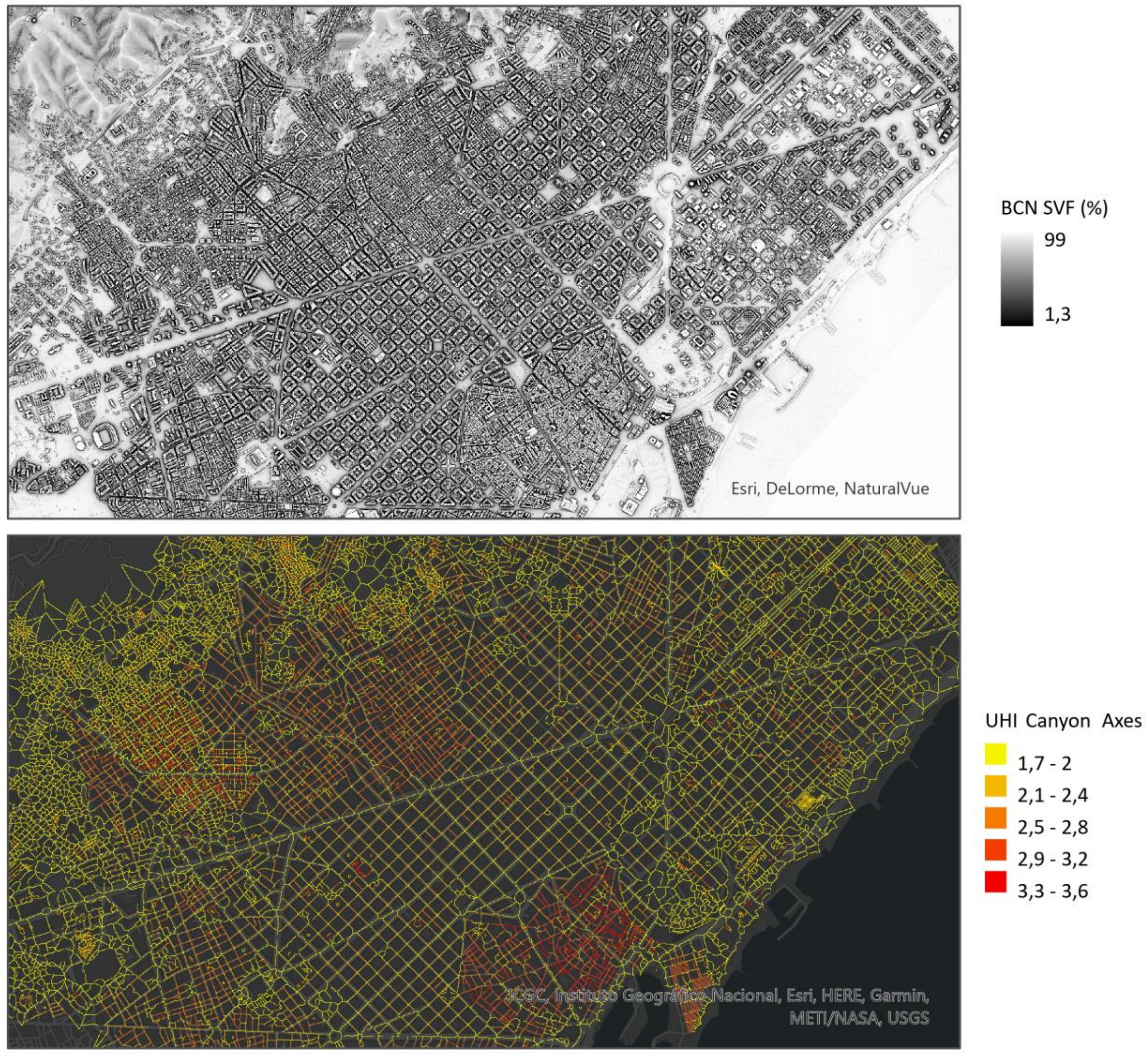
3.2. Detailed SVF map of Barcelona

The detailed SVF map of Barcelona is reported in Figure 2. The map depicts in grey scale the values of SVF of all horizontal surfaces, including roofs and streets. The SVF is expresses as a percentage (0-100), representing the ratio of sky seen by the surfaces.

The map clearly shows the different morphologies of the urban fabric of Barcelona determined by changes in building density, building typology and street network in terms of width of the streets and distance between intersections.

The impact of trees on the SVF has not been included in this map. For this reason, the parks and squares of the city appear as white patches.

Figure 2:
Top) Detailed SVF map of Barcelona. Bottom) map of the UHI intensity of the open spaces. The SVF map is available online: https://barcelonatech.maps.arcgis.com/apps/webappviewer/index.html?id=b7c1817870714402b610cc847f22827e).



3.3 Map of the UHI intensity across the city of Barcelona

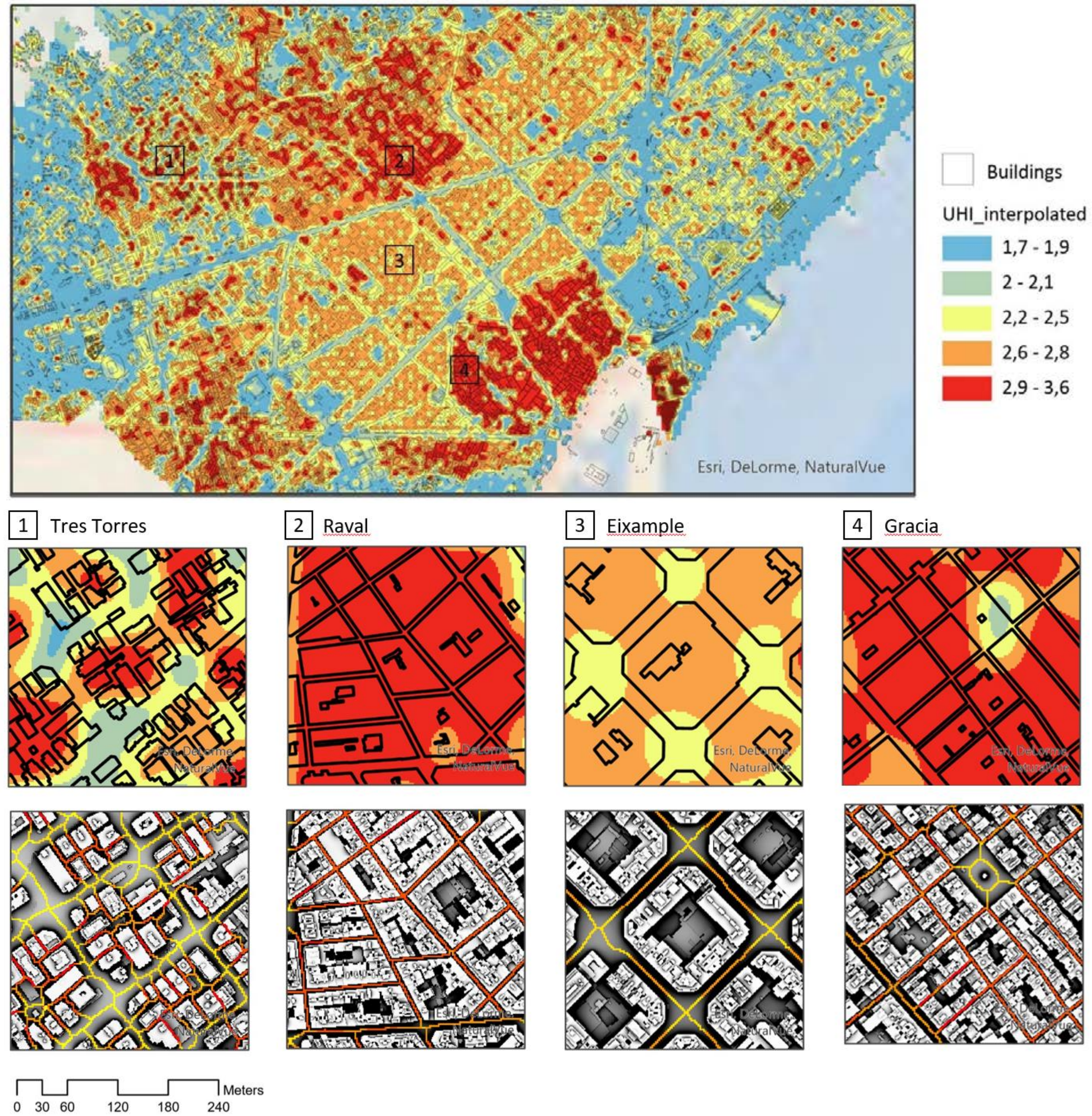
The bottom part of Figure 2 represents the map of the UHI intensity obtained by applying equation 1 to the SVF of the middle point of open spaces in Barcelona. The UHI map was generated considering the SVF of the horizontal surfaces at the ground level (i.e. excluding roofs), in accordance with previous studies correlating the UHI to the SVF of the middle point of urban canyons [9]–[11].

The map in Figure 2 provides two types of information. The colour of the lines indicates the expected nocturnal UHI intensity depending on the SVF of each point. In accordance with Equation 1, the UHI is higher in the narrow streets of the medieval city centre compared to more recent urban developments.

The map also clearly shows how the density of the street network varies in different neighbourhoods, according to varying size of the blocks.

The varying spatial distribution of the network of the open spaces allows to understand the resulting UHI intensity at the local scale, reported in Figure 3.

Figure 3:
Map of the local-scale nighttime UHI intensity in Barcelona and zoom on four urban textures of different urban morphology



The local-scale UHI intensity map is the result of the interpolation of the UHI intensity of the open spaces network over a 50m radius. The average air temperature is in fact the result of a wider source area than each single urban canyon. For this reason, the local-scale UHI intensity depends on both the UHI intensity in each urban canyon and the spatial distribution of the network of open spaces at the neighbourhood scale.

For instance, the texture 2 (Raval) is represented as a red patch, meaning that it is one of the hottest areas of the city during the night. This result is explained by the very low SVF of almost all the streets of that area, which prevents the urban surfaces to cool down at night by longwave radiation emission toward the sky.

Conversely, the texture 4 (Gracia) shows some cool spots across the hot urban fabric. Such cool spots are the squares of the neighbourhood, that have a higher cooling potential at night thanks to the significantly higher SVF compared to the typical street geometry of this area.

The texture 3 (Ensanche) is different from the previous cases for both block size and street width. The streets are wider, the block is larger and the frequent intersections in the street network increase the average SVF of the spaces between buildings. For this reason, this texture shows a lower UHI intensity at night

Finally, the texture 1 shows a high variability of the UHI intensity, because of a high spatial variability of the SVF. In this area, the street network is wide and with frequent intersections, as in the texture 3. Conversely, the building typology is very different from the previous one. Ensanche is composed of compact building blocks, while Tres Torres is composed of isolated buildings with smaller footprint but very close to each other. For this reason, the SVF between buildings is very low, while the SVF of the main street network is high. As a result, the interpolated UHI map shows a red patch in the middle of each block and much lower air temperatures in the space in-between blocks. However, this result is doubtful because the urban morphology of this urban texture is quite different from a typical urban canyon, where the facades of the buildings is assumed to be continuous along the block. For this reason, the atmospheric UHI intensity in such urban texture needs to be verified with measurements.

4. DISCUSSION OF THE RESULTS

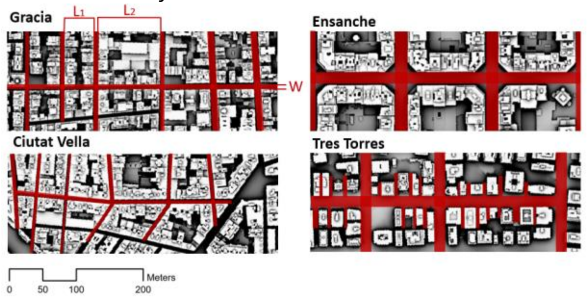
The results presented in this study have some limitations, based on the starting assumptions.

We have assumed that the UHI intensity only varies with the SVF of the open spaces. On the one hand, this is a reasonable assumption for a climate like the one of Barcelona, where the sky is clear most days of the year and therefore both the incoming solar irradiation and outgoing longwave radiation are strongly dependent on the portion of sky seen by the surfaces. However, other variables may affect the local-scale UHI intensity, like vegetation cover and anthropogenic heat from buildings and traffic, which may vary significantly even among similar urban morphologies.

Another limitation regards the validity of the relationship between SVF and UHI intensity, based on the simplification of the urban fabric to a series of regular - semi-infinite - urban canyons. This is an effective approach to reduce the complex urban morphology to a single parameter - the SVF – which allows to solve the urban energy balance in the bidimensional section of the street instead of the three-dimensional urban geometry. However, when applied to real-world urban fabrics, an actual "canyon situation" is difficult to find.

According to Oke [9], a urban canyon is defined by a ratio of the buildings height (H) to the street width (W) of more than 0.7 and a ratio of the block length (L) – distance between main intersections – to the building height above 6. In these conditions, the bulk of the flow above the building arrays does not enter the canyon and a skimming flow regime is established and the urban energy balance can be calculated just considering the geometrical ratio of the street. However, considering such ratios of the building height, street width and canyon length, none of the urban textures in Figure 3 would comply with the canyon situation. These textures have a street aspect ratio above 0.7, but none of them has a block length of more than 6 times the building height, due to frequent intersections in the street network (Figure 4).

Figure 4:
Width and intersections of the street network in four urban textures of Barcelona



In Gracia and Raval the width of the intersections is so small with respect to the block length that it is reasonable to assume a canyon-like situation. On the opposite, textures like Ensanche and Tres Torres cannot be modelled as semi-infinite bidimensional canyons, given the short distance between intersections and the discontinuity of the building facades.

Indeed, there is no evidence to state that an urban area where the distribution of SVF is very heterogeneous (e.g. Tres Torres) would have the same urban climate as another urban configuration with canyon-like morphology with the same average SVF, as assumed in the urban climate models and maps produced in this study. In fact, changing the building typology from a continuous block to isolated buildings in sequence has a strong impact on both the solar radiation absorbed by building facades and the anthropogenic heat emitted by the buildings into the atmosphere.

Given the importance of this topic, the next step of the research will be aimed at comparing the anthropogenic and radiative heat fluxes of more complex urban geometries to the equivalent canyon-like urban configuration, in order to define the range of validity of a canyon assumption.

5. CONCLUSION

The study presented a methodology to map the local-scale UHI intensity based on high-resolution SVF data, measurements, and simulations of the UHI intensity. The methodology proved effective to generate a city-scale map of the hot and cool spots across the city.

The results are deemed more reliable for those portions of the urban fabric that are more similar to a canyon-like configuration, considering both the vertical aspect ratio (H/W greater than 0.7) and the minimum street length (street length greater than six times the building height). These conditions are rare to find in a real city. For this reason, more investigations are needed to prove the validity of the urban canyon assumptions and to confirm the robustness of the correlation between SVF and UHI intensity.

ACKNOWLEDGEMENTS

This research is part of the project PID2020-116036RB-I00, funded by the Spanish Ministry of Science and Innovation MCIN/AEI/10.13039/501100011033.

REFERENCES

1. World Health Organization, & UN-Habitat. (2016). Global report on urban health: equitable, healthier cities for sustainable development. https://apps.who.int/iris/handle/10665/204715
2. Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban Climates*. Cambridge University Press.
3. Salvati, A., Coch Roura, H., & Cecere, C. (2017). Assessing the urban heat island and its energy impact on residential buildings in Mediterranean climate: Barcelona case study. *Energy and Buildings*, 146, 38–54. https://doi.org/10.1016/j.enbuild.2017.04.025
4. Salvati, A., Palme, M., Chiesa, G., & Kolokotroni, M. (2020). Built form, urban climate and building energy modelling: case-studies in Rome and Antofagasta. *Journal of Building Performance Simulation*, 13(2), 209–225. https://doi.org/10.1080/19401493.2019.1707876
5. Salvati, A., Monti, P., Coch Roura, H., & Cecere, C. (2019). Climatic performance of urban textures: Analysis tools for a Mediterranean urban context. *Energy and Buildings*, 185, 162–179. https://doi.org/10.1016/j.enbuild.2018.12.024
6. Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, 93(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1
7. Salvati, A. (2021). Urban form and climate performance. In V. Costanzo, G. Evola, & L. Marletta (Eds.), *Urban Heat Stress and Mitigation Solutions* (pp. 97–117). Routledge (Taylor & Francis Group). https://doi.org/10.1201/9781003045922
8. Salvati, A., Kolokotroni, M., Kotopouleas, A., Watkins, R., Giridharan, R., & Nikolopoulou, M. (2022). Impact of reflective materials on urban canyon albedo , outdoor and indoor microclimates. *Building and Environment*, 207, 108459. https://doi.org/10.1016/j.buildenv.2021.108459
9. Oke, T. R. (1988). Street design and urban canopy layer climate. *Energy and Buildings*, 11, 103–113. https://doi.org/10.1016/0378-7788(88)90026-6
10. Svensson, M. K. (2004). Sky view factor analysis – implications for urban air temperature differences. *Meteorological Applications*, 11(3), 201–211. https://doi.org/10.1017/S1350482704001288.
11. Unger, J. (2004). Intra-urban relationship between surface geometry and urban heat island : review and new approach. *Climate Research*, 27, 253–264.
12. Dirksen, M., Ronda, R. J., Theeuwes, N. E., & Pagani, G. A. (2019). Sky view factor calculations and its application in urban heat island studies. *Urban Climate*, 30(May), 100498. https://doi.org/10.1016/j.uclim.2019.100498
13. Mao, J., Yang, J. H., Afshari, A., & Norford, L. K. (2017). Global sensitivity analysis of an urban microclimate system under uncertainty: Design and case study. *Building and Environment*, 124, 153–170. https://doi.org/10.1016/j.buildenv.2017.08.011
14. Bueno, B., Norford, L., Hidalgo, J., & Pigeon, G. (2013). The urban weather generator. *Journal of Building Performance Simulation*, 6(4), 269–281. https://doi.org/10.1080/19401493.2012.718797

PLEA STGO 2022

November 22 - 25, 2022

EDUCATION AND TRAINING

DAY 01
11:15 — 12:45

CHAIR
JONATHAN BEAN

PAPERS
1535 / 1351/ 1482 / 1627 / 1655 / 1142

2ND PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Climate positive innovation and design

Graduate education to drive change in the built environment

JONATHAN YORKE BEAN[1]

[1] The University of Arizona

ABSTRACT: Decarbonization of buildings requires a new and interdisciplinary approach to education across the building sector, including architectural education. The paper outlines three high-level goals of a proposed program: 1) promoting systemic understanding of buildings, climate, and energy; 2) grounding field-specific knowledge in the context of the building industry as a market system; and 3) iterating between abstract principles and applied contexts to learn, test, and expand knowledge. Principles from Legitimation Code Theory inform a proposed sequence of courses that move students through a sequence of alignment, divergence, convergence, and application over four semesters.

1. INTRODUCTION

The opportunity to decarbonize the building sector will require new capacities of architectural education. Passive and low-energy architecture are widely seen as foundational to needed change and future innovation. Buildings that use less energy enhance the promise and potential of new approaches including distributed renewable energy, building-integrated photovoltaics, automated construction, and deep energy retrofits of existing buildings. While architecture has long been considered an interdisciplinary field, there is a pressing need for increased coordination and collaboration with other fields. This paper explains the rationale behind a graduate education program proposed to address this opportunity and outlines the sequence of courses in the proposed program.

2. OVERVIEW OF CURRICULUM AND LEARNING OUTCOMES

The proposed program is organized around three high-level learning goals.

2.1 Systemic understanding of buildings, climate, and energy

There is a litany of calls for architectural education to include considerations of energy and climate (Cosper, 2018; Dubois et al., 2016; Reynolds, 1977) and for building science to be integrated into programs of construction management (Laquatra, 2015) or engineering (King, 2010). Important efforts to respond to these gaps in knowledge have focused on establishing voluntary standards for built environment education. For example, the pilot BEE*now* Built Environment Education® certification examines the curriculum of architectural schools to determine that desired elements are present. Other efforts to articulate building science education, such as PNNL's "Guidelines for Building Science Education," present a granular matrix of the skills appropriate across a broad swath of building industry jobs (Metzger et al., 2015).

Recent work underscores the importance of instituting a systemic understanding of buildings, climate, and energy across the built environment workforce (Truitt et al., 2022). The proposed curriculum responds to these calls and adds to past efforts by focusing on the need to connect knowledge of building design and operation, the dynamics of climate and climate change, and the production, delivery, and carbon impact of energy systems. The proposed curriculum brings together three areas that have historically belonged to different academic disciplines. Thematic streams within the coursework of the proposed program focus on helping students make connections between disciplines and understand the interconnection of potential transformations within the distinct, but connected, fields of buildings, climate, and energy.

2.2 Field-specific knowledge grounded in the context of the building industry as a market system

To help students make sense of the interconnections between buildings, climate, and energy, the proposed program is grounded by distinguishing between three perspectives underpinning the field of energy transitions: the political, socio-technical, and techno-economic perspectives (Cherp et al., 2018). These perspectives can help students see past the blind spots of particular fields. In the context of architecture, for example, much of Kiel Moe's work has questioned the valorization of efficiency at the expense of a broader understanding of energy and energy (Moe, 2007, 2017). Peggy Deamer's work on labor has put a focus on architecture's role in capitalist systems (Deamer, 2020). Considering these critiques from the multiple perspectives of political, socio-technical, and techno-economic can help shed light on a broader consideration of how the paths leading to alternative futures can be reshaped.

The proposed program encourages students to see the building industry as a multifaceted market system (Araujo et al., 2010). Many theoretical perspectives from this dynamic field of work are broadly aligned with the socio-technical perspective, drawing from different strains of neomaterialist theory and theories of social practice. While there are important differences within and across these bodies of theory, many place value on specificity. Put another way, these theories contend that knowledge and action can only be understood in context.

A core tenet of Legitimation Code Theory (Maton, 2014), which draws from Bourdieuan field theory, contends that knowledge is field-dependent. This means that the form and content of knowledge itself varies across fields. In the context of the broader building industry, engineering knowledge is more likely to be abstract (knowing how to perform a certain calculation or procedure), whereas construction knowledge is more likely to be concrete (knowing how to work with a given material). Architectural knowledge combines elements of abstract and concrete knowledge with the additional requirements of telegraphing the right kind of knower, as expressed through preferences for (or against) particular architects and styles (Bean, 2019b; Carvalho et al., 2009). The proposed curriculum engages the dimension of Specialization from Legitimation Code to highlight the difference between the logics underpinning architectural education and those operating in different building industry fields.

2.3 Iterating between abstract principles and applied contexts to learn, test, and expand knowledge

Legitimation Code Theory offers a body of pedagogical research with tested methods that can be used to operationalize the third principle underpinning the proposed curriculum: the iterative journey between abstract concepts and applied contexts. This type of iterative movement, famously described by Herbert Simon as having the goal of "changing existing situations into preferred ones," (Simon, 1988) and evident in Schön's documentation of the interaction between a design student and critic (Schön, 1984) has long been a characteristic of design education in general and architecture education in particular. Legitimation Code Theory offers at least two rigorous, robust, and repeatable ways to proactively structure both curricular structures and discrete learning activities. One is evidenced by the body of work on the *semantic wave*: a mode of teaching that moves from abstract concepts, connects the abstract concepts to specific examples, and then moves back towards the abstract. This principle, which has been widely applied in the context of academic writing, has also been used to help teach chemistry (Blackie, 2014), identify learning opportunities in the teaching of fluid mechanics (Pott & Wolff, 2019), heat flow (Georgiou, 2015), and the second law of thermodynamics (Chinaka, 2021). A second opportunity is reflected in recent LCT work that develops the dimension of Autonomy (Maton & Howard, 2020). Studies of Autonomy focus on how teachers and students can create effective bridges between different sets of practices, essential to efforts to advance systemic understanding of buildings, climate, and energy across the built environment.

3. COURSE SEQUENCE

The following sections outline the course content and goals of each semester.

3.1 Semester 1: Alignment

The first semester has two goals:

1. ***Create shared knowledge of the potential of the built environment to address the climate crisis.*** Students will learn why passive and low-energy architectural strategies that deliver significant reductions in energy demand and load are critical to accelerate and scale the impacts of policy change and innovation in technologies and materials. This perspective will be learned through a class connecting core principles of passive building design to an understanding of climate and energy.
2. ***Informed by educational theory on student identity formation (Holmes, 2001), help students construct a new identity as a future climate professional.*** This course is currently under development using an expert-mentor model, with guest lectures from professionals and academics at the cutting edge of their fields. Regular lectures and supporting materials, such as peer-reviewed papers, newspaper articles, and online videos will supplement the lectures to help backfill student knowledge and provide a variety of entry points. In addition to their guest lecture, mentors will interact at several points during the semester with small groups of students, and will also describe to students their personal experience entering the building industry,

helping to illuminate the diversity of pathways into and through built environment careers of influence.

Two additional courses round out the first semester: one in real estate finance, the other focused on leadership and teams. These courses, which students will take alongside students enrolled in a graduate management program, will help bridge knowledge gaps in many architectural and engineering curricula. These gaps reduce the efficacy of professional architects and engineers because they must often learn basic business concepts on the job. In turn, these gaps create limitations on the ability of new professionals to exercise influence, especially early in their professional careers.

2.2 Semester 2: Divergence

After the immersive experience of the first semester, students will choose a concentration area, where they will work closely with a faculty subject matter expert in fields such as high-performance building, district energy, building-integrated photovoltaics, grid-interactive efficient buildings, or advanced materials. An intensive core course will cover key concepts and principles, while a case-study course will put this knowledge into social and theoretical context (Moore & Wilson, 2013). In a third class, students will undertake an applied consulting project. They will be teamed with students registered in professional business and information programs. These teams, which mirror cross-functional teams common in industry, will encourage both the reinforcement of the general knowledge about climate, energy, and buildings students learned in their first semester, and will help students practice relating the specialized knowledge gained in parallel courses in their area of concentration to their teammates from other fields. This two-way knowledge flow is influenced by core concepts from studies of teaching and learning and will have the added benefit of spreading awareness of climate, energy, and buildings to students from other disciplines.

Teams in the consulting class will work on a problem defined in partnership with an industry partner. Problems will be defined so that they demand students grapple with both the technical and strategic. For example, an HVAC company may be interested in having students work through problems and opportunities related to refrigerant changeover. Because refrigerant management and reduction have been identified as two of the greatest needs in addressing climate change and the need for cooling will only increase as the world continues to become warmer and more urban, this problem sits squarely at the nexus of buildings, climate, and energy. At the conclusion of the spring semester, students will be strongly encouraged to pursue a relevant paid summer internship. Program leadership will work with industry partners to offer students internship opportunities.

2.3 Semester 3: Convergence

Students will return in their third semester of the program for a collaborative studio-style course run in parallel with an advanced consulting course. Whereas the advanced consulting course will zoom in to address the complexities and nuances of the problem addressed in the first consulting course, the entire cohort of students will reconvene in a studio environment to learn in the context of a single building and site. Students may learn through an engaged studio or through a competition such as the Solar Decathlon, which has been shown to have great potential for high-impact teaching and learning (Bean, 2019a; Herrera-Limones, Millán-Jiménez, et al., 2020; Herrera-Limones, Rey-Pérez, et al., 2020; López-Escamilla et al., 2020). This semester will complete the transition to self-led learning, with each student charged with the responsibility to further develop their own area of expertise through application to a problem case. For example, if high-performance building, district energy, building-integrated photovoltaics, grid-interactive efficient buildings, and advanced materials are defined as the areas of concentration, students would be charged with integrating their research into a single, unified building design that demonstrates the potential of all five concentrations. The building program and site location will be chosen to map to pressing global challenges, such as the demand for high-density buildings in cooling-dominated regions (Kigali Cooling Efficiency Program, 2018), preparing students to work in a global context.

2.4 Semester 4: Application

The fourth and final semester of the program is intended to launch students into an impactful career in industry, at a nonprofit, or in government. Students will complete a thesis under the advisement of their concentration director and have the option of undertaking additional coursework or directed research to support their transition into the workforce.

3. PEDAGOGY

The program draws from established learning theory to shape both learner knowledge and identity. Significant and problematic social and professional barriers to change exist in existing built environment professions, for example between the values of architects, designers, and those in construction. In response, the pedagogy and structure of the program is informed by Legitimation Code Theory, which provides a framework for understanding the organizing principles that underpin professional fields. Graduates will benefit from connections with industry. These same connections will help affiliated faculty stay at the cutting edge in their fields and identify new and relevant research questions.

4. CONCLUSION

This paper outlines a proposed four-semester interdisciplinary program intended to instill a systemic understanding of buildings, climate, and energy. The program places passive and low-energy architecture in context with a systemic understanding of environment and energy while providing learners the opportunity to develop problem-solving and innovation skills in an applied context.

REFERENCES

1. Araujo, L., Finch, J., & Kjellberg, H. (2010). *Reconnecting Marketing to Markets*. Oxford University Press.
2. Bean, J. (2019a). *Thermodynamic Sunblock: Learning from the 2019 Solar Decathlon Design Challenge*. https://scholarsbank.uoregon.edu/xmlui/handle/1794/25107
3. Bean, J. (2019b). Coding knowledge. *Interactions*, *27*(1), 24–25. https://doi.org/10.1145/3371279
4. Carvalho, L., Dong, A., & Maton, K. (2009). Legitimating design: A sociology of knowledge account of the field. *Design Studies*, *30*(5), 483–502. https://doi.org/10.1016/j.destud.2008.11.005
5. Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Research & Social Science*, *37*, 175–190. https://doi.org/10.1016/j.erss.2017.09.015
6. Chinaka, T. W. (2021). Introducing the second law of thermodynamics using Legitimation Code Theory among first year chemistry students. *Cypriot Journal of Educational Sciences*, *16*(3), 981–994. https://doi.org/10.18844/cjes.v16i3.5772
7. Cosper, C. (2018). From Informational Barrier to Ethical Obligation: Evolving Perceptions of Teaching Energy in Architecture. *Building Technology Educator's Society*, *2019*(1). https://scholarworks.umass.edu/btes/vol2019/iss1/60
8. Deamer, P. (2020). *Architecture and Labor*. Routledge.
9. Dubois, C., Cloutier, G., Rosenkilde Rynning, M., Adolphe, L., & Bonhomme, M. (2016). City and Building Designers, and Climate Adaptation. *Buildings*, *6*(3), 28. https://doi.org/10.3390/buildings6030028
10. Georgiou, H. (2015). Putting physics knowledge in the hot seat. In K. Maton, S. Hood, & S. Shay (Eds.), *Knowledge-building: Educational Studies in Legitimation Code Theory* (pp. 176–192). Routledge.
11. Herrera-Limones, R., Millán-Jiménez, A., López-Escamilla, Á., & Torres-García, M. (2020). Health and Habitability in the Solar Decathlon University Competitions: Statistical Quantification and Real Influence on Comfort Conditions. *International Journal of Environmental Research and Public Health*, *17*(16), 5926. https://doi.org/10.3390/ijerph17165926
12. Herrera-Limones, R., Rey-Pérez, J., Hernández-Valencia, M., & Roa-Fernández, J. (2020). Student Competitions as a Learning Method with a Sustainable Focus in Higher Education: The University of Seville "Aura Projects" in the "Solar Decathlon 2019." *Sustainability*, *12*(4), 1634. https://doi.org/10.3390/su12041634
13. Holmes, L. (2001). Reconsidering Graduate Employability: The "graduate identity" approach. *Quality in Higher Education*, *7*(2), 111–119. https://doi.org/10.1080/13538320120060006
14. Joseph Laquatra. (2015). The Need for Building Science Education. *Journal of Civil Engineering and Architecture*, *9*(7). https://doi.org/10.17265/1934-7359/2015.07.003
15. Kigali Cooling Efficiency Program. (2018). *Cooling as a Service (CaaS)*. Kigali Cooling Efficiency Program. https://www.k-cep.org/wp-content/uploads/2018/07/Cooling-as-a-service-Knowledge-brief-6.7.2018_Final_online_v1.pdf
16. King, D. (2010). The great zero-carbon skills gap. *Construction Research and Innovation*, *1*(1), 24–29. https://doi.org/10.1080/20450249.2010.11873758
17. L. Blackie, M. A. (2014). Creating semantic waves: Using Legitimation Code Theory as a tool to aid the teaching of chemistry. *Chemistry Education Research and Practice*, *15*(4), 462–469. https://doi.org/10.1039/C4RP00147H
18. López-Escamilla, Á., Herrera-Limones, R., León-Rodríguez, Á. L., & Torres-García, M. (2020). Environmental Comfort as a Sustainable Strategy for Housing Integration: The AURA 1.0 Prototype for Social Housing. *Applied Sciences*, *10*(21), 7734. https://doi.org/10.3390/app10217734
19. Maton, K. (2014). *Knowledge and knowers: Towards a realist sociology of education*. Routledge.
20. Maton, K., & Howard, S. K. (2020). Autonomy: The next phase of dialogue between systemic functional linguistics and Legitimation Code Theory. *Journal of World Languages*, *6*(1–2), 92–112. https://doi.org/10.1080/21698252.2020.1720160
21. Metzger, C. E., Rashkin, S., & Huelman, P. (2015). *Guidelines for Building Science Education* (PNNL-24143). Pacific Northwest National Lab. (PNNL), Richland, WA (United States). https://doi.org/10.2172/1173025
22. Moe, K. (2007). Compelling Yet Unreliable Theories of Sustainability. *Journal of Architectural Education*, *60*(4), 24–30. https://doi.org/10.1111/j.1531-314X.2007.00105.x
23. Moe, K. (2017). Energy and Form in the Aftermath of Sustainability. *Journal of Architectural Education*, *71*(1), 88–93. https://doi.org/10.1080/10464883.2017.1260923
24. Moore, S. A., & Wilson, B. B. (2013). *Questioning Architectural Judgment: The Problem of Codes in the United States* (1 edition). Routledge.
25. Pott, R. W. M., & Wolff, K. (2019). Using Legitimation Code Theory to Conceptualize Learning Opportunities in Fluid Mechanics. *Fluids*, *4*(4), 203. https://doi.org/10.3390/fluids4040203
26. Reynolds, J. S. (1977). Something of a Gadfly. *Journal of Architectural Education*, *30*(3), 58–61. https://doi.org/10.1080/10464883.1977.10758112
27. Schön, D. A. (1984). Problems, frames and perspectives on designing. *Design Studies*, *5*(3), 132–136.

https://doi.org/10.1016/0142-694X(84)90002-4
28. Simon, H. A. (1988). The Science of Design: Creating the Artificial. *Design Issues*, *4*(1/2), 67–82. https://doi.org/10.2307/1511391
29. Truitt, S., Bean, J., Sullivan, J., Paranjothi, G., & Moe, A. (2022). *Completing the Circuit: Workforce Development for Advanced Building Construction and Grid-Interactive Efficient Buildings* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-80480. https://www.nrel.gov/docs/fy22osti/80480.pdf. https://doi.org/10.2172/1855580

The use of BIM tools in e-learning for architecture during the COVID-19 pandemic

A case study at the University of Brasília

RAQUEL NAVES BLUMENSCHEIN [1] PEDRO HENRIQUE FERREIRA MUZA[1]

[1] University of Brasília, PISAC (Innovative and Sustainable Park of the Built Environment)

ABSTRACT: This paper aims at exposing the experiences with the process of distance learning during the pandemic period in which the University of Brasilia carried out its activities remotely. The object of analysis is the performance of the students of Architectural Project VI of the Faculty of Architecture and Urbanism. It proposes to discuss the role of the BIM tool in the process of education of architectural projects. The method adopted for this work was divided into two phases. The first one referred to compiling theoretical information about e-learning in the field of Architecture and Urbanism. The second phase consisted in the application of an online questionnaire to the undergraduate students who were taking the discipline "Architectural Project – Complex functions: Prisons". In this stage, a qualitative analysis of data was sought to corroborate the theory identified in the previous stage. We can conclude that BIM can potentially contribute to achieving optimal results in the design process, considering the effectiveness of information exchange and communication. Project teams can also benefit from the interaction between members and collaborative tools, reaching better results. In the process of learning and developing projects at graduation, BIM also may signalize great possibilities to enrich the design process as a whole.
KEYWORDS: BIM (Building Information Modeling), architectural e-learning, COVID-19 pandemic.

1. INTRODUCTION

It can be argued that with the advent of Industry 4.0, a fourth industrial revolution is taking shape. This moment can be characterized by a strong technological slant impregnated in most processes. A few of them can be cited, such as the Internet of Things, the massive automation of industry with robotics, biotechnology, nanotechnology, and others [1].

In this sense, the impact of these changes has been discussed in the field of education, when speculating hybrid methods of tutoring. When the COVID-19 pandemic started in 2019, education systems had to be reinvented, incorporating newer technologies and online systems as a solution for the social distance. From this point of view, a discussion about Education 4.0 started to take place.

Long-distance Education appears as a fast, integrative and multimedia teaching modality, a digital technology that contributed for a potential massive information access [2]. This technology also made possible knowledge spread, providing conditions for continuity in the academic year during the mandatory quarantine period [3].

In this sense, the BIM (Building Information Modeling) tools may potentially collaborate to improve the new bottlenecks imposed by distance education when it comes to teaching Architecture and Urbanism. The core of BIM methodology is a collaborative framework in building design. In light of that, it can be argued that project teams may be benefited by using collaborative arrangements in order to improve the outcomes of a design [4].

This paper aims at exposing the experiences with the process of distance learning during the pandemic period in which the UnB (University of Brasilia) carried out its activities remotely. The object of analysis was the performance of the students of Architectural Project VI - Complex Functions, a subject of the FAU (Faculty of Architecture and Urbanism). Thus, it proposes to discuss the role of the BIM tool in the process of education of architectural projects.

The present research is divided in two stages, consisting of a literature review about e-learning in architecture and BIM collaborative tools. Subsequently, the second phase is related to a qualitative analysis of data collected in a survey carried out with students enrolled in the discipline mentioned. A limitation of this research is that the data collected cannot be used for applied statistical purposes. It only intends to corroborate with the present discussion.

2. ARCHITECTURE AND URBANISM E-LEARNING

The COVID-19 pandemic of 2020 may have exposed social problems in Brazil, as well as in the world, such as inequality and lack of access to education for a large part of the population. Given this situation, in-person classes were completely suspended, starting a race in search of the best e-learning methodology that could meet the needs of a student population as diverse and unequal as the Brazilian one.

Distance learning and remote emergency activities occurred at different paces in Brazil. For private education institutes, e-learning activities occurred more fluidly and rapidly due to previous experience with technology and the natural pressure to maintain the academic calendar. In the public sector, some universities chose to paralyze classes, partially or totally. Given the impossibility of ensuring equal conditions for students and professors to establish remote activities [5].

In the field of Architecture and Urbanism teaching, attempts to develop an online undergraduate teaching model proceed after the occurrence of the 2020 COVID-19 pandemic. Some regulatory agencies associated with the career have positioned themselves recently with the intensification of the debate due to the pandemic outlook, such as the CAU-BR (Brazilian Council of Architecture and Urbanism). There has also been notorious discussion about online architecture education on a global scale [6].

The concern of professional entities is genuine, however, given the situation of seclusion that was imposed by social isolation, e-learning came up as a suitable solution. Therefore, for the implementation of distance education, it was necessary to make important adjustments regarding pedagogical, technological skills or even the adaptation between the pedagogical model and the new reality, enhancing resources [7].

In relation to students, some issues urge to be pointed out, for instance, mental and physical problems caused by social isolation. Recently, RIBA (Royal Institute of British Architects) published a survey conducted with students during the pandemic. The results state that 58% of the students have mental health problems, 39% responded that their physical health had worsened, 45% isolated themselves [8].

Few researches discuss the impacts of the pandemic on the general education scenario, specifically in architecture. One may argue that the pandemic, on a global scale, exposed limitations and problems faced collectively. Precisely, in Brazilian reality, aspects such as the educational deficit, social and health problems and economic factors have raised the debate on the effectiveness of measures and actions of the current government in mitigating the effects of the pandemic. In public education, it can be said that political issues have a great impact on the government's investment in the successful implementation of e-learning technology.

3. BIM COLLABORATIVE TOOLS AND EDUCATION

When it comes to teaching Architecture and Urbanism, computational tools to support the development of architectural projects and products are commonly used. With the advent of new, more robust data technologies, software for architecture can be pointed as a key piece for learning. BIM tools increasingly appear as an alternative for project development, having potential for remote collaborations between various figures in the architectural process [9]. Yet, undergraduate didactic experiences using BIM methodology are still in a very early stage.

Information management in project development generates an impact on the final quality of the product, and it is extremely important that the information is available to professionals at all stages of the project, as decision-making performed inaccurately affects the quality of the project [10]. Furthermore, BIM must not be resumed as an application of computational tools, but also as a set that requires integration, collaboration, interoperability and multidisciplinary environment [11].

Collaboration implies outlining objectives and responsibilities, as well as results to be achieved. In this sense, it is essential to create innovative tools and solutions. Collaborative tools appear in the civil construction field to allow the development of online products. For instance, on-line CAD red-lining, markup, forums, logs registration, workflow and so on [12,13]. These tools enable team engagement and can deliver results that cannot be achieved by one.

To accomplish collaboration in the design process, interoperability and information integration are central. It is critical to exchange files effectively, using software and project methodologies that enable lean design progress. In this sense, interoperability can enable the creation of new value propositions, based on innovation values. To summarize, BIM process in architectural projects can be considered a highly collaborative process [14, 15].

It is argued that the slow adoption of the BIM methodology is mainly due to the lack of advanced computational sets and software maturity required to develop accurately complex industrial design applications [16]. Even having overcome some of the technological barriers, in Brazil, the adoption of BIM still happens slowly and heterogeneously across the country. This fact can be explained by the low professional training in BIM software, difficulties to change project paradigms and lack of investments.

In education, Through the possibilities that the BIM offers, its use in the classroom can enable a collaborative/integrated work between teachers of different areas of the same subject. Consequently, digital technologies associated with a change in project culture and in the way, professors think can help renew architecture and urbanism teaching by facilitating the process of knowledge integration in the Architecture course [17].

4. THE DISCIPLINE

The subject Architectural Project VI – Complex Functions – is one of the compulsory subjects in the curriculum of FAU, at UnB. The general goal of this discipline is the exercise of architectural design of complex functions, strengthening the design process. This proposal is based on an approach to the design process, in an integrated and systemic way. On the other hand, the course aims to develop, test, and demonstrate architectural and constructive solutions and space concepts, contributing to the innovation and sustainability of the productive chain of the construction industry, focusing on penitentiary facilities.

The course is organized in four units (Table 1), which content follows a sequence that starts from broader conceptual issues of contextualization and foundation of architecture, followed by project development stages and their constraints. The final product is a preliminary project of penitentiary facilities developed by student teams [18].

Table 1:
The discipline organization and its proposed activities highlighting the learning methodology proposed

Units	Activities proposed
Unit 1 Theoretical stage (Research and presentations)	Preparatory – Introduction
	Research: Technical conditioners
	Research: Project case studies – references
	Research: Technological solutions
Unit 2 Conception (Studio work and presentation)	Design of a master plan and chronogram
	Design practice focused on project – Brainstorm session
	Synthesis phase and prelaminar critical analysis
	3D Physical volume studies – Brainstorm session
	Conception of Building Design
	Final 3D physical model volume
Unit 3 Design development (Studio work and presentation)	Prelaminar Study development
	Products: Implantation studies, floor plans, facades, sections, internal and external perspectives, virtual and physical 3D models.
Unit 4 Results	Compilations of theoretical and practical findings
	Final presentations
	Overall evaluation of the semester

In the semester this work was registered, seventeen students took part in the subject, all of them regular Architecture students at UnB. The activities were performed online through the Microsoft Teams platform. The exchange of files and activities were done online through the Google Drive platform. The course had two weekly meetings, each one lasting a maximum of four hours. The course dynamics made these meetings flexible, with theoretical classes, team assessment, time for product development, and delivery presentations.

It is important to highlight a study carried out during the pandemic to characterize the overall student's situation and the viability of fully engaging in a long-distance education scenario. According to that Report, 82,10% of FAU's students use a personal computer for education purposes [19]. Regarding Internet connection, 48,8% of the students accounted to have problems with quality and stability of signal. Moreover, 78,4% of students described their home environment as totally or partially appropriate to e-learning. In particular, all participants enrolled in the discipline in the present research had full access to the Internet, computers, software of architecture and communication.

5. METHODOLOGY

The method adopted for this work was divided into two phases. The first one referred to compiling theoretical information about e-learning in the field of Architecture and Urbanism. Also, it was sought to theoretically define the attributes of BIM in the construction of a distance learning method. In this regard, a systematic review of articles was carried out using the Spocus, SciELO and Web of Science databases. The keywords searched were: "teaching", "architecture" and "BIM". A time frame of publications from 2000 to 2021 was used. Only peer-reviewed articles were selected.

The second phase consisted in the application of an online questionnaire to the undergraduate students of Architecture and Urbanism who were taking the discipline "Architectural Project – Complex functions: Prisons". In this stage, a qualitative analysis of data was sought to corroborate the theory identified in the previous stage. Through an online platform, Microsoft

Forms, the students were able to anonymously evaluate the performance of the subject, the main challenges of the online semester, positive points and their own learning level during the semester.

The Questionnaire was divided into two main sections. In the first part of the questionnaire, the students were invited to evaluate parameters referred to four different categories, for instance: Methods of the discipline, Pedagogical mediation by the tutors, teamwork and final products using BIM. The subsequent parameters are listed below:

- **Methods of the discipline:**
  Clarity of the method
  Sequence of Activities
  Proposed Works (products developed)
  Engagement in activities
- **Pedagogical mediation by the tutors:**
  Objectivity
  Effectiveness
  Assistance
- **Team work using BIM – Process:**
  Members Engagement
  Productivity
  Sharing work effectiveness
- **Final products using BIM – Results:**
  Level of Works (products developed)
  Students Engagement
  knowledge acquisition

For this section, the students could show their contentment regarding the topics using a Likert scale spired version. One could respond rather if it was an unsatisfied, neutral or satisfied experience throughout the semester.

The Second part invited the participant to elaborate a short answer (up to one hundred words) illustrating the negatives and positives points experienced in e-learning and developing a project in BIM software. The results of the first section of the questionnaire were analyzed and compiled as to indicate the percentage of satisfaction in participant's opinion regarding the parameters presented (Table 2 and Figure1). The second part of the data was combined in a table of most words used in answers collected (Table3).

6. RESULTS

Motivating and engaging students in e-learning activities configured a major challenge throughout the role process of the discipline. It can be argued that the level of engagement by the students has a direct effect on learning and in the quality of the final products expected to be due during the activities. As shown in the first part of table 2, 9,1% of students reported to be unsatisfied with engaging in activities, as 27,3% felt neutral about the products developed.

Among the positive points listed by the students, the presence of an aligned and concise method was essential for the proper progress of the proposed and performed activities. The pedagogical assessment by the tutors also played a key point according to the student's opinion (Table 2)

Another important topic was the use of BIM tools by the students, which enabled a greater fluidity of design development, information integration, and the collaboration of all parts involved in a remote and safe way. However, 45,5% of students reported to be "neutral" referred to the experience of "Sharing Work Effectiveness" (table 2). This may indicate that planning and using correctly tools to maximize the design process and its results in BIM environments is still a challenge that needs to be addressed. Students also reported the difficulty to collaborate due to file incompatibilities between different BIM Software.

Table 2:
Results of the first part of the questionnaire. Categories of analyses used and its subsequent Items evaluated by the students.

Parameter Evaluated	Unsatisfied (%)	Neutral (%)	Satisfied (%)
1. Methods			
Clarity of the method	0 %	0 %	100%
Sequence of Activities	0 %	16,2%	81,8%
Proposed Works (products developed)	0 %	27,3%	72,7%
Engagement in activities	9,1%	9,1%	81,8%
2. Pedagogical mediation			
Objectivity	0 %	0 %	100%
Effectiveness	0 %	9,1%	90,9%
Assistance	0 %	0 %	100%
3. Team Work -Using BIM			
Members Engagement	0 %	18,2%	81,8%
Productivity	9,1%	18,2%	72,7%
Sharing work effectiveness	0 %	45,5%	54,5%
4. Final products proposed – Using BIM			
Level of Works	0 %	27,3%	72,7%
Students Engagement	0 %	27,3%	72,7%
knowledge acquisition	0 %	9,1%	90,9%

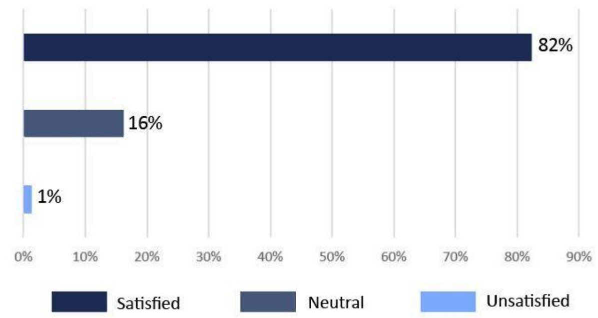


Figure 1:
Graphic showing student's overall level of satisfaction having in consideration the items previously demonstrated in Table 1

Another point was the students' preference for parametric BIM modeling over physical 3D models. The students also showed greater agility in the process of making boards and delivering products at the preliminary design level using BIM software. It can be inferred that the use of BIM brought greater agility, assertiveness, and flexibility to production. In general, as illustrated in figure 1, the overall level of satisfaction reached over 82% of the parameters judged by the students enrolled in the discipline.

Table 3:
Results of the second part of the survey. Most common words used by the students in answers

Words	Number of repetitions in answers
Communication	25 times
Difficulty	20 times
Organization	16 times
Connection	15 times
Group	13 times

It was possible to infer through the meetings in the entire semester that students were facing personal concerns related to the unique moment stated by the pandemic. Far more than healthy concerns, difficulties on a daily basis related to household issues, lack of proper setting to work and study at home, difficulty to communicate due to internet connection quality, contributed to intensify the insecure scenario.

In short answers, a positive point enumerated by the participants was the flexibility of working time to produce and study. Also, saving time due to no needing to commute appeared as a benefit of e-learning classes. As a result, groups reported having longer time to produce and organize their own duties. Moreover, using BIM software since early stage of design concept was pointed out as a key factor to optimize time and work on development stage of design.

The negative aspects recorded by the participants (table 3) in this analysis conceivably rely on a core matter: Communication. By means of all technological tools discussed previously that viabilities project design development and long-distance learning, altogether requires a high settings of communication proceeds, data exchange and the most important, the correct assimilation of information by the involved ones.

In Summary, objectivity to tackle design issues and develop solutions closely with the groups of students was a major concern with online assessment by the tutors.

7. CONCLUSION

Among all the challenges imposed by the COVID-19 pandemic starting in 2020, education had to go through major paradigm shifts. The challenge of implementing an e-learning system that would meet the demands efficiently was a process of great resilience. In general, the results of the present research carried out with undergraduate students of Architecture and Urbanism at UnB point to positive evaluations by the students, indicating a satisfactory learning outcome.

A large part of the discipline's success may have been assured by the students' degree of commitment and maturity, as it was a group that was about to graduate. In addition, the good quality of Internet access, computers and software were also a fundamental element to ensure students' learning. On the other hand, this reality does not generally apply to the UnB population.

BIM can potentially contribute to achieving optimal results in the design process. The effectiveness of information exchange and communication can be cited as benefits. Project teams can also benefit from the interaction between members and collaborative tools, reaching better results [20]. In the process of learning and developing projects at graduation, it can be said that BIM also may signalize great possibilities to enrich the design process as a whole.

8. ACKNOWLEDGEMENT

This research acknowledges all students enrolled in the discipline. Even in difficulties faced due to the COVID-19 pandemic, they managed to thrive and share their knowledge. The same can be said about all the University of Brasilia's staff.

9. REFERENCES

1. Schwab, K. (2016). *A Quarta Revolução Industrial*. São Paulo: Edipro.

2. Habowski, A. C.; Conte, E.; Jacobi, D. F. (2019). I*nterlocuções e discursos de legitimação emEaD*. Ensaio: Avaliação e Políticas Públicas em Educação, n. Ahead.

3. Pretto, N. L.; Avanzo, H. (2018). *Educação e arquitetura na era digital: um estudo sobre a expansão das instituições federais de ensino superior em Barreiras, Bahia*. Revista Espaço Pedagógico, v. 25, n. 1.

4. Succar, B. (2009). *Building information modelling framework: A research and delivery foundation for industry stakeholders.* "Automation in Construction".

5. Wilderom, M., Arantes P. (2020). *Arquiteturas da distância: o que a pandemia pode revelar sobre o ensino de Arquitetura e Urbanismo.* 02 Ago 2020. ArchDaily Brasil. <https://www.archdaily.com.br/br/944738/arquiteturas-da-distancia-o-que-a-pandemia-pode-revelar-sobre-o-ensino-de-arquitetura-e-urbanismo>

2. CAU-BR. (2019). C*AU/BR decide recusar registro profissional a alunos formados em cursos EaD.* caubr.gov.br, 2019. Disponível em: <https://www.caubr.gov.br/cau-br-decide-recusar-registro-profissional-a-alunos-formados-em-cursos-ead/>

7. Barros, D. M. V.; Guerreiro, A. M. (2019). *Novos desafios da educação à distância: programação e uso de Chatbots. Revista Espaço Pedagógico*, v. 26, n. 2, p. 410-431.

8. RIBA, Royal Institute of British Architects. (2019). *Covid-19 student survey: key findings: how is the crisis continuing to impact architecture students? Read the findings from our covid-19 student survey. How is the crisis continuing to impact architecture students?* <https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/riba-covid-19-student-survey-keyfindings> 2020.

9. Barison, M. B.; Santos, E. T. (2012). *Gestão e Tecnologia de Projetos. Ensino de BIM: Tendências atuais no cenário internacional,* p. 67–80.

10. Campestrini, T. F. (2015). *Entendendo o BIM: Uma visão do projeto de construção sob o foco da informação.* 1. Ed. Curitiba: Editora UFPR.

11. SOUZA, L. A de; Amorim, S. R. L.; Lyrio, A. de M. (2009). *Impactos do uso do bim em escritórios de arquitetura: oportunidades no mercado imobiliário. Gestão & Tecnologia de Projetos.São Paulo*. v. 4, n. 2, p.26-53.

12. Grilo, A. (1998). *The Development of Electronic Trading Between Construction Firms, Doctoral Dissertation*. University of Salford.

13. W. Kymmel. (2008). *Building Information Modeling — Planning and Managing Construction Projects with 4D and Simulatons*. McGraw-Hill.

14. National Building Information Modeling Standard (2007). *Transforming the Building Supply Chain Through Open and Interoperable Information Exchanges, version 1.0* — Part 1. Overview, Principles and Methodologies; NBIS.

15. Kocaturk T., Kiviniemi A. (2013). *Challenges of Integrating BIM in Architectural Education; Computation and Performance – Proceedings of the 31st International Conference on Education and research in Computer Aided Architectural Design in Europe, Delft*. The Netherlands, 18-20 September 2013, Volume 2. Edited by Rudi Stouffs and Sevil Sariyildiz. Brussels: Education and research in Computer Aided Architectural Design in Europe; Delft: Faculty of Architecture, Delft University of Technology.

16. Eastman, C., Teichols, P. , Sacks R. and Liston K. (2008). B*IM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*.

17. Leal, B.;Salgado, M. S. P*ARC Pesq. em Arquitetura e Construção* (2019) *Propostas de incorporação de BIM no curso de arquitetura e urbanismo*, p. 13.

18. Blumenschein, R. (2021). *Plano de Curso Projeto Arquitetônico – Funções Complexas. Prisões*. Faculdade de Arquitetura e Urbanismo – UnB.

19. Comitê de Apoio Discente. *Resultados do questionário acadêmico*. Faculdade de Arquitetura e Urbanismo – UnB. 2021

20. Grilo A., Jardim-Gonçalves R. (2010). *Value proposition on interoperability of BIM and collaborative working environments.* Automation in Construction V.19. P.522-530.

Mini Wind lab project

An interactive, numerical, physical wind simulation platform concept for teaching

RAFAEL ANDRÉS MOYA CASTRO [1]

[1] Universidad de Concepción, Facultad de arquitectura, Urbanismo y Geografía.

ABSTRACT: The mini wind lab project is a concept of a low-cost, open-source and portable teaching platform to perform simulations of wind flow on scaled building models. A first prototype of this tool was developed by a team in the Spatial Information Architecture Laboratory at RMIT University and its target audience were students of architecture and design. The main aspect of this platform is the integration of digital and physical technology for empirical experience of experimentation with the same tool (a physical mini wind tunnel, Arduino sensors and 3D software). With this approach, this tool allows non-wind expert students to plan, setup, perform and visualise experiments of wind simulations in real time, with a low level of knowledge and training. Thus, students can learn about analysis of aerodynamic phenomena near buildings, such as wind flow acceleration, turbulence and wind discomfort issues for pedestrians.

This paper presents a new version of this easy-to-use and low-cost tool that integrates fully open source technology, with additional simulation and visualisation techniques. The final aim of this project is to develop all the parts of this platform as a Do It Yourself kit for universities.

KEYWORDS: Wind tunnel, Urban Aerodynamics, teaching tool, urban wind, wind simulation

1. INTRODUCTION

Phenomena that conform to what we would call the micro-climate of our near environment, such as urban temperature, humidity and wind, are something difficult to visualise and quantify in non-specialised contexts. Aspects like air flow or wind in urban contexts are even more difficult to understand for most people, including architects, because of their lack of understanding of the science of fluid dynamics [1]. And this frequently means wrong conclusions about how airflow interacts with the shape of buildings [2]. Even though this kind of knowledge is more and more important for areas such as Sustainable Design, in many architecture and design schools there are not teaching programs that involve understanding wind simulation on buildings, because of the high, sophisticated and expensive technologies needed for these tasks. In addition, the experimentation methods and the basis of architectural science are not well implemented in many architecture school methodologies. On the other hand, there are limited digital tools for rapid urban climate analysis (especially for urban wind analysis) that are low cost, user-friendly, visually effective and with a teaching approach for architecture students [3]. But, either they are add-ons that depend of expensive 3D software (LadyBug Tools) or are not available any more (Autodesk-Vasary). Thus, there is a gap between the comprehension of wind phenomena around buildings and the methods to communicate and practice this knowledge to architecture students. New teaching tools are needed to introduce architecture students in the knowledge of complex scientific concepts, numerical data and analysis of microclimate and environmental design. Rather than using a traditional approach of book reading, I proposed a teaching method based on the use of Interactive Interface Technology [4], to allow students to explore, operate and visualise microclimate phenomena and data. For this reason, a team of Architects and Engineers have developed a concept for an easy to use and low cost platform for urban aerodynamic simulation and teaching in architecture and design schools. This platform involves digital and analogue technology for empirical experience of experimentation of the wind phenomena. The main idea behind this approach is the use of a mix of technologies to produce an augmented reality interface to visualise and understand non-visible phenomena and their complex data in a graphical way. At the moment, this concept has been developed and tested at the prototype level, in the Spatial Information Architectural Laboratory, between 2014 and 2016 [5]. The concept presented in this paper is an evolution of this first prototype, that includes new techniques of visualisation and the goal is to develop it as a Do It Yourself kit, available as an open source project and with a focus on pedagogical practice.

2. THE MINI WIND LAB CONCEPT

The mini wind lab project is a concept of a low-cost, open-source and portable teaching platform to perform simulations of wind flow on scaled buildings models. It was developed by a team in the Spatial Information Architecture Laboratory at RMIT University and its audience target are students of architecture and design. The main aspect of this platform is the integration of three simulation methods in the same tool, to conform a progressive workflow that conducts wind experiments. The idea of this strategy is to help non-wind expert students to plan, setup, perform and visualise experiments on wind simulations with a low level of knowledge and training.

The three components proposed to conform the complete workflow of the mini wind lab are: 1) an interactive simulation system with projection mapping technology to generate a first visualisation of wind patterns; 2) a numerical simulation system using open source CFD technology, 3) and a physical simulation system, that is based on a physical air flow tunnel using low cost wind sensors and Arduino technology (Fig.1).

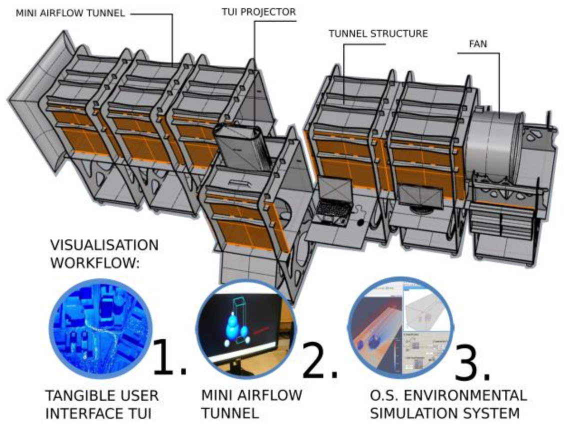


Figure 1: Mini Wind Lab Project.

The first developed prototype of this platform only included a mini physical airflow tunnel, an Arduino controller with wind sensors, and the use of 3D software to graphically visualise the data from the sensors in real time. However, there were some limitations, because the 3D software used to visualise the data was expensive and not Open Source, and it was difficult for the students to design the experiments and setup the location of sensors, without some training and knowledge about wind movement patterns. This new concept proposes a more complete workflow and additional open source technology to resolve these issues.

With these additions and changes, the new Mini Wind Lab's aim will be to allow students to run empirical experimentation methods to understand the wind movement around their building designs. With the mix of techniques and new accessories, the platform would allow using the outputs from one simulation to refine the settings of the next experiment in an iterative and intuitive process.

This tool is not for an accurate simulation of the wind phenomena, but it is suitable for preliminary understanding of aerodynamic phenomena near buildings, such as wind flow acceleration, airflow velocity fluctuations and turbulence intensity. In this way, it can be useful for students of architecture, landscape design, urban design and industrial design. Here, a basic knowledge of wind will be useful in the teaching programs of schools, and this tool could be valuable if the university doesn't have dedicated facilities for these areas.

At the moment, this concept is under a planning process to complete the final methodology and get some funding to build a new real model at a Chilean university.

2.1 The tangible user interface module

The first component of this platform is a tangible user interface (TUI) that would allow students to interact with digital information through the physical models of buildings. The advantage of this technology is the possibility of overlapping different layers of information (drawings, physical models, digital simulation). This method facilitates the compression of complex phenomena through the interactive manipulation of the models. Also, facilitate the collaborative discussion of the participants in a team. In fact, this approach has been used for experiments on urban planning in the MIT Media Laboratory [6].

Thus, the mini wind lab project could use this technique with a projection mapping system that projects a particle flow on three-dimensional building models. The idea is to simulate 2D patterns of wind around a model scale. This idea is based on the TTTHub project [7], developed by Flora Salim's team as an experimental tool for urban wind simulation (Fig.2).

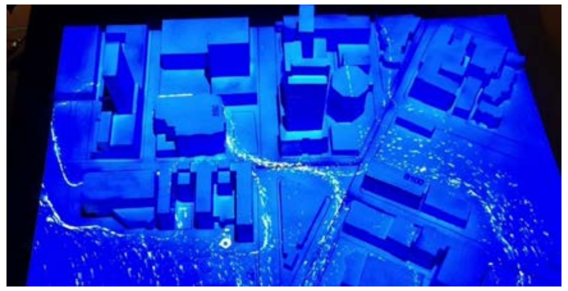


Figure 2: TTTHub project. An example of Tangible User Interface (TUI) to visualise urban wind flow [8].

The TUI would be the first part of a workflow where students will run a digital simulation on their models, to visualise the possible main wind patterns. With this preliminary information, they can understand the global context of their area of study, discover many areas of urban wind flow for further study, and define key aspects to setup the experiments with the mini wind tunnel, such as the location and position of the wind sensors.

The TUI module will have hardware elements and one software: the first element is a LiDAR scanner that will capture the shapes and position of the scale models. With that information, software on a PC can generate a digital 3D model and run a flow simulation (using a two-dimensional flow simulation algorithm). Finally, the visualisation of the flow will be overlapped on the physical model with a simple projector device. Moving the models' position will change the patterns of the flow in real time, and that will be displayed by the projection mapping system (Fig.3). This 2D simulation involves limitations, but in this context, it is fine because it is intended for qualitative and semi-quantitative educational demonstrations.

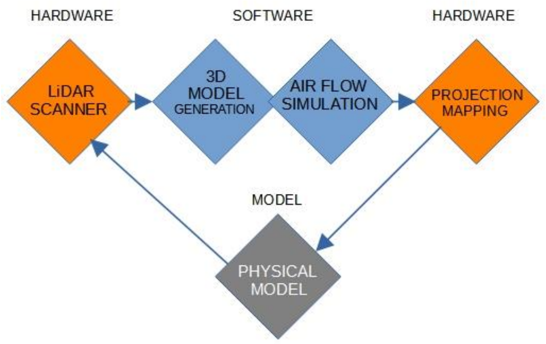


Figure 3: TUI module diagram for the mini wind lab.

2.2 The mini airflow tunnel (2014-2016)

The second module is a mini low speed airflow tunnel that includes an arduino controller connected to wind sensors. This arduino platform will be linked to 3D software to visually display the airflow data in real time (Fig.4) [9].

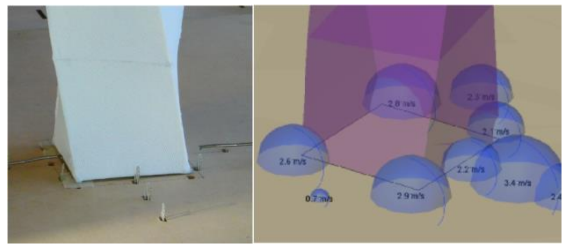


Figure 4: 3D graphic visualisation of sensor data in real time.

The original mini airflow tunnel project was the first prototype of the current Mini Wind Lab project. This tool involved the main concepts proposed for the mini lab, and it was built and tested from 2014 to 2016, in the current teaching environment with students of elective courses at RMIT University, in the CAADRIA conference Workshop and the SmartGeometry conference workshop [10].

For this new version, the mini airflow tunnel module will use a new digital platform for visualisation with open source 3D software linked to arduino sensors. The options for 3D software to connect to sensors can be Blender 3D or FreeCAD. Both are powerful software and can be adapted to work with hardware in real time. The task here will be to develop the necessary scripts to connect both systems.

The platform of electronics components has being already developed and tested in the first version of the mini airflow tunnel. The low-cost sensors are easy to find on the market [11]. The arduino technology is a powerful and easy to use system that provides the necessary components for control and sensing (Fig.5).

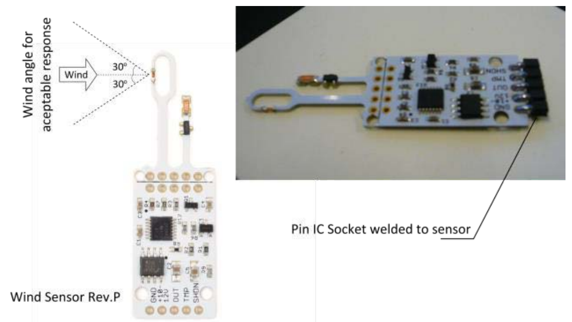


Figure 5: Commercial low cost wind sensor.

The structure of the mini airflow tunnel has a modular design to be built with low-cost materials (MDF panels), using a laser cutter machine (something very common in Architecture and Design Schools). With an assembly design, it can be adapted for different sizes and also can be dismantled to be relocated to a new facility (Fig.6).

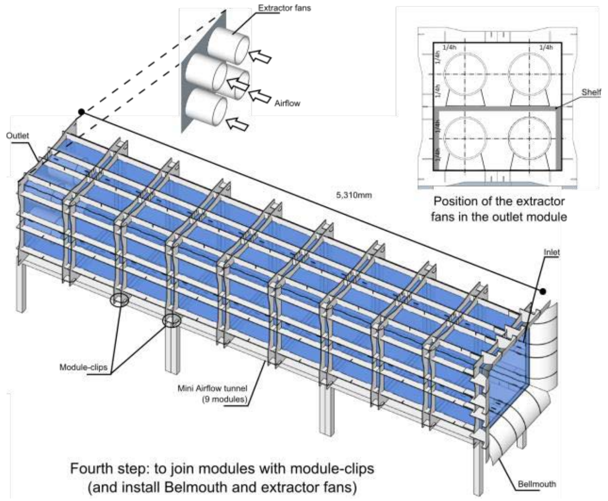


Figure 6: Mini wind tunnel structure.

2.3 Open Source environmental simulation system

The third module in the workflow of this Mini Wind Lab is a group of Environmental Simulation tools to run quick simulations. The idea is to extract results using these tools and overlap this information into the mini wind tunnel real-time visualisation. This way, it would be a comparison point for information that sensors are providing. There are a group of powerful and open source tools that can be used in this module: The Ladybug Tools plug-in for Rhinoceros 3D and Blender 3D is the first option. It includes features for different kinds of simulations using Radiance, EnergyPlus/ OpenStudio, Therm/ Window and OpenFOAM. An additional option is FreeCAD and its module CFD Workbench that can be used for airflow simulation. For a more complete graphical visualisation of the data, Paraview is a perfect option (Fig.7).

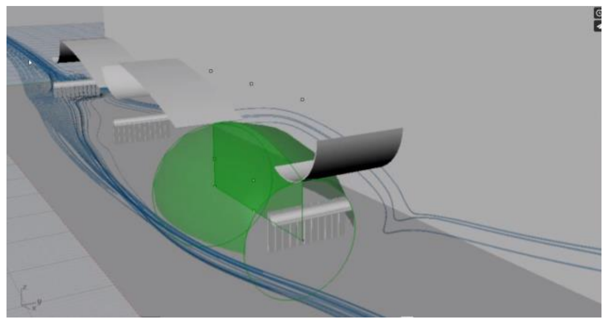


Figure 7: 3D visualisation of several data layers (model, CFD simulation, arduino sensor data).

The use of this tool will not only allow to extend the comprehension of environmental phenomena around buildings, for students. Also, their results can be used to project the information with the TUI. This way, the information can be represented in an augmented reality environment, with physical models displaying digital information.

3. MULTIPLE VISUALISATION METHODS

The main strategy proposed with the use of the Mini Wind Lab is to integrate and overlap different techniques of simulation and visualisation. Using Tangible User Interface (TUI) techniques, arduino and sensing technology, and simple CFD simulation, it is possible to recreate an augmented reality effect. With these overlapped layers of information, we can facilitate and extend the comprehension of students about wind and other possible environmental factors, using visual and graphical images in a physical and interactive environment, and with low cost resources [12]. The benefits of TUI tools for visual teaching, intuitive learning and team work are well documented. With the integration of real time sensing data visualisation, more possible workflows can be developed by students, while they learn about various technologies and experimentation methods (Fig.8).

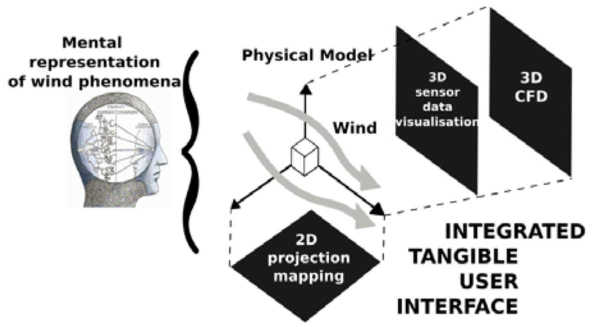


Figure 8: Cognitive diagram of the mini wind lab platform.

4. CONCLUSION

New teaching tools are needed to introduce architecture students to the knowledge of complex scientific concepts, numerical data and analysis of microclimate and environmental design. Rather than use the traditional approach of book reading, it is proposed a teaching method based on the use of Interactive Interface technology, to allow students to explore, operate and visualise microclimate phenomena and data. This paper presents the lastest version of a Mini Wind Lab concept that is possible to build using almost only low cost, open source tools. The approach that is tested with this tool is a multiple visualisation method, integrated into a single platform to conduct empirical and early stage simulations for educational purposes. A first prototype has been built and tested in teaching environments (international workshops and courses). The new version of this Mini Wind Lab implements a fully open source workflow and Tangible User Interface system. In this way, this platform will facilitate the understanding of wind phenomena for Architectural and design students in a friendly and ludic way.

REFERENCES

1. Burry, J. (2013). *Designing the Dynamics. High-performance sailing and real-time feedback in design*. Melbourne Books, Melbourne, Australia.
2. Aynsley, R. M. (1999). Shape and flow: The essence of architectural aerodynamics. *Architectural Science Review*, 42(2):69-74
3. Attia, S., Beltran, L., De Herde, A., and Hensen, J. (2009). Architect friendly: a comparison of ten different building performance simulation tools. *In Eleventh International IBPSA Conference*, pages 204-211, Glasgow, Scotland.
4. Maher, Mary & Kim, Mi jeong. (2006). The Impact of Tangible User Interfaces on Collaborative Design. *Proceedings of the Joint International Conference on Computing and Decision Making in Civil and Building Engineering*. Montreal.
5. The mini airflow tunnel project, [Online], Available: https://miniwindtunnel.wordpress.com/ [21 September 2021].
6. Ishii, H., Underkoffler, J., Chak, D., Piper, B., Ben-Joseph, E., Yeung, L., & Kanji, Z. (2002). Augmented urban planning workbench: overlaying drawings, physical models and digital simulation. *Proceedings. International Symposium on Mixed and Augmented Reality*.
7. Salim, F., (2014). Tangible 3d urban simulation table. *Proceedings of the Symposium on Simulation for Architecture & Urban Design SimAUD '14*, Society for Computer Simulation International, 61-64
8. TTTHub (Tangible Team Table) V1, [Online], Available: https://vimeo.com/65560216 [21 September 2021].
9. Prohasky, D., Moya, R., Watkins, S., Burry, J., and Burry, M. (2014). Wind sensing with real-time visualisations for designers - an approach to understanding wind phenomena for pedestrian comfort using low cost wind sensors. *Fusion - Proceedings of the 32nd eCAADe Conference* Vol 1. 165–171
10. Prohasky, Daniel & Moya Castro, Rafael & Watkins, Simon & Burry, Jane. (2016). Design Driven Physical Experimentation: A flexible wind sensing platform for architects. 239-248. *Proceedings of the 2016 CAADRIA Conference.*
11.https://www.tindie.com/products/climateguard/wind-sensor-with-i2c-anemometr-arduino/
12. Moya, R. (2015). *Wind analysis in the early design stage: an empirical study of wind visualisation techniques for architects* (PhD Thesis), Architecture and Design, RMIT University, Melbourne, Australia.

A shared curriculum for daylighting education to meet the educational needs of society

NIKO GENTILE [1], FEDERICA GIULIANI [2], MANDANA SAREY KHANIE [3], NATALIA SOKÓŁ [4], VALERIO ROBERTO MARIA LO VERSO [5], FEDERICA CAFFARO [6], MIKKEL KOFOD PEDERSEN [7], FEDERICA POMPILI [2], PIMKAMOL MATTSSON [1]

[1] Lund University, Faculty of Engineering, Lund, Sweden
[2] Niccolò Cusano University, Rome, Italy
[3] Technical University of Denmark, Lyngby, Denmark
[4] Gdańsk University of Technology, Gdańsk, Poland
[5] Polytechnic University of Turin, Turin, Italy
[6] University of Roma Tre, Italy
[7] Ladybug Tools LLC, Fairfax, VA, United States of America

ABSTRACT: This article describes the collaborative creation of the curriculum for a new eLearning programme on daylighting design of buildings targeting both traditional and lifelong learners. The programme consists of an online platform integrated with a summer school for practical applications. The curriculum was developed through several workshops with professionals, representatives of national bodies on building regulations, academics, and a survey distributed among professional and potential users. The goal was to create a curriculum able to match the educational needs of society and the status of research by bridging the current gap between requirements set on daylighting by the latest regulation and the low level of education on daylighting in university curricula.
KEYWORDS: NLITED; daylighting education, online platform; eLearning programme.

1. INTRODUCTION

This article describes the collaborative curriculum creation for an eLearning programme on daylighting design of buildings to target both traditional and lifelong learners. The process was conducted with professionals, representatives of national bodies dealing with building regulations, and academics. The goal was to build a curriculum able to meet the educational needs of society while reflecting the state-of-the-art of the current research on daylighting.

Research on daylight design has experienced an actual golden age during the past twenty years. Recent progress, like the widespread adoption of climate-based daylight modelling [1], the increased consensus on daylight glare prediction metrics [2], the advances on photobiology [3], the inclusion of daylighting into the procedure to calculate the energy demand for a building [4], have provided legislators and building professionals with new instruments to design for optimal daylighting. These are based on a synergy of goals related to energy saving, comfort (visual and thermal) and health for the occupants.

However, if on the one hand new knowledge entered national building codes, certification schemes (LEED, BREEAM, WELL) [5-7], and standards (EN17037:2018) [8], on the other hand, daylighting education is surprisingly missing in many architectural and engineering curricula [9,10].

As a result, professionals are asked to comply with daylight requirements, having received little to no specific education on the topic. There is a tremendous urgency for courses that could cover the needs of professionals at any development stage of their daylighting design education.

A new educational project devoted explicitly to daylighting education was conceived and made available online [11]: it is complementary to traditional curricula, modular, and is intended for both traditional students and life-long learners.

1.1 A new educational project

Studies that report knowledge gaps on daylighting education highlight widespread confusion over terminology, lack of knowledge on daylight regulations and standards, and poor use of daylighting design. This holds true even for students who attended courses where daylighting was also formally taught [9,10]. A picture emerges in which rudimentary knowledge is provided but little ability to apply is observed.

The educational project New Level of Integrated TEchniques for Daylighting education (NLITED) was created to bridge this knowledge gap. Four European partners coordinate the project: Niccoló Cusano University, Technical University of Denmark (DTU), Gdańsk University of Technology, and Lund University (LU). The project is co-funded by the EU Erasmus+ Programme.

One of the EU priorities is to impact society by involving stakeholders. In this sense, the project is based on a dense network of interested parties. A wide range of partners has been involved in each country, including educational institutions, building associations, construction companies, daylighting associations, and technical publishers.

The educational project offers a package based on an eLearning platform combined with summer schools. In this way, in-depth theoretical courses are provided online, while the summer school allows for collaborative hands-on sessions and networking. The platform was launched in January 2022, and a first summer school in Denmark was attended by 21 students in August 2022 [12].

2. METHODS

2.1 Workshops and questionnaires

Since the eLearning programme also targets professionals, the project coordinators decided to involve the stakeholders since the development phase of the curriculum. Such approach allowed the creation of a curriculum tailored to the needs of the target groups. The process documented in this paper supported the definition of an accurate need-based educational proposal.

Online workshops in the form of focus groups were conducted in the four partner countries. Each country organised three to four workshops with up to eight participants each. Invited participants were selected from the national networks of stakeholders.

In total, 14 workshops were arranged, with 63 participants, 37% of them coming from companies (architectural 11%; consultancy 21%; manufacturing-producing window manufacturers 5%), 5% from national bodies dealing with building legislation, and 58% from academic teaching staff (university professors 47%; consultant 11%).

A standardised procedure was adopted for the workshops, with the scope of ensuring consistency of responses across the four countries. All steps, including invitations to participants, questions to be asked, online questionnaires, were drafted and collected in a guidance document.

A first draft of the curriculum was created and sent out to the participants some days before the event. Such draft curriculum resulted from a previous brainstorming between the coordinators of NLITED. The reason for sending it was to have participants with a common understanding about the subjects to be discussed during the workshop (Table A1).

One of the key features of such document was that teaching topics were divided into modules, conceived as minimum learning units. Other key points were that the modules were independent of each other (*mix-and-match*), self-paced, and with no prerequisites required. The modules were created to grant 1 ECTS each.

Each workshop lasted between 180' and 240'. Depending on the audience, it was conducted in either English or the national language. It consisted of two parts.

1. The first part was a traditional focus group based on a semi-structured template to address the following subjects: daylight design practice and education, definition of necessary competencies, practicalities about e-learning, and opinions on the summer school. The template included main questions and detailed questions to be used in case of deadlock or to deepen concepts that have emerged (Table A2).
2. The second part consisted of a questionnaire distributed to the participants at the end of the workshop. It consisted of closed-ended questions asking for each daylight topic whether it was strategic to be included in the curriculum. 53 responses were collected (Figure A1).

After that all workshops took place, another questionnaire was developed and spread through social media to potential trainees of the eLearning programme. Also, this second questionnaire contained the list of topics of the draft curriculum (Table A1). In this case, the respondents were asked to indicate which topics (listed in Table A1) they would be interested in following through the eLearning platform. 60 questionnaires were returned. A total sample of 113 responses was therefore collected through the two rounds of questionnaires. Figure A1 illustrates the results.

2.2 Data analysis

The workshops were transcribed verbatim, and the textual material underwent content analysis. The first topic, 'daylight design practices/education', dealt with motivation for designing daylighting in the participants' daily work and with which tools or routines they used. The scope was to identify the motivational drivers for daylighting design. The NLITED educational offer could support these drivers by implementing them into the curriculum. Therefore, this topic was further analysed using an analysis matrix based on the Goal-Framing Theory [13,14] (Table A3). This theory assumes that human beings are prone to improve their condition in a given situation.

However, no one can improve his/her total condition since behaviour is chronically one-sided. Improvement will be selective, depending on the overarching goal that is important at a given moment. The theory proposes that three overarching goals seem to have evolved for human beings: a 'hedonic' goal, "to improve the way one feels right now"; a 'normative' goal to "act appropriately" for the group; and a 'gain' goal "to guard and improve one's resources". As for the other topics, the content analysis was limited to finding overarching themes. The closed-ended answers of the questionnaires were elaborated via a frequency analysis (Figure A1).

3. RESULTS

3.1 Motivations

Most professionals reported that daylighting design is performed almost entirely in compliance with standards and norms ('*normative goals*'). The normative documents are in the form of building energy regulations, building certifications as well as company policies: "*The first thing that we do is just to apply for a standard. Most of the time, like 90% of the time. Is BBR [Swedish building regulation, a.n.] fulfilled? Or, sometimes, LEED, BREEAM? It happens, but it rarely happens*". In other terms, legislation is the driver, even though this was sometimes reported in a disappointed manner: "*What we do with daylight is mainly proving that the regulation is fulfilled. Unfortunately, that is mainly by this local rule we have in Denmark with the 10% (glass area to floor area). Because we developed a very quick method to do that, so we just use our spreadsheet*". Daylighting can also help achieve the sustainability goals of the company, which are not normative in a strict sense. However, they are considered to place the company in a better spot regarding customers ('*gain goals*'): "*When we have the chance, and that is when the building program sets higher demands, we work integrated, so daylight, solar heating, energy consumption together and then we can get much better results. Nevertheless, that is when clients put these demands*". For some participants, daylighting is used in the projects because it can increase sales while saving energy: "*Daylight is a commercial opportunity, so we are also taking it once more, not only for the energy." "It has been shown that people buy more if they are running around in the store with daylight*".
For many participants, daylighting goes well beyond vision and requirements, towards non-visual effects of light. Most of the participants agreed that this is an aspect of terrific importance for the profession but not yet considered in the actual design process: "*Well, I put it this way. If I open my door tomorrow and there is a platypus sitting on my front step, I may be less surprised by that than some client coming to me and saying, we want you to do melanopic lux*".
As for '*hedonic goals*', quite a few professionals stated that they consider daylight design as "a mission". They feel committed to proposing daylighting design beyond regulations to their clients, having the well-being of buildings occupants in mind: "*I do it to improve people's health. That's my driving force*". Beyond norms and professionals or individual gains, these participants feel an intrinsic pleasure to work for a more and better-daylit future: "*We take the output from the rendering, the different sections, light, whatever, and then we work in Photoshop. So that is the creative part, where we get away from what is physically correct. Alternatively, we get further away from the simulation part and more into the interpretation. Your imagination of what it would be. It is much more about the atmosphere to convey what would it be like to be in this room. So, it is a bit, you can call it artistic interpretation, but we see it as an important tool, and trying to create spaces with light, scenarios, comfortable rooms*".

3.2 Beyond specialist daylighting education

Different considerations emerged during the workshops about the need to provide specialistic knowledge and actively involve students in the training process. Adding some inspirational parts to lectures (for instance, through case studies) can encourage the active participation of the students and thus increase their motivation. The interviewed professionals also pointed out the importance of feeling part of a community of learners to keep engaged, which is a crucial challenge in the eLearning process. Professionals recognized that other professional figures not directly involved in daylighting design need a basic understanding of daylighting because those are involved in the decisional process. Urban planners, for example, should be provided with essential daylighting tools and understanding, as their decisions have a considerable impact on daylighting in buildings.

3.3 Topics and structure

Despite having little time to follow educational courses, the professionals asked for more inspirational material, rather than only direct and dry information on how to design for compliance to legislation. All the workshops participants asked for self-paced courses since these can be taken during free time. Other issues mentioned were the need for courses that provide general knowledge and practical applications in the architectural design process and the flexibility to choose from the various topics to best suit individual needs. Some professionals argued that it would be helpful to propose a curriculum with a holistic view of daylighting design. That would balance simulation and field observations to overcome the stereotypes of *"an engineer working more in-depth with simulations (quantitative approach) and an architect working more in-depth with observations (qualitative approach)."*

3.4 Preferred topics

From the analysis of the results, we found a demand for more in-depth knowledge on the topics of daylight and daylighting. The educational project NLITED was well-received by all stakeholders involved, and the same applied to the online survey.

Participants have highlighted the need to go beyond merely national knowledge in all four countries, but the results show a greater desire for introductory courses. Moreover, this is confirmed by the first data on users who signed into the platform, which is now online: introductory courses are being more attended than the advanced ones.

From the ranking of the most voted topics in the surveys, users seem mostly interested not in the simulative parts, but in topics linked to environmental quality, occupant comfort and design culture (more than 80% of respondent). The reason could be that there are fewer courses on design and environmental comfort than on simulation and design aspects.

On the contrary, the most specialized modules were the least voted (≈50% of respondent), including the ones on new knowledge (BSDF data or circadian daylighting design) and detailed modules (modelling devices). It supports the idea that there is a need for a curriculum that can educate from prior knowledge about daylight.

5. THE FINAL CURRICULUM

The workshops' outcomes and questionnaires shaped the curriculum concerning both content and structure.

Content-wise, the curriculum covers five macro-topics (Figure 1):

- Daylight for humans, on the importance of daylight for visual and non-visual aspects.
- Daylighting design and culture, providing a historical overview of daylighting and information on daylighting components.
- Daylight and energy-saving, where daylighting is directly linked to the energy-efficient design of buildings.
- Daylight assessment, dealing with assessment methods and current standards and regulations.
- Simulation in-depth, covering both fundamental and advanced simulation tools for daylighting analyses.

Structure-wise, each macro-topic is provided with an initial popular course as an introduction, targeting people not directly involved in daylighting design. In addition, the topics are enriched with case studies and practical examples, in coherence with the quest for inspirational material.

On the other hand, some aspects of the draft curriculum were confirmed because they received positive feedback from experts. These are modules independent of each other, with no prerequisites to participate in any modules and a self-paced system. Each module is designed to have the student workload equal to 1 ECTS.

In the final version, the platform offers several advantages in terms of flexibility (users can customise the course to attend) and schedule (users can attend a given course at their convenient time).

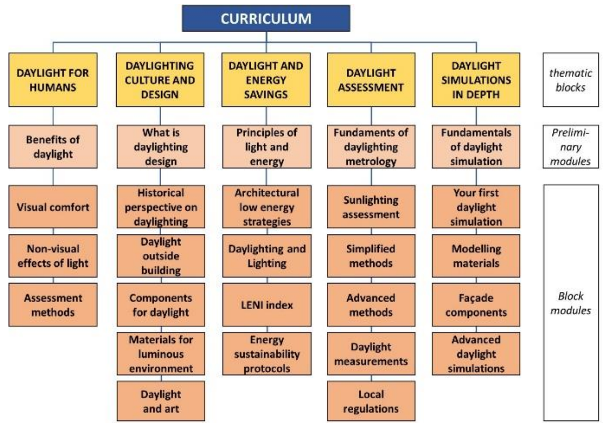


Figure 1: Outline of the final curriculum of the eLearning platform. Each block has an introductory module (Module 0) and a selection of mutually coherent modules. However, modules can be freely chosen by the learner.

6. CONCLUSIONS

This paper described the creation of a curriculum for an educational platform in daylighting design of buildings. The process was based on workshops held with professionals and academics and questionnaires administered to potential learners.

On the one hand, an attempt has been made to understand what drives daylighting design to offer courses tailored to the needs of professionals. The results of the workshops revealed that the normative goals are the leading force for daylight design.

More than one goal seems to be activated at the same time. E.g., some participants developed their early design tools for their clients. The tools allow for more accessible and analytical work by the participants (gain goal), which simplifies the procedure for compliance to norms (normative goal). A cultural change to value daylight design is needed among both the professionals and the clients.

On the other hand, an attempt has been made to understand which modules stakeholders considered necessary in the platform. Topics on visual comfort, perception, and cultural aspects are rated as the most relevant for the platform curriculum.

The final curriculum (Fig. 1) differs considerably from the project coordinators planned before running the workshops (Table A1). It suggests that educators would benefit from involving target groups at the planning stage of educational curricula. It may help create more attractive and valuable courses for professional development.

ACKNOWLEDGEMENTS

This paper is based on the results of the project New Level of Integrated TEchniques for Daylighting education (NLITED), co-funded by the Erasmus+ Programme of the European Union. Project Ref: 2020-1-IT02-KA203-079527.

REFERENCES

1. Brembilla, E., & Mardaljevic, J. (2019). Climate-Based Daylight Modelling for compliance verification: Benchmarking multiple state-of-the-art methods. *Building and Environment*, 158: p. 151-164.
2. Wienold, J., Iwata, T., Sarey Khanie, M., Erell, E., Kaftan, E., Rodriguez, R. G., Garreton, J.A.Y., Tzempelikos, T., Konstantzos, I., Christoffersen, J., Kuhn, T.E., Pierson, C. & Andersen, M. (2019). Cross-validation and robustness of daylight glare metrics. *Lighting Research & Technology*, 51(7): p. 983-1013.
3. Houser, K.W., & Esposito, T. (2021). Human-centric lighting: Foundational considerations and a five-step design process. *Frontiers in Neurology*, 12.
4. Lo Verso, V.R.M., & Pellegrino, P (2019). Energy Saving Generated Through Automatic Lighting Control Systems According to the Estimation Method of the Standard EN 15193-1. Journal of Daylighting, 6, 131-147.
5. USGBC (United States Green Building Council) (2020). LEED v4.1: Building design and construction.
6. BREEAM (2018). BREEAM UK new construction – Non-domestic buildings. Technical Manual SD 5078.
7. WELL (2018). WELL v2. The next version of the WELL Building Standard. International WELL Building Institute.
8. CEN (Comité Européen de Normalisation). (2018). Standard EN 17037: Daylight in buildings.
9. Giuliani, F., Sokol, N., Lo Verso, V. R., Viula, R., Caffaro, F., Paule, B., Diakite, A. & Sutter, Y. (2021). A study about daylighting knowledge and education in Europe. Results from the first phase of the DAYKE project. *Architectural Science Review*, 64(1-2): p. 169-181.
10. Lo Verso, V.R.M., Giuliani, F., Caffaro, F., Basile, F., Peron, F., Dalla Mora, T., Bellia, L., Fragliasso, F., Beccali, M., Bonomolo, M., Nocera, F., Costanzo, V. (2021). A Survey on Daylighting Education in Italian Universities. Knowledge of Standards, Metrics and Simulation Tools. *Journal of Daylighting*, 8: p. 36-49.
11. Giuliani, F., Khanie, M.S., Sokół, N., & Gentile, N. (2020). Discussing daylight simulations in a proposal for online daylighting education. BuildSim Nordic 2020 – International Conference Organised by IBPSA-Nordic, 13th-14th October 2020, Oslo.
12. internet site of the e-platform, omitted for blind review
13. Lindenberg, S., & Steg, L. (2007). Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social Issues, 63(1), 117.
14. Lindenberg, S. and Steg, L. (2013) 'Goal-framing theory and norm-guided environmental behavior', in Encouraging Sustainable Behavior: Psychology and the Environment

APPENDIX

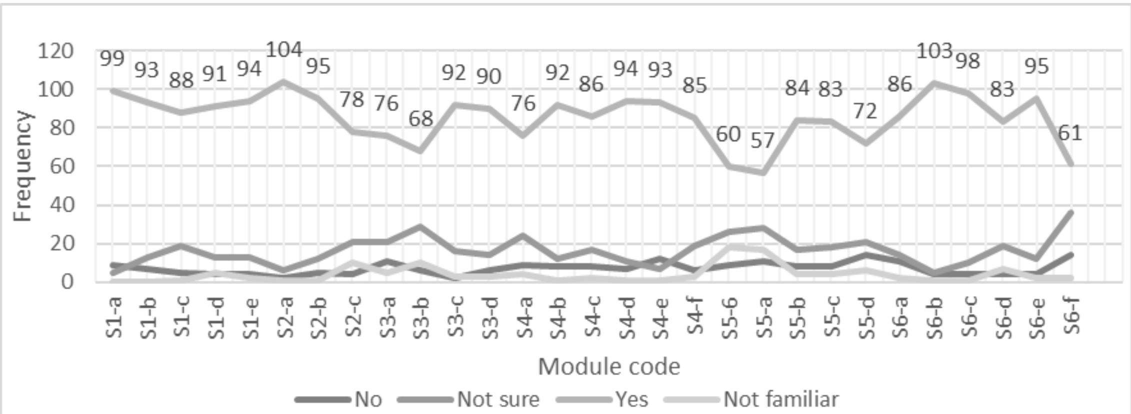


Figure A1: The graph shows the frequency of responses in favour, or not, of the presence of the various topics in the draft curriculum of the platform (see Table A1). Responses came from both workshop participants and potential users invited via social media and email channels (113 responses collected).

Table A1. Topics proposed in the draft curriculum submitted for screening by the target group and online volunteers.

Code	Module	Code	Module
S1-a	Daylighting benefits	S4-d	Fundamentals of daylight simulation
S1-b	Physical aspects of light and daylight	S4-e	Building the first model and running daylight simulations
S1-c	Fundamentals of lighting metrology – visible	S4-f	Daylight modelling and Parametric design
S1-d	Fundamentals of lighting metrology – circadian light	S5-6	Advanced simulations I – BSDF data
S1-e	Standards and Regulations	S5-a	Advanced simulations II – Circadian lighting design
S2-a	Visual comfort: assessments and methods	S5-b	Modelling Materials (reflective, refracting, etc.)
S2-b	Visual perception	S5-c	Modelling Components (windows, atrium, etc.)
S2-c	Non-image forming effects: advances and assessments	S5-d	Modelling Devices (solar pipes, sunlight mirrors, etc.)
S3-a	Energy management	S6-a	Daylighting design through the history of architecture
S3-b	Energy protocols (LENI, LEED, etc.)	S6-b	Example of good design (case of studies)
S3-c	Daylighting and Lighting: an integrated approach	S6-c	Daylight in urban, building and room-scale
S3-d	Energy saving strategies	S6-d	Side-lighting, top-lighting, core-lighting
S4-a	Solar geometry	S6-e	Daylight Design Elements: materials, components, and devices
S4-b	Daylight quality – simplified methods and rules-of-thumb	S6-f	In-depth: daylighting for exhibition spaces
S4-c	Measuring daylight, static and dynamic methods		

Table A2. Semi-structured interview template.

Topics		Questions
Daylight design / education	**Main question**	**Why and how do you design for daylighting?**
	Follow-up / Detailed questions	Which is the goal of daylighting design in your job? Do you have a group working on daylighting design? How do you assess daylight in practice? (Can you describe the typical workflows, software, tools, …?) Which type of daylight assessment do you usually perform? (including metrics)
Definition of competences (eModules)	**Main question**	**You have read our draft proposal for the course curriculum. How would you improve the proposal?**
	Follow-up / Detailed questions	Would you have liked to see something else there? Would you make use of the whole curriculum? Are there modules which are irrelevant for you?
ELearning – practicalities	**Main question**	**How and under which conditions would your work benefit from this online course?**
	Follow-up / Detailed questions	How would your career benefit from it? How would your company benefit from it? Which conditions would allow you (or your colleagues) to join the course?
Summer school	**Main question**	**The educational package we are creating includes a summer school. In your view, which conditions would make the summer school attractive to you?**
	Follow-up / Detailed questions	How do you think a summer school may support learning from the course?

Table A3. Analysis matrix for the motivation driving daylighting design, based on the Goal-Framing Theory [13-14]

Goal	Have the following or similar statements been mentioned during the workshops?
Normative goals	▪ There are legal requirements for daylight design, then I must do that ▪ It is part of my company policy/workflow to make this type of assessment, then I must do that ▪ There are the requirements for daylight standard and/or certificates that I must follow ▪ It is parts of sustainable building design (associated with energy-saving, good indoor environment, health and well-being) that I, as an professional, feel obligated to do
Gain goals	▪ Working with daylight design is a way to enhance my skills, knowledge and competences ▪ It is a way to advance my professional development as a daylight expert/daylight specialist ▪ It is a way to increase values of my work (e.g. aesthetics, pleasantness, and good quality architecture) ▪ Having competences in daylight design would attract more clients/students as well as those who concern about the importance of daylighting
Hedonic goals	▪ Working with daylight design is interesting and/or exiting ▪ Daylight design is challenging and carrying out the task is my great achievement ▪ There are strategies, methods and tools available to me and make it easier to work with daylight design (in general and also, at different design stages) ▪ Daylight design is a pleasure task to work with and would bring about many benefits

PLEA STGO 2022
WILL CITIES SURVIVE? EDUCATION AND TRAINING

PLEA 2022 SANTIAGO

Will Cities Survive?

New demand for training in energy efficiency in the built environment

The development of new postgraduate programs in Latin America

ANGELA DUB [1] SILVIA DE SCHILLER[1] JOHN MARTIN EVANS[1] GUIDO GUILLÉN GUTIÉRREZ[1]

[1] Maestría Sustentabilidad en Arquitectura y Urbanismo, FADU, Universidad de Buenos Aires

ABSTRACT: The new energy context in Argentina, with increasing gas imports, reduction of subsidies, need for new investments in exploration, extraction and energy distribution, requires innovations in professional and technical training, especially in areas related to the built environment. This paper presents the development of new courses on rational energy use that respond to this situation and official requests from the National Government. They arise from previous experiences at graduate and post-graduate level since 1984 in the University of Buenos Aires, given the need to train professionals and technicians in inter-disciplinary frameworks, train efficiency managers and energy managers in buildings, prepare specialists in the promotion of aspects of sustainable building, and train teachers and researchers to achieve an effective transfer to the productive sector. The case presented in this work emphasizes the contribution of the building design to energy efficiency to achieve sustainability in the built environment.

KEYWORDS: Education, Enegy studies, Latin America

1. INTRODUCTION

1.1 Energy context

The energy context in Argentina from the past decade, with increasing gas imports, reduction of subsidies to energy costs, a growing need for new investments in exploration, extraction and energy distribution, requires innovations in professional and technical training, especially in areas related to the built environment.

The 2020 National Energy states that 34.9% of the country's energy resources are used in buildings, 26.7% being for the residential sector, and the remaining 8.2% in commercial and public buildings (MINEM, 2020). Construction in all its stages (raw material extraction, construction and demolition) generates significant environmental impacts. 24% of greenhouse gas (GHG) emissions correspond to buildings.

This paper presents the development of new courses on rational energy use that respond to this situation and official requests from the National Government. These courses arise from previous experiences at graduate and post-graduate level since 1984 in the University of Buenos Aires, given the need to train professionals and technicians in inter-disciplinary frameworks, train efficiency managers and energy managers in buildings, prepare specialists in the promotion of aspects of sustainable building, and train teachers and researchers in order to achieve an effective transfer of information to the professional and building sectors. This work emphasizes the contribution of *building design* to achieve a sustainable urban future.

1.2 Changing legislative framework

Within the Argentine legislative framework, regulations were introduced with the objective of achieving a more sustainable building stock. Firstly, energy efficiency labeling was developed following building envelope transmittance (IRAM, 2010). This regulation defines different recommendations to achieve a sustainable building stock, but does not provide a methodology or is overlooked by an organization in charge to evaluate that these principles are applied. In addition, in 2012 bioenvironmental zoning was established for the country and the following zones were defined within the regulation: very hot (zone 1), hot (zone II), warm temperate (Zone III), cold temperate (zone IV), cold (Zone V) and very cold (Zone VI).

This regulation has now become a law in some provinces (Bs As. 2003 and 2010, for example), but its implementation is still complicated and there is a huge lack of qualified people for its evaluation, thus making it lose their potential.

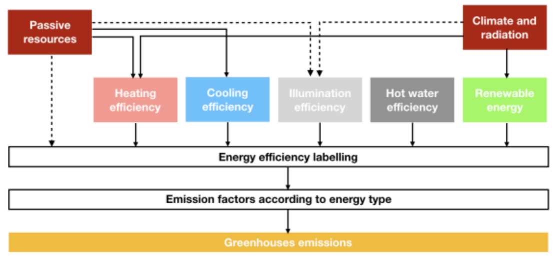


Figure 1: Contribution of passive design resources and its relationship with other aspects that contribute to energy efficiency, based on Author, 2017.

2. PROGRESS IN POSTGRADUATE PROGRAMS

2.1 Existing cases at the University of Buenos Aires

The University of Buenos Aires - the country's largest and most prestigious University - has been developing different programmes with the purpose of training researchers, teachers, technicians and professionals in the implementation of energy efficiency policies and measures for the production of environmentally responsible and economically effective environments.

The following are a selection of cases, demonstrating the growth and development of the field in Argentina:

- Interdisciplinary Master's Degree in Energy: This programme was established in 2010, as an outcome of the Interdisciplinary Program of the University of Buenos Aires on Sustainable Energies (PIUBAES) and the Center for Studies of Energy Regulatory Activity (CEARE). There are four faculties that participate in the project: Law, Engineering, Architecture and Economics. The program is mostly focused on energy legislation, conventional and non-conventional sources of energy, along with environmental aspects. Two subjects are devoted exclusively to energy efficiency. The first is called "Conservation and rational use of energy in the built habitat" and the second is called "Conservation and rational use of energy in industry and the electricity sector". Currently the master's degree has a wide variety of graduates from different careers, who are dedicated both to the legislative aspect of energy, and to the implementation of renewable energies and energy efficiency in the built habitat.

- Energy and Environmental Group, Engineering School: programme that offers courses in energy efficiency as well as a Master's degree in Sustainable Urban Technologies. It covers a wide variety of topics, ranging from climate change, urban vulnerability and complex city models. A particular seminar deals with energy efficiency problems: Energy Technologies.

Postgraduate programs	Registered professionals	Main focus	Starting date	School and Headquarters
Interdisciplinary MSc. in Energy and specialization career in the legal-economic structure of energy regulation	Different Professionals Interdisciplinary profile	Energy management	2011 - 2002	Centre for Studies of Energy Activity and Regulation, CEARE: Law School
Master program and Specialization in Sustainable Urban Technologies	Engineers and Architects	Technological integration at the urban level	2014 – 2008	Institute of Sanitary Engineering, IIS: School of Engineering
Energy Management Course	Technicians and Professionals	Use and operation of buildings	2017	School of Engineering
Master program in Sustainability in Architecture and Urbanism	**Engineers and Architects**	**Sustainability criteria and environmental strategies in habitat design**	**2018**	**Habitat and Energy Research Centre, CIHE: School of Architecture, Design and Urbanism**

Figure 2: Comparison between different energy-related post-graduate programs in Argentina. Source: UBA 2019, CEARE, 2016, FI-UBA, 2014.

These postgraduate proposals are complemented by the bachelor degree offer of the Faculty of Architecture, Design and Urban Planning. In 1984, the first subjects related to the sustainable theme were incorporated: *"Bioclimatic Design"* and *"Solar Architecture"*, to which the course *"Energy in Buildings"* was added in 1990. The annual average number of students taking at least one of these three subjects is between 500 and 600. Despite these figures, the offer within the University for postgraduate education on sustainability in architecture and urbanism was null.

3. NEW MASTERS DEGREE: SUSTAINABILITY IN ARCHITECTURE AND URBANISM (SAU)

3.1 Introduction to the programme

As a response to the current energy problems and those required by both the public and private sectors, the *"Sustainability in Architecture and Urbanism Masters"* (SAU) was created in 2018, based at the Faculty of Architecture, Design and Urbanism at the University of Buenos Aires.

The new Master's degree approved by the Board of Directors of the School of Architecture, Design and Urbanism and by the Superior Council of the UBA (2017), incorporates a background of experiences held in prior years at the same School, such as the *'Environmental Design Specialization Program'* (containing 240 hours of classes, where Research Papers and Projects were developed, with an extensive enrolment of students between 1994-2000), as well as from regular exchange programs held with other Postgraduate degrees, Masters programs and PhD programs with Mexico, Chile and Ecuador, and results of UBACyT research projects carried out at the Habitat and Energy Research Center (CIHE) since 1986. The SAU Master's proposal responds to the growing need to introduce innovations in architectural and urban design, aimed at achieving greater sustainability in the production of the built environment, minimizing its environmental impacts and reducing the demand for resources to achieve adequate levels of habitability and durability. Through the design of the course modality, it is proposed to promote three fundamental aspects:

- A flexible course: taught in modules, it enables the possibility of taking different module sequences as the number of correlative subjects is limited.
- Permanent link between practice and theory: each module includes a project integration workshop.
- Focus on Thesis production: the thesis plan is worked on and developed from the first module in the first four-month period, maintaining full continuity during the course.

3.2 Student backgrounds

Through a file that admitted students are asked to complete, it is possible to collect information about the student's background in teaching/research, Universities of origin, other courses taken, etc.

The Master's degree has enrollments once a year, so four cohorts have already passed since 2018. There are over one hundred students who have studied the master's degree since its beginning. The annual enrollment average is twenty-seven students.

Figure 3 shows the number of students admitted during the 2018-2021 period. The number of students decreases slightly after the year 2019. This is due to the uncertainty with the events that occurred during the first months of the year 2020 (COVID Pandemic).

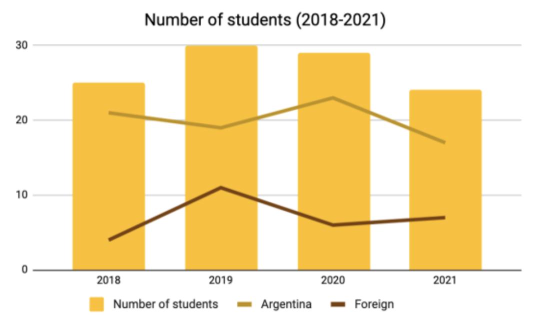


Figure 3: Number of students enrolled in SAU Master Programme. Source: Author, 2022.

It is of great relevance to observe the interest of candidates from other Latin American countries: the percentage of foreign master students is 25%, almost all of them being from South American countries. Although the total is completed by 10 countries, 33% comes from Colombian universities.

It can be noted that during the years of the pandemic, in which the master's degree was held online, the number of foreign students decreased in percentage, and the percentage of young people enrolled increased. This last point is explained due to the greater familiarity with digital environments. During 2021, this trend was reversed, returning to percentages closer to pre-pandemic times.

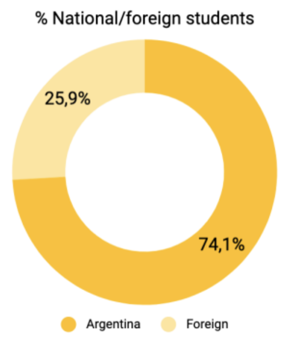


Figure 4: Proportion of national and foreign students enrolled in the 2018-2021 period. Source: Author, 2022.

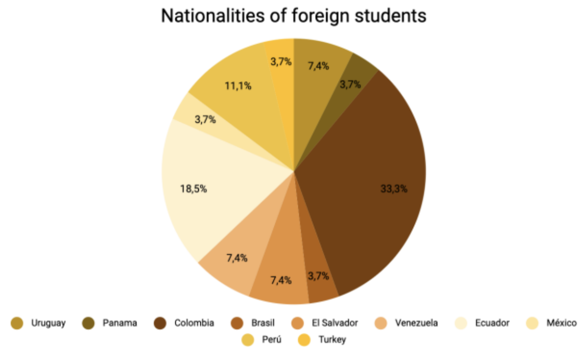


Figure 5: Nationalities of foreign students enrolled between 2018-2021. Source: Author, 2022.

Although the postgraduate course is proposed in an interdisciplinary way, the vast majority of students are architects, with a minority of engineers (3%), or industrial designers (3%).

32% of the architects enrolled in the programme have studied their bachelor degree at the University of Buenos Aires and took a sustainability-related course as part of their bachelor degree. These courses are still non-compulsory, so not all architecture graduates have training in sustainable development.

Lastly, in terms of knowledge transfer, 25% of the master's students are professors in both public and private universities or participate in research projects.

3.3 Master's degree structure

The master's degree is completed over two years, and consists of 704 classroom hours, divided as follows (FADU Resolution):

- An introductory, basic and mandatory module of thirty-two hours
- Five hundred and twelve hours, divided into four modules with core themes.
- One hundred and sixty hours of methodological training and thesis development.

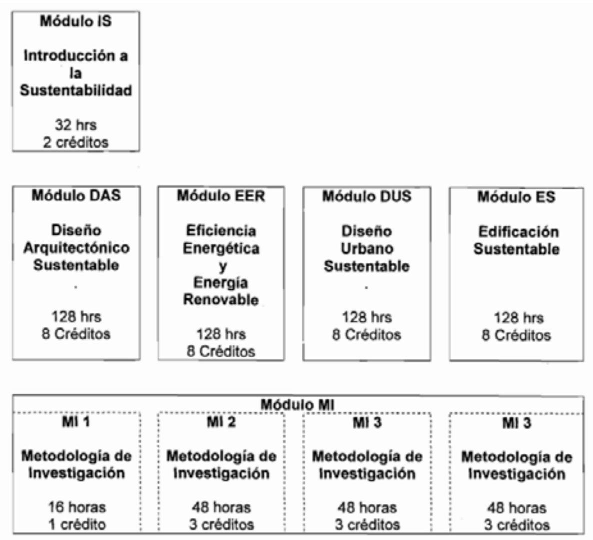


Figure 6: Master's curriculum composition. Source: UBA Board of Directors resolution, 2017.

Each of these modules lasts for four months and responds to the four main groups covered in the course: sustainable architectural design, sustainable urban planning, energy efficiency and renewable energy and construction systems.

As previously mentioned, each module is independent from each other, being correlative only with the introductory module, thus allowing the students to spread the course in more time if needed.

One of the modules responds directly to the problem of energy efficiency and renewables. This module discusses the role of the building sector in energy consumption, along with the integration of solar energy and other renewables from an efficiency point of view. The National Energy Balance (BEN) and the role of the built habitat in the energy matrix are analyzed. The incorporation of these themes into the design process is also studied.

The module is divided into four seminars of 32 hours each:

1. Energy and environment: energy demand, resources and impacts of conventional energy and potential and perspectives of renewable energy.
2. Solar energy in Architecture: analysis of the characteristics of solar radiation and active solar systems, opportunities for change in the energy matrix.
3. Building Energy Simulation: energy audits, verification and evaluation of the envelope.
4. Project integration: Application of architectural and urban energies within the architectural project.

Each of these seminars ends with a practical project, and in turn the final work of the module serves as an integrating exercise.

3.4 Other extracurricular activities / fieldwork developed during the course.

Throughout the course, exercises of an empirical nature are also proposed to exemplify the energy demand according to the density of the urban sprawl.

In urban terms, one of the exercises proposed every year is the measurement of the heat island effect (defined as the increase in temperature in relation to urban density and the size of the city (Evans, et al, 2001)). With Hobo-type measuring elements, manufactured by Onset Computer Corporation (2019), measuring the temperature at scheduled intervals, different tours were carried out throughout the city, with the aim of measuring the difference in °C in the densest urban areas.

The Professors were divided into groups, and each one was assigned a tour. Once done, the results were combined on the map of the City of Buenos Aires, and the temperature lines were outlined.

The result was the creation of a temperature map, which enables the understanding of the important climatic variations and thermal comfort, according to the scale. It was also made visible that certain urban events (avenues, green spaces, reflecting pools and places with prevailing winds) help to lower the temperature and, therefore, lower energy consumption.

Another activity that students are encouraged to do is to present their work and develop their lines of research at scientific conferences and knowledge-transfer events. To cite an example, the Faculty of Architecture, Design and Urbanism hosts a regional scientific meeting every year. As of 2018, several of the student's works were presented.

During the first half of 2020, and with the pandemic as a global panorama, a series of virtual talks were held with architects, politicians, economists and various disciplines, under the title "Sustainable Latin America". The objective was to invite regional references to promote exchange between countries and contribute, in a context of uncertainty, to consolidate a regional identity and promote the development of sustainable cities.

Finally, this year, the master's degree will develop a thematic table on energy efficiency at the University's main research exhibition, to transfer student work, as well as to disseminate and share the work with universities throughout the country.

4. CONCLUSIONS AND FOLLOWING STEPS

The progress in the postgraduate courses on energy efficiency in the building, presented in this work, represents an important effort to respond to the energy challenges stated in the introduction and contribute to the necessary modifications to be made to achieve a more sustainable built environment. In addition, the high enrolment in the new Masters degree demonstrates that the interest is latent at that the contribution towards a more sustainable environment is being carried out in an orderly manner.

As steps to follow in the programme's development, a central aim is to engage with other Universities around the world teaching similar programs to develop exchange seminars for students to further develop their Thesis/Dissertation research.

In addition, a series of publications featuring the most interesting research projects developed during the course are planned, backed by the University's Postgraduate Secretariat, in order to encourage students to participate in peer-reviewed journals.

Lastly, a regional conference is bound to be hosted by SAU in the upcoming years in order to consolidate the programme and the University of Buenos Aires as a production and research hub for sustainable development ideas within the Latin-American context.

ACKNOWLEDGEMENTS

The contribution of the development of content for the formation of postgraduate courses in which CIHE researchers and teachers actively participate, incorporating the procedures, experimentation and results of UBACyT Research Projects with funding from the SECyT-UBA is very much valued.

REFERENCES

1. MINEM (2017), Organizational Chart, Ministry of Energy and Mining, Buenos Aires, [Online], Available at https://www.minem.gob.ar/www/706/23979/organigrama.html [30-09-2019]
2. UBA (2019) Anex 1, Resolution CUDAP. EXP-UBA 32.986/2017 Approval of the creation of the Master in Sustainability in Architecture and Urbanism. University of Buenos Aires [Online] Available at http://www.uba.ar/archivos_uba/2017-09-13_32986.pdf. [15-05-2019]
3. EVANS, DE SCHILLER. (2017), The role of Passive Low Energy Design in Energy Labelling of Housing, Proceedings, Passive and Low Energy Architecture Congress, University of Heriot Watt, Edinburgh.
4. IRAM 11900 policy. Energy benefits in homes. Energy efficiency calculation and labeling method.
5.Balance Energético Nacional (2020), National Ministry of Energy, Argentina. [Online] Available at https://www.argentina.gob.ar/economia/energia/hidrocarburos/balances-energeticos

Sustainable attitudes project

The university acting in the education and popularization of news energy-saving lamp technologies

HELENA CÂMARA LACÉ BRANDÃO[1]

[1] Universidade Federal do Rio de Janeiro, Brazil

ABSTRACT: The future of sustainable buildings in the age of emergency depends not only on large initiatives, but also on small sustainable attitudes aimed at education and the popularization of new technologies that positively impact the environment among the population. From this perspective, universities as institutions that not only generate and transmit knowledge, but also act as transforming agents in society, through dialogues with their external community, play an extremely important role. The performance of these educational institutions is the theme of this article. The paper has as subject one of the extension actions of the Sustainable Attitudes project, developed by LabCA - Laboratory for Creation and Analysis of Environments of the Federal University of Rio de Janeiro, which focuses on dissemination and assimilation of new energy saving lamp technologies. This action is the result of a Brazilian society demand identified in the research about the information that lamps packaging should contain at Brazil, published in the PLEA 2017 proceedings. Therefore, the article focuses on the Education and Training track and intends to show the initiatives created during the covid-19 pandemic and its results over two years.

KEYWORDS: sustainable initiatives, education, popularization, lamps, energy efficiency

1. INTRODUCTION

The education and training of individuals has an important impact on the future of sustainable construction and, within this theme, universities play an extremely important role. They act as transforming agents, contributing to the development of the community through the students' education and training, which must go through teaching, research and extension.

These three activities are in line with the institutions' commitment to transmit, generate and disseminate knowledge, aiming at the construction of the local socioeconomic and environmental reality, through a dialogic interaction between their internal and external communities, in the search for answers to the countless challenges of humanity.

These three fronts of action, although have different characteristics, not happen in isolation. They feed back themselves into the formation of knowledge, which leads them to be carried out inseparably, shaping the character of Universities.

In the brazilian scenario, the search for this characteristic of higher education institutions is driven by the inclusion of extension activities in the undergraduate courses curriculum. Currently, this inclusion follows the provisions of resolution no. 07 of December 18, 2018, of the CNE - National Council of Education, which establishes the guidelines for extension in brazilian higher education and regulates the provisions of goal 12.7 of Law n. 13,005/14 [1].

By this resolution, extension activities must comprise at least 10% (ten percent) of the total student curricular workload of undergraduate courses, and must be part of the courses curriculum. This change aims to prepare not only future higher education professions, but the training of graduates who will exercise citizenship, think critically about the society in which they live, act in order to reduce social inequalities, assuming a commitment to building your society.

Within this perspective, with the intention of collaborating in the role of the Federal University of Rio de Janeiro as a transforming agent of society, the Sustainable Attitudes extension project was born with the purpose of carrying out actions together with its community , observing the demands identified through the results of the research developed in the LabCA - Laboratory for Creation and Analysis of Environments, as is the case of the action aimed at the education and popularization of news energy-saving lamp technologies, which is addressed in this paper.

This action is the result of research on the information that lamp packaging must contain in Brazil, that was published in the PLEA 2017 proceedings [2], and of its developments, published in the ENCAC/ELACAC proceedings of 2019 [3] and 2021 [4].

2. THE SUSTAINABLE ATTITUDES PROJECT

The Sustainable Attitudes project is an action that encompasses several extension activities dedicated to the education and popularization of science and technology that promotes the insertion and dissemination of technological innovation products and processes in the market.

The objective is to encourage changes in the population's consumption pattern, such as in the production of goods and services currently offered. All project activities begin from society demands identified by research that are developed by members of the LabCA group.

Conceived to be developed in person, it was necessary to adapt its format to the advent of the Corona Virus pandemic that emerged in society in 2020, when the activities would begin.

One of its extension actions that soon adapted to the new format was aimed at helping the population, with a focus on the city of Rio de Janeiro, to correctly consume the new lamp technologies available on the market. The LabCA research group had identified this demand from society on their studies, once incandescent lamps with which people were used to were no longer available in the brazilian market, since 2017.

In Brazil, the Ordinance MME/MCT/MDIC nº 1.007, of December 31, 2010 [5] started to regulate the minimum levels of energy efficiency of incandescent lamps, stipulated by Inmetro - National Institute of Metrology, Standardization and Industrial Quality, a Brazilian federal autarchy, through the Brazilian Labelling Program (PBE), applied to manufacturers and suppliers since 1984.

Due to this ordinance (BRASIL, 2010) [5], incandescent light bulbs in this country were progressively no longer manufactured and imported between 2010 and 2016, and their commercialization was also gradually phased out by 2017.

The energy-saving lamp technologies, that have become the available product, present a range of variations in terms of luminous properties, unlike the incandescent lamp, that dominated the brazilian residential market for more than half a century.

The choice of these new products could not be made only through their energy flow, as much as this data contributed to energy efficiency in the built environment. Published studies [2] had already shown the need for the packaging of these new lamps launched on the market to inform photometric units in addition to the power of the equipment, so that the choice of the product was also based on luminous comfort. It was important to report the quantity of light as its quality.

the LabCA research that continued this study, however, observed that it was not enough to inform these data, it was also necessary to help the consumer to interpret them. With this in mind, the research group worked on the elaboration of pictograms on photometric units that can be used by manufacturers in Brazil to improve the visual communication of lamp packages [3].

The proposal consisted of adopting the suggested pictograms (Fig. 1) with other signs that the same research identified as commonly used on lamps packaging at Brazil (Fig. 2).

Figure 1:
Photometric units pictograms created by the LabCA research group

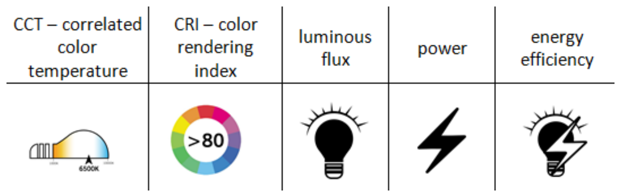
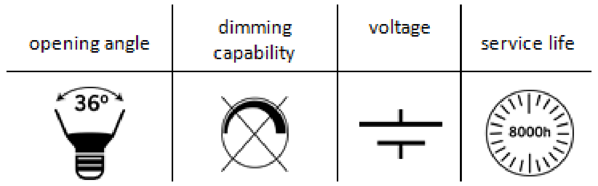


Figure 2:
Signs already commonly used on lamps packaging at Brazil



As part of the pictogram elaboration process [6], the communication capacity of the signs created by LabCA was evaluated through a public opinion survey [4] and the result was satisfactory. Besides all pictograms being interpreted correctly by the participants, the public also commented that the signs helped to identify the photometric units of the lamps and that their presence on the product packaging would help to correctly consume the equipment.

From these studies, the research group realized that there was a demand from society to better understand the luminous properties and their photometric units in order to correctly consume the new lighting equipment available on the market.

In this way, understanding the responsibility of universities as transforming agents, the group develops an extension proposal aimed at the community of Rio de Janeiro, based on the question: Do you know how to choose a light bulb?

From this simple question, two fronts of activities were created by the Sustainable Attitudes extension project: 1) production of educational activities on moodle platforms; 2) production of educational videos that are released on the research group's social networks.

3. RESULTS

Since March 2020 to December 2021, the two fronts of the extension project were carried out as follows: 1) a question and answer challenge called Modern Lighting vs. Contemporary Lighting, which certifies participants, was held on the university's moodle platform, known as AVA - Ambiente Visual de Aprendizagem (virtual learning environment) [7] (Fig. 3); 2) an educational video on how to correctly choose a light bulb was posted on the research group's social networks [8] (Fig. 4).

Figure 3:
Production of educational activities on Moodle platforms

Figure 4:
Educational videos available on LabCA's social network.

The means of communication on both fronts are accessible to people who are deaf or hard of hearing. The videos have captions and sign language interpretation is provided for all content in synchronized media, respecting the level AAA criteria for obtaining inclusive web design provided by the Web Content Accessibility Guidelines (WCAG) created by the World Wide Web Consortium (W3C) [9], which are standards recognized by many countries.

The challenge launched at AVA - Ambiente Visual de Aprendizagem (virtual learning environment) has already delivered more than 100 certificates between July 2020 and December 2021. The educational video had 229 views since its publication on September 24, 2020 until December 2021. The activities developed on both fronts demonstrated the interest from the population to the topic addressed by the extension action.

The design and implementation of these actions, now accessible to the public, required a lot of work and time. In the AVA - Ambiente Visual de Aprendizagem (virtual learning environment), it was necessary to understand how to interact with a moodle platform to create an activity that was didactic and, at the same time, fun. The intention was to talk about innovation, more precisely, technological innovation, but for a lay public that does not necessarily intend to specialize, but to know better the product they consume.

Innovations in lighting equipment, such as LED (light-emitting diode), which more than a new lamp technology is a new proposal for light, invade people's homes every day. However, this purchase is often not due to the lighting these products can provide, but because it has reduced the home's energy bills. Equipment that saves energy ends up being chosen not for the environmental benefits, but for the financial ones. Other times it is because these products are the ones available on the market and the public consumes them without knowing how to recognize the luminous properties that the equipment offers.

The activity at AVA - Ambiente Visual de Aprendizagem (virtual learning environment) started in March 2020, but was only made available to the public in July 2020.

The educational video made available on the research group's social networks has also gone through a long process since its conception. As in the AVA - Ambiente Visual de Aprendizagem (virtual learning environment), it was necessary to work with a simple and direct language that would arouse people's interest in watching all the didactic content. The idea was the same as the virtual learning environment, but the communication route was different.

There was already a material available that had been created for an event in 2019, but had to be edited and adapted for social media. It was also necessary to develop the video within the standards of inclusive web design for people who are deaf or hard of hearing. LabCA has partnered with another university extension project, TradInter Lab - Laboratory for accessible audiovisual translation and Libras-Portuguese interpretation of the Department of Letters and Libras [10], to provide subtitles and sign language interpretation for all synchronized media content.

This activity started in middle of 2020 and the educational video was shared on LabCA's social networks in September 2020.

For their individual actions, both projects had being highlighted in the UFRJ extension newsletter, called *Comunica Extensão* (Fig. 5).

Figure 5:
UFRJ extension newsletter, called Comunica Extensão, august edition

The two fronts of the Sustainable Attitudes extension project were carried out by undergraduate students from the Federal University of Rio de Janeiro under the guidance of a professor linked to LabCA research group. The participation of students in the activities design is a characteristic of university extension actions and, in the case of UFRJ, it is aligned with the institutional values [11] of preparing students to exercise citizenship, to think critically about the society in which they live and to act in order to reduce social inequalities, assuming a commitment to building their own society.

These were the results obtained so far with the activities that aim to promote the insertion and dissemination of news energy-saving lamp technologies available on the market. However, the Sustainable Attitudes project is already opening other fronts that deal with this same theme and others equally focused on the results of LabCA research related to innovation.

The expectations are focused on access to the target audience through other social networks of the research group and UFRJ radio, which annually issues public notices for participation in audio programs. Regardless of the project's performance format, the central idea is to always be aligned with the mission [11] of its Higher Education Institution to contribute to the scientific, technological, artistic and cultural advancement of society.

4. CONCLUSION

The article showed that the university can help in the education and popularization of new lamp technologies that, by saving energy, contribute to energy efficiency in the built environment and, consequently, to sustainable architecture.

These equipment are different from the product that the population was used to consuming and its difference is not only in the electricity it consumes to generate light, but also in the light produced.

As happened in the first decades of the 20th century in Brazil, when educational institutions, together with other organizations, played an important role in the dissemination of the incandescent lamp in society and in the popularization of the electric lighting system, now, in the beginning of the 21st century, universities can greatly collaborate with the transformations promoted by new primary light source technologies, such as LED devices. This initiative mainly impacts residences, where the consumption of light bulbs is made by a lay public, in most cases.

As a transforming agent of society, universities must act in their external community from a dialogical interaction, based on the inseparability of teaching, research and extension. In the case in question, this understanding produced sustainable initiatives that could be carried out during the COVID-19 pandemic and that, however small, are important in the era of emergency.

REFERENCES

1. BRASIL. Conselho Nacional de Educação. Resolução n.º 07, de 18 de dezembro de 2018. Estabelece as Diretrizes para a Extensão na Educação Superior Brasileira e regimenta o disposto na Meta 12.7 da Lei nº 13.005/2014, que aprova o Plano Nacional de Educação - PNE 2014-2024 e da outras providências. *DOU*, Brasília - DF, 19 de dezembro de 2018, n.º 243 . S. 1, p. 49.
2. BRANDAO, H. C. L.; CARVALHO, M.; SOUZA, F., (2017). The Importance of The Information Regulation Available in The Lamps Packaging. In: *PLEA 2017, Edinburgh, UK. Design To Thrive: proceedings - Plea 2017 conference*. Edinburgh, UK: NCEUB, 2017, v.2, p. 3159 – 3166.
3. BRANDAO, H. C. L.; WEHRS, R. F. L.; PEIXOTO, H. C. F.; PINTO, A. S. H.; SILVA, L. G. O.; CARVALHO, M., (2019) As Informações sobre Propriedades Lumínicas Contidas nas Embalagens de Lâmpadas: uma questão importante para o consumo correto do equipamento e para sua aceitação no mercado In: *XV ENCAC & XI ELACAC, 2019, João Pessoa, Paraíba – Brasil*; v. 1, ISBN: 978-85-89478-45-8.
4. BRANDAO , H. C. L.; COSTA, L. P. B.; SOUZA, D. A. P, (2021). Pesquisa de opinião pública para avaliação de pictogramas a serem usados em embalagens de lâmpada: estratégia voltada para eficiência energética em iluminação. In: *XVI ENCAC & XII ELACAC, 2021, Palmas, Tocantis – Brasil*; v. 1. p. 1420-1428, ISBN: 978-65-99670-20-6.
5. BRASIL. Ministério de Minas e Energia; Ministério da Ciência e Tecnologia; Ministério do Desenvolvimento, Indústria e Comércio Exterior, (2010). Portaria Interministerial nº 1.007, de 31 de dezembro de 2010. Aprova a Regulamentação Específica de Lâmpadas Incandescentes na forma constante dos Anexos I e II à presente Portaria. In: *DOU*, Brasília - DF, 06 de janeiro de 2011. S. I, p. 44.
6. MODLEY, Rudolf, LOWENSTEIN, Dyno. (1952). Pictographs and Graphs: how to make and use them. Nova Yorque.
7. Iluminação moderna x iluminação contemporânea. [question and answer challenge], (2021). Available: http://ambientevirtual.nce.ufrj.br/course/view.php?id=1881 [22 august 2020].
8. Você sabe escolher uma lâmpada? [Online], (2021). Available:https://www.youtube.com/watch?v=HOUQaz20AlU [22 august 2021].
9. Web Content Accessibility Guidelines (WCAG) Overview, [Online], Available: https://www.w3.org/WAI/standards-guidelines/wcag/ [22 august 2021].
10. TradInter Lab: Laboratório de tradução audiovisual acessível e interpretação Libras-português [Online], (2021). Available: http://www.libras.letras.ufrj.br/tradinterlab/ [22 august 2021].
11. UFRJ - Missão, Visão e Valores. [Online], (2021). Available: https://ufrj.br/acesso-a-informacao/institucional/missao-visao-e-valores/ [22 de outubro de 2021].

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 01
11:15 — 12:45

CHAIR
ULRIKE PASSE

PAPERS
1392 / 1243 / 1469 / 1414

3RD PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Adequacy of weather data standards to assess building passive performance during summer

An application to French buildings

JOSHUA PIÑAS [1, 2], ROBIN GOBERT [1, 3], JEAN-MARIE ALESSANDRINI [1], MAEVA SABRE [1], SAMY KRAIEM [1], GILLES LEFEBVRE [2], WEI LIU [3], CHARLES PELE [1]

[1] CSTB Champs-sur-Marne, 84 av. Jean Jaurès F-77420 Champs-sur-Marne, France
[2] Univ Paris Est Creteil, CERTES, F-94010 Creteil, France
3 Division of Sustainable Buildings, Department of Civil and Architectural Engineering, KTH Royal Institute of Technology, Brinellvägen 23, Stockholm 100 44, Sweden

ABSTRACT: The energy, environmental and social cost of the spread of HVAC systems in housing in France calls to investigate the impact of climate change on buildings' cooling energy needs. From the Energy Performance Observatory database of buildings, annual cooling energy needs are calculated with the thermal model of the French regulation, COMETh. For these simulations, nine different climate projections from 1981 to 2058 are used with the RCP8.5 scenario, as well as representative years (reference and extreme), constructed from these projections. The cooling needs of a large number of buildings increase from very low values in the past to non-negligible needs in the future. The study of mean and standard deviation of the needs explains this evolution according to two phenomena: an increase in average needs (Phen1), and a repetition and/or intensification of the extreme years (Phen2). Classification by the k-average algorithm shows that we can use representative years to identify vulnerable buildings. This classification brings out differentiated buildings groups along 2 axes: passive and active buildings (Phen1) which can independently be adapted or not to future extremes years (Phen2). In particular, some buildings require special attention, as they are passive on average, but sensitive to future extreme years.
KEYWORDS: Cooling needs, Climate projections, Representative years, Classification.

1. INTRODUCTION

Due to climate change and heatwaves (Riberon et al., 2006), an increase of residential use of air conditioners from 5% in 2005 to 13% in 2016 (Rolland, 2018) was observed in France. This trend was confirmed recently for the entire air-conditioners market since sales increased from 400 000 in 2015 to 823 000 units in 2020 (CODA Stratégies, 2021).

The spread of air conditioning systems would increase electricity demand, greenhouse gas emissions and external temperature resulting from its thermodynamic cycle (de Munck et al., 2013). To limit this spread, the French Thermal Regulation for buildings (RT2012) promotes passive design strategies (the architecture and the building envelope characteristics). Indeed, it requires not exceeding an energy need threshold for comfort and lighting (Videau et al., 2013). The different combinations in passive strategies can be evaluated using a Building Performance Simulation (BPS) to calculate, for instance, cooling needs.

However, past climate observations are still used in the regulation's BPS. Climate change and future projections are therefore not taken into account even though they may have an impact on the spread of cooling systems. This should lead to reconsider the current standards used to define weather data for BPS. As a result, this paper focuses on the relationship between external future climate conditions and building thermal responses, in the context of thermal regulation and standards.

It aims to (1) evaluate the impact of climate change on building cooling needs, (2) assess the relevance of using representative future climate files to classify buildings in term of cooling needs, and (3) identify those at risk, where the installation of an air conditioner could or will be necessary.

2. METHODOLOGY

This paper follows a four-step method: (i) a selection of 77 collective buildings from the Energy Performance Observatory (OPE) database, (ii) a construction of different climate data files based on future projections and past observations, (iii) a calculation of cooling needs using BPS, and (iv) an analysis of the thermal responses under different climate models and a classification regarding cooling needs for the 77 buildings.

2.1. Building selection

Since RT2012, the characteristics of new buildings, built after 2014, and their associated results are stored in the OPE database (Directorate-General for Energy, 2018). From this database, we selected 77 projects. The selection criteria were: (a) the project contains a single building, (b) the building has at least one collective housing area, and (c) the collective housing must have a cooling need.

2.2. Climate conditions

Three types of climate data are used in this paper, from Paris Montsouris location: (a) past and future times series (both are predicted), (b) reference representative years, and (c) extreme representative years.

(a) For the construction of the predicted past and future climate data, we used 9 climate projections between 1981 and 2019 from the EURO-CORDEX database (Moss et al., 2010). These projections are combinations of Global Climate Models (GCMs) and Regional Climate Models (RCMs) that we consider equiprobable as shown in Table 1. For each of them, only the Representative Concentration Pathway (RCP) 8.5 is considered (Gobiet & Jacob, 2011), which is the most pessimistic gas emission scenario also considered as "business as usual". Beforehand, a bias-correction procedure (Kraiem et al., 2020) was used by employing ERA5 observed data over the same period (1981-2019), followed by a Hermite cubic interpolation from 3 hours to 1 hour.

Table 1: *9 combined climate models with scenario RCP 8.5*

N°	Global Climate Model (GCM)	Regional Climate Model (RCM)
1	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN 63
2	CNRM-CERFACS-CNRM-CM5	SMHI-RCA 4
3	ICHEC-EC-EARTH	SMHI-RCA 4
4	ICHEC-EC-EARTH	SMHI-RCA 4
5	ICHEC-EC-EARTH	SMHI-RCA 4
6	MOHC-HadGEM2-ES	CNRM-ALADIN 63
7	MOHC-HadGEM2-ES	ICTP-RegCM4-6
8	MOHC-HadGEM2-ES	MOHC-HasREM3-GA7-05
9	MPI-M-MPI-ESM-LR	ICTP-RegCM4-6

(b) The ISO 15927-4 provides a method for creating a year of climate data, representing a period of several years, to assess the average annual energy needs for heating and cooling (ISO, 2005). Using at least 30 years enables to overcome the internal variability of climate (Maher et al., 2020). Thus, from the predicted data, over the periods (1981-2019) and (2020-2058), two reference years were created for the past and future periods, respectively.

(c) Also from the predicted data, past (1981-2019) and future (2020-2058) extreme years are constructed using a method strongly inspired by the Netherlands standard (NEN, 2020) based on parts 2, 4 and 5 of the same ISO 15927 standard (ISO, 2005).

As a result, we have 78 predicted years (1981-2058), two reference years and two extreme years of climate data for the past and future. Combined with 77 buildings and 9 models, this represents more than 56 000 simulations as shown in Table 2.

Table 2: *Summary of simulations*

Period	Climate	Years	Models	Buildings	Total
Past	Predicted	39	9	77	27 027
	Reference and extreme	2			1 386
Future	Predicted	39			27 027
	Reference and extreme	2			1 386
					56 826

2.3. Building Performance Simulations

The 56 826 BPS were performed using COMETh, which is the thermal model used in the French building thermal regulation RT2012. It relies on a 5R1C thermal network model. Such model has proven to be efficient at estimating cumulative indicators such as heating and cooling energy needs (da Silva et al., 2016). The simulation calculates the "bioclimatic" need. This is the consumption of an ideal energy system, with an efficiency of one, and systematically reaching the set temperature. This measure allows ignoring the active energy systems and measures the actual passive performance of the building. Furthermore, in the context of the regulation of buildings energy performance, the internal loads and ventilation, limited to the hygiene flow rate, are conventionally established.

2.4. Analysis and classification

Our analysis includes 3 steps.

First, we assess the impact of climate change on buildings by observing, between the past (1981-2019) and the future (2020-2058), the average cooling needs and the related Standard Deviation (SD), defined as follows for the past:

$$\overline{N}_{past} = \frac{1}{39}\sum_{i=1981}^{2019} N_i \tag{1}$$

$$\Delta N_{past} = \sqrt{\frac{1}{39}\sum_{i=1981}^{2019} (N_i - \overline{N}_{past})^2} \tag{2}$$

where N_i are the annual cooling needs for year i, $\overline{N}_{past}$ is their past mean, ΔN_{past} is their past SD.

Second, we compute for a given model, two distributions (39 past and 39 future annual cooling needs) for 77 buildings to understand their evolution.

Third, we perform two parallel classifications of the 77 buildings with the k-means algorithm. The first clustering is based on the Euclidean distance from one building to another in a 27-dimensional space consisting of the following variables (past, future average needs and future SD for the 9 models):

$$\{\overline{N}^1_{past}, \overline{N}^1_{futu}, \Delta N^1_{futu}, \ldots, \overline{N}^9_{past}, \overline{N}^9_{futu}, \Delta N^9_{futu}\}$$

Similarly, the second clustering takes into account 27 alternative variables based on the past, future reference years and extreme future year for the 9 models:

$$\{N^1_{ref,past}, N^1_{ref,futu}, N^1_{ext,futu}, \ldots, N^9_{ref,past}, N^9_{ref,futu}, N^9_{ext,futu}\}$$

Finally, we display the different clusters on graphs in two dimensions, being projections of the 27 dimensions space. This helps to observe the distinction between groups according to different variables.

3. RESULTS AND DISCUSSION

The results are detailed by following the 3-point analysis approach presented in section 2.4.

3.1. Two climate change impact phenomena

Fig. 1 shows, for each building and for each model, the average future cooling needs as a function of the average past cooling needs. For each model, we observe a linear pattern. All the linear regressions are above the y=x curve, which corresponds to an increase in cooling needs. This increase varies according to the models with slopes ranging from 1.1 to 2. We thus have a first phenomenon (Phen1) of proportional increase in needs: *a shift effect of the needs on average.*

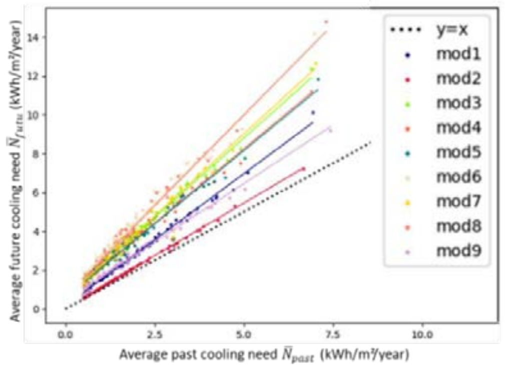


Figure 1: *Average future cooling needs based on average past cooling needs for the 77 buildings and 9 models.*

A similar linear behaviour is observed in Fig. 2 which represents, for each building and for each model, the future cooling needs SD as a function of the past cooling needs SD. All the points are above the y = x curve, which corresponds to an increase of the SD (the slopes are ranging from 1.2 to 1.8). In particular, this leads to more intense and/or more frequent extreme needs. This is the second phenomenon (Phen2): *the stretching of the SD.*

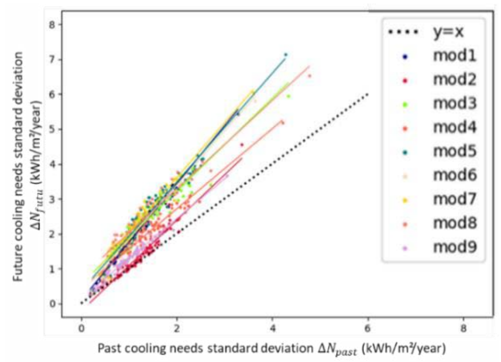


Figure 2: *Future cooling needs SD based on past cooling needs SD for the 77 buildings and all models.*

The linear trends could be due to the homogeneity of the selected buildings (same type of use, the same air exchange rate, and RT2012 compliant buildings).

3.2. Distribution in past and future cooling needs

Fig. 3 shows the past (blue) and future (red) cooling needs distributions, for the 77 buildings and model 6. On the left side of the distributions (low needs), we note that the number of past annual cooling needs is higher than the future. Conversely, on the right side (needs above an arbitrary threshold); the number of future annual cooling needs is greater than the past. Thus, a large number of individuals has exceeded the arbitrary threshold between past and future. This migration may be due to the increment in mean (Phen1) or the repetition and/or intensification of extreme years (Phen2).

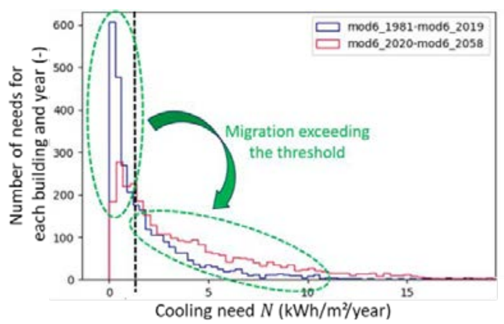


Figure 3: *Distributions of past (1981-2019) and future (2020-2058) cooling needs for model 6*

More than the increase in consumption, the crossing of the threshold and the creation of a need, whether it is on average (Phen1) or punctual (Phen2) are the real issue. Indeed, the transition from a nearly-zero cooling need to a significant cooling need could potentially requires the installation of an air conditioner.

We observe that other models give similar distributions in shape (thanks to the bias correction of the models over the past period and the linearity observed for all the models Fig. 1 and 2) but not in quantitative value (since the slopes are different for each model). The question is to distinguish passive buildings from those vulnerable to climate change. Taking into account the health risks associated with heat waves, the latter will potentially require the installation of an air conditioner. Thus, the priority is to identify the different groups of buildings according to their sensibility to climate change.

3.3. Classification and identification

This section is divided in three sections. The first one shows the comparison between two building classifications and the other two sections illustrate the clusters in a bi-dimensional space.

Two classifications comparison

Table 3 compares the clusters of 77 buildings (column 1) that are made by the two k-means classifications: on the one hand, with the 27 mean and SD variables (cluster name in column 2), and on the other hand with the 27 reference and extreme variables (cluster name in column 3). Each colour represents a cluster. There are nine clusters for each of the two classifications. Without going into technical details, the choice of nine clusters was made by studying the percentages of variations obtained by a Principal Component Analysis (PCA) (Yang, 2019).

Table 3: *Comparison of the two clustering (each line is a building, with its corresponding cluster colours for the first and second classifications)*

Building	1st clustering	2nd clustering
19 zone_1	0	3
20 zone_1	0	3
20 zone_2	0	3
29 zone_2	0	3
32 zone_2	0	3
43 zone_18	0	3
51 zone_1	0	3
51 zone_2	0	3
54 zone_1	0	3
54 zone_2	0	3
1 zone_1	7	3
29 zone_1	7	1
32 zone_1	7	1
70 zone_1	7	1
75 zone_1	7	1
2 zone_1	1	7
3 zone_2	1	7
18 zone_3	1	7
21 zone_4	1	7
28 zone_1	1	7
36 zone_1	1	7
44 zone_1	1	7
55 zone_1	1	7
67 zone_3	1	7

Building	1st clustering	2nd clustering
11 zone_1	3	0
18 zone_2	3	0
21 zone_2	3	0
30 zone_1	3	0
66 zone_3	3	0
67 zone_2	3	0
3 zone_3	3	4
4 zone_1	3	4
8 zone_1	3	4
17 zone_1	3	4
25 zone_1	3	4
48 zone_1	3	4
60 zone_1	3	4
66 zone_2	3	4
69 zone_1	3	4
74 zone_1	3	4
37 zone_2	8	4
7 zone_2	8	6
9 zone_1	8	6
23 zone_2	8	6
37 zone_1	8	6
46 zone_1	8	6
50 zone_1	8	6
77 zone_1	8	6

Building	1st clustering	2nd clustering
10 zone_1	5	5
15 zone_1	5	5
26 zone_1	5	5
33 zone_1	5	5
40 zone_1	5	5
52 zone_1	5	5
59 zone_3	5	5
76 zone_1	5	5
5 zone_1	4	2
17 zone_2	4	2
49 zone_2	4	2
50 zone_2	4	2
70 zone_2	4	2
71 zone_1	4	2
19 zone_2	6	8
23 zone_1	6	8
62 zone_1	6	8
58 zone_1	2	8
58 zone_2	2	8

We observe that the 2 classifications give very similar results. Only 2 buildings are not classified in the same cluster from one classification to the other ("1.zone_1" and "37.zone_2"). Moreover, the cluster n°3 (1st clustering) is divided into 2 clusters (n°0 and n°4, 2nd clustering). In return, clusters n°6 and n°2 (1st clustering) are combined into a single cluster (n°8, 2nd clustering).

The representative climate files (2nd clustering) lead to an equivalent clustering while requiring much less computation than the first one. Indeed, we recall that the use of reference years allows to divide by 20 the number of simulations performed and presented in Table 2.

First group distinction (Phen1)

Fig. 4 and 5 represent future reference cooling needs as a function of past reference cooling needs for each building, coloured according to its clusters, and for models 4 and 7, respectively. These are two bi-dimensional projections of the 27-dimensional space in which the classification was done.

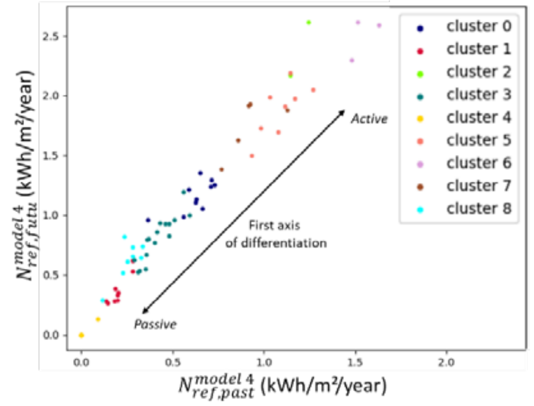


Figure 4: *Future reference as a function of past reference cooling needs for model 4*

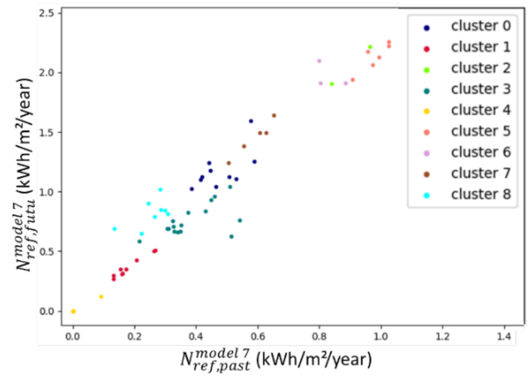


Figure 5: *Future reference as a function of past reference cooling needs for model 7*

CLUSTER DIFFERENTIATION AXIS: We first observe a linear behaviour of the future and past reference years as in Fig. 1. We thus observe a first distinction between the different clusters on this linear axis. On the one hand, the passive buildings (bottom left) have low cooling needs in the past and in the future. On the other hand, the active buildings (top right) have high cooling needs in the past and in the future. This is a first axis of differentiation of the clusters.

PHENOMENON 1 (PHEN1): The increase of the average needs has the effect of transforming the buildings, initially passive, into active buildings in the future: this is notably the case of the clusters in the center (n°0 blue and n°7 brown). These groups are vulnerable to climate change for Phen1. Belonging to these groups may lead to a long-term purchase of an air conditioner, but all the models should be used for a quantitative approach.

We observe that the groups, on the bottom left, which are passive on average have different colours (n°1 red, n°3 teal and n°8 cyan) while their points are close to each other. Why would the k-means algorithm distinguish them? The answer can be seen in a second projection.

Second group distinction (Phen2)

Fig. 6 and 7 show the future extreme cooling needs as a function of past reference needs for each building, coloured according to its clusters, and for models 4 and 7, respectively. As before, these are 2 two-dimensional projections of the space in dimension 27.

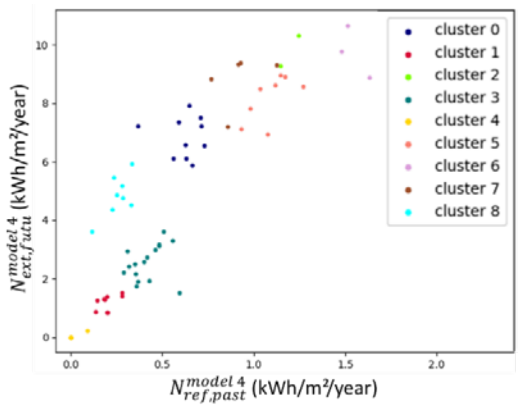


Figure 6: *Extreme future as a function of past reference cooling needs for model 4*

CLUSTER DIFFERENTIATION AXIS: We observe, contrary to the linear behaviour of the previous figures, a stretching of the clusters on the future extreme values. Indeed, for groups having similar average needs (aligned on the same vertical axis), they differentiate on their extreme cooling needs: for instance, cluster n°3 (teal) and n°8 (cyan). This is therefore a second axis of distinction of clusters. At the bottom, clusters are adapted to the extreme future. In contrast, at the top, clusters are not adapted to the extreme future. In summary, Fig. 7 shows the two axis of differentiation.

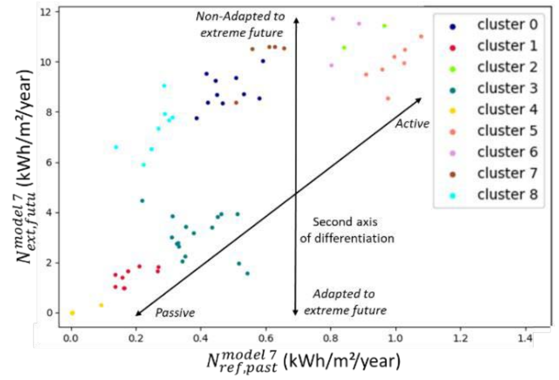


Figure 7: *Extreme future as a function of past reference cooling needs for model 7*

PHENONMENON 2 (PHEN2): The vulnerability of buildings not adapted to future extremes is at the origin of a punctual creation of cooling need and/or represents a health risk. For example, if we had considered only past – future reference cooling needs, cluster n°8 (cyan) would not have been differentiated from cluster n°3 (teal). However, we observe that the cooling needs of future extreme years are much more significant than the reference years. Belonging to cluster n°8 therefore leads to a health risk and/or the possibility of purchasing an air conditioner immoderately (Phen2). Concerning the impact of extreme climates in the purchase of an air conditioner, it would be interesting to study the probability of occurrence of these types of climates. Whatever the model chosen, the buildings' clusters can be classified using 2-differentiation axis:

- Clusters 1, 3 and 4 like passive and adapted.
- Cluster 8 like passive not adapted (Phen2).
- Clusters 0 and 7 from passive to active (Phen1).
- Clusters 2, 5 and 6 like active.

The description of the buildings physical characteristics did not reveal any clear building parameter that would differentiate them a priori, despite the approach limited to cooling needs. In addition, the great homogeneity of the buildings can also explain this result. Walls insulation may be the discriminating parameter as the temperature increase is the main effect of climate change. However, in summer in France, its impact is difficult to quantify a priori because:

- it is of 2[sd] order in the well-insulated buildings studied with an air change rate limited to the hygiene flow rate,
- its thermal effects are antagonists, limiting heat transfer during the day and confining heat indoors at night.

4. CONCLUSIONS AND PERSPECTIVES

(1) The study evaluates, on a large sample of buildings, the impact of climate change according to two dimensions: an increase in the average and an increase in the internal variability of the climate (SD and extreme). These two effects induce the migration from low past cooling needs to non-negligible future cooling needs that may require the purchase of an air conditioner.

(2) The study has shown the relevance of using representative years (reference and extreme) to classify buildings in accordance with their cooling needs. The approach developed showed that it was possible, for the selected sample, to reduce the number of simulations by 20 and maintain satisfactory results.

(3) The classification highlighted two main distinctions axis between buildings: active or passive, and adapted or not adapted to the extreme future. The proportional increase in average cooling needs could tomorrow transform several buildings considered passive today into active buildings (Phen1). On the other hand, a group of buildings that today have low needs will be particularly sensitive to future extremes (cluster 8). With a low average exposure to needs, they may give the impression of being well adapted to future changes. However, they could present a health risk for their occupants exposed to high ambient heat from time to time (Phen2). Therefore, these buildings should receive special attention.

To distinguish one group of buildings from another, an analysis of the buildings characteristics should further be explored. A more heterogeneous population of buildings, extended to existing residential buildings should also be studied. Besides, It would be useful to extend this developed methodology to other RCP scenarios and other regions in France.

It should be highlighted that the huge number of calculations has been made possible by the existence of a database of buildings already modelled for dynamic thermal simulations (OPE). The data format is only compatible with a dynamic thermal simulation software (COMETh) which limits the possibilities of confrontation with other tools.

One of the limitations of this work is the 39 - years period used (the longer the period, the lower the internal variability). Another is the extreme years constructed considering extreme events over 5 days, another period could lead to different results.

ACKNOWLEDGEMENTS

The studies described in this paper were supported by the CSTB Research Program and the LoPACC project financed by ADEME.

REFERENCES

CODA Stratégies. (2021). La climatisation de confort dans les bâtiments résidentiels et tertiaires. *ADEME. Final Report*. 20-22.

da Silva, D. Alessandrini, J-M., Videau, J-B., & Millet, J-R. (2016). Evaluation et perspectives du modèle thermique de COMETh, le cœur de calcul de la réglementation thermique des bâtiments neufs. *Conference: IBPSA 2016*.

de Munck, C., Pigeon, G., Masson, V., Meunier, F., Bousquet, P., Tréméac, B., Merchat, M., Poeuf, P., & Marchadier, C. (2013). How much can air conditioning increase air temperatures for a city like Paris, France? *International Journal of Climatology*, *33*(1), 210–227.

Directorate-General for Energy. (2018). EU Building Stock Observatory [Data set]. https://data.europa.eu/data

Gobiet, A. & Jacob, D. (2011). A new generation of regional climate simulations for Europe: The EURO-CORDEX Initiative. *WCRP Open Science Conference.*

ISO. (2005). Hygrothermal performance of buildings. Calculation and presentation of climatic data (ISO 15927).

ISO. (2017). Thermal performance of building components — Dynamic thermal characteristics — Calculation methods (ISO 13786).

Kraiem, S., Alessandrini, J-M., Rey, A. (2020). fTMY - Documentation. *Internal CSTB report* : *unpublished*

Maher, N., Lehner, F., & Marotzke, J. (2020). Quantifying the role of internal variability in the temperature we expect to observe in the coming decades. *Environmental Research Letters*, *15*(5), 054014.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, *463*(7282), 747–756.

NEN. (2020). Hygrothermal performance of buildings - Climatic reference data (NEN 5060+C1).

Riberon, J., Vandentorren, S., Bretin, P., Zeghnouir, A., *Salines, G., Cochet, C., Thibault, C., Heniii, M., & Ledrans, M.* (2006). Building and urban factors in heat related deaths during the 2003 heat wave in France. *HB 2006 - Healthy Buildings: Creating a Healthy Indoor Environment for People, Proceedings, 5,* 323–326.

Rolland, A. (2018). Modes de vie et pratiques environnementales des Français. *French Ministry of Sustainable Development,* 35-38.

Videau, J-B., Alessandrini, J-M., Hass, B., Pele, C., Millet, J-R,. Jallet, P., Reynier, L., Fleury, E. (2013). An Introduction to the Development of the French Energy Regulation Indicators and Their Calculation Methods. *Clima 2013*.

Yang, X-S. (2019). 5 — Logistic regression, PCA, LDA, and ICA. In ICA. *Introduction to Algorithms for Data Mining and Machine Learning* (pp. 91-108) Academic Press.

PLEA SANTIAGO 2022
Will Cities Survive?

Optimization-based design of insulating cementitious foams combined with phase change materials for NZEBs

FACUNDO BRE[1, 2], ANTONIO CAGGIANO[3], EDUARDUS A. B. KOENDERS[1]

[1] Institut für Werkstoffe im Bauwesen, Technische Universität Darmstadt, Darmstadt, Deutschland
[2] Centro de Investigación de Métodos Computacionales (CIMEC), UNL, CONICET, Predio "Dr. Alberto Cassano", Colectora Ruta Nacional 168, Paraje El Pozo, Argentina
[3] DICCA - University of Genova, Genova, Italy

ABSTRACT: This work aims to introduce a new multiobjective optimization method for designing insulating cementitious foams combined with phase change materials (PCMs) to improve the energy performance of buildings. To achieve this, the multiobjective Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and EnergyPlus software are dynamically coupled. Parametric models for PCMs and insulating cementitious foams are implemented in EnergyPlus to optimize their thickness and the PCM melting temperature. The BESTEST 900 from ANSI/ASHRAE Standard 140-2011 is chosen as a case study to evaluate the performance of the different designs. As objective functions, the annual heating and cooling loads are calculated in Sofia city, Bulgaria-EU. The results reveal several conclusions in terms of physics correlations between the design variables and objective functions. Regarding the total annual loads, the best design reduces 8.95% of the loads (compared to the Baseline model) by using 10 cm of cementitious foam combined with 2.5 cm of PCM with a melting temperature of 24.41 °C.
KEYWORDS: Energy conservation, Insulating cementitious foam, Phase change material, Multiobjective optimization, Building performance simulation.

1. INTRODUCTION

Developing new building materials is a key research area to reduce the energy consumption in buildings and related CO_2 emissions. Researchers have conducted major efforts for developing two main types of materials regarding their application in buildings: insulating materials and energy storage materials.

Insulating materials are useful for reducing the thermal transmittance of building envelopes and controlling their heat loss and/or heat gain [1]. Typical insulating materials such as polyisocyanurates, extruded and expanded polystyrenes, and mineral and rock wools can achieve a very low thermal conductivity. However, most of these materials are highly flammable and have low recyclability. Thus, cementitious foams have great potential as insulating materials because of their low thermal conductivity, and their advantages of being non-flammable, non-toxic, and fully recyclable.

Moreover, energy storage materials can accumulate excess heat from indoor air and can be used to cool buildings efficiently. In particular, phase change materials (PCMs) have attracted great attention from the construction sector to improve the energy efficiency of buildings [2]. While undergoing their phase transition, PCMs can store and release large amounts of heat energy and have a stabilizing thermal effect inside buildings [3]. Despite its enormous energy-saving potential, successful use of passive PCM-based systems in buildings is not implicitly guaranteed. This is because the performance of passive PCMs strongly depends on their complete daily thermal cycles [4].

Within this context, the NRG-STORAGE project [7] proposes a new cementitious foam with embedded micro-encapsulated PCM, so-called NRG-FOAM, aiming to achieve a lightweight material with an advanced insulation property and enhanced heat storage capacity.

Although the thermal properties of new materials can be measured using proper laboratory experiments, their real performances and optimum design have to be carried out at the building scale. Advanced building performance simulation tools are a suitable method to achieve it, which can predict the performance of the new materials in the built environment while considering real local climate conditions [5].

In this first effort, a multiobjective optimization method is proposed to find the optimal designs of insulating cementitious foams combined with PCMs in buildings. To achieve this, the multiobjective Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and EnergyPlus software are dynamically coupled. As a case study, the BESTEST 900 is chosen to evaluate the annual heating and cooling performances of the different feasible designs.

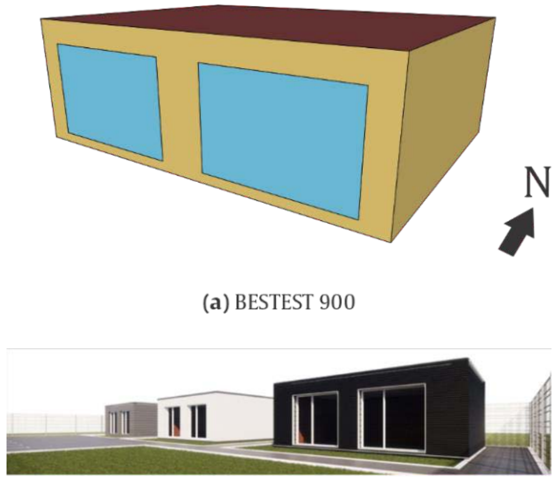
2. METHODOLOGY

2.1 Case study

The ANSI/ASHRAE Standard 140-2011 BESTEST 900 is employed to evaluate the performance of several foam-PCM designs applied to a typical wall structure [6]. The BESTEST is a basic test for building energy simulations, consisting of a single thermal zone with no interior partitions and two South-facing windows, see Fig. 1a. To characterize the performance of this building, the BESTEST 900 has an ideal HVAC system, whose thermostat control is set to 20 °C as the lower limit for heating and 27 °C as the upper limit for cooling.

Three real-scale BESTEST 900 buildings are currently under construction in Sofia, Bulgaria. These are demo prototypes that will be used to experimentally measure the performance of several NRG-FOAMs, developed within the NRG-STORAGE project [7]. So, a numerical model of this real scale BESTEST 900 is implemented in EnergyPlus 9.0 following the characteristics detailed in [6].

Figure 1:
Case study building. (a) BESTEST 900; (b) Prototypes under construction in Sofia (With courtesy of GBS Bulgaria).



2.2 Multi-objective optimization approach

Mathematically, the building performance optimization is posed as the following bi-objective optimization problem,

$$\text{Minimize } [f1(x), f2(x)], \quad (1)$$

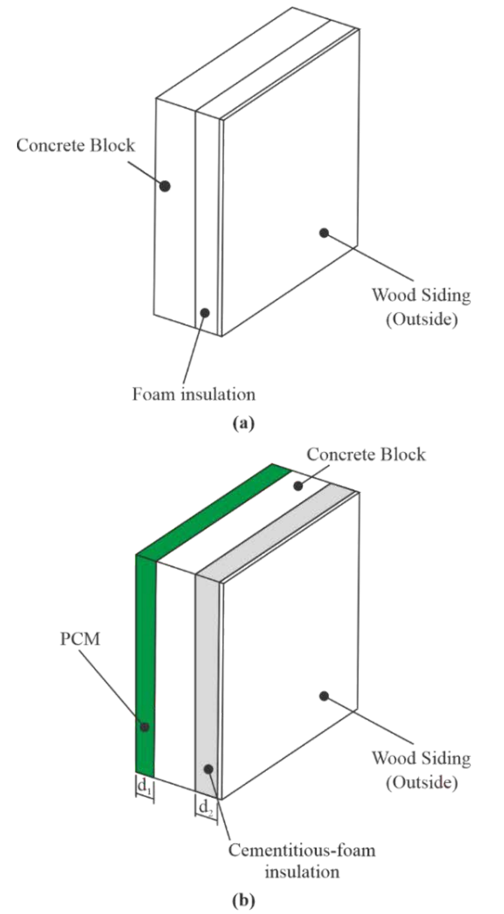
where x = [d_1, T_{peak}, d_2], being d_1 the thickness (m) of the PCM, T_{peak} the peak melting temperature (°C) of the PCM, and d_2 thickness (m) of the cementitious insulating foam. The objectives f1(x) and f2(x) are annual heating and cooling loads obtained as a result of the EnergyPlus simulations for the recent typical meteorological year (TMYx.2004-2018 [1]) in Sofia, respectively.

2.3 Description of thermophysical properties of materials and design variables

Fig. 2 shows schematically the configuration of the wall construction for the Baseline model and the proposed one. The position of the PCM and the cementitious insulating foam among the wall layers can be observed in Fig. 2b.

Concrete foams (see Fig. 3) are made of cement paste (or sometimes mortar) in which a very high amount of air voids is entrapped by using an appropriate foaming agent. Cementitious foams are non-flammable, possess an extremely high flowability (also suitable for 3D printing), a very low specific weight, generally contain no aggregates, and have outstanding thermal insulation properties. Based on a proper mix design, a wide range of densities can be attained (varying from 90 to 300 kg/m³), as well as different porosities with particular pore size distributions.

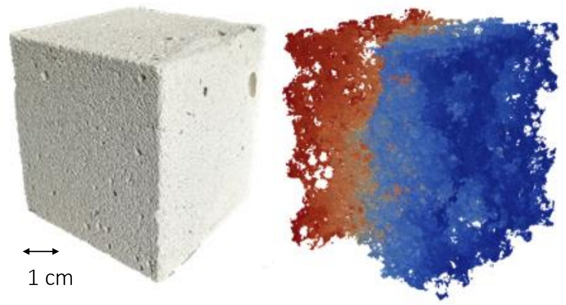
Figure 2: *Wall construction material configuration. (a) Baseline model; (b) Proposed wall.*



[1] see data available in http://climate.onebuilding.org/

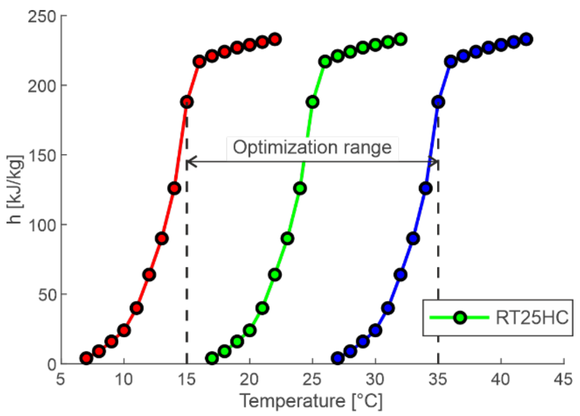
The thermophysical properties of the cementitious foam are taken from [8]. This foam was designed with a targeted dry density of 180 kg/m³ while using a water-to-cement ratio for the cement paste of 0.4.

Figure 3:
Typical concrete foam and 3D heat flow schematization.



The Rubitherm RT25HC [9] is chosen as reference PCM. With this, a shift of +10/-10 °C is numerically allowed for the enthalpy curve (latent capacity) of the material to study the optimal melting temperature (T_{peak}) in the optimization task, see Fig. 4. The latent thermal capacity of PCM is represented by the PCM model (*MaterialProperty:PhaseChange*) of EnergyPlus [10]. The main input in this model is the enthalpy-temperature curve of the PCM.

Figure 4:
Enthalpy curve of the PCM as a function of the temperature and the considered optimization range.



Tables 1 and 2 show the thermophysical properties of the wall construction layers for the Baseline model and the ones proposed herein, respectively. The optimization ranges for the cementitious foam and the PCM thicknesses are also specified in Table 2.

Table 1:
Thermo-physical properties of the wall construction elements for the Baseline model.

Elem.	K [W/(m K)]	Thickness [m]	Density [kg/m³]	Cp [J/(kg K)]
Concr. Block	0.51	0.1000	1400	1000
Foam Insul.	0.04	0.0615	10	1400
Wood Siding	0.14	0.009	530	900

Table 2:
Thermo-physical properties of the wall construction elements for the proposed optimization.

Elem.	k [W/(m K)]	Thickness [m]	Density [kg/m³]	Cp [J/(kg K)]
PCM RT25HC	0.200	0.001-0.025	820	2000 (sens.)
Concr. Block	0.510	0.100	1400	1000
Cement Foam	0.059	0.010-0.100	180	938
Wood Siding	0.14	0.009	530	900

2.4 Implementation and setup of the optimization

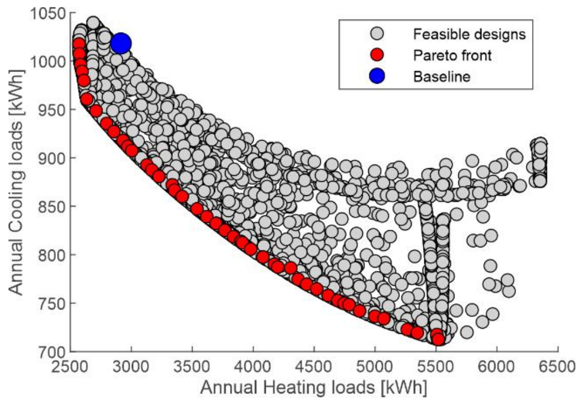
To solve the optimization problem (1) for the case study, the NSGA-II optimization algorithm [11] is dynamically coupled with EnergyPlus to find the optimal design parameters that minimize both the heating and cooling loads. The implementation of the optimization algorithm is described in detail, in our previous work [12]. The optimization problem is solved by using a population size of 48 individuals and 100 generations, resulting in 4800 EnergyPlus simulations.

3. RESULTS

Fig. 5 shows the multiobjective optimization results obtained for the mentioned BESTEST 900 case study. These include the best trade-off (Pareto front) between heating and cooling loads and all the feasible designs evaluated during the optimization. Furthermore, the heating and cooling loads demanded by the Baseline model are also shown to have a reference for the improvements reached by the optimized designs.

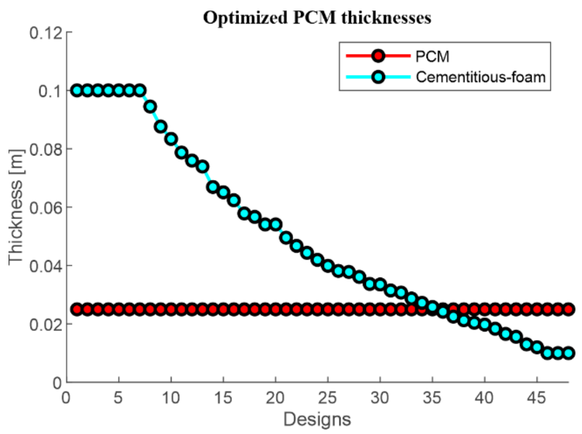
From these results, it can be seen that there is a wide range of designs for the variables analyzed. In this space, several designs can reduce the cooling loads but increase the heating ones in comparison to the Baseline configuration. Moreover, there are a few designs that reduce the loads for both heating and cooling compared to the Baseline model.

Figure 5:
Optimization results of the annual ideal loads, for heating and cooling, considering the case study in Sofia.



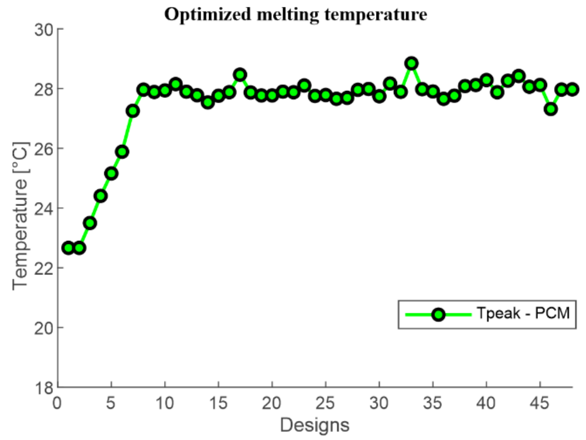
To better understand the physics behind the optimal designs (Pareto front), the optimum thicknesses of the cementitious foam and PCM are shown in Fig. 6. The designs go over the Pareto front from the solution with the best performance for heating (Opt-1) to the solution with the best performance for cooling (Opt-48). It can be observed that the thickness of the cementitious foam (insulation material) is the thickest one allowed (10 cm) to reduce the heating loads (Opt-1), and from here, it decreased until reaching the thinnest one allowed (1 cm) for minimizing the cooling loads (Opt-48). Moreover, all optimized designs chose the thickest PCM.

Figure 6:
Optimal thicknesses for the cementitious foam and PCM for each design on the Pareto front.



Regarding the optimum melting temperature of the PCM, Fig. 7 shows the optimum T_{peak} obtained for each design on the Pareto front (Opt-1 to Opt-48). The design with the best performance for heating (Opt-1) employs a PCM with a peak melting temperature of 22.66 °C, while after that, the optimum T_{peak} increases up to 28 °C and stays around this value for reducing the cooling loads.

Figure 7:
Optimized T_{peak} of the PCM obtained for each design on the Pareto front.



To enable quantitative analysis, Table 3 summarizes the performance of obtained optimum designs and their relative energy savings in comparison to the Baseline model. The configuration of these optimized designs is described as well.

The best design for reducing the heating loads (Opt-1), achieves 11.76% of heating savings but almost did not reduce the cooling loads (0.06%), resulting in an 8.73% saving on the total loads. Conversely, Opt-48 achieves a 30.01% of reduction for cooling but had increased heating loads by 89.38%, resulting in a 58.47% increase in the total loads. Regarding the best design for reducing the total loads, the Opt-4 is the best option on the Pareto front. This design archives a reduction of 8.95% for the total loads by saving 11.34% and 2.14% for the heating and cooling loads, respectively. The configuration of this design compromises 10 cm thickness for the cementitious foam combined with 2.5 cm of PCM, and this PCM has a T_{peak} of 24.41 °C.

Table 2:
Configuration and energy performance of the Baseline and optimized designs.

	Baseline	Opt-1	Opt-4	Opt-48
Heating load [kWh]	2914.14	2571.34	2583.8	5518.74
Cooling load [kWh]	1018.04	1017.46	996.28	712.51
Total load [kWh]	3932.18	3588.80	3580.0	6231.25
Heating saving [%]	-	**11.76**	11.34	-89.38
Cooling saving [%]	-	0.06	2.14	**30.01**
Total saving [%]	-	8.73	**8.95**	-58.47
d_1 [m]	-	0.025	0.025	0.025
T_{peak} [°C]	-	22.67	24.41	27.97
d_2 [m]	-	0.10	0.10	0.01

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

4. CONCLUSION

This paper introduced a multiobjective methodology to optimize the design of an insulating cementitious foam combined with phase change material (PCM) in buildings. To address this, the multi-objective Non-dominated Sorting Genetic Algorithm-II (NSGA-II) was dynamically coupled with annual EnergyPlus simulations for the BESTEST 900 from ANSI/ASHRAE Standard 140-2011. Parametric models for the cementitious foam and PCM were implemented in the EnergyPlus simulations to study the optimal thicknesses of the materials along with the PCM melting temperatures.

The optimization results showed that heating and cooling loads have a complex and contradictory relationship regarding the design variables. Therefore, a simulation-based and multiobjective-based optimization approach is needed and highly recommended for performing the optimization of the PCM melting temperatures as well as of the insulation thickness in buildings.

Regarding the cementitious insulating foam, the optimum design for reducing heating loads is achieved for a thickness of 10 cm, while a thickness of 1 cm is necessary to minimize the cooling loads. This latter shows that insulation materials have to be carefully designed by also considering the building typology and local climate.

As for the PCM, all optimum solutions on the Pareto front employ the thickest option of 2.5 cm but were combined with different melting temperatures related to the performance of the design. A melting temperature of 22.66 °C was necessary for reducing the heating loads while a melting temperature of around 28 °C was preferred for reducing the cooling loads.

Regarding the optimal combination of the design variables, there is a design that can reduce the heating loads up to 11.76% and another design that can reduce the cooling loads up to 30%. In terms of total loads, the best design reduced 8.95% of the loads by using 10 cm of cementitious foam combined with 2.5 cm of PCM with a melting temperature of 24.41 °C. Here, it was demonstrated that it is possible to improve the original wall configuration by the optimum combination of a cementitious foam with a PCM. It may be worth noting that an improved performance compared to the original results was achieved by an increased thickness of the cementitious foam. This is because the building typology was dominated by heating loads and the original insulation had a lower thermal conductivity than the employed cementitious foam.

Finally, the proposed methodology showed great robustness to explore the optimum solutions for optimized building designs that use PCMs. Future works will be focused on adapting and employing the methodology to design the NRG-FOAMs panels planned to be tested at a real scale BESTEST 900 buildings of the NRG-STORAGE project.

ACKNOWLEDGEMENTS

The results found in this work are part of the *0E-BUILDINGS* action. This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement N° 101024627 (https://cordis.europa.eu/project/id/101024627).

This work also represents a study of the research activities of the NRG-STORAGE project, financed by the European Union H2020 407 Framework under the LC-EEB-01-2019 call, H2020-NMBP-ST-IND-2018-2020/H2020-NMBP-EEB-2019, IA type (https://cordis.europa.eu/project/id/870114/).

REFERENCES

1. Aditya, L., et al. (2017). A review on insulation materials for energy conservation in buildings. *Renew. Sustain. Energy Rev.*, 73, 1352-1365.
2. Cabeza, L. F., and Chàfer, M. (2020). Technological options and strategies towards zero energy buildings contributing to climate change mitigation: A systematic review. *Energy and Buildings*, 219, 110009.
3. Cascone, Y., et al. (2018). Optimisation analysis of PCM-enhanced opaque building envelope components for the energy retrofitting of office buildings in Mediterranean climates. *Appl. Energy*, 211, 929-953.
4. Saffari, M., De Gracia, A., Fernández, C., and Cabeza, L. F. (2017). Simulation-based optimization of PCM melting temperature to improve the energy performance in buildings. *Applied Energy*, 202, 420-434.
5. Bre, F., Lawrie, L. K., Crawley, D. B., and Lamberts, R. (2021). Assessment of solar radiation data quality in typical meteorological years and its influence on the building performance simulation. *Energy Build.*, 250, 111251.
6. ASHRAE, "ANSI/ASHRAE Standard 140-2011: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs", Atlanta, GA, USA, 2011.
7. Integrated porous cementitious Nanocomposites in non-Residential building envelopes for Green active/passive energy STORAGE (NRG-STORGE). https://nrg-storage.eu/.
8. Gilka-Bötzow, A., Folino, P., Maier, A., Koenders, E. A., and Caggiano, A. (2021). Triaxial Failure Behavior of Highly Porous Cementitious Foams Used as Heat Insulation. Processes, 9(8), 1373.
9. Rubitherm Technologies GmbH; RT25HC datasheet. Accessed: February 1, 2022.
10. Tabares-Velasco, et al. (2012). Verification and validation of EnergyPlus conduction finite difference and phase change material models for opaque wall assemblies (No. NREL/TP-5500-55792). *NREL*, United States.
11. Deb, K., et al. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE transactions on evolutionary computation*, 6(2), 182-197.
12. Bre, F., and Fachinotti, V. D. (2017). A computational multi-objective optimization method to improve energy efficiency and thermal comfort in dwellings. *Energy and Buildings*, 154, 283-294.

Catalogue of urban surface finish materials

Optimizing solar energy management in Latin American cities located in different climatic zones

GLORIA PEREZ[1], ORISELL MEDINA-LAGRANGE[2], FERNANDO MARTIN-CONSUEGRA[1], NOELIA ALCHAPAR[3], VIRGINIA FLORES SASSO[2], PATRICIA MARTINEZ[4], CLAUDIA COTRIM PEZZUTO[5], LUIS PRADO[6], CARMEN ALONSO[1], MAX ARNSDORFF[6], BORJA FRUTOS[1], ANA GUERRERO[1], SAGRARIO MARTINEZ-RAMIREZ[7], JUAN OJEDA[4], LETZAI RUIZ-VALERO[2]

[1]Instituto de Ciencias de la Construcción Eduardo Torroja (IETCC), CSIC, Spain
[2]Pontificia Universidad Católica Madre y Maestra (PUCMM), Dominican Republic
[3]Instituto de Ambiente, Hábitat y Energía (INAHE), CONICET, Argentina
[4]University of Valparaiso, Chile
[5]Pontifical Catholic University of Campinas, Brasil
[6]Universidad Mayor de San Andrés, Bolivia
[7]Instituto de Estructura de la Materia (IEM), CSIC, Spain

ABSTRACT: The use of surface materials with adequate thermo-optical properties at pavements, facades and roofs is an effective strategy to optimize the management of solar energy in cities, mitigate urban overheating and improve energy efficiency in their buildings. This work presents an analysis of urban surface finish materials in five cities that cover a wide range of geographic and climatic locations along Latin America: Campinas (Brazil), La Paz (Bolivia), Mendoza (Argentina), Santo Domingo (Dominican Republic) and Valparaíso (Chile). One residential neighborhood was selected in each city with special need for urban and building rehabilitation. A unified procedure was defined to examine the in-use urban finishing materials and collect preliminary data affecting their interaction with solar radiation at the five neighborhoods. The results indicate that in-use materials were not selected according to the specific climatic characteristics of each location. These preliminary data were compiled into a catalogue that will be expanded in future research with the experimental thermo-optical properties of the in-use materials and those locally available for urban rehabilitation. The final objective of the research is the proposal of urban surface materials adapted to the local conditions in each city and considering sustainability aspects as well.
KEYWORDS: Solar energy, urban sustainability, surface materials

1. INTRODUCTION

Rising temperatures and heat waves constitute one of the main effects of Global Change on the climate and intensify one of the main current environmental challenges: the warming of urban areas. It is estimated that the percentage of urban population in Latin America is 80% and the forecast is that it will increase to 88% in the year 2050 [1]. It is therefore essential that, both in the rehabilitation and in the development of cities, measures be implemented to mitigate this effect. However, the research papers on urban heat island effect in this area of the world are, for the moment, scarce [2,3].

On the other hand, the high-altitude Andin regions are characterized by a cold weather and a high intensity of solar radiation. In this case, the main problem is not urban overheating, but the need to maximize the use of solar energy to improve indoor comfort and reduce the heating demand in buildings.

The optical and thermal properties of the surface materials in buildings and pavements define the percentage of solar energy absorbed and the speed at which this energy is radiated into the atmosphere. Consequently, these are critical parameters for the temperature of the urban environment and of the indoor conditions in buildings. Therefore, it is possible to mitigate overheating in cities and improve energy efficiency in their buildings by using surface finishing materials with thermo-optic properties that optimize solar energy management [4,5,6].

The general objective of the research pursues the selection of sustainable surface finishing materials with thermo-optical properties that optimize solar energy management at Latin American cities. As a first step, it is necessary to identify and catalogue the materials currently in use in the cities. Latin American countries share a similar history during colonial times and similar languages that provide important cultural, social, and economic links between them. However, they have different climatic conditions and socio-economic evolution throughout more recent times, which have given rise to varied urban configurations. To include these configurations in the research, the cities analyzed must cover a wide range of geographic locations, climatic conditions, and demographic and economic characteristics throughout Latin America. In this context, a cataloging of surface finish materials has been addressed in five Latin American cities: Campinas (Brazil), La Paz (Bolivia), Mendoza (Argentina), Santo Domingo (Dominican Republic) and Valparaíso (Chile). A specific neighborhood has been selected in each city that represents deprived areas with special need for urban and building rehabilitation. The cataloguing methodology has been defined and the catalogue has been initiated with a set of qualitative data that will be complemented with the thermo-optical properties, sustainability aspects and properties related to the material application.

This information will be used to evaluate the potential improvement of sustainability that could be obtained through the substitution of current materials by others available in the local market.

2. METHODOLOGY

The methodology of the research was developed in three steps.

2.1. Assessment of Latin American cities involved in the study

In the first place, the main parameters that define the cities participating in the study were collected and compared. The parameters include those determining the local solar irradiation: latitude, altitude and climatic conditions as defined by the Koppen-Geiger classification [6]. The temperature (minimum, maximum and mean annual values), the mean relative humidity and the mean Urban Heat Island were considered, as parameters closely related to the main problems of urban discomfort and energy inefficiency of buildings in each location. Finally, the population, the surface of the urban area and the Gross Domestic Product characterizing each city was included in the comparison to approach the capability of addressing rehabilitation solutions.

2.2. Selection of neighborhoods to be included in the research

As a second step, one specific neighborhood was selected in each city for the analysis, following consistent criteria in all the cases. The criteria include that the neighborhoods be located at homogeneous areas of mainly residential use and with a clear need for urban/buildings rehabilitation due to discomfort conditions attributable to urban envelope materials. In addition, only safe areas were considered, which may be visited with no specific risk for a detailed analysis and measurement of envelope materials.

2.3. Definition of a catalog of urban surface finishing materials

Cataloguing of surface finishing materials in use at pavements, facades and roofs of the selected urban areas was addressed. A data collection sheet was structured to collect the information corresponding to each material. The sheet is segmented in two parts associated to the two steps of data collection. In the step presented in this work, preliminary data were collected, including the material application, frequency of use, appearance (color and texture), nominal properties, availability and estimated cost. Different types of data sources were allowed, as in-situ sampling, Google Earth images or previous research works.

These preliminary data were compiled in a catalogue that will be expanded in the second step of the research.

3. RESULTS

3.1 Characteristics of the studied cities

Table 1 shows the parameters selected to define and compare the five cities participating in the study. The latitudes range from locations close to equator, as La Paz and Santo Domingo, to the latitudes around 33°S in Mendoza and Valparaíso, with Campinas at an intermediate value. This parameter influences the inclination of solar radiation and consequently its heating capacity of urban surfaces. This capacity is also determined by the altitude, being especially high in the case of La Paz, which is located at an altitude of 3500 m in the Altiplano of the Andes. At the opposite side, two low-altitude coastal cities are analyzed, Santo Domingo and Valparaíso. The distance to the coast and the presence of surrounding mountains, as the Andes in La Paz and Mendoza, determine the cloudiness in each location.

The climatic characteristics of the selected cities are very different as a consequence of the different locations: Campinas (Brazil) is placed in the category of warm temperate climates and specifically in dry-winter humid subtropical climate (Cwa), La Paz (Bolivia) in a polar tundra climate (ET), Mendoza (Argentina) in an arid desert climate (Bw), Santo Domingo (Dominican Republic) in a tropical savanna climate with dry winter characteristics (Aw) and Valparaíso (Chile) in a temperate Mediterranean warm summer climate (Csb). Regarding the demographic and economic aspects, most densely populated cities are La Paz and Campinas, which differ significantly in their Gross Domestic Product (GPD). La Paz, Mendoza and Valparaíso show medium to low density and GPD values.

The data collected in Table 1, confirm that the areas of analysis cover a wide range of geographic and climatic locations and of demographic and economic characteristics along Latin America. This variety justifies the interest in performing a comparative study of the urban surface finish materials in these cities and their behavior under solar radiation.

Table 1:
Characteristics of the cities under analysis.

Parameter	Campinas	La Paz	Mendoza	S. Domingo	Valparaíso
Latitude	22°48'S	16°29'S	32°54'S	18°28´N	33,03° S
Altitude (m)	680	3500	764	14	250
Climate [ref]	Cwa	ET	Bw	Aw	Csb
Direct normal irradiation per year (kWh/m^2)	1781	2425	2189	1750	1966
Temperature (°C)	12/32/22	-2/15/7	1/37/18	20/32/26	11/18/14
Mean Relative Humidity (%)	70		52	83	75
Mean Urban Heat Island (°C)	3-6		6.5		
Population (million people)	1.22	0.86	1.09	1.04	0.30
Urban surface (km^2)	795		168	104	402
% Gross Domestic Product	0.9	28	4	67.9	10.4

Note: Temperatures are given as minimum/maximum/mean annual values.

3.2 Characteristics of the selected neighborhoods

Specific urban areas were selected for the study that comply with the general selection criteria detailed in section 2 and present other peculiarities of interest. The different morphologies of these areas are shown in Figure 1.

In Campinas (Brazil) a neighborhood in the district of Campo Grande was selected. Developed from 1950 without an adequate urban planning and infrastructures, most of the buildings are single storey and distributed in an organic morphology with streets width in the range of 9-12 m and around a 5% of vegetation coverage. The district includes various sectors exposed to high and very high vulnerability with subnormal urban agglomerations, which have become special areas of social interest for regularization by the City Council.

In La Paz (Bolivia), the adjoining neighborhoods Huacataqui and Chualluma were analyzed. While the former is representative of the conventional urban envelopes of the city, Chualluma represents the current transformation of the facades, redecorated with geometric patterns and brightly colored ethnic murals to enhance the identity of the area. These are basically pedestrian areas with 1-2 story houses, distributed in an irregular urban morphology, which adapts to the sloped topography of the site. The streets are narrow, plenty of stairs and without vegetation. They belong to the six "Barrios de Verdad" of the city, a public project for urban rehabilitation of vulnerable neighborhoods with special involvement of the inhabitants.

In Mendoza (Argentina) the analysis was performed at the Cementista neighborhood, which is a peripheral residential area representative of social neighborhoods in the city. It has a homogeneous building typology, characterized by 1-2 story houses. The area is characterized by an orthogonal grid morphology, in the form of checkerboard with rectangular blocks, street widths (vehicular zones) in the range from 9 to 12 meters and a 13% of the surface covered by urban forestry. The high potential of urban rehabilitation is related to the high percentage of built area (80%).

In Santo Domingo (Dominican Republic), the selected area was the San Miguel neighborhood, which is one of the oldest quarter of Santo Domingo´s Colonial City, dating from the 16^{th} century. The current layout, from an intervention made in the 1970s, is a grid with rectangular, square, and triangular blocks. The paved streets have a width of 5 to 6 m, while the buildings are 1 to 4 stories and vegetation coverage is found in a 7% of the space. Urban rehabilitation of the area is expected to be performed in the near future.

a) Campinas. Campo Grande.	b) La Paz. Chualluma - Huacataqui.	c)Mendoza. Cementista.	d)Santo Domingo. San Miguel.	e) Valparaíso. Quebrada Márquez

Figure 1:
Morphology of the neighborhoods studied. Reference: Google Earth Pro, 2022

In Valparaíso (Chile), the selected area was the Quebrada Márquez, housing complex, located within the founding area of the city. The complex was built in the mid-20th century and presents social housing buildings in a block system. The blocks are 5 story buildings developed in a reticular morphology, with an urban grid in the form of checkerboards staggered along the slope. The area is characterized by eminently pedestrian and narrow streets, crossed by stairs and passages and without vegetation. The complex has the category of patrimonial protection called "Typical Zone" and is one of the most representative sectors of this urban singularity.

3.3 Preliminary data collection

Surface finishing materials at pavements, façades and roofs that are in use in each of the urban areas studied were inspected in-situ or using Google Earth images. A first set of data were obtained for the different materials and collected in data sheets as the one shown in Figure 2 (for façade materials). The sheet is divided in a first set of general data to identify the material and the manner and the frequency in which it is observed in the area of analysis.

The second part of the sheet refers to morphological characteristics of the material affecting the interaction of the surface with solar radiation. A third set (not shown in Figure 2) will be completed in future research to include the thermo-optical properties of the surface material. Finally, a set of indicators related to sustainability is added and will be extended in the future.

A catalogue was generated with the data sheets corresponding to all the surface finish materials in use in the studied neighborhoods. This information will be used to perform a comparative analysis, considering the characteristics of each location (Table 1). Optical characterization of surface finish materials will be performed by in situ measurement techniques and laboratory tests.

A. GENERAL INFORMATION	
Reference	**CP F 2**
Image	
Location at facade/wall	Complete
Percent use	20%
B.1. MORPHO-MATERIAL CHARACTERISTICS	
Surface material	Brick
Color	Orange
Tone	Medium
Texture	Smooth
Size of unitary element	Medium
B.3. SUSTAINABILITY INDICATORS	
Cost ($ x m^2)	
Type of technology	Traditional
Range	Economic
Availability in local market	High

Figure 2:
Example of the data sheets used to collect the preliminary set of data from in use surface materials.

Figures 3 and 4 show an extract of the catalogue, including the images of the most frequent surface finishes in the pavements and the façades, respectively, in the areas studied.

A first analysis of the collected data indicates that the most used materials at pavements in all the areas studied are asphalt for vehicular use and concrete for both vehicular and pedestrian use. Soil pavements were also observed in Campinas, La Paz and Valparaíso (Fig. 3.b, 3.e and 3.n, respectively), and stone is used in Mendoza (Fig. 3.i) and more predominantly in Valparaíso (Fig.3.o). Finally, brick as surface finish material in sidewalks was only observed in Santo Domingo (Fig. 3.l)

Pigmented mortars and painted renders are highly frequent surface materials in the façades of the five areas. They are predominantly colored white or in the range from yellow to red. Exceptions are the façades of the Chualluma neighborhood in La Paz, intentionally decorated in a wide variety of bright colors (Figs. 4.d and 4.e). Part of the blocks in Quebrada Márquez (Valparaíso) show a characteristic green render, as observed in Fig. 4.n.

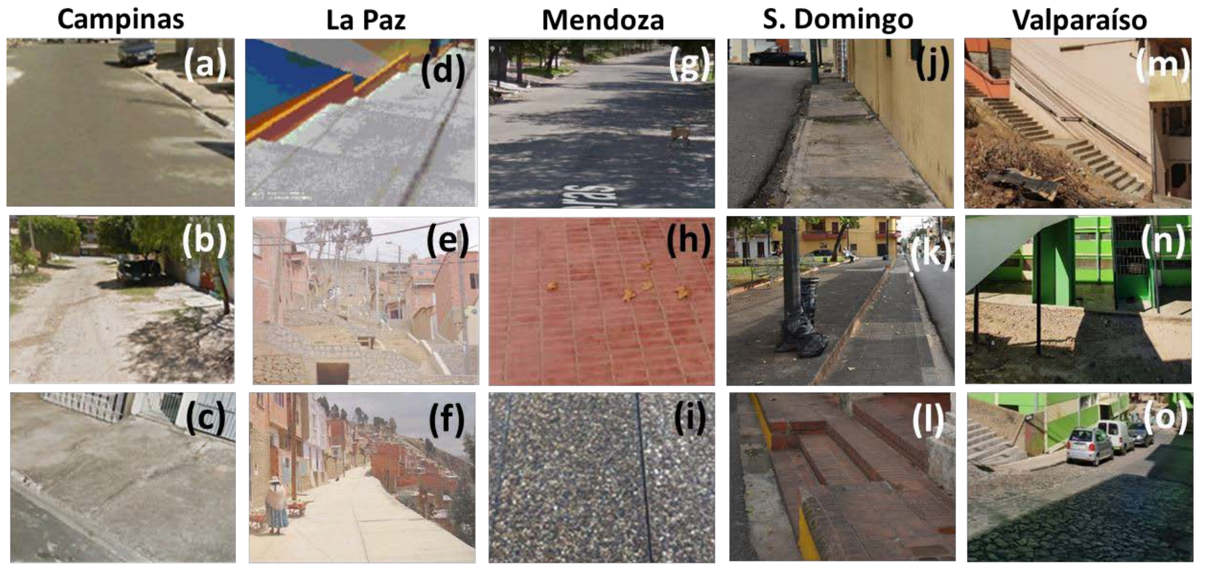


Figure 3:
Predominant surface finish materials catalogued in pavements of the neighborhoods under study.

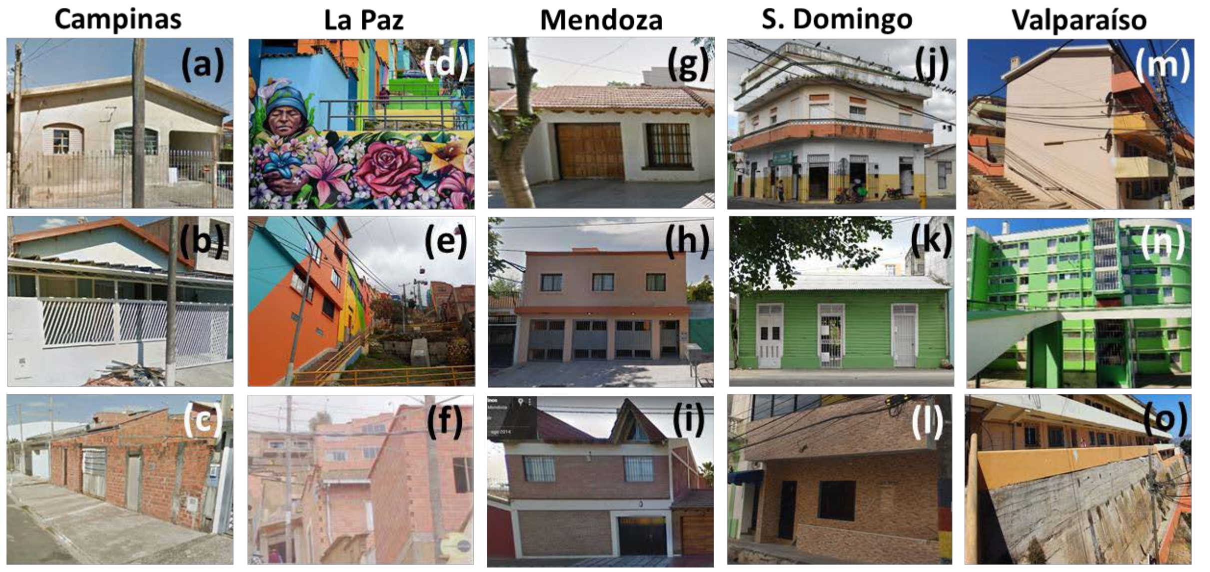


Figure 4:
Predominant surface finish materials catalogued in facades of the neighborhoods under study.

Exposed brick facades were frequently observed as well in the neighborhoods of Campo Grande (Campinas. Fig. 4.c), Huacataqui (La Paz. Fig. 4.f), San Miguel (Santo Domingo, Fig. 4.l) and Cementista (Mendoza, Fig. 4.i). Finally, minority observed materials were wood façades in San Miguel and reinforced concrete walls in Quebrada Márquez (Figs. 4.k and 4.o, respectively).

Regarding the roofs, sheet metal roof was observed as surface finish material in all the urban areas analyzed and was the predominant option in those of Valparaíso and La Paz. Cementitious flat roofs are usual in Santo Domingo neighborhoods and ceramic tiles were observed in inclined roofs in Campinas and Mendoza. Finally, polymeric flat roofs were only observed in the case of Cementista area, in Mendoza.

The results from the preliminary data collection evidence the use of similar materials in the five urban areas analyzed, in spite of the significantly different characteristics and conditions described for each of them in sections 3.1 and 3.2. This means that the choice of surface finish materials in these areas does not correspond to the climatic and environmental conditions in which they are inserted. In fact, they respond to the use of globalized technologies that implement materials with high thermal inertia. These technologies and materials are more suitable for cities more distant from the Equator than those analyzed in this study.

Another evidence obtained from the study and observed in Figs. 3 and 4 is the degradation of the surface finish materials in part of the neighborhoods. This degradation affects the thermo-optical response of the materials and must be taken into account in future research.

4. CONCLUSION

This paper describes the first stage of a research addressing the improvement of urban sustainability in Latin American cities through the optimization of solar energy management.

Preliminary data of the surface finish urban materials were collected with a unified methodology in disadvantaged neighborhoods of 5 cities representing different climatic conditions. The data were organized into data sheets, gathered in a catalogue to ensure an efficient data management and a reliable comparison of the results from different locations.

The results indicate that the materials currently in use in the studied neighborhoods were not selected according to the specific climatic characteristics of each location. This means that a more detailed research is of interest, to analyze the potential substitution of current materials by others adapted to local conditions.

With this idea in mind, the catalogue will be extended in the future with the experimental thermo-optical properties of the surface finish materials. Other properties related to their performance and sustainability (transport properties, thermal properties, carbon footprint, durability, etc.) will be assessed as well. The gathered information will be included in a life cycle analysis of the materials, in which the origin of the raw materials and manufactured elements will also be considered. Similar data of the materials available at the local markets for urban retrofit will be included as well.

From this information, a suitable strategy to improve the urban sustainability will be assessed, based on the substitution of the current urban materials by others with optimized properties for the climate conditions of each area. Strategies to mitigate urban overheating through the reduction of solar energy absorption will be defined for areas affected by high temperatures. On the contrary, solutions to reduce the heating demand of buildings through the enhancement of solar gains will be proposed for colder areas.

The methodology initiated in the present work is intended to be extended to other cities. Specifically, it will be implemented in a similar analysis under progress by the authors in deprived neighborhoods of Madrid (Spain).

ACKNOWLEDGEMENTS

This paper is part of the project INCGLO00008 "Mitigation of Urban Warming in Ibero-America through the thermo-optical response of construction materials", funded by the Spanish Research Council, CSIC (Spain). The authors also acknowledge the funding from the Spanish Ministry of Science and Innovation through the project PID2020-114873RB-C31.

REFERENCES

1. United Nations. World Urbanizations Prospect 2018, [Online], Available: https://population.un.org/wup/ / [20 June 2021].
2. Gonzalez-Trevizo, M.E., Martínez-Torres, K.E., Armendariz-Lopez, J.F. et al., (2021). Research trends on environmental, energy and vulnerability impacts of Urban Heat Islands: An overview. *Energy and Buildings*, 246: 111051.
3. Correa, E., de Rosa, C., Lesino, G., (2005). Urban Heat Island Features in the city of Mendoza, Argentina. The Effects of Urban Configuration and the Climatic Conditions. In *Proceedings of PLEA 2005. The 22th Conference on Passive and Low Energy Architecture*. Lebanon, November.
4. United Nations Environment Programme (2021). Beating the Heat: A Sustainable Cooling Handbook for Cities. Nairobi.
5. Santamouris, M. and Yun, G.Y. (2020). Recent development and research priorities on cool and super cool materials to mitigate urban heat island. *Renewable Energy*, 161: p. 792-807.
6. Rojas-Cortorreal, G. *et al.* (2019). La infraestructura verde como herramienta de mitigación y adaptación urbana en la ciudad de Santo Domingo, República Dominicana. En *XIII CTV 2019 Proceedings: XIII International Conference on Virtual City and Territory: "Challenges and paradigms of the contemporary city"*: UPC, Barcelona, October 2-4, 2019. Barcelona: CPSV, 2019, p. 8672. E-ISSN 2604-6512. DOI http://dx.doi.org/10.5821/ctv.8672
7. Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., Jurgen Grieser, Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, *15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130

PLEA SANTIAGO 2022
Will Cities Survive?

Automatic mesh generator for urban Computational Fluid Dynamics simulations

JUAN MARCELO GIMENEZ [1,3] AND FACUNDO BRE[2,3]

[1] Centre Internacional de Mètodes Numèrics en Enginyeria (CIMNE), Barcelona, Spain
[2] Institut für Werkstoffe im Bauwesen, Technische Universität Darmstadt, 64287 Darmstadt, Germany
[3] Centro de Investigación de Métodos Computacionales (CIMEC) CONICET/UNL, Santa Fe, Argentina

ABSTRACT: Despite the well-known potential of Computational Fluid Dynamics (CFD) to enhance the prediction of Building Performance Simulation (BPS) models, several barriers prevent BPS simulators from actively using CFD. A recognized obstacle is the proficiency required to get a high-quality computational mesh to study the atmospheric boundary layer (ABL) flow in actual urban environments. Hence, this work aims to present and validate an automatic tool to generate and discretize a virtual wind tunnel from an urban geometry model given as an input. The development comprises an unattended procedure that analyzes the buildings and their components (walls, openings, shadings), determines dimensions of the domain and grid refinements that abide by the best practice guidelines, and finally constructs the mesh. Case studies with isolated and non-isolated buildings show the robustness and capabilities of the developed tool. A mesh convergence study is carried out to assess the sufficiency of the spatial discretization for ABL simulations.
KEYWORDS: Urban environment, Atmospheric boundary layer flow, Computational fluid dynamics, Building performance simulation, Computational mesh, Natural ventilation

1. INTRODUCTION

It is well known the need for feeding Building Performance Simulations (BPS) with data computed by Computational Fluid Dynamics (CFD) simulations (Cóstola et al., 2009). For instance, the wind-induced pressure distribution on the building openings is an essential input data for Airflow Network (AFN) models, and highly influential in the Natural Ventilation (NV) results (Gimenez et al., 2018). Moreover, thanks to the growing computing capabilities CFD can obtain detailed information about the urban microclimate, useful to predict the energy performance of buildings, and the comfort and health of citizens in both, indoors and outdoors environments (Toparlar et al., 2017).

The construction of high-quality meshes is a prerequisite for successful CFD simulations. A set of best practice guidelines ensures the reliability and accuracy of the CFD predicted results, including a detailed description of the desired features for the computational grid (Tominaga et al., 2008; Franke et al., 2011; Marzei and Carmeliet, 2013). Among the latest works, Du (2018) has proposed a systematic mesh generation method controlling the mesh quality over the entire domain. However, the effort and difficulties of manually generating proper meshes for geometrically complex real urban environments prevent BPS simulators from being active CFD users.

In this context, Bre and Gimenez (2022) introduced *CpSimulator*, a platform that comprises a set of fully automatic CFD-based tools to perform atmospheric boundary layer (ABL) simulations. In that work, the automatic tool to generate the computational grid from a geometry file given as an input was summarized and applied to the study of simple models. The current work improves the procedure for managing complex urban environments. The geometry of the target building and its surrounding environment, using the EnergyPlus input format (IDF), is processed, reconstructed, and placed in a computational wind tunnel, which is then automatically discretized. The focus is put on computing the characteristic sizes of the building surfaces to assess an adequate local mesh resolution. In addition, the automatic detection of the urban envelope is introduced to ease the split of the spatial domain and improve the calculations in the urban area. Several case studies, involving isolated and non-isolated buildings, show the capabilities of the developed tool. Additionally, the sufficiency of the spatial discretization generated by the automatic tools is assessed through a mesh convergence analysis of ABL simulations.

2. METHODOLOGY

The unassisted procedure to reconstruct the target building and its environment and generate the computational domain involves a sequence of steps described next.

2.1 Geometry Input

The description of the geometry of the building and its environment should accomplish: a) the +z coordinate is the height direction and the true North is aligned with +y coordinate, b) length units should be in meters, and c) the building geometry should be split into different surfaces according to their usage (e.g., walls, roofs, floors, windows, etc.). The input format advised is IDF, the same generated to perform BPS in the EnergyPlus software. The automatic tools process specific objects such as *zones*, *surfaces*, *openings* (doors, windows), and *shadings*. In the case of urban models, it is suggested to represent the surrounding environment by using *shading* objects. So, the target buildings are automatically identified through the target zones included in the IDF file. Otherwise, the geometry is considered a unique and isolated building.

2.2 Virtual Wind Tunnel definition

First, the bounding box of the input geometry is automatically computed by an analysis of each surface of the target buildings and their environment.

The geometry is relocated such that the center of coordinates is placed at the centroid of the target buildings at ground level. Thus, the geometry is introduced in a computational wind tunnel domain, whose external limit is a polygon of 24 sides to reuse the same mesh for the several simulations required due to varying the wind incidence angle.

The dimensions of the computational domain abide the COST Action 732 European best practice guidelines for CFD simulation of flows in the urban environment (Franke et al., 2007). So, the height and radius of the "cylindrical" domain, i.e. H_{domain} and $((W_{outflow} + W_{building})/2$ respectively, are defined such that guarantee a blockage ratio lower than 17% for horizontal and vertical directions to avoid virtual accelerations (Blocken, 2015). For this, it can be demonstrated (Bre & Gimenez, 2022) that two conditions should be simultaneously accomplished:

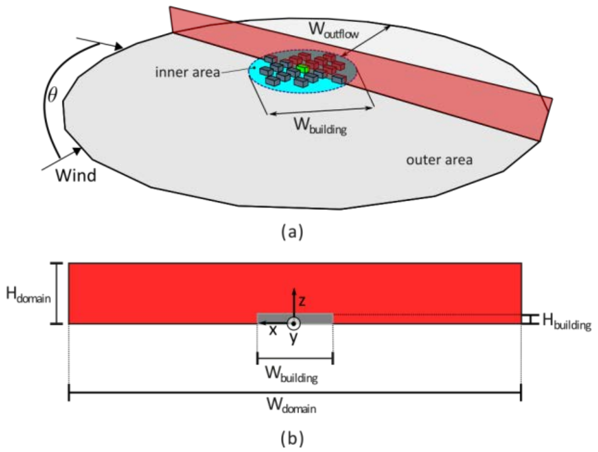
$$\frac{H_{domain}}{H_{building}} = 6, \text{(1.a)}$$

$$W_{outflow} = \max\,(15 H_{building}, 2.5\, W_{building}), \text{(1.b)}$$

where $H_{building}$ is the height of the tallest building, and $W_{building}$ is the maximum projected frontal width of the building (or urban envelope) for any wind incidence, see Figure 1.

Detecting the urban envelope enables the split of the domain into two distinct spatial areas to impose different mesh refinements and to gain versatility for the specification of the boundary conditions. In the outer area, the buildings or other obstacles are present, but they are modeled implicitly by the aerodynamic roughness length z_0, which is estimated using the roughness classification of Wieringa (1992). The inner area represents the ground surface among the explicitly modeled buildings and other obstacles. In actual urban environments, the small-scale features are not explicitly represented (sidewalks, benches, fences, trees, hedges, etc.), so they should be implicitly modeled. To reproduce experimental wind tunnel results, imposing on this area the aerodynamic roughness of the turntable is convenient.

Figure 1:
Virtual wind tunnel for the CFD-based simulations:
(a) the 3D perspective of the resulting computational domain for a case study of a generic urban area; (b) reference dimensions.



2.3 Meshing process

The meshing procedure is based on the *snappyHexMesh* tool. Initially, a background hexahedral mesh, with homogeneous cell size DX, is recursively refined to shape the input surfaces that define the buildings and the boundaries of the computational domain. Next, the mesh is fitted to the surfaces splitting the hex cells around the objects, and finally, the mesh is shrunken back and prismatic cell layers over the building surfaces are inserted.

The entire process is unassisted but is controlled by several parameters set in advance. The key of the development is the capability to automatically define the refinement levels on the surfaces and inside predefined volumetric regions for a given reference cell size DX defined as:

$$DX = (1 - m)\, DX_1 + m\, DX_2, \text{(2.a)}$$

$$DX_1 = 0.75 \min\,(H_{building}, W_{building}), \text{(2.b)}$$

$$DX_2 = 0.75 \text{ mean}\,(H_{building}, W_{building}), \text{(2.c)}$$

where $m = 0.375$. This specification allows defining a proper reference size for cases studies with different aspect ratios, this is, from a very low rise building or a residential urban envelope to an isolated high-rise building.

A second automated analysis of each input surface enables exporting the STL files and computing local reference lengths to feed the meshing tool (see Algorithm 1).

As presented in Algorithm 1, the ratios between global and local sizes, which define the refinement levels, are computed for each object. This allows meshing geometries where surfaces with very different length scales are simultaneously present.

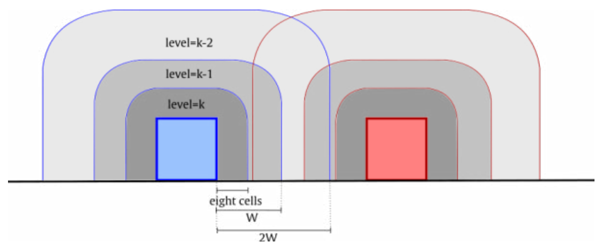
Algorithm 1:
Automated analysis of an .IDF. The parameter `ncells=6` *for surfaces on targetBuilding and* `ncells=1` *otherwise.*

```
1) foreach surf in surfaces
 1.1) extract vertex coordinates and
 1.2) transform points with locals relativeNorth, and
origin and globals NorthAxis and zeroDispl
 1.3) foreach opening in surf
  1.3.1) get ref length as dx=min(lenght(edges))
  1.3.2) export the STL
  1.3.3) remove the opening from surf
 1.4) get ref length as dx=min(lenght(edges))
 1.5) export the STL of the resulting surf
2) foreach shad in shadings
 2.1) extract vertex coordinates and
 2.2) transform points with globals NorthAxis and
zeroDispl
 2.3) detects if it is attached to a targetBuilding
 2.4) get ref length as dx=min(lenght(edges))
 2.5) export the STL
3) per surface, opening and shading determine the
refinement level k=min(K) such as
                  ncells < dx/(DX/2^K)
```

To guarantee that grid lines are perpendicular to the walls and correctly reproduce the flow separation, prismatic cells layers are placed on every surface of the target building and the ground located in the inner area.

The number of cells between two buildings or in-between two surfaces of the same building is not explicitly imposed. The refinement level imposed in this region is a consequence of the volumetric refinement through distance bubbles required. Considering a building of width *W*, where the required refinement level on its surfaces is *k*, we impose four bubbles: (eight-cells length, k), (W, k-1), (2W, k-2), (4W, k-3), where the first value is the distance to building and the second the minimum refinement level demanded. The number of cells in between is a consequence of the surface refinement level, the layers on each opposite surface, and the volumetric mesh distance-based refinement, see Figure 2.

Figure 2:
Volumetric refinement through distance-bubbles.



The quality of the computational cells is controlled via the maximum skewness, the non-orthogonality, and the aspect ratio parameters. The mesher prioritizes these requirements over a strict conforming of any detail of the geometry. The resulting high-quality hex-dominant mesh is well suited for the finite volume method because of the low truncation errors and the fast iterative convergence.

The final number of elements of the mesh can be accurately predicted a priori (without generating the mesh), since it is a consequence of the DX and the set of refinement levels demanded. This fact is used by CpSimulator to estimate the computational effort that supposes a given request.

2.4 ABL simulations

The ABL flow is considered as an incompressible homogeneous viscous fluid flow. The steady Reynolds averaged Navier-Stokes (RANS) approach is adopted. The closure models employed to estimate the turbulent viscosity are the renormalization group (RNG) k-ε model (Yakhot et al. 1992) for low-rise buildings and the k-ω SST model (Menter 1994) for high-rise buildings.

For the inlet boundary conditions, the approaching wind profile for a neutral ABL is modeled using boundary conditions suggested by Richards and Hoxey (1993). A critical requirement is to guarantee that the inflow ABL profile imposed preserves its shape throughout the upstream domain despite the distance from the inlet to the building, i.e. maintains the horizontal homogeneity. Thus, a compatible wall function that depends on z_0 is applied on the ground and a fixed shear stress condition on the top (Heargraves and Wright 2007). A summary of the boundary conditions employed is given in Table 1.

Table 1:
Summary of the boundary conditions employed.

Location	Velocity	Pressure	Turbulence
inlet	ABL	Zero grad.	ABL
outlet	outflow	outflow	outflow
outer ground	no-slip	Zero grad.	ABL wall functions
inner ground	no-slip	Zero grad.	ABL or std. wall functions
top	Shear stress	Zero grad.	Zero grad.
Building walls	no-slip	Zero grad.	std. wall functions

The time-averaged RANS equations are solved using an implicit, segregated, three-dimensional finite volume method (FVM). Pressure-velocity coupling is solved with the SIMPLE algorithm (Ferziger and Peric 2002). The running procedure starts the simulation with velocity and turbulent fields initialized everywhere to the free-stream conditions. To diminish the failure probability, an under relaxation is set during the first one hundred iterations. Then, it is gradually deactivated, while spatial and time discretization schemes are switched to second-order to get less diffusive results. The iterative solving process continues until the normalized residuals for continuity, velocity components, and turbulent fields have decreased by five orders of magnitude each one.

3. CASE STUDIES

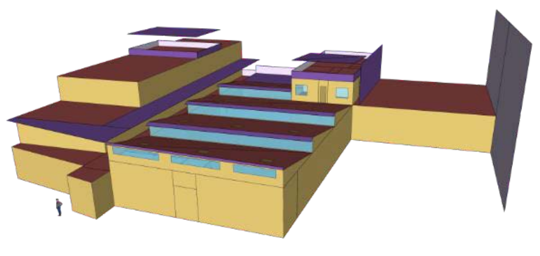
3.1 Isolated Building

A first case study is a complex isolated building in which a non-standard floor-plan and surfaces with very different length scales are simultaneously present. Figure 3a shows the geometry obtained from the IDF file, while the resulting mesh after the automatic process is observed in Figure 3b. The grid consists of just over 1 million polyhedral cells, where 95% of them are hexahedral. The maximum non-orthogonality and skewness are 55 and 7, respectively, which guarantees a proper mesh quality for numerical simulations with the FVM.

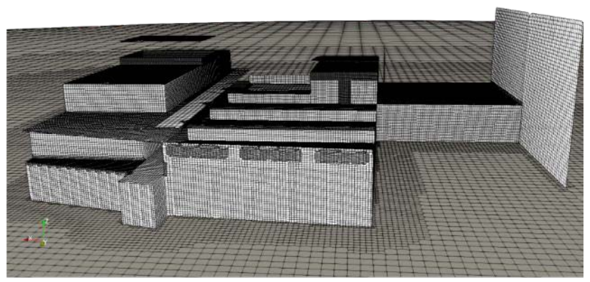
The geometric model includes complex architectural objects. *Shading* objects are employed to represent the *floating* roofs (the columns are not modelled), the lateral wall and several eaves. These very thin elements are modelled with *baffles*, i.e. mesh objects without thickness. The cell faces that represent these thin walls are duplicated and treated as boundary faces, which enables computing the flow over their two sides.

Moreover, the model includes several windows and doors, see Figure 3a. A separated mesh surface (patch) is assigned to each of these openings, which eases defining the refinement level, imposing different boundary conditions (open or closed) and performing post-processing tasks.

Figure 3:
Isolated case study. (a) Geometric model (courtesy of Marieli Azoia Lukiantchuki, UEM Brazil); (b) Automatic mesh generated.



(a)



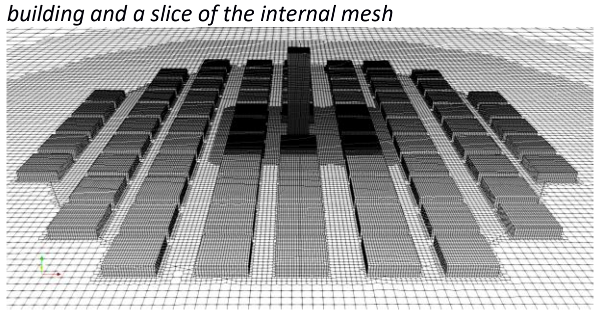
(b)

3.2 Urban Centre

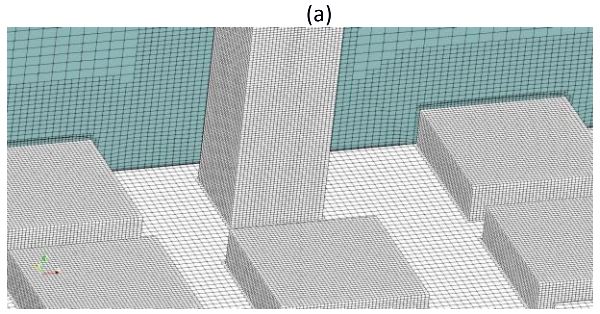
The urban case study considered is the Case D of the Validation benchmark tests provided by the Architectural Institute of Japan[1]. The model comprises a high-rise building surrounded by city blocks. As the objective of the benchmark is to predict flow velocities in specific samples located between the highest building and its neighboring buildings, they are considered as *target buildings* for the meshing procedure.

Figure 4 shows a general view of the mesh obtained, where the inner and outer areas are noticeable. The discretization consists of just more than 1.5 million polyhedral cells. From these, 95% are hexahedral, while the maximum skewness is 4.5 and the average non-orthogonality is 7.8. Less than 10 faces present a non-orthogonality larger than 70. These faces are found in the conjunction of the prismatic layers on the ground and on the building surfaces, near to its corners. In spite of these rare faces, the grid generated shows the adequate features suggested in Franke (2007) to obtain reliable CFD results. For instance, the minimum grid resolution of ten cells per cube root of the building volume and ten cells per building separation to simulate flow fields is fully satisfied.

Figure 4:
Automatic mesh generated of a non-isolated case study for the AIJ Case D. (a) General view; (b) Close up view to the main building and a slice of the internal mesh



(a)



(b)

3.3 Sufficiency of the spatial discretization

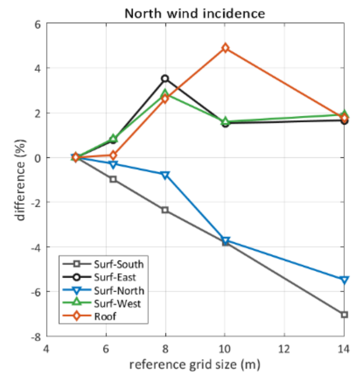
A sensitivity analysis of the CFD results to the computational grids generated by the automatic meshing procedure is evaluated. The standard configuration described above is tested against successive refinements and coarsening. The reference size of the background grid, DX, is modified manually while both the volumetric and surface refinement levels are kept constant. Therefore, the same refinement ratio is applied to the grid spacing normal to the walls, the spacing at flow boundaries, and at junctures in the geometry.

CFD simulations were carried out and the mean wind pressure coefficients ($\bar{C}_p$) on selected surfaces of the target buildings are computed. The $\bar{C}_p$ differences for a given surface between using a grid level k and a very-fine mesh are quantified with the relative difference, where the average of $|\bar{C}_p|$ is chosen to normalize the absolute difference. To summarize these indexes into a single value, the normalized root-mean-square error for the grid level k ($NRMSE^k$) is defined as:

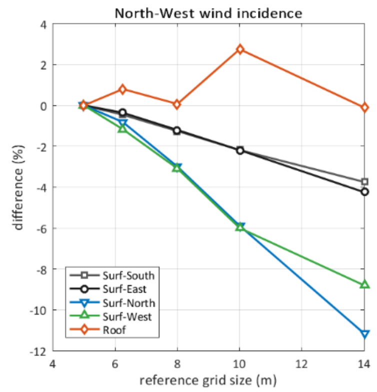
$$NRMSE^k = \frac{RMSE^k}{\sigma}, \qquad (3)$$

where $RMSE^k$ is calculated using the differences of the predictions of $\bar{C}_p$ between the k and the very-fine grids considering all the surfaces, while σ is the standard deviation of the $\bar{C}_p$ predictions using the very-fine grid. A value of zero in the indicator of Equation (3) means a perfect agreement.

Figure 5:
Percentage differences obtained per surface for the Cubic building. (a) North wind incidence. (b) North-West wind incidence.



(a)



(b)

Cubic building. The prediction of the C_p on the surfaces of a cubic building of 10 m per side is studied for North (N) and North-West (NW) wind incidence angles. The building is aligned such that each surface can be labeled with the cardinal point to which points. The wind profile imposed corresponds to suburban terrain conditions. The automatic procedure determines a DX = 8 m. This standard value is manually varied to get coarser or finer grids. Relative differences are presented in Figures 5a and 5b.

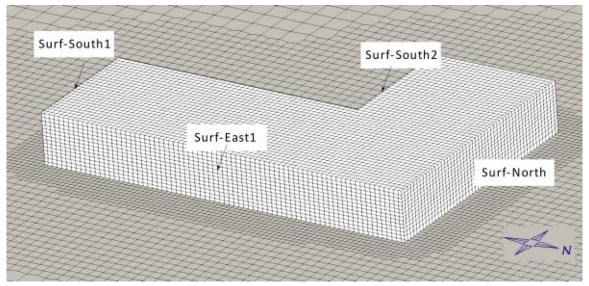
When the standard refinement is used, the $\bar{C}_p$ percentage differences are lower than 4% regarding using a very fine mesh. Computing the change ratio of the solutions for the three finest grids, it can be shown that the solution is in the asymptotic range of convergence. Monotonic convergence for the prediction of $\bar{C}_p$ is not achieved only on specific cases, as the roof on the cubic building with North-West wind. More insight is needed to discern potential drawback factors as the grid stretching and mesh quality near the corners.

Table 2:
Summary of the mesh configurations evaluated and their RMSEs for the cubic building.

DX	Cells	NRMSE (N)	NRMSE (NW)
14	31400	0.0444	0.0697
10	74228	0.0346	0.0422
8	138333	0.0272	0.0211
6.25	275597	0.0072	0.0079
5	530285	0.0	0.0

L-shape floor-plan building. This non-convex floor-plan building has 26 m of width, 38 m of breadth, and 5 m of height. The concave surfaces, i.e. Surf-East1 and Surf-South2 are 25 m and 13 m in length, respectively, see Figure 6. Suburban terrain conditions are also considered. North (N) and South (S) wind incidence directions are studied. The automatic procedure determines a DX = 4 m. This value is manually varied to obtain successive grid coarsenings and refinements.

Figure 6:
L-shape Building case study. Coarsest mesh and surface labeling.



1- https://www.aij.or.jp/jpn/publish/cfdguide/index_e.htm

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Table 3:
Summary of the mesh configurations evaluated and RMSEs for the L-shape building case study.

DX	Cells	*NRMSE (N)*	*NRMSE (S)*
10	93443	0.0541	0.0672
7.8	181716	0.0494	0.0476
5.4	414457	0.0401	0.0226
4	1131404	0.0139	0.014
3.2	2156679	0.0097	0.0125
2.8	3020852	0.0	0.0

Discussion. Evaluating the behavior of the normalized root-mean-square error on Tables 2 and 3, grid convergence is detected: as the refinement is increased, *RMSEs* are monotonically approaching to zero for any case studied. In particular, this metric is lower than 3% when the standard mesh configuration is employed.

In conclusion, the spatial discretization generated by the automatic procedure allows getting reliable $\bar{C}_p$ results. The accuracy is restricted to the own limitations of the RANS model employed, whose real numerical solution could differ from the true physical solution. The results obtained also confirm that the reference size of the background mesh could be employed in the platform as a tuning parameter to improve the confidence level of the solutions at the expense of a major computational effort.

4. CONCLUSIONS

A tool for the automatic meshing of a given geometry of a target building and its environment was introduced. The resulting computational wind tunnel domain accomplishes the recommendations in the international guidelines for the best practices for the CFD simulation of flows in urban environments. The automatic evaluation of local lengths of each surface of the geometry is the key for guaranteeing a proper level of grid refinement. The presented tool has shown great robustness since in most cases, and despite the complexity of the analyzed case, the automatic procedure achieves meshes with a large percentage of hexahedral cells, favoring the quality of the numerical solution obtained. The results obtained also confirm that the reference size of the background mesh could be employed as a tuning parameter to improve the confidence level of the solutions.

ACKNOWLEDGEMENTS

Authors would like to the National Agency for Scientific and Technological Promotion (ANPCyT), Argentina, via the projects PICT-2018 Nº 03252 and PICT-2018 Nº 02464, Res. Nº 401-19 for funding this work. J. Gimenez acknowledge the financial support from the CERCA programme of the Generalitat de Catalunya, and from the Spanish Ministry of Economy and Competitiveness through the "Severo Ochoa Programme for Centres of Excellence in R\&D" (CEX2018-000797-S)

REFERENCES

1. Blocken B. (2015). Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Building and Environment, 91: p. 219–245.
2. Bre, F., and Gimenez, J.M. (2022) A cloud-based platform to predict wind pressure coefficients on buildings. Building Simulation, 15: p. 1507-1525
3. Cóstola D, Blocken B, and Hensen JLM (2009). Overview of pressure coefficient data in building energy simulation and airflow network programs. Building and Environment, 44: p. 2027-2036.
4. Du Y., Mak C., and Ai Z (2018). Modelling of pedestrian level wind environment on a high-quality mesh: A case study for the HKPolyU campus, Environmental Modelling & Software, 103: p. 105-119.
5. Ferziger JH, and Peric M (2002). Computational Methods for Fluid Dynamics. Springer Science & Business Media
6. Franke, J., Hellsten, A., Schlünzen, H. and Carissimo B., (2011). The COST 732 Best Practice Guideline for CFD simulation of flows in the urban environment: a summary. International Journal of Environment and Pollution 2011 44(1-4): p. 419-427
7. Gimenez, J.M., Bre, F., Nigro, N.M. et al. (2018) Computational modeling of natural ventilation in low-rise non-rectangular floor-plan buildings. Building Simulation, 11: p. 1255-1271.
8. Hargreaves D.M., and Wright N.G. (2007). On the use of the k–ε model in commercial CFD software to model the neutral atmospheric boundary layer. Journal of Wind Engineering and Industrial Aerodynamics, 95: p. 355–369
9. Menter FR (1994). Two-equation eddy-viscosity turbulence models for engineering applications. AIAA Journal, 32: p. 1598-1605.
10. Mirzaei P., and Carmeliet J. (2013) Dynamical computational fluid dynamics modeling of the stochastic wind for application of urban studies, Building and Environment, 70: p. 161-170.
11. Richards P.J., Hoxey R.P. (1993). Appropriate boundary conditions for computational wind engineering models using the k-ε turbulence model. In: Murakami S (Ed), Computational Wind Engineering 1. Oxford, UK: Elsevier.
12. Tominaga, Y., Mochida, A., Yoshie, et al. (2008). AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. J. Wind Eng. Ind. Aerod. 96(10-11): p. 1749-1761
13. Toparlar Y., et al. (2017) A review on the CFD analysis of urban microclimate. Renewable and Sustainable Energy Reviews, 80: p. 1613-1640.
14. Yakhot V, et al. (1992). Development of turbulence models for shear flows by a double expansion technique. Physics of Fluids A: Fluid Dynamics, 4: p. 1510-1520.
15. Wieringa J. (1992). Updating the Davenport roughness classification. Journal of Wind Engineering and Industrial Aerodynamics, 41: p. 357-368.

PLEA STGO 2022

WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

ARCHITECTURE FOR HEALTH AND WELL-BEING

DAY 01
11:15 — 12:45

CHAIR
MAUREEN TREBILCOCK

PAPERS
1346 / 1407 / 1145 / 1652

4TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA 2022 SANTIAGO
Will Cities Survive?

Lighting planning for a resilient urban environment

Visual Comfort and well-being in the city during the night

REBEKA VITAL[1] HANAN PERETZ[2]

[1] Shenkar – Design.Engineering.Arts
[2] Ariel University

ABSTRACT: This paper presents a historical review of urban lighting, in order to understand the complexity of artificial lighting conditions of todays' cities. In an effort to define guidelines for sustainable lighting strategies for resilient cities, this paper outlines the main focal points that need to be taken into consideration when planning lighting. The different layers of contemporary lighting are presented and innovation in each area is discussed. Through these topics, this paper presents lighting planning strategies that can contribute to intelligent resilience of urban built environments. The aim is to propose a different approach to urban lighting planning; a kind tailor-made for the main users of cities – the pedestrians - by creating a suitable environment that contributes to the urban experience at night. We explore how we can integrate the layer of street lighting, in balance with the other layers of urban lighting, in order to direct and enrich the street experience at night, and not just as a by-product of the planned vehicle traffic. Creating such lighting conditions in the urban areas will serve the present needs of the city dwellers, while not compromising the environment and endangering the wellbeing of future generations.

1. INTRODUCTION

Lighting has been part of our night-time urban environment since antiquity. Starting with the utilization of candles and oil lamps in ancient Greek and Roman civilization, street lighting has been a basic component of urban outdoor planning throughout the centuries (Table 1).

	Light Source	Technology	Location	Morphology	Space Quality	Special Development
Ancient & Medieval Times	Torch	Fire	Change	Movement	Dynamic	
16th Century	Candles	Candles	Bellow windowsills	Volumes	Facades	Diversity
17th Century	Lanterns	Mounting	Hanging in the street edges in the middle of the street	Edges		Schedules
End of 17th Century - Oil lighting	Oil lighting	Reflectors	Every 20m	small sequence	Continues-Rhythm	Regulations
18th Century - Gas Lighting	Gas lighting Candelabra	Lenses	Lamp posts	High repetitive	Dominant	2 Scheduales: Sunset-sunrise Moon
End of the 19th - Moon light tower	Arc lamps	Light	Square, main public places	Singularity	Reference point	
End of the 19th Century - Electric light		Efficiency	Everywhere	Uniformity	Even	Planned for cars

Table 1: Summary of historical overview of urban lighting

Humans managed to cross the frontier of darkness in their cities with the development of artificial lighting. Lighting planning became an integral part of urban design and reached new levels of complexity as artificial luminaire technologies and smart systems developed. On the one hand, humans managed to adapt the night-time environment to their needs for visual comfort and secure environments. On the other hand, our cities today have reached levels of visual overstimulation at night, light-pollution, and an overall psychologically unhealthy night environment. In many cases, urban lighting is merely functional and lacking hierarchy, thus not enriching our perception of the built environment.

2. HISTORICAL BACKGROUND

Lighting of the public space during the night hours is a broad and important subject with many parameters. The historical review presented here focuses on the way artificial lighting appeared and developed on a technical level and how it affected city dwellers. It should be noted that this historical overview mainly refers to Europe and America and the technologies that appeared there.

2.1 Ancient & Medieval Times

The initial purpose and function of street lighting was security. It was used by the Greek and Roman civilizations, utilizing oil lamps, mostly because they provided long lasting and moderate flames.

The Romans had a "laternarius", which was the term for a slave responsible for lighting up the oil lamps in front of their villas. This task was kept up until the Middle-Ages when the "link boys" escorted people

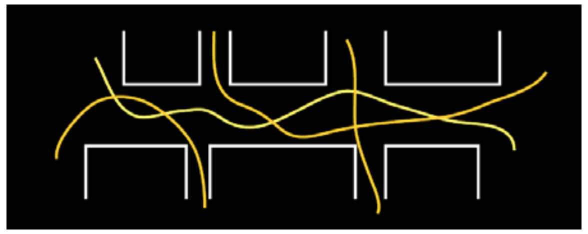


Figure 1: Lighting scheme, Ancient & Medieval Times, streets are dynamically lit according to the movement of people in the public space

from one place to another[1]. Night watchmen carried weapons and torches with them on their rounds. Anyone who did not carry a light was regarded as suspect and could be arrested on sight. The light escort service created dynamic lighting, movement in space, and changed with time, with movement, according to people's needs (Fig.1).

2.2 16th Century

The first attempts to create permanent street lighting were made in Paris in the sixteenth century. By a parliament decree, during the winter months, a lantern should be hanging out under the level of the first-floor windowsills before six o'clock. It was to be placed in such prominent position so that the street received sufficient light[2]. This "navigation lights" provided the city streets with structure and order by putting the attention on the volumes and the borders that created the space (Fig.2).

Figure 2: Lighting scheme, 16th Century

2.3 17th Century

In the late seventeenth century, lanterns were mounted on cables above the streets rather than on houses (Fig.3). The diversity of private lanterns was replaced by standard lanterns, consisting of a candle in a glass box. Initially, 2,700 lanterns were installed in Paris. By the 2nd half of the eighteenth century the number had risen to about 8,000.[3] The lanterns were attached to cables strung across the street so that they hung exactly over the middle of the street. To control the precise time at which they should be lit or extinguished, lighting schedules were made. These calculated the exact times of sunrise and sunset, as well the hours of moonlight for each month. Over time the variable distance between lanterns was standardized and reduced to every third house (Fig.4). Later the brightness of the lanterns was also improved by using reflectors and changed from candles to oil lantern with several wicks.[4]

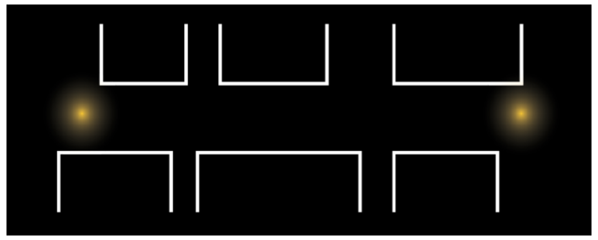


Figure 4: Lighting scheme, 17th Century

2.4 End of 17th Century -Oil Street Lighting

In 1669 Jan var der Haeyden developed an oil lantern for street lighting, which was first used in Amsterdam. The lanterns were hung in the middle of streets using transverse cables. In open spaces (squares, gardens...) they were hung on hangers or brackets attached to iron. The lanterns were set at 5 meters above ground and were lit and monitored during the night by employees, who were assigned 20 lanterns each.

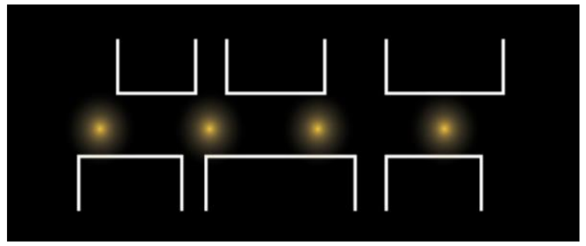


Figure 3: Lighting scheme, End of 17th Century

2.5 19th Century- Gas Lighting

In 1792, the Scotsman William Murdoch and French JP Minckelers made gas lamps used with the principle of distillation of coal in a closed chamber. However, only after more than 20 years of various experiments did the industrial production of gas lanterns really begin. The first public street lighting with gas was at Pall Mall, London in 1807. In 1812, the first gas company in the world came into being in London. Less than two years later, Westminster Bridge was lit by gas. The earliest lamps required a lamplighter that toured the town at dusk, lighting each of the lamps separately, but later designs employed ignition devices that would automatically strike the flame when the gas supply was activated.

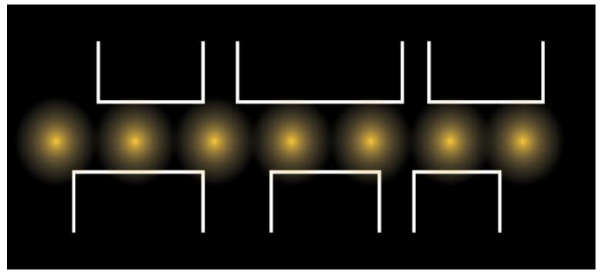


Figure 5: Lighting scheme, 19th Century- Gas Lighting

The first street lighting lanterns were set solely on wall brackets or were suspended (Fig.5). In 1830 the first candelabra appeared. It was around 1850 that lighting truly started to spread throughout France. Candelabra were placed all over the country, making way for coexistence between oil lighting and gas lighting. The candelabra had the advantage of having its gas conveyed by pipes. In Paris around 1840, in order to consider the moonlit nights on which street lighting is normally reduced, two types of street lanterns were developed. Permanent lanterns which burned from sunset to sunrise, and variable lanterns which were lit only when the moonlight was not bright enough to light the streets[5].

2.6 End of the 19th Century- Moon Light Towers

Moonlight towers are lighting structures designed to illuminate big areas of a city at night (Fig.6).The structures were popular in the late 19th century in cities across The United States and Europe and were most common in the 1880s-1890s. In some places they were used when standard street-lighting systems. Elsewhere they were used in addition to existing gas street lighting. The towers were designed to illuminate areas of several blocks at once. Arc lamps were the most common method of illumination, known for their exceptionally bright and harsh light. As incandescent electric street lighting became common, the prevalence of moonlight tower systems began to wane.[6]

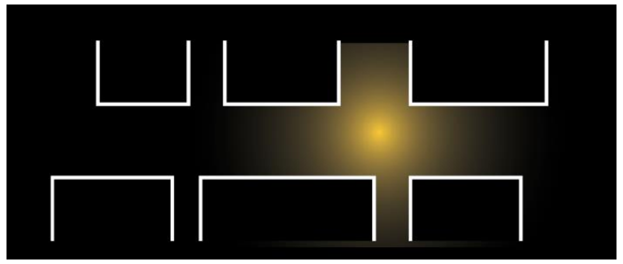


Figure 6: Lighting scheme, End 19th Century, Moon Light Towers

2.7 End of the 19th Century – Electric Street Lighting

The first electric streetlights employing arc lamps were developed by the Russian Pavel Yablochkov in 1875.This was a carbon arc lamp utilizing alternating current. Yablockov candles were first used to light the "Grand Magasins de Louvre", Paris. This improvement was one of the reasons why Paris earned its nickname "City of Lights".

The technology of these lamps was not yet fully developed, their use was highly energy consuming, and the light output unsatisfactory, therefore a poor value for money compared to gas lighting. Not until the early 20th century through the work of Thomas Edison, who filed the patent for this technology, did the electric lights began to compete with gas lighting. Between 1910 and 1940, many major cities were connected to the electricity grid, and electric lamps using incandescent lamps were gradually replacing gas lanterns. The last gas lanterns disappeared from France in the mid-1960s[7].

The first discharge lamps that were heavily used in street lighting emerged in the 1930s[8]. These came in the form of a tube in which two electrodes were placed in its ends. The tube contained mercury gas and its inner wall was covered with a fluorescent powder.

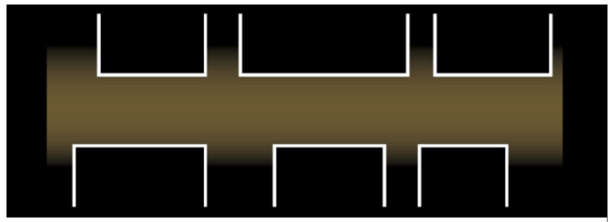


Figure 7: Lighting scheme, End of the 19th Century – Electric Street Lighting

They quickly took the name of fluorescent tubes and their general use started in 1945.

In 1932 the first sodium vapour lamp appeared. In its debut it was presented as a long light bulb, 10 centimetres wide. It emitted a light radiation by passing an electric arc in a medium rich in sodium. This type of lamp emitted a yellow-orange light.

Facilities using sodium lamps, today called low-pressure sodium lamps, started developing in 1950. Fluorescence and sodium coexisted; each technology having its own advantages and disadvantages. [9]

2.8 Metal halide lamps

The first metal halide lamp was put on the market in the U.S. by General Electric in 1961. It used a mixture of mercury and iodides (negative ions) of sodium. The light obtained, having a white with pink hue, was unsatisfactory. Work carried out in 1965 was far more adequate. The lamp emitted light of a bluish-white colour.[10]

Until the early 20th century when lighting was reserved only for citizens in cities, most of the achievements of public lighting were brought in from small towns (Fig.7). The facilities were very expensive and so installed for a population that had the means to afford them. After the First World War electric streetlights began to spread and the developments of manufacturers were increasingly brought to the big cities. Until about 1970, requirements for public lighting were primarily functional. Its role was almost exclusively reserved for the purpose of security[11]. The late 1960s saw the emergence of new needs in terms of lighting, putting more and more emphasis on aesthetics.

2.9 Generalization of lighting style

The aesthetics of the products in daytime had become more and more important. In this framework developed what was promptly called "style lighting". The meaning of this is the manufacture of new products by reusing the design of old lanterns and adapting it to electric lighting. It is difficult to date the appearance of lighting styles as most major cities had not replaced some of their old gas lanterns by the late 1950s.

Today street lighting is designed mainly for vehicles. According to CIE regulations, the intensity of illumination is determined by direct relationship to the number of cars in the street, with almost no reference to the pedestrian. There is also a clear demand for uniformity in the intensity of illumination.

Conflict areas occur whenever vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users, or when the existing road is connected to a stretch with substandard geometry, such as a reduced number of lanes or a reduced lane or road width. For conflict areas, luminance is the recommended design criterion.

The data tables reinforce the understanding that the way we plan our city street lighting is dull. The lighting is designed according to the number of vehicles and by the number of nodes regardless of the pedestrian street space. There is no real reference to a person's visual perception and the space that holds the street lighting. Obviously, we need to have regulations for street lighting, but should vehicles be the main influential component, when they have their own lights? Are the streets designed for vehicles or pedestrians? What about the human scale? Human's perspective and visual perception? We have a reference to the number of cars, why is there no reference to the amount of people who walk in the street? The perspective according to the regulations is extremely narrow and doesn't take a lot of factors into account, for example: references to rush and low hours, references to the proportions and materials of the street and other important parameters that affect the experience of the urban space after dark.

3. LIGHT, DARK AND THE PARADOX OF ARTIFICIAL LIGHTING

1. In the beginning God created the heavens and the earth. 2. Now the earth was formless and empty, darkness was over the surface of the deep, and the Spirit of God was hovering over the waters. 3. And God said, "Let there be light," and there was light. 4. God saw that the light was good, and he separated the light from the darkness. 5. God called the light "day," and the darkness he called "night." And there was evening, and there was morning—the first day.

(Genesis 1, verses 1-5).

In the creation of the world's story, we are told about the first separation between light and darkness. God creates the light and by doing so defines the solar cycle throughout the day. This concept of separating light and darkness might be obvious for modern people, but it entails a rich history and deep meanings about the daily functioning of people in general and in the urban sphere specifically. Light and darkness have a complex relationship. Darkness is in fact the lack of light and vice versa, light is lack of darkness. Generally, like in genesis, light creates positive associations. It is associated with life, clarity, and safety, while darkness leads to negative associations. Darkness is the void, emptiness, the scary, and it is leading to a sense of insecurity. Light and darkness have direct influence over human beings and about our daily activity.

On a physiological basis, the human vision system is divided to two separate systems, one for daytime and the other for night-time. Daytime vision is performed by the retinal cones. They are designated for vision in clear light, enabling a sharp vision. During night-time, vision is conducted by rod cells. These cells have nearly no conversion of colour so, naturally, the human vision during darkness is monochromatic. Light times are the ones dedicated for wakefulness and activity, while darkness is dedicated for introversion and sleeping.

With the development of artificial lightning humans try to prolong the hours of activity. The invention of electricity and the use of artificial lightning are a focal turning point for the functioning ability of the city and the life in it. The usage of light, and specifically the use of street lightning, has become over the years part of the key infrastructure of the components that compose the public areas and the urban experience during night-time.

4. WHAT MAKES UP URBAN LIGHTING

When we examine contemporary artificial lightning in the city as an infrastructure, a series of key questions rises – what makes up urban lighting, who does it serve and what is its purpose?

The night-time cityscape is comprised of several layers of lighting, which together with traffic signals and signs organize and define the visual environment at night. The night, usually a time of darkness and silence, is slowly being dominated by people. We have managed to cross the boundary of darkness using artificial lighting, which offers us an illusion of security. We are so dependent on the sense of sight that only by extending it into the night can we feel secure in our ability to understand and control our environment.

4.1 Street Lighting

The brief historical review shows that urban lighting developed surrounding navigation within the city. In the 21st century Street lighting is designed, first and foremost, for roads. The light is adapted to functionality, safety and security requirements.

Nowadays, the planning of our street lighting is based primarily on the regulations and parameters deriving from the speed of vehicles, the number of lanes, the number of intersections, and so forth (having adopted the full European standard for road lighting - EN13201). The regulations create a situation where the road is the main thing that is illuminated, even though the car has its own lighting and drivers are even able to manage without street lighting. Drivers on the road will experience the urban space for

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

seconds or minutes, whereas the actual consumers - who experience the urban space for many more minutes or even for hours - are the pedestrians; yet they don't even constitute a key parameter in the design of street lighting.

Doesn't illuminating the streets with equal uniformity, result in us losing the diversity of the city? Why, instead of using light to emphasize certain places, we choose to light the streets in a uniform manner instead?

4.2 Elevation Lighting

A lot of the lighting in our urban built environments nowadays, comes from lighting building elevations. This layer of lighting is considering the e of buildings, lighting up some of them, leaving others in darkness or outlining them through silhouetting (Fig.8).

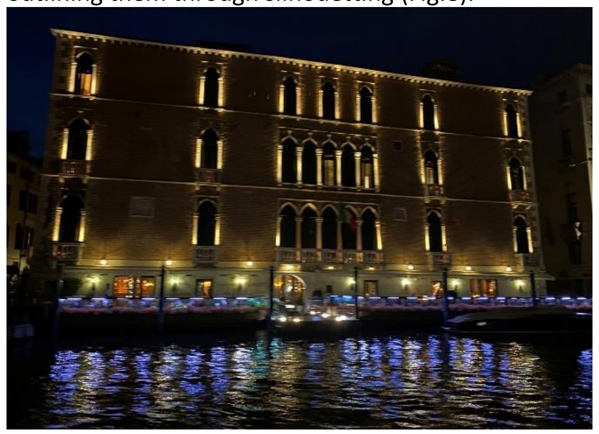


Figure 8: Lit Elevation in Venice, Italy.

Façade lighting aims to create an ambience in the urban fabric and accentuating architectural elements. In addition, it contributes with indirect lighting to the illumination of the streets and pedestrian areas.

Depending on the function of the building, façade lighting needs to take into consideration the topic of glare and energy consumption. For residential building, it is important to correctly aim façade lighting so that it doesn't trespass into the interiors. Regarding energy consumption, working hours of this layer of light should be considered, in order to avoid wasteful spending and unnecessary light pollution.

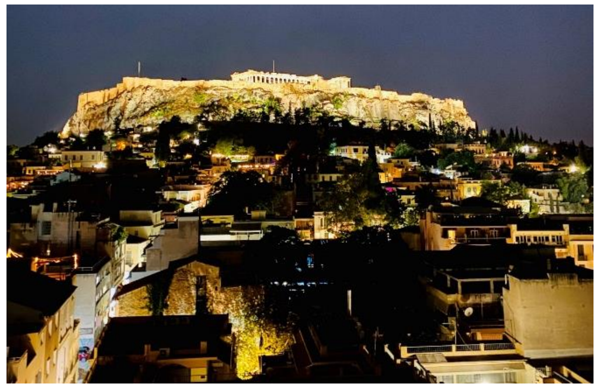


Figure 9: Acropolis by night, Athens, Greece.

4.3 Monument Lighting

Monument light is highlighting important monuments within the city. This layer creates focal points within the urban fabric, while reinforces the understanding of the importance of such heritage sites to the collective memory, while contributes to place making (Fig.9).

4.4 Landscape & Hardscape Lighting

This layer of lighting is accentuating the "green" within the city and is mostly oriented towards pedestrians. There are different techniques for plant and tree lighting, like up-lighting and moonlighting. Often hardscape lighting can be integrated into the built environment, like within urban furniture, staircases or built walls (Fig.10).

Figure 10: Lighting integrated in open amphitheatre in residential plaza, Tzur Itzhak, Israel.

When planned thoughtfully, landscape and hardscape lighting does not aim to flood all areas with light. Rather, it aims through the contrast of light and darkens to emphasize elements and to create immaterial boundaries.

5. PLANNING AND DESIGN METHODOLOGIES

Technological advancements have generated a wealth of knowledge in the field of artificial lightning. Smart cities nowadays, start taking into consideration, that lighting conditions in the city should not be static throughout the night. Streetlamps can react to people's presence and lower their illumination to minimal levels when no one is around.

This is the beginning of rethinking the ways the public areas are lit[12]. This paper offers a method for designated and unique thinking about the lightning of the public area, in a manner that enriches the urban experience and creates new places.

At the basis of this method there is a basic relationship between light, space, and usage. These concepts constitute the basis for planning of artificial lightning during dark hours, as the light corresponds and is adapted to the type of space and its usage. There are countless parameters that affect this relationship and our choices as planners in public areas – biology, focus, time, visibility, context, urbanism, sustainability, psychology, safety and security, and the depth perception of the space are just some of them to name a few. A coherent design process and methodology aims to group all of them together to a series of basic variables to improve and facilitate the process of planning the lightning of public areas, while highlighting the importance of an urban master plan that addresses lightning as a parameter that can generate urbanism during night-time.

The urban master plans include endless laws and regulations related to traffic, statutory status and urban regeneration. Still, such methodology should examine the entire city and identify appropriate lightning situations for specific areas and different hours of the day. It is important for an urban lightning master plan to include eight key parameters: Strength, distribution, shadow, reflection, dazzling, colour, dynamism, and the type of light[13]:

Strength – Artificial lightning enables a wide range of illumination levels and the usage of each should be done accurately. How dark should it be and how lit? The strength of light should be adapted to the usage of the specific space in the city while considering the type and the time of usage.

Distribution and Contrast – What are the lit and the dark areas in the city? The distribution of light can be controlled and done precisely. Should we consider the way different built volumes, cut or influence the way the light is distributed? What is the shape of the light as it encounters the volume? Do we transfer the light through a filter to create varying colour or texture? All these, influence the way the light and space are perceived by the users.

Shadow – Shadow is a direct outcome by the way we illuminate space. Shadow is considered a meaningful and important issue with significant practical and psychological implications. Therefore, when we plan the illumination in the city, we should plan while considering the direction of light and shadow, natural angles, and their characteristics.

Reflection – Reflections are tricky. The city is full of reflections created by lightning, materiality, volumes, and the encounters between them. To have high-quality planning we must deepen our understanding into the way planning creates different reflections and to the qualities we can produce from them.

Glare – This is one of the most problematic phenomena in the human experience, creating a sense of insecurity and lack of orientation in space, but also high levels of glare can physically and psychologically harm the users. Therefore, it is important to understand where and in which situations glare can be caused, and to what extent.

Colour – Artificial lightning comes in a spectrum of colour temperature and in a variety of colours. Colour has a critical influence on the human experience in space, and therefore we must identify the desired colour, while addressing the character of each place and its use. What is the colour of the light? Which filters are applied?

Dynamism – Today, most street lightning is static. To create a high-quality experience of the public sphere we need to aim for a dynamic system. A system that can change and vary according to parameters related to natural light in space and the light projected from signs, private houses, and cars. Moreover, as the technology and smart cities develop, we can think about sustainable systems that can react to human presence and can be turned on and off according to the patterns of usage in designated spaces.

5. CONCLUSIONS

An analysis of today's lighting planning methodologies indicates that the main purposes of street lighting are visual uniformity and vehicle traffic. The number of pedestrians and their visual perception do not affect the amount of light and how the street is lit. The lighting in our cities is mostly static and constant throughout the night. This causes for a higher level of energy consumption and light pollution.

Our lighting planning strategies need to be oriented towards dynamic lighting, that reacts to the city dwellers as well as to the varied lighting conditions at any given night. All layers of urban lighting need to be addressed in a comprehensive manner, for lighting to enrich the human experience. Functionality and energy-efficiency will of course, remain parameter of lighting planning. By having a wholistic approach for urban lighting planning we can achieve visual comfort and well-being for the dwellers of the future sustainable and resilient city.

REFERENCES

1. Schivelbusch, W, (2005). Nightfall fear in the street, from Sense of the city: an alternate approach to urbanism, pg 65.
2. Schivelbusch, W, (2005) Nightfall fear in the street, from Sense of the city: an alternate approach to urbanism, pg 66.
3. Schivelbusch, W, (2005). Nightfall fear in the street, from Sense of the city: an alternate approach to urbanism, pg 68.
4. Histoire de l'éclairage public en France. [Online], Available: http://phozagora.free.fr/?page=zoom_histoire e 1.5.2011
5. Garber, M. (2013) Tower of Light: When Electricity Was New, People Used It to Mimic the Moon
6. Histoire de l'éclairage public en France. [Online], Available: http://phozagora.free.fr/?page=zoom_histoire e 1.5.2011
7-10. Ibid
11. CIE, International Lighting Vocabulary, 1987.
12. Krause, K. Regulating Urban Lighting: Prospects for Institutional Change. Urban Lighting, Light Pollution and Society, p.125-140.
13. Lilijefors, A., (1999). Lighting –Visually and Physically, KTH Stockholm.

Effect of window glazing colour and transmittance on human visual comfort

SNEHA JAIN [1], JAN WIENOLD[1], MARILYNE ANDERSEN[1]

[1] Laboratory of Integrated Performance in Design (LIPID), Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

ABSTRACT: Occupants' visual comfort in an indoor space strongly depend on the quantity and quality of the daylight inside the space which can be altered with the type of window glazing. In this study, we compared the visual comfort perception of participants with sun in their field of view under two types of glazing: color-neutral and blue-tinted electrochromic glazing. The main experimental variables are the color and visible light transmittances of the glazing. The aim was to determine the influence of these variables on participants' discomfort glare, view out and color perception. We found that the discomfort glare was perceived more strongly with blue-tinted glazing compared to the color-neutral glazing for a range of (low) transmittances. We also found that the colors of outdoor elements were rated non-natural in case of blue-tinted glazing compared to color-neutral glazing. The outside view was perceived more restricted in blue-tined glazing compared to color-neutral glazing even though both of them maintain view clarity.
KEYWORDS: Visual comfort, Daylight, Window glazing, Color, Glare

1. INTRODUCTION

Windows and shading devices play a key role in allowing sufficient daylight into the buildings and providing a view to the outside. Current developments in the switchable electrochromic (EC) glazing technology facilitate daylight modulation for better thermal and visual comfort while maintaining the view to the outside [1], [2]. Electrochromic materials employed in commercially available smart glazing technology exhibit a spectral shift towards short wavelengths range in their darkened state, causing them to appear blue [3]. Therefore, the usage of this technology may alter the spectrum and the correlated color temperature of daylight inside the space, which have been shown to influence human visual comfort and health [4]–[6]. Previous studies on switchable electrochromic glazing have reported their positive influence on thermal and visual comfort, their capability in controlling glare and associated user satisfaction [7][8]. Studies have also shown that occupants prefer color-neutral illumination to ensure natural looking environments [9], [10]. With the recent developments in EC materials to improve the color-neutrality of the switchable glazing in the dark state, it seems plausible that the alteration of daylight spectra is minimized while further reducing the transmittance for glare control [11], [12]. To our knowledge, there are currently no studies comparing the visual comfort perception of blue-tinted EC glazing with color-neutral glazing at low transmittance levels.

To address this gap, we conducted a between-subject study under blue-tinted EC glazing and color-neutral glazing of different low transmittance levels to investigate the effect of glazing color and transmittance on occupants' visual comfort perception. For the blue-tinted glazing, we installed a commercially available EC glazing, whereas to create color-neutral glazing, we installed color-neutral window films with low transmittance on clear acrylic panels fixed to a double-pane glazing. We evaluated and compared participants' responses to lighting environment, discomfort glare, color rendering, and view clarity to the outside under the blue-tinted EC glazing and color-neutral glazing.

2. METHOD

2.1 Experiment Design

A between-subjects study involving 20 participants in blue-tinted EC glazing and 55 participants in color-neutral glazing was conducted in a South-facing semi-controlled daylit office-like environment from 2019 to 2021. Experiments were conducted during the winter months under sunny conditions to benefit from low sun angles, thereby enabling to have the sun as the only glare source visible in the participants' central field of view (FOV). The experimental setup and glazing configuration are shown in Fig.1.

We exposed the participants to four experimental conditions in the blue-tinted and color-neutral glazing systems. In this article, we analyse three experimental conditions from each of the glazing type to have similar experimental scenarios for comparisons purpose. To create the conditions, we only varied the transmittance of the windowpane through which the sun was visible to the participants ("Sun Window" in Fig.1). We evaluate three levels of transmittance under blue-tinted glazing (τ_v = 0.14%, 0.6%, 1.6%) and the color-neutral glazing (τ_v = 0.36%, 1.25%, 3.4%). These experimental conditions are labelled as B1, B2, B3 for blue glazing and N1, N2, N3 for the color-neutral glazing in the increasing order of their sun window transmittances. Their properties are listed in Table 1.

Figure 1 Participants performing the tasks in blue-tinted glazing (left) and in color-neutral glazing (right)

The top-right windowpane was kept at maximum transmittance to allow sufficient daylight ("Daylight window" in Fig.1.) and to minimize the effect of low color-rendering inside the room. The remaining of the four window panes were kept at constant transmittance of 3.7% for blue-tinted glazing and 4.8% for color-neutral glazing. As our initial design intention was to keep the color-neutral and blue-tinted glazing at the same level of transmittance, we made sure to order color-neutral glazing with similar transmittance values as the blue EC glazing. However, when confronted with our findings, we measured the spectral transmittances of the EC glazing in a dedicated glazing and nano-technology lab facility. The measured transmittance values were found to be substantially lower than the ones received from the EC manufacturers. This explains the difference in τ_v values between the two experiments.

The room temperature and desk illuminance levels were constantly measured during the experiments and were kept within recommended levels to have constant conditions and avoid any confounding effects. However, the ambient lighting conditions were slightly higher in case of neutral glazing owing to the higher window transmittance as stated above. A manufacturer-calibrated HDR camera with a 180° fish-eye lens and equipped with a vertical lux sensor was used to capture

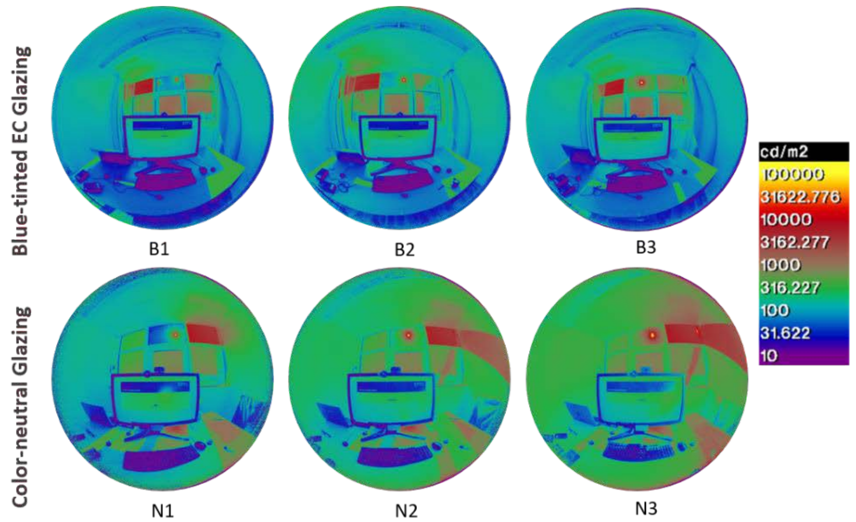


Figure 2 Falsecolor images of the test conditions shown to the participants with changing visible light transmittance of the sun window for blue-tinted and color-neutral glazing

the luminance distribution in the field of view and record vertical illuminance at eye level. Figure 2 presents a sample of captured falsecolor luminance HDR images of the experimental scenes. A spectrometer was installed behind the screen looking towards the window to record the spectral irradiance inside the room near participants' view point. Further details on the test room setup can be found in [8].

2.2 Experiment protocol

The experiments were conducted in the morning until early afternoon for two hours per participant on clear sky days. Participants were first briefed about the protocol and then answered some background questions about their demographics and indoor environmental preferences. Afterwards, they were exposed to four test conditions in randomized order to avoid any order bias. Their desk position was rotated for each scene in a way to keep the sun always in their central FOV. Each scenario was preceded by a break (~ 5-10 minutes), where they wore an eye mask to dark adapt, during which researcher took the measurements and changed the glazing transmittance to prepare the room for next scenario. The exposure duration to each condition was about 15 minutes.

During the exposure time, participants were given a typing task that allowed them to visually adapt to each condition. Afterwards, they filled a questionnaire reporting their level of comfort. Participants evaluated discomfort glare, lighting levels, color perception and view clarity associated with each scenario on different rating scales. During the break, we captured HDR images of each experimental condition from participant's eye height and measured respective vertical illuminance. The falsecolor HDR images of the scenes are presented in the Figure 2. These images were later processed to derive the scene luminance maps and calculate glare metrics using evalglare (v. 3.02)[13].

2.3 Subjective questionnaires

Participants answered an online survey questionnaire about the discomfort glare, view out perception and color perception after exposed to each testing condition. These questions were answered on the binary, categorial (Likert) or ordinal scales adapted from the previous visual comfort studies [14]–[16] with an aim to minimize the potential response bias that can be created by the rating scales. We analysed the responses pertaining to discomfort glare, color perception and view out in the subsequent section.

3. RESULTS AND DISCUSSION

3.1 Experiment conditions

We performed statistical analysis on the cleaned dataset after removing the datapoints with unstable weather conditions and ensuring stable conditions throughout all the experiments. Table 1 summarizes the visual properties of all the experimental conditions under blue-tinted and color-neutral glazing and the percentage of participants reporting discomfort in each condition.

Table 1 Summary of the data measured for all the experimental conditions.

	Scene	Glazing τ_v	Mean DGP	Mean E_v (lux)	Mean CCT (in K)	% of ppl reporting discomfort
Blue-tinted EC glazing	B1	0.14%	0.32	670	8627	16%
	B2	0.6%	0.41	1050	9783	53%
	B3	1.6%	0.50	1650	10427	89%
Color -neutral glazing	N1	0.36%	0.35	1770	5320	17%
	N2	1.25%	0.44	2200	5308	36%
	N3	3.4%	0.54	3300	5372	78%

The mean Daylight Glare Probability (DGP) values derived from the captured HDR images directly relate to the glazing transmittance, while the mean Correlated Color Temperature (CCT) values calculated from the measured spectral irradiance relate to the overall color inside the room measured near participant's view point. The ambient lighting levels are represented by the total vertical illuminance (Ev) measured at eye level. We can assess that the ambient lighting was a higher in case of neutral glazing due to the higher window transmittances. While the measured CCT values are higher in blue-tinted glazing conditions compared to the color-neutral conditions that has similar CCT for all four conditions.

3.2 Discomfort Glare perception

Figure ***3*** and Figure **4** shows the percentage of subjective votes experiencing discomfort glare on 'Yes/No' scale under all the glazing transmittances for blue-tinted and color-neutral glazing respectively. It can be observed from the figures that scene B1 with sun window transmittance 0.14% performs best in minimizing discomfort from glare for 84% of the participants under blue-tinted glazing, whereas similar or lower level of comfort can be achieved under color-neutral glazing for the scene N1 with sun window transmittance of 0.36%. The DGP value is higher for N1 scene compared to B1 scene indicating that the glare should have been perceived higher in color-neutral glazing, however, we observe that people are tolerating glare better under color-neutral glazing compared to blue EC glazing. We can observe similar trends for all the remaining experiment scenes, e.g., comparing B2 of blue-tined glazing where 53% of participants are reporting discomfort with the N2 of color-neutral glazing where only 36% of participants are reporting discomfort which has higher mean DGP values.

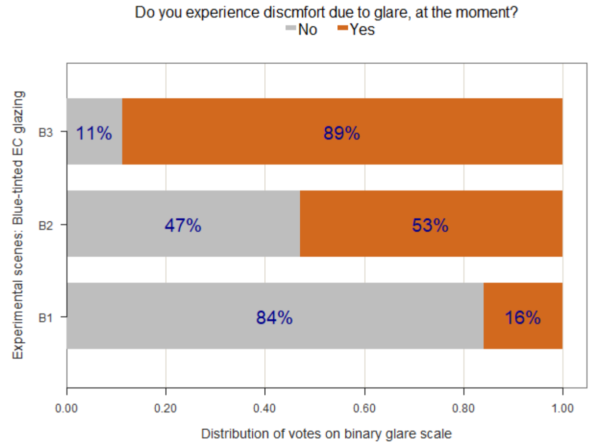


Figure 3 Glare vote distribution under blue-tinted glazing for three different glazing transmittances

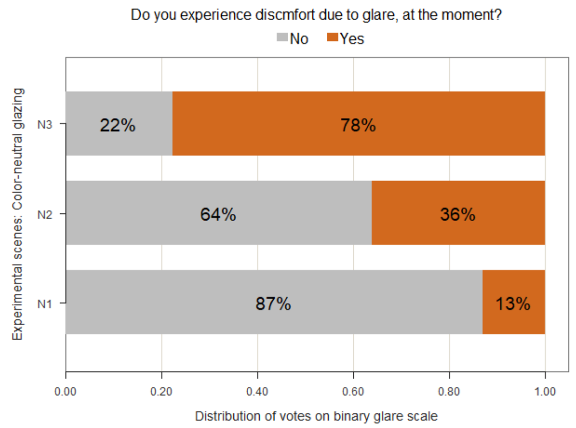


Figure 4 Glare vote distribution under color-neutral glazing for four different glazing transmittances

To further validate these findings, we calculated DGP threshold values using the closest topright method in precision-recall curves [17], which are the borderline values between the comfort and discomfort. We found higher threshold value for color-neutral glazing (DGP=0.48) compared to blue-tinted glazing (DGP=0.40), which led us to conclude that the glare was perceived as stronger with the blue-tinted glazing.

3.3 View Out perception

Participants rated the clarity of the view out through the glazing on a 10-point scale from not clear at all to very clear. The outside view was the same for both the color-neutral and blue-tinted glazing type since the test rooms were located next to each other. In case of color-neutral glazing, view to the outside was rated as not clear in 18% of the cases whereas in blue-tinted glazing view was rated as restricted or not clear in 37% of the cases. This is surprising since both types of glazing maintain a clear view to the outside. It could be due to the blue-shift if we consider that blue-tinted glazing may have a negative impact on how clearly the outside view is perceived. This is not really reinforced, however, by the answers regarding satisfaction with outside view, which was rated similarly in both the glazing types with 75% satisfaction in blue-tinted glazing and 77% in color-neutral glazing. We should also note the limitation that the window transmittances were slightly different in color-neutral glazing compared to the blue-tinted glazing which could affect the comparison of view out perception between the two glazing types.

3.4 Color perception

As observed in Table 1, blue-tinted glazing has much higher CCT compared to the color-neutral glazing. The quality of the color in blue-tinted glazing and color-neutral glazing is demonstrated in Figure 6 in terms of the average chromaticity coordinates of the test conditions in comparison to the CIE D65 illuminant representing the white point.

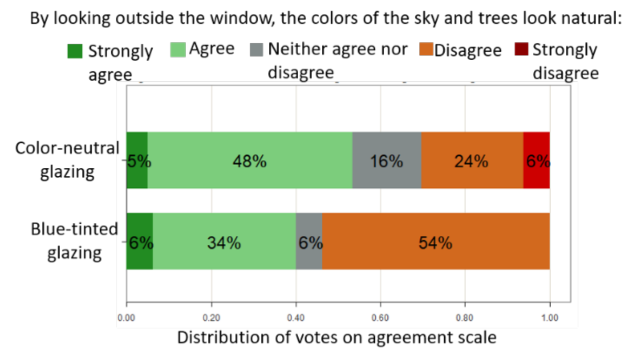


Figure 5 Votes on the color perception of the outdoor environmental elements

As shown in *Figure 5*, the colors of the outdoor elements rendered by the blue-tinted glazing were found to be non-natural by 54% of the participants whereas in color-neutral glazing the colors were reported non-natural by 30% of the participants. The colors of the indoor elements were rated as natural in both blue and color-neutral glazing by a majority of participants. This can be explained by the strategy of having a daylight window at maximum transmittance that allows the daylight inside the room without altering its color.

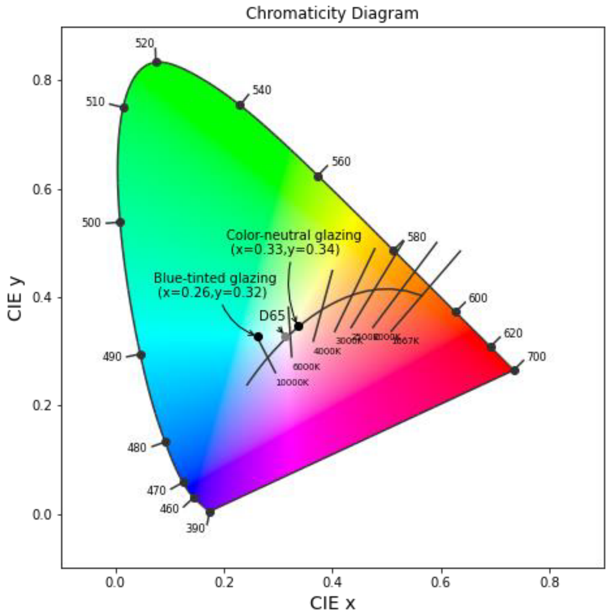


Figure 6 Chromaticity coordinates (x, y) representing the experimental scenarios (mean values) for blue-tinted and color-neutral glazing with the blackbody locus.

4. CONCLUSION

This study evaluated the occupants' perception of visual comfort and quality aspects of a daylit office-like test room with blue-tinted and color-neutral glazing. We found that the colors of the outdoor environment were not perceived natural in blue-tinted glazing compared to color-neutral glazing for a majority of participants. The view to the outside was voted as being clearer in color-neutral glazing compared to blue-tinted glazing, even though both glazings maintain a clear view to the outside. The color-neutral glazing performed better than the blue-tinted glazing in minimizing discomfort from glare when the sun is in the field of view of the participants. A τ_v = 0.14% was required in case of blue-tinted glazing to provide comfortable conditions to the majority (=84%) of participants, whereas a similar level of comfort was reached under color-neutral glazing at τ_v = 0.36%. This finding might have an origin in a combination of psychological and physiological factors related to color vision of human eye. Further investigations are required to elucidate these results.

The results of the study provide valuable insights for the building façade industry. They suggest that the development goals for the switchable glazing technology should be towards improving the color-neutrality for achieving user satisfaction and better glare control.

ACKNOWLEDGEMENTS

The work is funded by Swiss National Foundation project (SNF) grant for the project "Visual comfort without borders: interactions on discomfort glare" number 200020_182151. We would like to thank M. Lagier and A. Schüler for conducting the spectral transmittance measurements of the glazing.

REFERENCES

[1] A. Piccolo and F. Simone, "Effect of switchable glazing on discomfort glare from windows," *Building and Environment*, vol. 44, no. 6, pp. 1171–1180, Jun. 2009, doi: 10.1016/j.buildenv.2008.08.013.

[2] "Switchable facade technology ('swift') | SWIFT Project | FP5 | CORDIS | European Commission." https://cordis.europa.eu/project/id/ENK6-CT-1999-00012 (accessed Feb. 12, 2021).

[3] R. Baetens, B. P. Jelle, and A. Gustavsen, "Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review," *Solar Energy Materials and Solar Cells*, vol. 94, no. 2, pp. 87–105, Feb. 2010, doi: 10.1016/j.solmat.2009.08.021.

[4] Hh. Arsenault M and M.-C. Dubois, "GLAZING COLOUR TYPES, DAYLIGHT QUALITY, AROUSAL AND SWITCH-ON PATTERNS FOR ELECTRIC LIGHTS".

[5] J. Fekete, C. Sik-Lányi, and J. Schanda, "Spectral discomfort glare sensitivity investigations," *Ophthalmic and Physiological Optics*, vol. 30, no. 2, pp. 182–187, Mar. 2010, doi: 10.1111/j.1475-1313.2009.00696.x.

[6] M. Aries, M. Aarts, and J. van Hoof, "Daylight and health: A review of the evidence and consequences for the built environment," *Lighting Research and Technology*, vol. 47, no. 1, pp. 6–27, Feb. 2015, doi: 10.1177/1477153513509258.

[7] E. S. Lee, E. S. Claybaugh, and M. LaFrance, "End user impacts of automated electrochromic windows in a pilot retrofit application," *Energy and Buildings*, vol. 47, pp. 267–284, Apr. 2012, doi: 10.1016/j.enbuild.2011.12.003.

[8] S. Jain, C. Karmann, and J. Wienold, "Behind electrochromic glazing: Assessing user's perception of glare from the sun in a controlled environment," *Energy and Buildings*, vol. 256, p. 111738, Feb. 2022, doi: 10.1016/j.enbuild.2021.111738.

[9] S. Jain, C. Karmann, and J. Wienold, "Subjective assessment of visual comfort in a daylit workplace with an electrochromic glazed façade," *J. Phys.: Conf. Ser.*, vol. 2042, no. 1, p. 012179, Nov. 2021, doi: 10.1088/1742-6596/2042/1/012179.

[10] J. Mardaljevic, R. Kelly Waskett, and B. Painter, "Neutral daylight illumination with variable transmission glass: Theory and validation," *Lighting Research & Technology*, vol. 48, no. 3, pp. 267–285, May 2016, doi: 10.1177/1477153515620339.

[11] M. Lagier, A. Bertinotti, O. Bouvard, L. Burnier, and A. Schüler, "Optical properties of in vacuo lithiated nanoporous WO3:Mo thin films as determined by spectroscopic ellipsometry," *Optical Materials*, vol. 117, p. 111091, Jul. 2021, doi: 10.1016/j.optmat.2021.111091.

[12] J. Fleury, L. Burnier, and A. Schüler, "Electronic properties and ion migration of 'in vacuo' lithiated nanoporous WO3:Mo thin films," *Journal of Applied Physics*, vol. 131, no. 1, p. 015301, Jan. 2022, doi: 10.1063/5.0074455.

[13] J. Wienold, "Evalglare–A new RADIANCE-based tool to evaluate daylight glare in office spaces," 2004.

[14] W. K. E. Osterhaus and I. L. Bailey, "Large Area Glare Sources and Their Effect on Discomfort and Visual Performance at computer Workstations," in *Proceedings of the 1992 IEEE Industry Applications Society Annual Meeting*, Houston, TX, USA, 1992, pp. 1825–1829. doi: 10.1109/Ias.1992.244537.

[15] C. Pierson, "Discomfort glare perception from daylight: influence of the socio-environmental context," UCL - SST / ILOC - Faculty of Architecture, Architectural Engineering, Town Planning, 2019. [Online]. Available: http://hdl.handle.net/2078.1/222924

[16] G. Chinazzo, "Combined effects of daylight transmitted through coloured glazing and indoor temperature on thermal responses and overall comfort," *Building and Environment*, p. 15, 2018.

[17] T. Saito and M. Rehmsmeier, "The Precision-Recall Plot Is More Informative than the ROC Plot When Evaluating Binary Classifiers on Imbalanced Datasets," *PLoS One*, vol. 10, no. 3, p. e0118432, Mar. 2015, doi: 10.1371/journal.pone.0118432.

PLEA SANTIAGO 2022
Will Cities Survive?

Folk memory and temperature measurements for thermal comfort in vernacular courtyard houses of Saudi Arabia's hot arid climate

Residents' memories of living in Al-Khabra vernacular mud brick houses

MOHAMMED ALGHAFIS [1,2] MAGDA SIBLEY [1] ESHRAR LATIF [1]

[1] Welsh School of Architecture, Cardiff University, United Kingdom, CF10 3NB
[2] Department of Architecture, College of Architecture and Planning, Qassim University, Saudi Arabia, 52571

ABSTRACT: This paper presents the results of the first study of its kind as it investigates the memories of space use and thermal comfort of the previous inhabitants of eight vernacular mud brick courtyard houses of Al-Khabra in Al-Qassim hot-arid region in the centre of KSA. This paper fills a knowledge gap about recording the memories of previous residents' behavioural and cultural aspects of their space use of courtyard houses and their perception of thermal comfort while recording the temperatures inside and outside their abandoned houses. The paper presents first the architecture of eight vernacular houses and analyses their embedded environmental passive strategies and associated social and cultural practices. It then presents the results of measurements and interviews conducted during the summer of 2020. The outside air temperature varied between 25.5°C and 44°C, while indoor rooms' temperatures ranged between 33 to 37°C. The indoor temperatures observed on the west-facing rooms were higher than the other sides of buildings up to 2.0 °C. Interviewees mentioned that the west side of their houses was the most thermally uncomfortable during summer. Information gathered from interviewees provides a better understanding of the behavioural adaptations strategies which include horizontal and vertical mobility inside the house.

KEYWORDS: Hot-arid, Thermal comfort, Behavioural adaptations, Perception, Vernacular houses

1. INTRODUCTION

Indoor environmental quality has become an increasingly important aspect of building design in recent decades, with most people spending the majority of their leisure and working hours in indoor environments, particularly during the COVID-19 "lockdown" situation. Demands for more energy-efficient structures have set the parameters for studies of thermal comfort. Behavioural adaptations and thermal comfort in extreme temperatures is a growing research field, particularly in the context of climate change and the COVID-19 pandemic. Residents in hot arid regions in the Kingdom of Saudi Arabia (KSA) have lived for many years with extreme temperatures and have adapted their vernacular architecture and behaviour to cope with such an extreme climate.

It has been widely acknowledged that the contemporary and excessive use of air conditioning units has led to a number of health issues such as respiratory problems and a lack of Vitamin D due to household members staying indoors most of the time. Previous research on thermal comfort in housing in KSA has been increasing in the last two decades [2,3,4,11], in addition to studies conducted in other countries of the Gulf region [7,8,9,10].

Most of these studies are focused on contemporary housing using measurements and behavioural aspects to investigate thermal performance of buildings and the behavioural and cultural aspects of the residents. However, research which combines perceptual and measurements data collected in vernacular houses in KSA are inexistent. Only one research was found that investigates the thermal performance of vernacular houses in Al-Derriah settlement with a focus on measurements to assess the role of evaporative cooling in courtyards in hot arid climates in enhancing thermal comfort in KSA [2].

This could be explained by the fact that most vernacular settlements are abandoned / or not occupied by their residents as is the case of the settlement of Al-Khabra in Al-Qassim region, Saudi Arabia.

Vernacular houses' thermal comfort has never been investigated from the point of view of their previous original inhabitants. Previous studies on vernacular houses involving occupants have taken place in KSA. However, the occupants involved in these studies consist mainly of low-income migrants who have moved to these houses because of low rent [5]. These houses have been changed to adapt to multi-occupancy use of residents who are not the original local population.

This study is based on interviews with older generations who lived in the vernacular houses with no air conditioning and moved into air conditioned houses. They are the last generation who has lived in the vernacular houses. This generation had a different comfort expectation than the current generations. Their memories of comfort are therefore important to record.

This study is the first one of its kind as it traces some of the original inhabitants of the courtyard houses of Al-Khabra, who left the settlement thirty years ago and investigate their memories of thermal comfort as occupants of the houses. A sample of eight previous residents from the now older generation of Al-Khabra settlement (who moved out 1991 to newly built concrete frame and block infill villas. These eight previous residents of Al-Khabra were contacted in August-September 2020 to take part in online or face to face interviews about their lifestyle in their old houses. Interviews were conducted in the summer of 2020, during the most thermally stressing time. These interviews took place at the same time when data loggers for measuring indoor and outdoor temperatures were installed in eight vernacular mud brick houses that had been rehabilitated but not occupied.

The proposed paper aims to fill the knowledge gap about investigating residents' perception, behavioural, and cultural aspects of thermal comfort and their relationship to objective measurements of temperature in vernacular single-family houses in Al-Khabra.

The vernacular architecture of the selected sample of eight vernacular houses is analysed alongside its associated social, cultural, and spatial practices as revealed through the oral history of their previous inhabitants. In addition to this, the occupants were also asked about their memories of perception of thermal comfort inside the houses during the extreme summer heat, and compare them with the objective measurements of temperature inside the houses.

2. METHODOLOGY AND CASE STUDIES

2.1 Methodology and equipment

The research employs mixed methods calibrated to address the research objectives, comprising both quantitative and qualitative methods. The four selected methods of data collection and analysis linked to the research objectives are as follows:

1. Semi-structured interviews with the residents of the selected case study houses, using recorded telephone and online interviews with both male and female the adult residents. The subjects are Saudi citizens, aged between 40 and over 75 years old.
2. Site visits and direct observation of the housing units and their environment.
3. On-site measurements of outdoor and indoor temperatures and evaluation (quantitative).
4. Analyses of data collected through interviews and from data loggers.

The study relies on the oral memory of previous residents. It combines in-situ scientific measurements of temperature and former residents' perceptions of the thermal comfort of the studied vernacular houses where measurements are taken. The themes in the study include investigating the thermal comfort of the studied vernacular houses and understanding how were the spaces used and organized.

The current study used one main tool, HOBO Pendant 8K Data Loggers with supporting tools (e.g. HOBO Optic USB Base Station and software), applied due to their small size and ease of installation. HOBO pendant data loggers for temperature measurement are cost-efficient and small, making it easy to deploy them almost anywhere, facilitated by their high portability, and their long life batteries. These operate in indoor and outdoor environments, logging temperatures ranging from -20° to +70°C (-4° to 158°F). Fig.1 shows the tool installed in some rooms at height of 1.5 meters. It should be noted that all doors and windows were kept closed as much as possible during the data collection, to minimise air infiltration into the spaces.

Figure 1: HOBO loggers installed in vernacular houses

2.2 The case study houses and their context

The eight case study houses are located in Al-Khabra village in the west of Al-Qassim region in central KSA. It is located at 26.33 latitude and 43.97 longitude, situated 606 m above sea level. Buraidah is the capital of Al-Qassim. This region has been significant due to its agriculture value to KSA.

The houses were selected on the basis of their current condition and the availability of their previous occupants who could be found after they had left the site in the early 1990s. It was possible to connect five houses to their previous occupants, for the remaining three case study houses were familiar to the previous occupants interviewed in this research. Seven of the case houses have been rehabilitated between 2013 and 2016 by Al-Khabra Municipality but not occupied, one house (B8) has not been rehabilitated but are still standing in relatively.

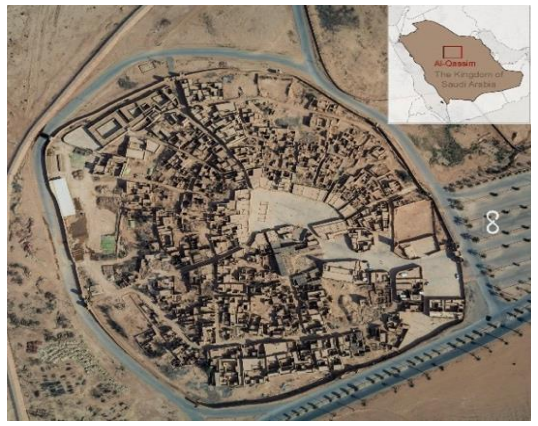


Figure 2: Top view of Al-Khabra by Saleh Ahmed Alhuthlul

Many aspects should be considered in determining housing typologies; but the most important are climate and culture. Through history, the availability of building materials, lifestyle, and climate have had major impacts on local architectural built forms. Vernacular buildings were well-adapted to climatic aspects and contexts in their design, planning and construction, as well as to the low rise high density urban scale of the heritage settlements.

The basic construction materials are limestone, adobe and wood and the structural system used in Al-Khabra village is a load-bearing structure. Limestone was used for foundations of walls, adobe for walls and roofs; wood was used for structure of roofs, doors and window, and it is known as athel (tamarix tree) [1]. All materials were brought from surrounding areas and integrated in the construction of the houses and the settlement.

Wall thickness in Al-Khabra buildings is 400 mm adobe sun-dried brick and 40 mm mud plaster. Adobe material properties were collected from different resources due to the available data limitation to model thermal properties values like specific heat, and thermal conductivity etc. [3, 6].

Table 1: Thermal properties of the adobe construction

Material	Thickness	Thermal Conductivity (W m-1 K-1)	Density (Kg/m3)	Specific Heat (J/kg K)
Adobe wall	0.5	0.730	1650	1000
Adobe roof	0.3	0.730	1650	1000
Adobe with straw	0.025	0.180	440	900
Palm tree fronds	0.015	0.166	600	1200

The combination of narrow streets and houses arranged around courtyards to achieve the balance between environmental comfort (through increased shaded spaces) and privacy through inward looking courtyard buildings. Houses had secure access to the inside, controlled via long blocks of housing with few outside openings, whereas the large openings were directed to the inside courtyards of houses. Cool air circulation was improved via narrow openings as illustrated in the following participant's observation:

''Windows in some places were at a high level of the external wall, whereas large openings were located in low level of the walls towards central courtyards for smoke extraction in winter and air circulation in summer'' (Al-Hudaythi 2020)

The twisting narrow streets reduce exposure of the buildings and urban spaces to sand storms, which are common in the region. The spaces provided amidst the houses of vitality and suitable for social interactions, while the street system and neighbourhood cul-se-sacs preserved the privacy, security, and physical and mental rest of local residents.

The climate of the Central Region is mainly a desert one, with minimal, rainfall, and an intense hot-arid summer. This climate makes living more complicated and challenging for residents due to the harsh summer conditions. In Al-Qassim, summer temperatures often reach above 40°C, with very low humidity (Table2).

Table 2: Average maximum temperature and relative humidity, January-December 2020 (Source: NCM 2020).

Month	T max	RH max
JAN	22°C	54%
FEB	26°C	43%
MAR	30°C	37%
APR	36°C	33%
MAY	41°C	20%
JUN	43°C	13%
JUL	42°C	13%
AUG	44°C	14%
SEP	43°C	14%
OCT	38°C	23%
NOV	31°C	43%
DEC	24°C	55%

Due to generally low yearly rainfall, vernacular houses in the Middle East have flat roofs, which traditionally served multiple functions as living areas, where people couple prepare food, dry clothes, and sleep in hot weather. A modern roof, conversely, would serve to radiate heat throughout the night. This was reflected in the following participant's observation:

"Sleeping on the roofs of vernacular houses is like having a fridge under you, while sleeping on roofs of modern homes like having an oven under you"
(Ali Al-Salamh 2020)

2.2.1 Case studies results

This section illustrates the analysis of all 8 vernacular houses (Fig.6) and one example of the 8 houses to explain in details the local vernacular architecture of Al-Khabra mud brick houses and their integration in the urban context of the settlement, as illustrated in (Fig.3).

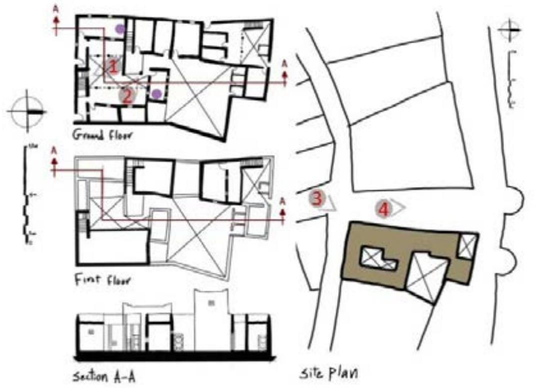


Figure 3: Architectural plans, site location, section for B1, and the purple circle means the loggers that were installed.

Figure 4: Internal and external pictures for B1.

Building 1 (B1) has two floors and three internal courtyards. It has seven rooms on the ground floor and four rooms on the first. The dimensions of the house are 26 by 15 metres. The building is rectangular in plan and shares its wall with neighbours in the east side. It has short distances to other buildings on the south and west sides (4 and 7 metres respectively). The house has three entrances; two for family (private) on the north and west side, and the other for guests (semi-private) on the south side. The house is very close to the northern village entrance. It was built after 1800 and was refurbished in 2016 by Al-Khabra Municipality, using the same local building materials. (Fig.3) shows the floor plans, section, and site location of the house. (Fig.4) illustrates the internal courtyard, external façade, and northern village entrance. North-south (NS) and South-west (SW) facing rooms on the ground floor were selected to measure the air temperature, with room floor area of 14.50 m^2 and 27.25 m^2 for NS and SW rooms, respectively. The graph (Fig.5) shows the measurement of air temperature for NS and SW facing rooms. The collected data in the NS facing room presented that the average indoor temperature ranged between 33.3 to 34.7°C, while the SW room illustrated higher indoor air temperature ranging from 35 to 36.5°C.

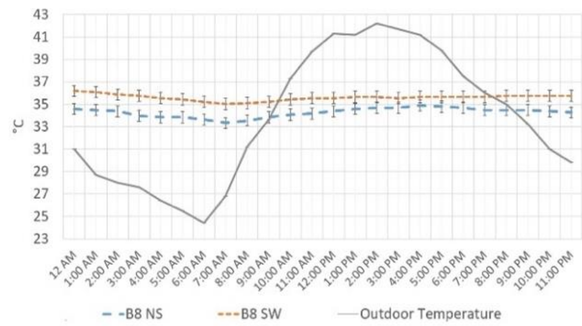


Figure 5: Air temperature in B1 during a 24-hour

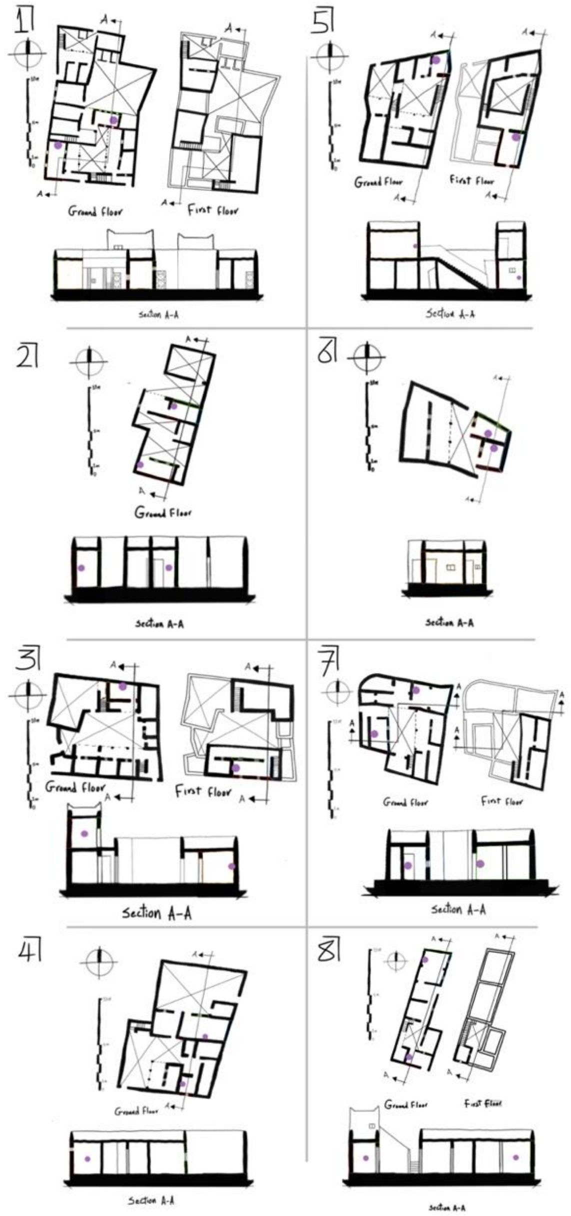


Figure 6: Plans, and sections of all houses

Figure 7: The location of the houses that have been rehabilitated, except B8 in yellow colour

3. RESULTS AND DISCUSSION

The collected data indicates that outside air temperature has a diurnal temperature range (DTR) of 18.5°C, with a minimum of 25.5°C during the night and a maximum of 44°C during the day.

On the other hand, indoor rooms' average temperatures varied between 33 to 36°C exhibited almost no noticeable DTR change, except in one single space: south-west (SW) room in B8 which has not been rehabilitated. The following Table 3 summarises all chosen rooms.

Table 3: Summarizing all chosen rooms in the hot season over a 24-hour (SD means standard deviation).

	Room location	Mean	SD	Min	Max	Room area m²
B1	GF NS	34.2	0.42	33.3	34.7	14.78
B1	GF SW	35.6	0.27	35.0	36.5	27.01
B2	GF NSE	36.3	0.37	35.8	36.9	20.88
B2	GF SN	36.0	0.57	35.0	36.7	21.76
B3	GF SW	36.7	0.42	36.0	37.2	15.51
B3	FF NSE	36.4	0.59	35.5	37.1	18.88
B4	GF NE	35.1	0.45	34.4	35.8	39.84
B4	GF S	36.0	0.21	35.5	36.2	20.68
B5	GF NSE	35.0	0.36	34.2	35.5	18.86
B5	FF NSE	35.3	0.19	35.1	35.7	31.62
B6	GF NE	35.3	0.60	34.4	36.2	19.08
B6	GF SEW	36.0	0.12	35.8	36.3	13.30
B7	GF NSE	35.4	0.57	34.4	36.0	25.84
B7	GF SE	35.6	0.27	35.0	36.1	21.84
B8	GF NE	36.2	0.48	35.1	36.9	35.36
B8	GF SW	36.6	1.70	33.7	38.6	18.36

The other studied rooms exhibited the effect of the high exposed thermal mass of mud building materials and delayed heat absorption and release compared to concrete materials, in addition to the heat island effect. The reason there was no obvious diurnal change in the indoor spaces was the absence natural ventilation. Closed doors and windows prevent air circulation inside rooms, and consequently low infiltration allows warm air to stay inside, which contributed to keep temperatures high, but reasonably steady.

The majority of interviewees mentioned that the west side of their houses was the most thermally uncomfortable during summer (See West facing rooms in B1, B3, B6, and B8). They tend to avoid using the rooms with external walls exposed to the west. Most respondents also explained their preference for using the North side of the house because it is cooler and tends to catch cool breezes, while in winter they prefer the eastern side in the morning to get the warm sunshine of Al-Qassim short winter.

An interesting spatial practice revealed by the interviewees is the tendency of men to gather outside the houses in the morning and sit on benches along the east facing walls to enjoy the heat coming from the sun and catch up on the latest of the neighbourhood. These types of sitting areas in public spaces for men are referred as ''Al-Mishraq'' which means the morning rising sun. It is also designed to make the most of the sun rise during winter after the dawn prayer. Al-Mishraq is therefore an important adaptive environmental strategy allowing the residents to enjoy a public space that thermally comfortable in winter because of its orientation. Furthermore, Al-Mishraq was used next to the souq, the open market, as described by one of the respondents:

''*people used to sit outside in a place called the ''warm Mishraq'' ... Al-Mishraq time is a place where the sunshine shines, until it rises (perpendicular) at noon''* (Abdullah Al-Tasan 2020)

The interviewees recalled that people slept upstairs in summer and inside in winter. This relates to the thermal mass of construction materials. Mud bricks radiate heat from the exterior to interior spaces relatively slowly, due to their thickness (40-60 cm) and thermal properties. When the sun is hitting the exterior surfaces, it takes until late afternoon for the heat to transfer to the internal face of the wall and begin heating the internal space. Consequently, internal spaces are relatively cooler during the day, and warmer at night, thus people traditionally escaped hotter internal temperatures at night by sleeping on the vernacular houses' roof, benefitting from the time lag thermal mass impact of vernacular construction. This was reflected in the following participant's observation:

''In the summer, we sleep in an open place, such as courtyards or roofs ... we do not sleep in rooms at all and its advantage if dawn comes people are awake and we hear the call of prayer, but now the air conditioning is over your head and your feet are numb and there is no one who will wake you up except for the alarm and you wake up lazy this is the differences''. (Abdullah Al-Oremah 2020)

Information gathered from interviewees provides a better understanding of the adaptive strategies that the residents of the vernacular houses of Al-Khabra have adopted to mitigate the extreme temperatures of the summer. These are behavioural adaptations which include horizontal and vertical mobility inside the house, bearing in mind that all the spaces are multifunctional with the exception of the Majlis and the kitchen.

4. CONCLUSION

Identifying structures suitable for use in testing representative vernacular housing was very difficult, due to the dearth of inhabited houses and sites in a state of good repair particularly in terms of the presence of doors and windows in their fittings.

The chosen case study buildings were under the supervision of Al-Khabra Municipality, which preserved them by applying the same building materials and methods of vernacular construction, which made them appropriate examples of a vernacular building to understand thermal performance and to conduct thermal tests.

The paper presents first the architecture of eight vernacular houses and analyses their embedded environmental passive strategies and associated social and cultural practices. It then presents the results of measurements and interviews conducted during the summer of 2020, when temperatures are at their extreme. The collected data indicates that outside air temperature has a diurnal temperature range (DTR) of 18.5°C, with a minimum of 25.5°C during the night and a maximum of 44°C during the day while the indoor rooms' average temperatures varied between 33 to 36°C exhibited almost no noticeable DTR change, except in one single space.

The indoor temperature of west facing rooms were relatively high, therefore people generally try to avoid this side to the building as stated by the majority of participants. In summer people preferred the north side because the north breeze in cooler, while they preferred eastern sides to get sunlight in Al-Qassim short winter. In B1, for instance, the difference between the recorded indoor temperature of north-south (NS) and south-west (SW) rooms is about 2°C, with a maximum temperature of 34.7°C and 36.5°C for NS and SW rooms, respectively.

The recorded indoor temperature of all eight vernacular dwellings in selected rooms ranged from a low of 33.3°C to a high of 38.6°C (reported in a single case), with a mean of about 35.4°C. There was a high fluctuation in one room (SW room in B8), with standard deviation of 1.70. This is likely anomalies due to B8 has not been rehabilitated or doors and windows were not being tightly closed, and there were cracks in the walls, in addition of being on the western side.

The fieldwork measurements in summer 2020 provided a deeper understanding of the various temperatures in the vernacular case study houses. The results of the fieldwork provide the foundation to understand how vernacular houses performed and how the residents of the vernacular houses of Al-Khabra have adopted to mitigate the extreme temperatures of the summer. These are behavioural adaptations which include horizontal and vertical mobility inside the house.

ACKNOWLEDGEMENTS

This work has been developed from the results of a research project entitled: Investigating Thermal Comfort in Vernacular and Contemporary Houses in Al-Qassim: Technical, Cultural and Behavioural Factors. The research project was granted by Cardiff University and conducted by the authors.

REFERENCES

1. Alghafis, M., Sibley, M., and Latif, E. (2022). A Review of Existing Literature in Saudi Domestic Architecture. Conservation of Architectural Heritage, pp.261-271
2. Al-Hemiddi, N.A. and Al-Saud, K.A.M., (2001). The effect of a ventilated interior courtyard on the thermal performance of a house in a hot–arid region. Renewable Energy, 24(3-4), pp.581-595.
3. Al-Oraier, F., (2005) Thermal analysis of traditional adobe dwellings in Riyadh City, Saudi Arabia. Cardiff University.
4. Alshaikh, A. and Roaf, S., (2016), April. Designing comfortable, low carbon, homes in Dammam, Saudi Arabia: The roles of buildings and behaviours. In Proceedings of 9th Windsor Conference: Making Comfort Relevant, Cumberland Lodge, Windsor, UK (pp. 7-9).
5. Alsheliby, M., (2015). Crisis of traditional identity in the built environment of the Saudi cities (Doctoral thesis, Newcastle University).
6. Bahobail, M. A. (2012). The mud additives and their effect on thermal conductivity of adobe bricks. JES. Journal of Engineering Sciences, 40(1), 21-34.
7. Fadeyi, M.O., Alkhaja, K., Sulayem, M.B. and Abu-Hijleh, B., (2014). Evaluation of indoor environmental quality conditions in elementary schools ʼclassrooms in UAE. Frontiers of Architectural Research, 3(2), pp.166-177.
8. Heidari, S., & Sharples, S. (2002). A comparative analysis of short-term and long-term thermal comfort surveys in Iran. Energy and Buildings, 34(6), 607-614.
9. Indraganti, M. and Boussaa, D., (2018). An adaptive relationship of thermal comfort for the Gulf Cooperation Council (GCC) Countries: The case of offices in Qatar. *Energy and Buildings*, 159, pp.201-212.
10. Khodakarami, J. and Knight, I., (2008). Required and current thermal conditions for occupants in Iranian hospitals. HVAC&R Research, 14(2), pp.175-193
11. Mady, M; Anna, K; Haitham, S., (2019). Examining the thermal performance of vernacular houses in Asir Region of Saudi Arabia. *Alexandria Engineering Journal*, 58.2: 419-428.

PLEA SANTIAGO 2022
Will Cities Survive?

Well-being in office spaces from the occupants' perspective

A qualitative approach

MAUREEN TREBILCOCK-KELLY [1]; JAIME SOTO-MUÑOZ [2] ; PAULINA WEGERTSEDER-MARTINEZ [1]; RAUL RAMIREZ-VIELMA [3]

[1] Departamento Diseño y Teoría de la Arquitectura, Universidad del Bío-Bío, Chile.
[2] Departamento Ciencias de la Construcción, Universidad del Bío-Bío, Chile.
[3] Departamento de Psicología, Universidad de Concepción, Chile.

ABSTRACT: There is no consensus on the definition of well-being in the built environment, but rather a wide range of approaches that deal with physical, psychological and social dimensions. There is a need for a holistic approach in order to understand what makes a building healthier and positive for occupants' well-being, which is particularly important in offices, where people spend an important part of their lives. This paper addresses the research question: which characteristics of the office spaces contribute - both positively and negatively - to occupants' well-being and why? The methodology consisted of a qualitative approach based on interviews to 44 occupants of 9 office buildings located in different cities in Chile. The interview questionnaire contains open-ended questions that addressed the topic at different scales: workspace, building, and location/surroundings. The data analysis was performed with the software NVivo. The findings suggest that at the scale of the workspace, occupants relates wellbeing to building qualities that provide comfort and somehow enhance their productivity, while at the scale of the building and surroundings, they relate well-being with places for social interaction and features that provide psychological well-being, such as daylighting, views out and the presence of green areas (biophilia).
KEYWORDS: Well-being, comfort, offices, occupants

1. INTRODUCTION

There is no consensus on the definition of well-being in the built environment, but rather a wide range of approaches that deal with physical, psychological and social dimensions [1-5]. The terms 'comfort', 'health' and 'well-being' are often used interchangeably without a clear definition of each term [1]. Altomonte et at [2] explain that comfort has been mostly confined to acceptance of environmental conditions, while health has been confined to the prevention and limitation of negative stressors. In contrast, well-being relates also with positive stimuli that encourages the design of environments that enhance occupants' experience [1, 2].

Atkinson et al [3] state that the concept of well-being, however defined, can have no form or expression without consideration of place. Whilst some quantitative approach treat place as a static container, others have reflected on more complex relations between people and their built environment.

It is however difficult to translate complex paradigms into design strategies and standards, forcing to move from holistic concepts into more reductionists definitions [2]. Some of the advances in addressing well-being in buildings have been made in the field of sustainability. Green building ratings systems - such as LEED - include criteria for occupants' health and well-being that focus mainly on indoor environmental quality. New building rating systems - such as WELL and Fitwel - have been developed to guide the design for health and well-being, covering different aspects in a comprehensive way, with a focus on indoor air quality and health.

A scoping review performed by Hanc et al [4] found out that well-being outcomes are ambiguous and the contribution of well-being dimensions to building occupants is not clear. There is a need for a holistic approach in order to understand what makes a building healthier and positive for occupants' well-being and not only what limits their discomfort [6]. This is particularly important in office buildings, where people spend an important part of their lives.

Therefore, this paper addresses the research question: which characteristics of the office spaces contribute- both positively and negatively - to occupants' well-being and why? It aims to contribute to a better understanding of the concept of well-being in the built environment from a holistic perspective and a bottom-up approach.

2. METHODS

The methodology was based on a qualitative bottom-up approach and it consisted of semi-structured interviews to 44 occupants of 9 case studies located in different cities in Chile (Fig 1).

2.1 Case studies

The criteria for selecting the case studies relied on evidence of being best available practice at local level. Currently, best practice in office building design in Chile is guided by green building rating systems LEED and CES (the national certification system Certificación de Edificio Sustentable), as both systems comprise credits for indoor environmental quality. All case studies are certified by either LEED, CES, or both, and have been built and occupied during the last years.

Figure 1: Photographs of the case study office buildings

2.2 Research interviews

Within each building, the researchers interviewed 3 to 6 occupants, including 1 person responsible for the operation and management of the building, with a total of 44 research interviews that comprise the data for this paper. The interview questionnaire was developed according to the research question.

This paper presents the findings of 4 open-ended interview questions that aim to identify specific aspects of the building that impact positively and negatively on the occupants' well-being at different scales: work space, building, and building location/surroundings (Table 1). The questionnaire included a preliminary question aimed at gathering spontaneous responses on the favourite space in the building before raising the topic of well-being, with the idea of identifying qualities of the building that the occupants value.

Table 1: Topics of the interview questions

1. Favourite space in the building
2. Characteristics of the workspace that have a positive and negative effect on your well-being.
3. Characteristics of the office building that have a positive and negative effect on your well-being.
4. Characteristics of the building surroundings and location that have a positive and negative effect on your well-being.

It is important to note that the interviews took place during the COVID 19 pandemic in 2021, so some of the participants were working from home. Therefore, the questionnaire was administered either face-to-face or via remote communication platform (zoom), and it addressed the occupants' experience in their office building before the pandemic.

The data was analysed with the software program NVivo 12, specialised for the analysis of qualitative research. The program allows to organise qualitative data in main themes and sub-themes derived from the responses of the occupants. Wordclouds and code matrixes were developed in order to assist the analysis and interpretation of the results. As the data of this paper is mostly qualitative, the analysis was made in a narrative manner.

3. FINDINGS

The findings are organised according to the different scales that were addressed by the interview questions.

3.1 Favourite space

The main purpose of the first question was to identify the spaces that were valued by the occupants as their favourite space and the reasons behind their choices. The wordcloud in Fig 2 shows the terms that were mentioned most frequently by the 44 interviewees, which cover actual spaces (which is your favourite space?) as well as qualities (why?).

The interviewees identified three type of fspaces: coffee corners and canteens (10 references); outdoor spaces such as terraces and courtyards (8 references); and their own workspace (9 references). The first two type of spaces were generally connected, e.g. the canteen or cafe ("casino" and "cafeteria" in Fig 2) is connected to the terrace ("terraza" in Fig 2), and were valued mainly for the opportunity to meet their colleagues in a relaxed manner, but also for architectural qualities that enable them to connect with nature in terms of views and daylight ("vista" and "luz" in Fig 2).

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

Figure 2: Wordcloud of favourite space in the building (interviews)

The workspace was valued for being comfortable and quiet, but mostly for being the space ‘of their own’.

Therefore, the findings suggest that some occupants prefer spaces for social interaction while other prefer private spaces, but in all cases the architectural attributes that were raised relate to connection with nature: light, air, sunshine, views, greenery, breeze, etc.

3.2 Scale of the workspace

At the scale of the workspace, occupants relate well-being with comfort; mainly lighting and visual comfort (17 references), ergonomics (15 references) and thermal comfort (12 references).

Daylighting, artificial lighting and views out were mentioned several times as a positive attribute of their workspaces (“iluminación” and “luz” in Fig 3). The HVAC system and its ability to maintain a constant indoor temperature was considered positive for their well-being, while problems with the HVAC system becomes the main source of complaint due to discomfort and its effect on health, such as colds.

Figure 3: Wordcloud of well-being at the scale of the workspace (interviews)

In addition, they valued the quality and size of the office furniture, particularly the ergonomic chair (“silla” in Fig 3) and size of the desk and space between different workstations. This was an important aspect, as some interviewees considered that having small desks too close to each other has a negative impact on their well-being and their ability to perform their jobs properly.

On the other hand, noise and distractions in open plan spaces were raised as negative aspects for their well-being due to their impact on concentration. However, open plan spaces were valued for allowing interaction between co-workers, simplifying team communication. This suggests that both positive and negative qualities of open plan spaces were raised spontaneously by the occupants in terms of the impact on their jobs.

The lack of environmental control was also mentioned as a negative feature by some occupants who believe that the opportunity to open a window or to adjust the thermostat would benefit their well-being.

Although the interviewees did not explicitly mention the term “productivity”, the idea of being comfortable to do their jobs remain behind both the positive aspects (team communication) and the negative aspects (noise and distractions) of their workspaces.

Figure 4: Photograph of the workspace of a case study

3.3 Scale of the office building

At the scale of the office building, the occupants mentioned a wider variety of aspects that impact their well-being in comparison to the scale of the workspace.

They expect their office building to provide a comfortable environment in terms of daylighting and temperature, but they also value to be able to ‘do everything within the building’. They value having spaces within the building for meal breaks and social interaction such as coffee corners and canteens (“casino” in Fig 5); for sports such as gyms and bicycle parking (“gimnasio” in Fig 5); and even practical features such as cash machines. In addition, they mentioned the positive impact of green areas within the building such as terraces and courtyards where they can ‘de-stress’.

A very important quality for occupants’ well-being at building scale is everything that allow them to move easily and safely within the building (“seguridad” in fig 5) which includes efficient lifts and car parks (“ascensores” and “estacionamientos” in fig 5).

Figure 5: Wordcloud of well-being at the scale of the office building (interviews)

The image of the building was also valued in terms of being modern and attractive (“bello” in Fig 4), especially in those cases were they have moved from older office buildings, which is the common case.

LEED certification came up in the interviews as a positive quality of the building in relation to domotics and sustainability. The idea of working in an intelligent building that uses renewable energy was valued by the interviewees.

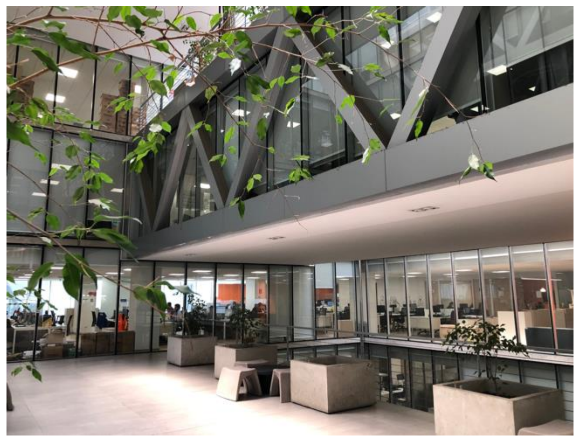


Figure 6: Photograph of a common space within the building - case study

3.4 Scale of the building location and its surroundings

At this scale occupants relate well-being mostly to accessibility and facilities. Location is very important in terms of reducing travel distance and time to work (“ubicación” in Fig 8). Being close to public transport such as the metro benefits their overall well-being. They also value a building location that provides different facilities in the surrounding area, such as restaurants and shops.

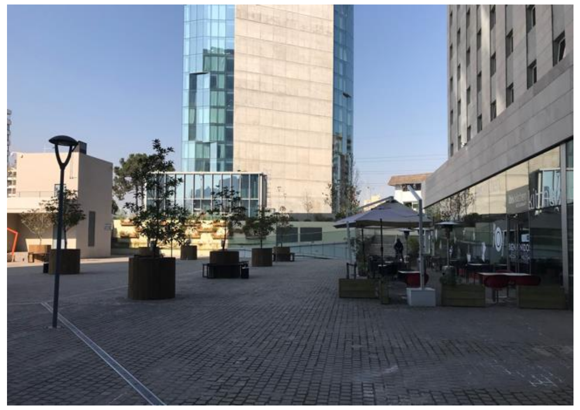


Figure 7: Photograph of a building surrounding – case study

In addition, having green areas such as parks in the surroundings was also mentioned (“parque”, “plaza” and “verde” in Fig 8). Some interviewees mentioned the opportunity to train in the park at lunch as a very positive aspect.

Safety was also mentioned at this scale, as some interviewees – particularly female – do not feel safe in the building surroundings due to bad lighting and long distance to the public transport.

Figure 7: Wordcloud of well-being at the scale of the building surroundings and location (interviews)

3.5 References from the interviewees

Figure 9 shows the number of references that were given by the interviewees at each building scale; either positive or negative. The majority of references were given at the scale of the office building (total of 250 references), which were also very varied and generally positive (163 references). The scale of the workspace had 166 references, while the scale of the building location and surroundings had 182 references.

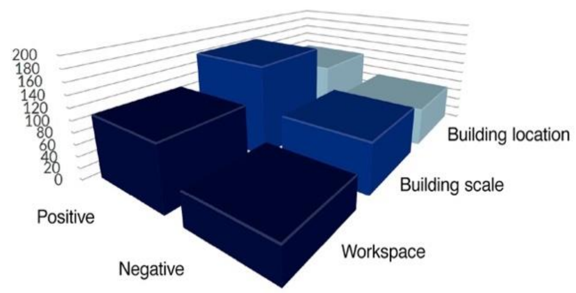


Figure 9: number of references given by the interviewees at different scales

At all different scales occupants mentioned mostly positive aspects, which could relate to the fact that the case studies are 'best practice' (LEED/CES certified buildings), but also to the positive connotation that the term well-being ("bienestar" in Spanish) could have on the interviewees.

4. DISCUSION

The findings suggest that at the scale of the workspace, occupants relates well-being to building qualities that provide comfort and allow them to do their jobs properly (Fig 10). At this scale, physical well-being (ergonomics and environmental comfort) seems to be more important than psychological or social well-being that were mentioned at the scale of the whole building.

However, there are no references to health (only colds and flu due to poor thermal environment), so physical well-being relates mostly to the idea of being comfortable right-now, without much consideration to long term consequences of bad ergonomics or poor environmental conditions on health.

Some references at the scale of the workplace also relates to psychological aspects of well-being, such as noise annoyance and disturbance; and the effect of daylight for the mood and de-stress.

Interestingly, none of the interviewees mentioned air quality at all, which suggests that they are less sensitive to that stimulus than to noise, light and temperature. This fact contrasts the priority that air quality criteria have in certification schemes. Occupants do not consciously relate air quality with well-being and its potential effect on health.

At the scale of the office building, occupants relate their well-being to a wide variety of aspects that respond to physical, psychological and social dimensions of the concept. At this scale, they expect the building to provide all sorts of facilities that will enhance their well-being and thrive their lives. The office building is somehow considered as a safe space where they can not only work but also fulfil their needs for social interaction, physical activities, nourishment, de-stress and connection with nature (biofilia). It is interesting to note that at this scale the building embraces well-being in a holistic way, in line with the needs of human life.

At the scale of the building surroundings and location, well-being narrows down to practical issues of transport and safety.

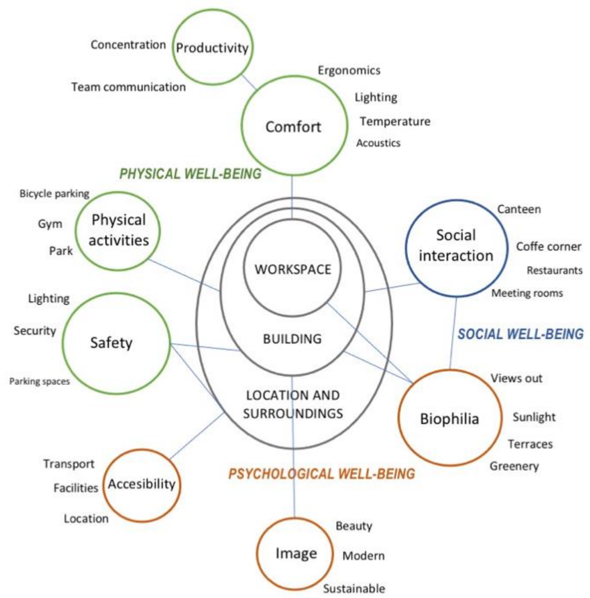


Figure 10: dimensions of well-being at three scales: workspace, office building and location/surroundings

The diagram in Figure 10 shows the main concepts derived from the data. At the centre, it contains the three scales of inquiry: workspace, building and building surroundings. The main themes that arose from the data are organised around those three scales, where some of them relate to more than one scale, e.g. concepts of biofilia came up at the scale of the workspace (lighting and views) as well as at the scale of the office building (greenery, terraces, sunlight). Themes that relate to physical well-being are highlighted in green; themes that relate to psychological well-being are highlighted in brown and themes that relates to social well-being are highlighted in blue. Evidently, some of the themes relate to more than one dimension of well-being, e.g. he concept of safety within the building and also within the building surrounding deals with physical aspects (being safe) as well as psychological aspects (feeling safe).

Interestingly, participants did not mention aspects related to physical health when asked about well-being, such as allergies, headaches of muscular affections that could be a consequence of the quality of the workspace. The reason for this could be that they are less conscious of long term effects of the indoor environment and much more conscious of present conditions in terms of comfort and satisfaction.

5. CONCLUSION

The novelty of this paper relies on the qualitative approach to well-being in office spaces from the perspective of the occupants. The research interview based on open-ended questions that addressed well-being at different scales within the office building allowed to identify the main well-being criteria.

Conclusions stress out that at the scale of the workspace, occupants prioritise aspects of comfort that allow them to do their jobs properly, focusing on physical dimensions of well-being. However, at the scale of the office building, occupants expect their workplace to enhance their well-being at physical, psychological and social dimensions. The building is expected to become a safe place where they can not only work but also fulfil most of their needs for social interaction, physical activities, nourishment and de-stress.

Although the interview questions addressed both negative and positive aspects, it is interesting to note that occupants mentioned far more qualities that enhance their well-being, in contrast to the majority of research studies that focus on ways to reduce discomfort and prevent health in office buildings [7].

ACKNOWLEDGEMENTS

This paper is part of the research project Fondecyt Regular Nº 1201456 by ANID. The authors would like to acknowledge the support of the research group on Energy Poverty and Environmental Comfort.

REFERENCES

1. Rohde L, Larsen TS, Jensen RL and OK Larsen, (2020). Framing holistic indoor environment: Definitions of comfort, health and well-being. *Indoor and Built Environment*, 29(8): p. 1118-1136. **https://doi.org/10.1177/1420326X19875795**
2. Altomonte S. et al. (2020). Ten questions concerning well-being in the built environment. *Building and Environment*, 180. **https://doi.org/10.1016/j.buildenv.2020.106949**
3. Atkinson, S . Fuller, S. and Painter J. (2012) Wellbeing and Place. Routledge.
4. Hanc M, McAndrew C and M Ucci (2019). Conceptual approaches to wellbeing in buildings: a scoping review. *Building Research & Information*, 47(6), pp 767-783. **https://doi.org/10.1080/09613218.2018.1513695**
5. Awada M et al (2021). Ten questions concerning occupant health in buildings during normal operations and extreme events including the COVID 19 pandemic. *Building and Environment,* 188. https://doi.org/10.1016/j.buildenv.2020.107480
6. Wierzbicka A et al (2018). Healthy Indoor Environments: The Need for a Holistic Approach. *International Journal for Environmental Research and Public Health,* 1874(15). 10.3390/ijerph15091874
7. Colenberg, S, Jylhä, T & Arkesteijn, M. (2021) The relationship between interior office space and employee health and well-being – a literature review, Building Research & Information, 49:3, 352-366, DOI: 10.1080/09613218.2019.1710098

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 01
11:15 — 12:45

CHAIR
FELIPE ENCINAS

PAPERS
1640 / 1417 / 1608 / 1507 / 1107

5TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

How much does your building weigh?

An exploration into different early design stage LCA workflows

NEWMARCH, EMILY RUTH[1]; DONN, MICHAEL[1]; DOWDELL, DAVID[2]; TWOSE, SIMON[1]; SHORT, FIONA[3]

[1] Victoria University of Wellington, New Zealand
[2] Building Research Association of New Zealand
[3] Warren and Mahoney, New Zealand

ABSTRACT: This paper explores different approaches to implement life-cycle assessment (LCA) in the early stages of design. LCA is important to include in the early design stages as it informs the designer of parts of the building that have high embodied carbon. Addressing embodied carbon early in the design has high value as changes to a building's structure or form are easiest made during the first few weeks of a building's design process. Therefore, getting access to LCA results easily is critical, however, estimating the building quantities in such an early stage is difficult. To explore the application of different early design workflows, this paper focuses on three pathways that are available using tools produced by One Click LCA. Results from each workflow are compared against a LCA undertaken of the same case study building at a detailed design stage. Strengths and weaknesses of each workflow are analysed and the paper contributes recommendations for designers looking to analyse embodied carbon during early design.

KEYWORDS: Life-cycle assessment, early design workflow, embodied carbon, commercial office building

1. INTRODUCTION

The success of improved energy efficiency in buildings has shifted the focus of carbon management away from operational carbon to embodied carbon. As a result, LCA tools are being increasingly adopted [1]. However, a common barrier to their application is the requirement for a lot of detailed inputs [2], which are only available once most of the design decisions have been made. As with setting up an energy efficient design, calculating embodied carbon from the early stages of a project is the lowest cost option to obtain the highest performance [3], [4]. This paper explores the potential of applying different workflows for implementing LCA in early design to the estimate of embodied carbon for an office building in New Zealand. The purpose is to develop a workflow that can benefit designers in the early design stages of a project by providing a simple means to test many different strategies.

1.1 Challenges with estimating embodied carbon in early design

The measurement and management of embodied carbon throughout the design process has been widely discussed [1], [5], [6]. To mitigate embodied carbon in buildings, a designer needs to consider the carbon intensity of building materials, the efficiency of their application and the efficiency of the whole building form [7], [8]. Unlike the design of products, almost every building is unique due to differences in site conditions and brief requirements. This means that the set of embodied carbon mitigation strategies must also be unique to the design of a building.

To explore the benefit of different embodied carbon mitigation strategies during early design, several tools have entered the market to assist designers in early design decisions. A limitation of many of these tools is the reference buildings used to build the assumptions of how much carbon each building element will consume (foundation, façade etc). Whilst reference buildings might be appropriate for countries with similar conditions to the original reference building, in other countries with different building requirements there is a risk of under or over-estimation. Mistaken estimation of embodied carbon can go undetected due to the disconnect between the simplified inputs required by the tools and the building forms being explored during concept design. To resolve the disconnect, this paper explored multiple methods to generate quantities from typical input tables to parametric workflows.

1.2 Potential of parametric approach to generating quantities in early design

Put simply, a parametric design workflow is a way of linking decision variables with geometry [9]. Parametric modelling has been made accessible to design practice through visual programming software like Grasshopper and Dynamo. The combination of these scripting languages with 3D software like Rhino or Revit provides a platform that bridges mathematical logic to qualitative assessments of building form. A benefit of engaging with a parametric platform to generate material quantities for an LCA, is the simplification of the process [10], and the connection with a 3D model that resembles design qualities being explored through building form. The connection to a 3D form also has the potential to improve the user's ability to check for implausible quantities that are being input into the LCA.

2. METHOD

To calculate embodied carbon using LCA, tools and plugins produced by One Click LCA were used as they all connect to a consistent material database [11]. A commercial office building in New Zealand, with a detail design stage Revit model, was used as a case study to form a base line. Results from each early design LCA were compared to the LCA from the detailed design stage (fig 1).

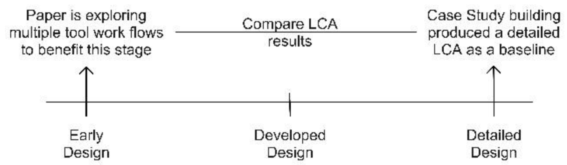


Figure 1: Overview of method

2.1 Detail Design Stage LCA Workflow

The base line LCA was completed using detailed material quantities from a Revit model that were input into a full LCA tool produced by One Click LCA [12]. Figure 2 outlines how the quantities from Revit were extracted by splitting all element type build-ups into individual materials and combined to create total quantities that were then mapped with materials from One Click LCA's data base.

2.2 Early Design Stage Workflow using Carbon Designer to generate quantities

To assess how the accuracy of embodied carbon estimations from One Click LCA's marketed fastest early design tool, Carbon Designer [13], the inputs were matched as close as possible to the case study building and the two LCA results were compared. Figure 2 illustrates the process of how quantities are automatically estimated and materials automatically assigned to quickly generate results outlining the embodied carbon results per building element. Figure 3 provides a more detailed example of a typical table to input a building's geometry and classifications on the left column and the automatically calculate quantities for review the following two right columns.

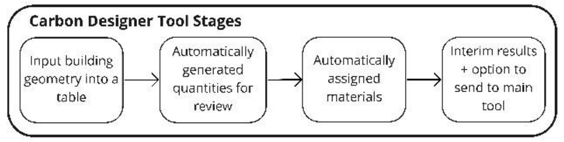


Figure 2: Carbon Designer workflow

Figure 3: Example of typical table in Carbon Designer tool by One Click LCA

2.2 Early Design Stage Workflow using Parametric Tools to generate quantities

To explore the use of a parametric modelling method, simplified building elements were generated in grasshopper and baked into separate layers in rhino. The One Click LCA rhino plug-in was used to calculate results [14]. Figure 4 shows an overview of the proposed parametric workflow. Figure 5 illustrates an example of how quantities are generated using Grasshopper and Rhino.

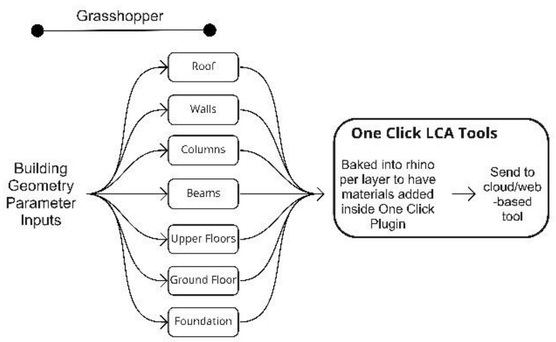


Figure 4: Parametric workflow using Grasshopper, Rhino and One Click LCA

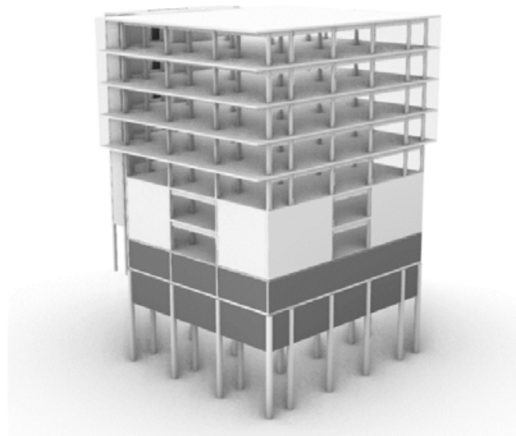


Figure 5: Example of Rhino model with geometry generated in Grasshopper

2.2 Method to merge workflows.

The parametric workflow is limited by not necessarily generating quantities for smaller or more detailed elements like finishes, doors, and stairs etc. To explore a workflow that has the same building calculation scope as the detailed model the material quantities from the 3D Rhino model were merged with data from Carbon Designer. The purpose was to evaluate the accuracy of the estimation when modelled and non-modelled elements are combined into one set of quantities. Figure 6 illustrates the method to merge workflows.

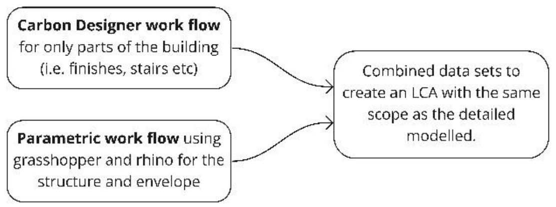


Figure 6: Combined workflows

3. RESULTS

This section covers the results from early design LCA workflows to estimate the embodied carbon in an office building from New Zealand. The results are displayed in totals, life-cycle stages, building elements and resource types to walk through the interpretation of the results from a high level down to the detail.

3.1 Overview of LCA Results

Comparing the full set of LCA results in Figure 7, it appears the parametric model has made a better estimate of the true building's geometry. The LCA result from the merged workflow increased, as expected, but is still within an acceptable range compared to the detailed LCA. The difference between the two carbon designer estimates is a change in envelope ratio. The automatically generated quantities for windows is 20% of the building's envelope. However, the case study office building was in a business park and did not connect to any other buildings, allowing all four sides to have windows. The true ratio was closer to 80% and this was updated in the second estimate using the tool. Doing so caused the results to increase slightly.

It is expected in the early design stages, especially when the building geometry has been simplified or the full building calculation scope of elements hasn't been completed, that there will be variation in expected results at the detailed design stage. The advice from One Click LCA is to assume a ±30% tolerance during the early design stage. Figure 7 shows the tolerance applied to each set of results. Additionally, the same tolerance has been applied to the detailed LCA results and projected across all results using a line to illustrate an acceptable range.

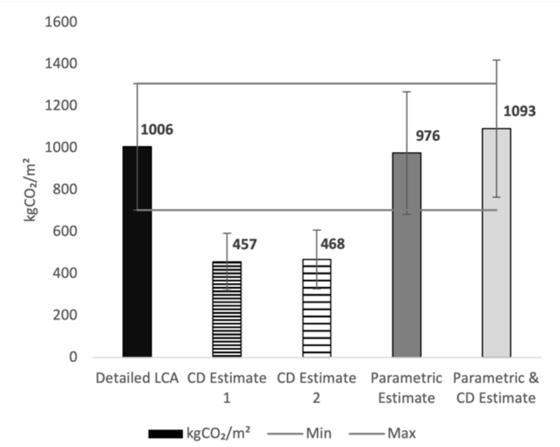


Figure 7: Overview of LCA results ($kgCO_2/m^2$)*
*All results exclude benefits from module D and biogenic carbon.

Figure 7 illustrates a proportion issue with the assumption of a percentage based tolerance. Both LCA's estimates produced in Carbon Designer underestimated the embodied carbon of the office building by more than 50%. Consequently, the tolerance band is significantly smaller and appears to make the results seem more accurate. A potentially more appropriate approach would be to apply a fixed tolerance band at this stage, for example ± $150kgCO_2/m^2$.

3.2 LCA results per life-cycle stage

At a glance, Figure 8 shows all LCA results follow the same pattern, however the results from Carbon Designer have consistency underestimated the amount of embodied carbon in each life-cycle stage compared to the detailed LCA. When inputting the building form into the table within Carbon Designer the quantities generated appeared reasonable. The underestimated results are an early indication that the materials automatically matched to the quantities are not representative of those found in New Zealand.

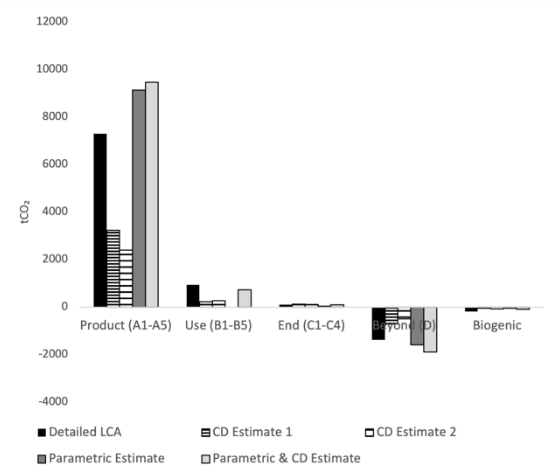


Figure 8: LCA results per life cycle stage (tCO_2)

The LCA results from the parametric workflow show the opposite problem to those calculated from Carbon Designer. These results show a significant overestimation of results in the Produce and Beyond the Life-Cycle Stages. As the materials needed to be manually mapped to the quantities, New Zealand appropriate materials were applied within One Click LCA's Rhino Plugin. Therefore, the high product stage and the benefits beyond the life cycle is an early indication that the generated quantities for metals are too high.

3.3 LCA results breakdown per building element

Breaking down the results into more detail, the cause of the underestimation by the Carbon Designer workflow and the overestimation of the parametric workflow become more transparent.

Results across almost all building elements (fig 10) the two estimates using Carbon Designer underestimated the result. In the foundations, the tool was given inputs to allow for the highest level of seismic strength, deep piles up to 15m in soft soil, grid span and building height. As all these inputs are reasonable for the case study building, the results reinforce that the default materials the tool is applying to these elements are not like those available in New Zealand.

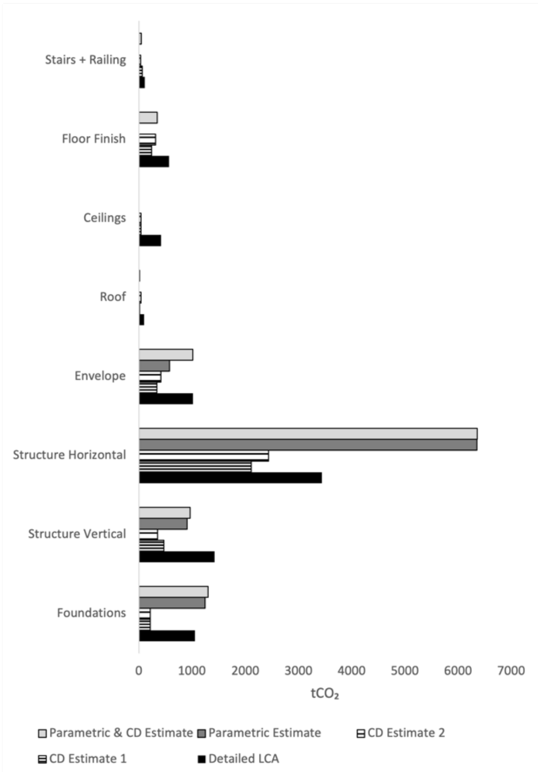


Figure 9: Breakdown of LCA results per building element (tCO_2)

Further, the change from 20% glazing to 80% between Carbon Designer estimate 1 and 2 and only marginally increased the impact of the envelope. The addition 60% of envelope being changed to glass, indicates that the carbon intensity for the solid verse transparent envelope elements have materials with similar carbon intensities. The ceiling is another area where the underestimate is significant enough to barely register on the results panel.

In contrast the foundation elements generated parametrically calculated a reasonable estimate. The parameters to generate the quantities were similar to those input to Carbon Designer, which suggests that a closer match in materials is the reason for the close comparison. However, whilst the foundations produced a close result, the comparative pattern between the detailed LCA and the parametric estimate was not consistent across all building elements. Notably the vertical and horizontal structures produced results that were under and over-estimated respectively. The vertical structure includes the steel columns and the horizontal structure includes the steel beams and concrete floor slabs. Whilst the geometry for a concrete slab is straight forward and difference in section are unlikely to create a big difference, the same is not true for steel structural elements. Steel has a high carbon intensity, making the estimated quantity of steel important to get within a reasonable range. The difference in profile area between a solid rectangle or circle compared to the I beam shape is significant and would undoubtedly inflate the quantities.

For both the vertical structure and horizontal structure were generated with the same script but different dimensions. This script was created to generate the profile of an I-beam that is typical in New Zealand buildings. In the vertical elements, the volumes of steel were underestimated compared to the detailed LCA. In the horizontal elements, the volumes of steel were overestimated compared to the detailed LCA. This suggests that there can be an element of human error when generating quantities through this method. The user modelling the building had a background in architectural design but was not an engineer. Risk of incorrectly sizing the steel element could happen in two ways: 1) overall dimensions of the beams or columns, 2) thickness of steel web and flange.

An identified limitation of the parametric workflow was a limited building element calculation scope. In Figure 10 the elements that were excluded from the calculation were the Stairs + Railings, Floor Finishes, and Ceilings. In the detailed LCA all these elements contributed a relatively low amount and the exclusion of them didn't warp the results too heavily. The workflow that merged quantities from Carbon Designer and the parametric model, did supplement results in the missing elements. However, like in other areas, the materials selected should be evaluated to make sure they are a good representation of what is available in New Zealand.

3.4 LCA results breakdown per resource type

Across all LCA's metals were the highest contributing material, which makes sense for an office building with a primary steel structure (fig 11). Taking a focused examination of the materials automatically assigned in Carbon Designer is was found that the tool assumes a 60% recycled content for structural steel. However, in New Zealand this value is on average between 10-15%.

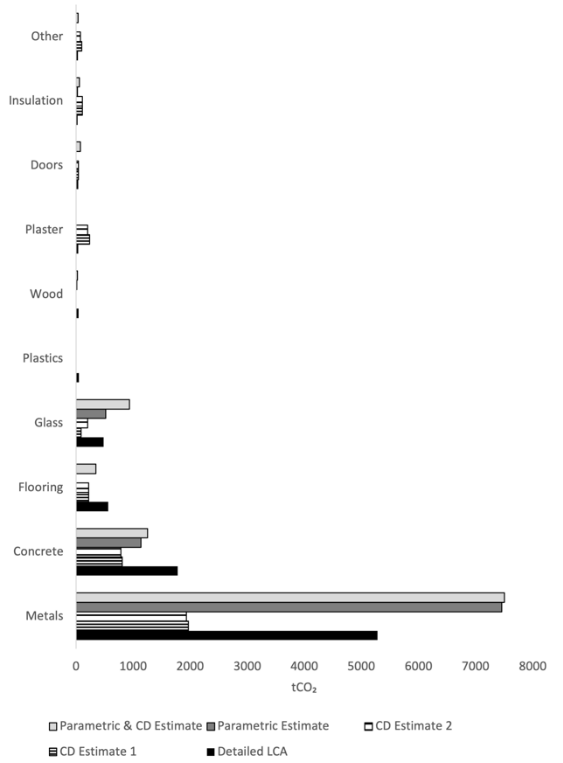


Figure 10: Breakdown of material resource types

It is known that the same material was used in the detailed LCA and the model with parametrically generated quantities. Figure 10 identified the horizontal and vertical structures were showing inaccurate results compared to the detailed LCA. With figure 11 it can be determined that the steel I-beams were miss calculated due to the high quantity of metals present in the results of figure 11. From figure 10 the element contributing more than usual was the horizontal structure. In the model the horizontal structure is made up of a reinforced concrete slab and steel beams. As it is the metals that are contributing more than expected it is reasonable to determine that the steel I-beams have been sized incorrectly.

3.5 A comparison of quantities generated for steel

It has been consistently observed and reinforced that the steel quantities have not been reasonably generated in any of the early design LCA workflows. Figure 12 shows that the quantities for Beams was the most incorrectly generated in both the tool (Carbon Designer) and human (Parametric parameter).

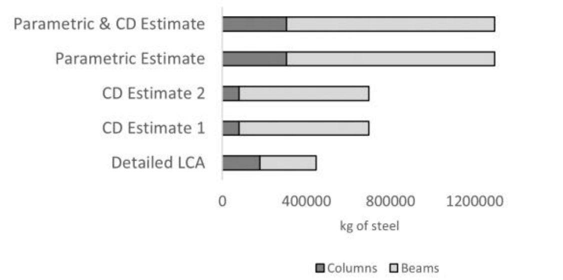


Figure 11: Comparison of steel quantities generated in each workflow

4. CONCLUSION

To ensure projects have the best chance of staying within critical carbon budgets, it is important that embodied carbon emissions are evaluated from the beginning of the project. As a contribution towards this necessity, this paper explored a range of LCA workflows for early design using currently available tools produced by One Click LCA.

It is inevitable in the early stages of design, where less information is known, to accept a reasonable performance range over a precise outcome of embodied carbon. In the LCA comparison between the detailed and concept design completed of the case study building, the acceptable range was expected to be ±30%. However, the results from the concept design LCA was under half the size of the detailed calculation (fig 7). This level of underestimation of embodied carbon drew attention to built-in assumptions within the tool that inadequately represented a New Zealand office building. These assumptions included ratio of glass façade to solid external walls and additional structure due to seismic load requirements and being built on reclaimed land.

To visually connect the generated quantities for different building elements and the overall building form, a parametric building script was created in grasshopper to generate the approximate geometry of the building. The script was built as a proof of concept to demonstrate the potential of the workflow being used during concept design. The results from the parametrically generated geometry came within the 30% tolerance of the detailed LCA. However, through a more rigorous analysis of the results from the different workflow both had weakness. In response to strengths and weakness of both workflows, this paper contributes a series of recommendations for designers.

4.1 Recommendations for designers using Carbon Designer

This paper explored a case study of an office building in New Zealand. The case study illustrated the importance of using a localised set of assumptions around the embodied carbon content of different materials. Therefore, it is recommended to develop a local reference building that tools like Carbon Designer can draw information from. Using a reference set of assumptions will allow glazing ratios and recycled content in generic data to be more reasonably represented.

4.2 Recommendations for designers using a parametric modelling workflow.

A clear benefit of being able to parametric generate geometries is that the designer can quickly test and explore different strategies during the early design stages. However, for buildings that use a steel structure where the profile of the member is essential for generating quantities, it is recommended to design with a higher level of detail. Additionally, for buildings that require an engineer, like an office building in a seismically active country, an engineer should be involved in the sizing of columns and beams. The involvement of an engineer in early design stage element sizing could be through the form a guide providing approximate size ranges for different building heights or spans. In the absence of appropriate guides, designers should consult a structural engineer early for guidance on approximate member sizes.

ACKNOWLEDGEMENTS

To be added to the final version of the paper.

5. REFERENCES

[1] F. Pomponi and A. Moncaster, 'Scrutinising embodied carbon in buildings: The next performance gap made manifest', *Renew. Sustain. Energy Rev.*, vol. 81, pp. 2431–2442, Jan. 2018, doi: 10.1016/j.rser.2017.06.049.

[2] F. N. Rasmussen, T. Malmqvist, and H. Birgisdóttir, 'Drivers, barriers and development needs for LCA in the Nordic building sector – a survey among professionals', *IOP Conf. Ser. Earth Environ. Sci.*, vol. 588, p. 032022, Nov. 2020, doi: 10.1088/1755-1315/588/3/032022.

[3] R. Marsh, F. Nygaard Rasmussen, and H. Birgisdottir, 'Embodied Carbon Tools for Architects and Clients Early in the Design Process', in *Embodied Carbon in Buildings: Measurement, Management, and Mitigation*, F. Pomponi, C. De Wolf, and A. Moncaster, Eds. Cham: Springer International Publishing, 2018, pp. 167–190. doi: 10.1007/978-3-319-72796-7_8.

[4] A. A. Morini, M. J. Ribeiro, and D. Hotza, 'Early-stage materials selection based on embodied energy and carbon footprint', *Mater. Des.*, vol. 178, p. 107861, Sep. 2019, doi: 10.1016/j.matdes.2019.107861.

[5] C. De Wolf, F. Pomponi, and A. Moncaster, 'Measuring embodied carbon dioxide equivalent of buildings: A review and critique of current industry practice', *Energy Build.*, vol. 140, pp. 68–80, Apr. 2017, doi: 10.1016/j.enbuild.2017.01.075.

[6] J. Gantner, W. Fawcett, and I. Ellingham, 'Probabilistic Approaches to the Measurement of Embodied Carbon in Buildings', in *Embodied Carbon in Buildings: Measurement, Management, and Mitigation*, F. Pomponi, C. De Wolf, and A. Moncaster, Eds. Cham: Springer International Publishing, 2018, pp. 23–50. doi: 10.1007/978-3-319-72796-7_2.

[7] MBIE, 'Building for Climate Change: Transforming the Building and Construction Sector to reduce emissions and improve climate resilience', New Zealand Government, New Zealand, Jul. 2020.

[8] M. of B. MBIE Innovation and, 'Whole-of-life embodied carbon emissions reduction framework', *Innov. Employ.*, p. 24, 2020.

[9] E. Touloupaki and T. Theodosiou, 'Optimization of Building form to Minimize Energy Consumption through Parametric Modelling', *Procedia Environ. Sci.*, vol. 38, pp. 509–514, Jan. 2017, doi: 10.1016/j.proenv.2017.03.114.

[10] A. Hollberg, 'A parametric method for building design optimization based on Life Cycle Assessment', Apr. 2017, Accessed: Jun. 03, 2020. [Online]. Available: https://e-pub.uni-weimar.de/opus4/frontdoor/index/index/docId/3800

[11] 'LCA Database of Building products: local and global data for your LCA', *One Click LCA® software*. https://www.oneclicklca.com/support/faq-and-guidance/documentation/database/ (accessed Sep. 30, 2021).

[12] 'Net Zero Carbon tool', *One Click LCA® software*. https://www.oneclicklca.com/net-zero-carbon-tool/ (accessed Sep. 30, 2021).

[13] 'Carbon Designer: Easy Baseline Buildings & Carbon Optimization', *One Click LCA® software*. https://www.oneclicklca.com/carbon-designer/ (accessed Sep. 30, 2021).

[14] 'Rhino Integration', *One Click LCA Help Centre*. https://oneclicklca.zendesk.com/hc/en-us/articles/360016862320-Rhino-Integration (accessed Sep. 30, 2021).

PLEA SANTIAGO 2022
Will Cities Survive?

Courtyard as a microclimate modifier of buildings in hot climates: A parametric Study

ALQADI, SHIREEN BADER[1 2]; ELNOKALY, AMIRA[2]; KAFAFI, AHMAD [3]; IRFAYIEH, WALA[3]

[1]Birzeit University
[2]University of Lincoln
[3]Palestine Polytechnic University

ABSTRACT: the courtyard is one of the passive cooling strategies in traditional buildings and is reported to reduce a building's heating and cooling energy consumption and decrease the dependence on mechanical heating and cooling to reach the comfort levels. In this paper three critical factors of courtyard design were tested which are orientation, shape factor and aspect ratio of the courtyard to find their impact on the thermal comfort and energy demand for heating and cooling purposes were tested in a hot climate. The study used in summer and winter time using design-builder. The impact was for the square and rectangular courtyards.
KEYWORDS: Energy performance, hot climate, courtyard, aspect ratio, shape factor, orientation.

1. INTRODUCTION

Humans throughout history aimed to control the built environment to meet their ambitions. They used several strategies that depended on the available technologies at the time. This used to include thick wall and pitched roofs in the cold areas and small opening and water fountains in hot areas. The courtyard was also one of the widely used strategies that people adopted in hot climates and can be found in vernacular architecture of hot areas such as Egypt Syria and Algeria, due to their significant influence on enhancing thermal indoor conditions.

Roughly, 40% of energy is consumed by the building sector (Atlam and Rabiee, 2016), with a very large proportion of its generated electricity from non-renewable resources (Elnokaly et al, 2019). The consequences countries globally face today, due to climate change is causing a steep increase in air temperature due to heat waves, coupled with significant use of HVAC systems, with special reference to hot climates, that only surge the energy demand. This unsustainable use of our resources has expanded the anthropogenic polluted heat, and in turn, the urban heat island. The 'building envelope' has been identified by various studies to reduce heat gain, and hence energy consumption, through controlling the heat flow in and out of the building through shading, orientation, form, and its thermal insulation (AlQadi, Sodagar & Elnokaly, 2018; Okba, 2005). Traditional and vernacular architecture featured varied properties such as natural ventilation, shading, thermal mass, and passive cooling techniques as some of the most important passive design features to achieve higher comfort levels (Elnokaly and Elseragy, 2013; Fathy, 1986). Concomitantly, studies argue that in hot-arid climate regions, 70 to 80% of total energy consumption is consumed in the operation of active cooling systems (Koch-Nielsen, 2013; Ayoub and Elseragy, 2018). To a large extent limitations in the understanding of environmental and thermal performances of architectural forms and geometries hampered their recognition by clients and the construction industry (Elseragy and Elnokaly, 2007).

Zeng et.al (2011) argues that there are other attributes that influence indoor thermal comfort such as thermo-physical properties of the building's envelope material. Oher researchers (Meyn and Oke, 2009; Ramamurthy et. al, 2015; Santamouris, Synnefa and Karlessi, 2011) identify the roof optical properties, specifically the albedo, thermal emissivity and the roof insulation to play a vital role in the energy balance of buildings. Other key features are the traditional curved roof forms (vaults and domes) that have many advantages in reducing the total heat gain from the roof and therefore, providing a passive cooling effect for buildings (Elseragy and Elnokaly, 2008).

2. Review of courtyard design

Qualitative and quantitative explanations were previously presented on the impact of courtyards in hot-arid regions to act as a microclimate modifier and maintain lower indoor temperatures and channel breezes during the hot summer.

The courtyard is considered one of the oldest passive techniques of adapting and modifying climate conditions, and a low cost passive design strategy to provide thermally comfortable spaces (Soflaei, 2016). This typology can be traced back to 5000 years ago when were built in the Middle East and China (Soflaei, 2011) as a way to protect residences from bad weather and unfriendly neighbours (Reynolds, 2001).

A courtyard is defined as an enclosed space open from above and surrounded by buildings (Edwards, 2006). Its commonly applied as a microclimate modifier for its environmental potentials (Muhaisen, 2006; Almhafdy,2013; Taleghani, 2020). To achieve the best environmental conditions for humans with limited energy such as the ability to mitigate high temperatures, channel breezes and adjust the degree of humidity, it acts as a source of airflow to provide thermal comfort for the residence (Taleghani, 2020; Saxon, 1986; Sthapak, 2014). especially when its design was based on examined criteria, such as form, size, area, orientation, shading devices, vegetation, ground ratio, aspect ratio, shape factor, perimeter ratio and water pond (Muhaisan and Gadi, 2005; Ahmad, 2013; Markus, 2016).

Courtyard efficiency is mainly affected by its geometrical, environmental and physical features like geometrical configurations (Putri et al., 2020), orientations, proportions and formal design variants. Environmental features like natural ventilation, thermal performance and thermal comfort conditions for different climatic regions (Ghaffarian Hoseini, 2015).

The microclimate performance of courtyards is critically dependent on orientation and aspect ratio (Meir,1995).

3. METHOD

The methodological procedure is realized through an analytical approach that utilises Design-Builder (DB) (Ref) Version5 program. DB is a well-known program used in different research work since it has the proficiency to investigate multi-objectives of energy performance in individual buildings or in a group/array of buildings (ALqadi, 2018). This research parametrically investigates the energy demands/ performance of identified courtyards, seeking a better understanding of the reciprocal relationship and impact of the square and rectangular shaped courtyards and the resulting comfort levels in both summer and winter.

Using the DB in the hot climatic region of Alramtha, Jordan was tested for energy demands in summer and winter to reach a thermally comfortable indoor environment for a hot climate zone. The climatic region was chosen to examine the efficacy a courtyard could be to adjust the microclimate when the temperature is the highest in the hot zone and its impact also during winter. The literature shows that the different ratios affecting the thermal performance of the Courtyard are the shape ratio (L / W ratio) and the aspect ratio (H / W Ratio) (Muhaisen, 2006; Muhaisen & Gadi, 2005; Muhaisen & Gadi, 2006), which have a main role on the thermal performance of the Courtyard, also the influence of the Orientation on these ratios and on the thermal performance of the courtyard, in general were tested to find out the best scenarios for a courtyard building accordingly.

Three different ratios were taken for the Shape Factor (Ratio), which are: a square ratio (1:1) a rectangular ratio (1:2) and a rectangular shape with aspect ratio of (2:3). The three shapes were assessed against three parameters which are the height of with ratios 0.5, 1, and 1.5, and then these scenarios were tested according to the four different orientations as follows: E-W / NW-SE / N-S / SW-NE. These cases where then studied with all of their variables on the energy performance during summer and winter (see Figures 1,2).

3.1 Location: Al Ramtha, Jordan

The study was implemented in al-Ramtha district/Jordan. The researchers opted for the empirical investigation method due to its suitability to the study aim and nature.

Ar-Ramtha is a city situated in the far northwest of Jordan near the border with Syria. It covers 40 km² on a plain 30 km northeast of the Jordan River and is considered the second largest city in Irbid Governorate Irbid (Population and Statistics council, 2017).

Figure 1:

Location of Al-Ramtha (From: https://mapcarta.com/W379035377)

Al-Ramtha encounters a Mediterranean climate, where the summer is hot and long (four months on average), with cool nights. Diurnal differences are seen in Alramtha with temperatures ranging in summer from 27 °C– 33 °C. Spring and fall temperatures are thermally comfortable for a human's body, they range from 17 °C– 23 °C. The winter is cold and night-time temperatures record sometimes below 0 °C. Snowfall is experienced once or twice a year. The yearly average number of days with rain is 77. The lowest temperature ever recorded in Al-Ramtha was −18 °C in the blizzard of 1992 (Jordan Meteorological Department, 2022).

4. RESULTS

4.1 Square shaped court

For the square-shaped court, the simulation showed that an increase of aspect ratio decreases the monthly cooling energy during summer from 500kw/h to 360kwh, and the monthly heating energy during winter reduced from 160kwh to 90kwh in the hot climate (Figures 3 and 4). The results show that an increase of courtyard aspect ratio in the square case generally decreased the amount of energy needed for cooling. This is due to the shadings created on the courtyard's wall, which decreased the solar radiation received (See Figures 2 and 3)..

4.2 Rectangular court with 2:1 ratio

Figures 4 and 5 show the court with a rectangular shape with 2:1 ratio, the simulation showed that the best orientation for hot zone climate to be north-south, where the shorter side is exposed to direct sun radiation in the peak time of the day. Also, it was found that the higher the aspect ratio the more efficient performance the court provide, where the monthly cooling energy demand decreased from 50 kWh to 360 kWh, and heating energy demand decreased from 150 kWh to 80 kWh monthly.

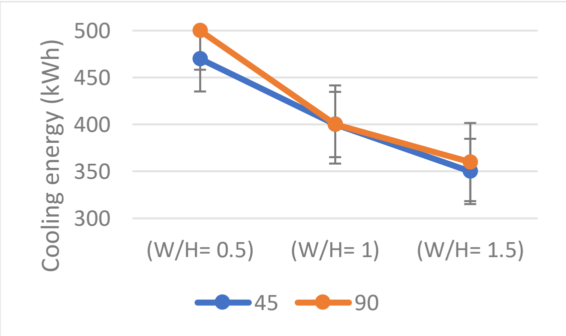


Figure 2:
Total cooling loads of square shape

Again, the results show the courtyard aspect ratio in this case decreased the amount of energy needed for cooling. This is due to the shadings created on the courtyard's wall, which decreased the solar radiation received. But the increase of the aspect ratio decreased the heating energy up to 1 aspect ratio then increased again when the W/H= 1.5.

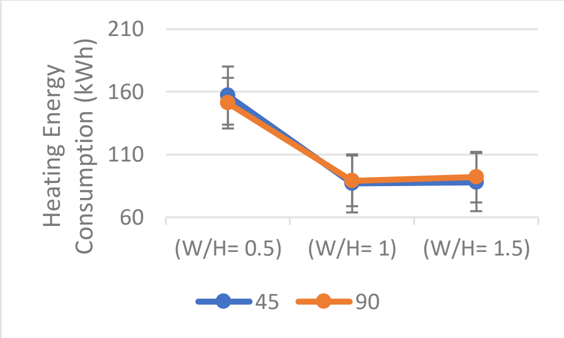


Figure 3:
Total heating loads of square shape

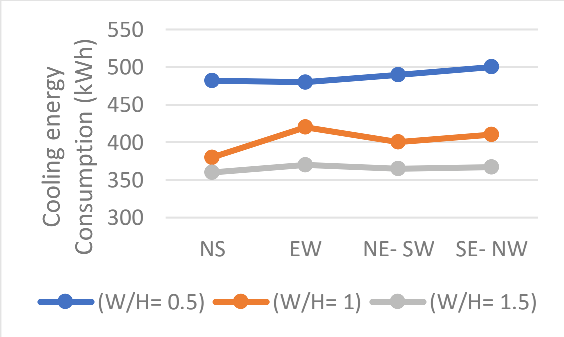


Figure 4:
Total cooling loads of rectangular shape factor2:1

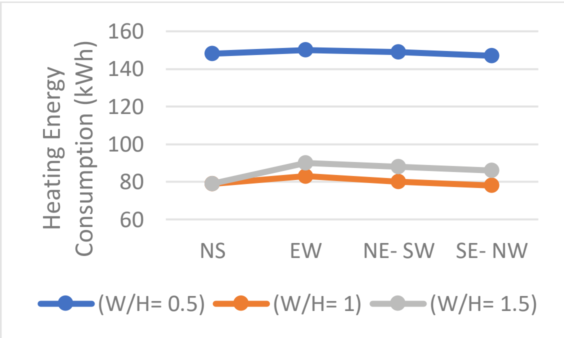


Figure 5:
Total heating loads of rectangular shape factor 2:1

4.3 Rectangular court with 2:3 shape factor

For the rectangular courtyard shape with 2:3 shape-factor, simulation results showed no differences from the performance of the 2:1 shape-factor courtyards where the best orientation was north-west, and the increasing aspect ratio would decrease energy demands for cooling and heating needs, where the simulation showed decreasing in energy demands for cooling from 490 kWh to 360 kWh and decreasing in heating energy demands from 150 kWh to 85 kWh. Again here, when the aspect ratio increases the cooling energy decreases. However, this impact becomes very minimal in heating, where the optimum energy consumed is when the W/H=1 (Figures 5 and 6).

Figure 5:
Total cooling loads of a rectangle shape factor 2:3

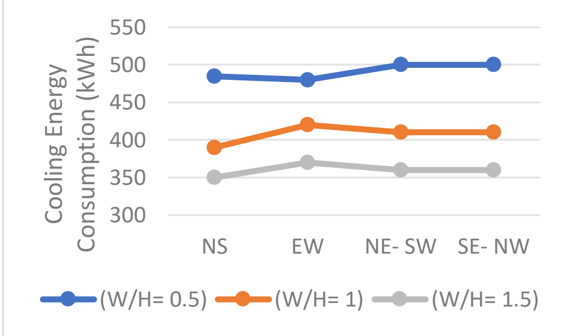
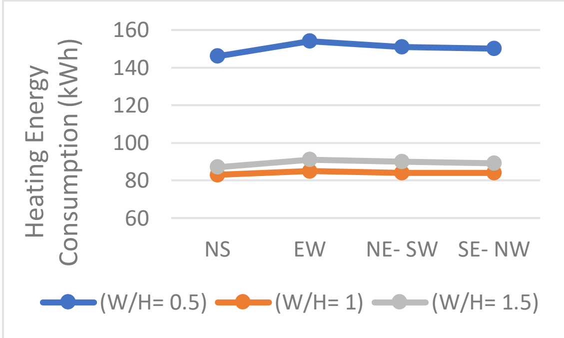


Figure 6:
Total heating loads of a rectangle shape factor 2:3



From the last three cases, we can notice that the shape-factor have less impact on the energy performance (as the cooling energy ranged between 350-500 kWh in all the cases, and between 70-160 kWh for the monthly heating energy consumption).

5. DISCUSSION

The shape-factor effect was found to have minimal impact on the thermal performance of the courtyard. However, the orientation and in turn, the location of the sun have a direct Impact on the amount of the generated shading conditions on the adjacent walls and hence, the energy use. Generally, the lower the sun's altitude, the more the shadows produced on the internal Surfaces and vice versa. More precise results necessitate further cases to be investigated in the evaluation as well as validating the simulated models with field and data /measurement, that can be conducted as future studies. The design of this study and method can be generalized to different climates and forms of courtyards with conducting the same procedure for design optimisation in different climates.

Although, courtyards are considered a heritage passive design vocabulary in the design of buildings in most of the Middle East and North African countries, however, there has been a steep decline in its adoption in today's contemporary Architecture. There can be many reasons for this decline, such as the scarcity of land, the trend towards high rise building apartments or imitating western housing typology. Today's energy and climate challenges all over the globe should allow us to reflect on the use of courtyards and its long-standing history in Architecture as a passive micro-climate modifier and revisit its use in our contemporary housing design. Hence, the use of courtyards would not only provide an aesthetic architecture solution, an outdoor garden, a family breather, but its adoption to enhance thermal comfort, energy efficiency and sustainable measure within the building design. Designing Post-Pandemic, it will offer a place for the family to meet outdoors, for friends to gather in a safe, outdoor and clean environment with adequate airflow. The COVID-19 and the lockdown situation has taught Architects and Building Developers that if there is an opportunity to provide a private outdoor space within the housing development it is important to do so. Concomitantly, today, Post-COVID we as a design community are definite that access to open outdoor space will redefine dense housing developments, and courtyard adoption can be one of the solutions to this problem.

6.CONCLUSION

The courtyard is a traditional passive design strategy to achieve thermally comfortable buildings in hot-arid zones. Simulation results showed that for hot climate zones, the best direction for courtyards is north-south due to minimizing the exposed areas to direct solar radiation. The increase of the courtyard aspect ratio in the square case generally decreased the amount of energy needed for cooling. This is due to the shadows created on the courtyard's wall, which decreased the solar radiation received. The same was found in the case of a rectangular court with shape factors of 2:1 and 2:3. For the heating energy, increasing the aspect ratio did not have a significant impact on the heating energy in the square shape. However, it had decreased the heating energy in the rectangular shapes up to W/h=1, then it started increasing again due to the shadings that are formed in the courts where W/h= 1.5. Generally, increasing aspect ratio affects positively the courtyards' performance efficiency, and as the ratio was more or equal to 1.5 it performs effectively due to the shading effect which reduces heat gain during the day. According to simulation results, shape-factor effect on the thermal performance of the court was minimal. Covid pandemic has showed us that we architect can still learn from the heritage buildings which used to control the microclimate passively and with no harm on the environment while presenting a comfortable outdoor for the families and friends to socialize and meet. Using simulation to understand the exact performance of this feature can help us to develop the domestic buildings in the hot climates.

REFERENCES

- Ahmad, Sabarinah (2013), Courtyard Design Variants and Microclimate Performance, Procedia - Social and Behavioral Sciences 101(3–4):170–180
- Almhafdy, N. I. (2013). Analysis of the Courtyard Functions and its Design Variants in the Malaysian Hospitals. Procedia - Soc. Behav. Sci., pp. 171–182
- Atlam, B. and Rapiea, A. (2016) Assessing the future of energy security in Egypt, Int. J. Energy Econ. Pol. 6 (4) 684e700.
- AlQadi, S.B., Sodagar, B. and Elnokaly, A. (2018) Estimating the heating energy consumption of the residential buildings in Hebron, Palestine, J. Clean. Prod. 196 2018). ISSN 0959-6526.
- Ayoub, M. and Elseragy, A (2018) Parameterization of traditional domed-roofs insolation in hot-arid climates in Aswan, Egypt, Energy Environ. 29 (1) (2018) 109-130.
- Construction and Building Materials - CONSTR BUILD MATER 20, 435–440
- Edwards, B. (2006). Courtyard Housing: Past, Present, Future. Taylor & Francis Group
- Elnokaly, Amira, Ayoub, Mohamed and Elseragy, Ahmed (2019) Parametric Investigation of Traditional Vaulted Roofs in Hot-Arid Climates. Renewable Energy, 138. pp. 250-262. ISSN 0960-1481
- Elnokaly, A. and Elseragy, A (2013) Sustainable heritage development: learning from urban conservation of heritage projects in non-western contexts, European Journal of Sustainable Development, 2 (1) (2013) ecsdev.org).
- Elseragy, A. and Elnokaly, A (2007) (Assessment criteria for form environmental performance of building-envelope in hot climatic regions, in: Proceedings of the Passive and Low Energy Architecture 24th International Conference PLEA 2007, Republic of Singapore, Singapore, 2007, pp. 156-162.
- Elseragy, A. and Elnokaly, A (2008) Proposal of sustainable and eco-exurban communities at the western desert development corridor in Egypt, in: Proceedings of CSAAR 2008, Instant Cities: Emergent Trends in Architecture and Urbanism in the Arab World, April 2008, Sharjah, UAE. Publication Press.
- Fathy, H (1986) Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates, University of Chicago Press, United States.
- Jordan Meteorological Department (2022). Jordan Meteorological Department. Retreived from: https://www.weatherbase.com/weather/weather.php3?s=55204&refer= ; Retrieved 12 September 2022.
- Koch-Nielsen, H. (2013) Stay Cool: A Design Guide for the Built Environment in Hot Climates, Routledge.
- F. Soflaee, W. Z. (2011). , Sustainability of vernacular courtyard houses (comparative study of vernacular courtyard houses in China & Iran). 13th International Conference on NonTraditional Materials and Construction Technology (NOCMAT13). Changsha, China
- Farzaneh Soflaei, M. S. (2016). Traditional Iranian courtyards as microclimate modifiers by considering orientation, dimensions, and proportions. Frontiers of Architectural Research, pp. 225-238.
- Ghaffarianhoseini, U. B. (2015). Thermal performance characteristics of unshaded courtyards in hot and humid climates, . Build. Environ., pp. 154–168.
- Mahaya, Chafik, Zemmouri, Noureddine, Elnokaly, Amira, Benharra, Houda (2022) Solar Access Assessment in Semi-Arid Urban Context: An Application Study for Ten Urban Forms of Existing Apartment Buildings Districts in Batna City, Algeria, Accepted Manuscript in Sustainable Cities and Society on 17th of April 2022
- Markus, B. (2016, sep). A Review on Courtyard Design Criteria in Different Climatic Zones . African Research Review , pp. 181-192.
- Meyn, S.K. and Oke, T.R. (2009) Heat fluxes through roofs and their relevance to estimates of urban heat storage, Energy Build. 41 (7) 745-752.
- Meir, P. &. (1995). On the microclimatic behavior of two semi enclosed attached courtyards in a hot dry region. Building and Environment, pp. 563-572.
- Muhaisen, A & Gadi, M.B. (2005) Mathematical model for calculating the shaded and sunlit areas in a circular courtyard geometry, Building and Environment, 40 (2005), pp. 1619-1625
- Muhaisen, A. & Gadi, M.B. (2006) Shading performance of polygonal courtyard forms, Building and Environment, 41 (8) (2006), pp. 1050-1059
- Muhaisen, A. (2006); Shading simulation of the courtyard form in different climatic regions Build and Environment, 1 (12) (2006), pp. 1731-1741
- Okba, E.M. (2005) Building envelope design as a passive cooling technique, in: Proceedings of Passive and Low Energy Cooling for the Built Environment, Santorini, Greece, 2005, pp. 467-474.
- Population and Statistics council (2017) "Population of Jordan 2017" (2017) (PDF). Archived from the original (PDF) on 25 August 2018. Retrieved from: https://web.archive.org/web/20180825062939/http://dosweb.dos.gov.jo/DataBank/Population_Estimares/2017/PopulationEstimatesbyLocality.pdf . Retrieved 1 SEPTEMBER 2022.
- Putri Melati, Gusti Antaryama, Ima Defiana (2020), Effect of courtyard aspect ratio on annual cooling energy of highrise apartment in surabaya, The Journal of Technology and Science, 31(3)
- Ramamurthy, P., Sun, T., Rule, K. and Bou-Zeid, E. (2015) The joint influence of albedo and insulation on roof performance: an observational study, Energy Build. 93 (2015) 249-258.
- Reynolds, J. (2001). Courtyards: Aesthetic, Social, and Thermal Delight. Wiley, US .
- Santamouris, M., Synnefa, A. and Karlessi, T. (2011) Using advanced cool materials in the urban built environment to mitigate heat Islands and improve thermal comfort conditions, Sol. Energy 85 (12) (2011) 3085-3102.
- Saxon, R. (1986). Atrium buildings—design and development. London : Longmans.
- Sthapak, S. &. (2014). Courtyard houses: An overview. Recent Research in Science and Technology.
- Taleghani, M. ,. (2020, 10 8). Environmental impact of courtyards - A review and comparison of residential courtyardsbuildings in different climates. Journal of Green Building, pp. 113-136.
- Zeng, R., Wang, X., Di, H., Jiang, F. and Zhang, (Y. 2011) New concepts and approach for developing energy efficient buildings: ideal specific heat for building internal thermal mass, Energy Build. 43 (5) 1081-1090.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA 2022 SANTIAGO
Will Cities Survive?

Daylight discomfort glare in home workspaces
influencing factors and adaptation

VINCENT BUHAGIAR[1]; KIMBERLEY PSAILA DIACONO[1]

[1]Department of Environmental Design, Faculty for the Built Environment, University of Malta, Malta

ABSTRACT: In the wake of the COVID pandemic, office workers were constrained to adapt a home niche to work from home. This paper links the perception of daylight discomfort glare in adapted home workspaces, with particular emphasis on the presence of a view and task difficulty. In addition, the investigation seeks to recognise possible trade-offs made, to avoid or accept discomfort glare. Furthermore, the research explores the role of the view quality and its benefits to the occupants' wellbeing and the perception of architectural space, in association with visual comfort and perception of glare. The research questions are addressed through an intensive literature review and a questionnaire to gather qualitative information about the participant and their respective home workspace. Quantitative scientific data was collected using a light meter and a mobile app. The investigations highlighted the positive consequences on the wellbeing of occupants working from home, through availability of natural light, access to an aperture and view satisfaction. Glare control did not affect work productivity. The desire for a view and daylight was considered a worthy trade-off for a sense of feel-good factor. In the absence of such facilities subjects experienced psychological and physiological challenges, as well as a drop in productivity at the home-workplace.

KEYWORDS: discomfort glare, daylight, view quality, task difficulty, adapted home-workspace

1. INTRODUCTION

In the context of climate change, energy efficiency has become one of the primary challenges among architects in architectural design, focusing on efforts to reduce dependence on HVAC systems and artificial lighting. This gave rise to other complex predicaments. Working in an artificially lit environment persistently, for a long time, is considered detrimental to the occupants' physiological and psychological health[1]. On the other hand, working in a natural lit environment is believed to lead to decreased levels of stress and discomfort. Studies across several fields have presented evidence that daylight is desirable in the interior spaces that humans frequent, in particular for long periods of time. The most logical manner to admit daylight in buildings is through windows. These apertures are crucial to provide a view and a connection to the outdoor surrounding environment. The growing amount of evidence also suggests that people tend to react positively to daylit indoor spaces for two major reasons that fulfil the basic human needs namely, to experience environmental stimulation and visual ability to carry out tasks [1]. In spite of all this knowledge the current lighting design standards do not respond to the health concerns raised in relation to light and occupants. Lighting standards and glare indices have been founded on one single principle: the visual performance. However, as lighting standards are changing and glazed areas are increasing, the visual comfort of occupants is rarely considered. One of the most common effects of daylight is uncomfortable solar glare on display screens while working, which interferes with the occupants' well-being, [2]. In scientific research, glare is defined as the visual sensation attributable to an intensity of light in the field of vision that is greater than the intensity of light that the eyes can adapt to at that moment in time,[3].

As the Covid-19 pandemic spread globally, we all had to adapt to a dramatic shift in our way of life, both at work and at home. Offices and academic institutions had to shut down. This pushed everyone to spend more time at home more than ever. The way homes have been adapted to the new COVID-related needs does not necessarily mean better working conditions – albeit for most, if not for all of us. Visual comfort at the adapted home-office, is but one aspect of this research. It tackles both qualitative and quantitative issues related to architectural planning, the view, daylight glare, work productivity versus a sense of well-being when working form home; this is the epitome of new studies in this emerging cross-over.

2. RESEARCH OBJECTIVES

The research paper provides an insight on how the working environment impacts the visual comfort of its occupants, describe and examine the current state of home workspaces and questions the potential role of interiors on the occupants' visual comfort. The potential influencing factors in the perception of daylight discomfort glare have been categorised into three groups, namely, (i) factors related to lighting levels, (ii) factors related to observers as human subjects, and (iii) related to space context. The last two categories have been generally ignored in standards and mathematical equations. Among other things, this study seeks to determine whether factors related to observers such as the task difficulty carried out can influence the perception of discomfort glare. Another objective of this research is that of identifying if the 'attractiveness' of the view outside the aperture impacts the psychological perception of discomfort glare during screen time. This will provide a clearer understanding of what type of view is considered 'attractive'. An important goal of this study is to determine any trade-offs that are consciously or unconsciously made by the occupants which are influenced by the perception of discomfort glare.

3. LITERATURE REVIEW
3.1 Malta and its Climate

The Republic of Malta is an archipelago of three islands, the main inhabited islands are Malta and Gozo. Over 35% of employment at national level is in industries that require employees to spend the majority of the hours of the workday carrying out screenwork, [4]. This implies that a substantial percentage of the said workforce is potentially experiencing visual discomfort such as discomfort glare at the workplace, that is deemed insignificant or openly ignored.

The Köppen climate classification categorises Malta as Csa, that is the climate is mild, generally warm and dry. The average hours of daylight during the winter months are 10.3 hours, in contrast to the 14-hour days in the summer months. Malta is located at latitude 35°52'N, in the centre of the Mediterranean Sea, experiencing the typical Mediterranean high sunlight exposure with a high solar altitude in summer and low altitude in winter. The direct sunlight available is reduced in winter due to the higher cloud cover, meaning that high amount of sunlight is diffused. On the other hand, as cloud cover is low during summer very intense solar radiation is experienced. Subsequently, the diffused sunlight in winter combined with a low altitude sun present the possibility of a consistent source of discomfort glare on screens, [5].

3.2 Glare and Comfort

A significant outcome of high levels of illuminance is glare. When a bright source of light happens to be in the field of view a veil of light manifests itself over the surroundings. The viewer will be nearly completely blinded if close to the light source or experience limited visual performance if further away,[6]. Discomfort glare is defined as an unpleasant effect that does not necessarily impair the sense of sight. As discomfort glare is a subjective effect it poses a difficulty to properly measure it. The potential factors that influence discomfort glare can be classified into three categories: lighting-related, context related and subject-related factors.

The research focuses on the influence of view, a context-related factor. An interesting quality view depends on how much information it contains, the more information a view provides of the surrounding environment the more engaging is the view. A good view is considered to have three levels, the ***lower*** level is the foreground that includes paving and vegetation, the ***middle*** level includes man-made or natural objects such as other buildings, hills and trees and finally the ***upper*** level consists of the distant elements of the view that is the sky and natural or man-made skyline, [6]. However, the quality of the view is complex to rate as it involves subjective judgements. Hopkinson believed that the view of the outside acts as an enhancing or mediating factor as the occupants' tolerance to discomfort glare increases when offered a view with a multitude of engaging information,[7]. The view outside is potentially influencing the health, productivity and well-being of occupants. Studies concluded that the attractiveness of the view does influence the perception of discomfort glare, [8].

The second factor this research focuses on is the task difficulty, a subjective-related factor. The visual task difficulty is associated to the observer's ability to deduce information from the stimulus within the field of view. A poor visual performance assessed by a subject can result from the difficulty of the task that influences the tolerance to discomfort glare, [9]. The studies carried out have investigated the influence of task difficulty on the perception of daylight discomfort glare; these failed to validate this hypothesis.

4. RESEARCH METHODOLOGY

The research methodology is twofold, starting with a literature review, followed by the second part of the research, that is the attainment of primary qualitative and quantitative date. This entailed field research that included questionnaires with subjects working from their residences accompanied by numerical data. Data collected was then reviewed by comparing and contrasting the findings with those reviewed in the preliminary research and detecting conclusions.

Table 1: Suggested thresholds of DGPs at three levels of glare sensation

Thresholds	Quartile method	PPD method	Mean
Imperceptible – perceptible	0.23	0.20	0.22
Perceptible - disturbing	0.25	0.22	0.24
Disturbing – intolerable	0.26	0.25	0.26

The qualitative component of the mixed methods methodology implemented was carried out through a questionnaire. This was distributed among individuals working from home through an electronic link to the online questionnaire. The participants were not made aware that the study aims to determine the influence of contextual factors on the perception of discomfort glare, not to bias the participants focus on these factors. The online questionnaire was composed of 18 questions related to various themes and the participants had to answer it once, between 09:00 and 16:00 given that the participant had been carrying out screenwork for at least for 30 minutes. The online questionnaire was circulated among employees from diverse fields of office work for 24 days. The participant's susceptibility to survey fatigue was an essential concern which led to a majority of multiple-choice and 5-point scale rating questions. The questionnaire was divided into four main sections:

Section 1 – Personal Information
Section 2 – Workspace Information
Section 3 – Visual Comfort
Section 4 – Lighting Conditions

The participants were also asked to share a photograph of the view out the nearest aperture and highlight any bright areas, if present. The photographs were used to determine the quality of the view by answering several multiple-choice questions to assess the view quality, [10].

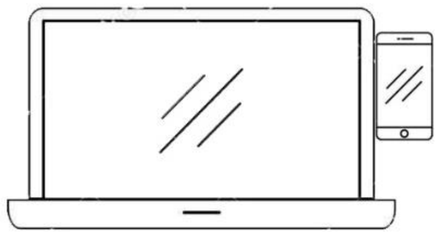


Figure 1: Gathering quantitative data [vertical illuminance] by a light meter application on the participants' phone.

The quantitative approach adopted in Section 4, as the final part of the questionnaire, where the participants were asked to download a light meter application on their phone and take readings of the vertical illuminance next to the computer screen approximately at eye level and record the number in lux, as indicated in figure 1. The vertical illuminance was used to calculate the Daylight Glare Probability (DGPs) as proposed by Wienold, as expressed by equation 1.

$$DGPs = 6.22 \times 10\text{-}5\ Ev + 0.184 \quad (1)$$

Ev – illuminance (lux)

The resultant DGPs were then compared to the suggested thresholds at three different glare sensations that are based on the predicted percentage of discomfort (PPD) method, as shown in Table 1. A major source of error encountered throughout the research was the variable factors of environmental characteristics of the various residences such as the difference in the reflective surfaces, finishes of walls and ceilings as well as the variability of the sunlight during the day and weather conditions under which the survey was taken. Other sources of error include discrepancies in illuminance readings as each value was measured with different devices depending on the sensitivity of the camera on the mobile phone.

5. FINDINGS AND DISCUSSION

The questionnaire was distributed, and data was collected from a total of 51 voluntary participants with a well-balanced gender distribution, ranging from 18 years to 65 years of age and inexperienced in the field of lighting. All the participants grew up in Malta, thus all were subject to the same indoor and outdoor climatic conditions for the greater part of their lives; this eliminated any possible inconsistencies from subject-related influence on the perception of discomfort glare. The online questionnaire was distributed for 24 days, from 24th May 2021 to 16th June 2021, throughout these weeks the weather was moderately consistent: sunny skies with patchy white clouds. An association between the participants age and the estimated amount of time spent at the workspace was observed. The majority of the participants spending between 6 to 8 hours at their workspace were observed to be between the age of 18 to 25 years, while most of the participants within the range of 26 – 35 years spend between 4 to 8 hours at their workspace. In terms of associations with age, it was observed that among the age groups of the participants the majority worked next to an aperture within a six-meter distance. In fact, only 17% of the participants had no access to an aperture and as a result lacked adequate natural light, thus relying on artificial lighting during their working day. The study focuses on the perception of discomfort glare due to daylight, meaning that 83% of the responses were valid since these participants heavily rely on daylight.

Figure 2: View of participant #32 – general view quality 8 points

The majority of participants justify relying on daylight in home workspaces to the positive influence on their general health, productivity and mood. In addition, other factors mentioned include the possibility to catch a glimpse of the surroundings beyond the enclosed workspace. The observers' glare assessment based on the glare sensation vote resulted in 10% of the total responses rating the glare as 'uncomfortable'. By applying the model for DGPs as expressed by equation (1), the resultant DGPs can be compared to the suggested thresholds. Based on this comparison it can be elucidated that the self-assessments of the discomfort glare carried out by the participants and the DGP model are correspondent with the suggested thresholds presented in Table 1. Furthermore, the results show that half of the participants that evaluated the glare as uncomfortable, claimed to be highly satisfied with the view out of the nearest aperture. In fact, these participants rely heavily on daylight to light their workspace and claimed to keep the window curtains/blinds open on the grounds of having the opportunity to glance outside during the day.

Upon assessment of the photographs of these views, it can be concluded that these views comprise three vertically stacked levels rendering them as 'good views' offering as much information of the context as possible. In contrast, the other half of the participants were dissatisfied with the view out their nearest aperture and also stating that they kept the window filters closed. It was noted that these views suffered from absence of one of the three levels or were mostly presenting information related to the urbanised environment. These results could be interpreted to deduct the trade-off these participants were willingly or at times unwillingly making to accept uncomfortable discomfort glare when highly satisfied with the view out the nearest aperture. The participants preferred having the opportunity to interact with their surroundings and manage the uncomfortable glare rather than eliminate it altogether by closing the window curtains/blinds. Hence, they are ready to make the trade-off: an outside view with a little glare, as opposed to an internal view (only), with no glare. Hence for their own sense of wellbeing they opted for the interaction with the outside world (albeit even if somehow limited).

Based on a 5-point scale, the participants assessment of the discomfort glare as 'perceptible' add up to 14% of the responses. On the contrary to the previously discussed responses, a number of the self-assessments of the perception of discomfort glare and the DGPs are not consistent with the suggested thresholds. These results demonstrate the need for further investigation of the contextual influence and interpretation of the data. In these instances, the glare was negatively influenced by the context. On further investigation of the views, it is revealed that the two lower levels were missing, or the view provided limited to no information about the context.

The most prevalent observers' discomfort glare assessment was 'acceptable' by a 50% total response rating. The DGPs expressed by Equation 1, and the participants assessments once again differ from the suggested thresholds as per Table 1. In a similar way to the other findings the perception of discomfort glare has been positively or negatively influenced by the quality and satisfaction of the view. A specific result that slightly differs from the others demonstrated the trade-off to accept the discomfort glare, confirmed by the DGPs model, to be able supervise the children playing outside (perhaps a safety concern, more than a luxury). The participants' glare assessment results revealed that neither of the participants was experiencing 'intolerable' discomfort glare. On the other hand, a quarter of the participants relying on daylight indicated their glare assessment as 'neutral' implying they were not experiencing any visual discomfort. The majority of the responses and DGPs corresponded to the suggested thresholds.

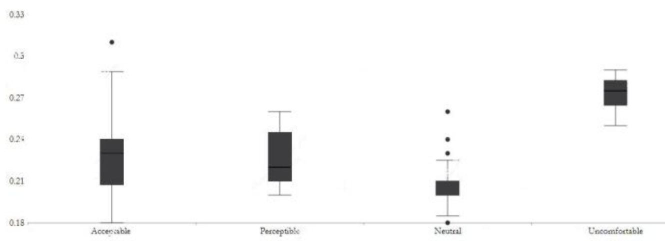


Figure 3: Boxplot of DGPs for glare assessment votes.

The box plot as shown in Figure 3, plots the DGPs on the y-axis and the participants' assessment of the perception of discomfort glare on the x-axis. The graph clearly illustrates the inter-quartile ranges overlap between the first three discomfort glare votes and the outliers, therefore demonstrating that the perception of discomfort glare is influenced by several factors other than the vertical illuminance and the lighting conditions of the workspace.

The participants who claimed to rely on artificial lighting, trade off the physiological and psychological benefits of natural light and the enhancing factors of the engaging information provided by a view. This is preferred in order to avoid discomfort glare or excessive amounts of natural light that distracts or causes visual discomfort. Others still rely on daylighting, but experience visual discomfort thus make use of window treatments to adjust according to the time of day. The findings show that this trade-off is often willingly made because of low view satisfaction (site context). On the other hand, the occupants that rely on daylighting and experience discomfort glare frequently accept it. They know that it corresponds to increased productivity, improved moods and perhaps above all, an inherent opportunity to engage with the surroundings for a potential better visual comfort and feel-good factor, as highlighted in figures 4 and 5.

Figure 4: View of participant #48 – general view quality 1 point

The secondary focus of the study carried out was to demonstrate the influence of task difficulty on the perception of discomfort glare. In this regard the questionnaire also gathered data regarding the assessment of the task difficulty and the estimated amount of time the participant spends at their residential workspace. The findings illustrated that task difficulty evaluated as high to moderate by the participants themselves, claimed a less visual discomfort due to discomfort glare than what the suggested thresholds according to the DGPs model claim.

Table 2: Participants' task difficulty and assessment of perception of discomfort glare.

Task difficulty	Discomfort glare assessment	Suggested threshold
2	Acceptable	Perceptible - disturbing
2	Acceptable	Imperceptible – perceptible
5	Acceptable	Disturbing - intolerable
4	Perceptible	Disturbing - intolerable
4	Uncomfortable	Perceptible - disturbing

On the other hand, the participants that evaluated a low task difficulty assessed the perception of discomfort glare higher than the suggested thresholds. These findings show, in contrast to the expectations, that discomfort glare is not task dependent. One of the misleading factors that influenced this study and outcome is the broad variety of tasks that participants were carrying out. This was impossible to predict from day one of the survey. In addition, when the participants assessed the difficulty of their tasks, this introduced a margin of error as a participant could assess a task difficulty higher or lower than another participant carrying out a similar task – thus such an opinion is truly subjective.

Another possible factor that could have introduced bias is the repetition of the task/s carried out, this influences the judgment of the task difficulty (or perhaps verging on boredom, thus sparking dissatisfaction at the desk).

Figure 5: View of participant #1 – general view quality 5 points

6. CONCLUSION

This research has shed light on the ability of architectural planning to influence and improve the well-being of occupants, while recognising some limitations in the adapted layout design strategies. The outcome of this study also emphasises the values of context and climate, apertures, lighting and health. Once again, the investigation highlighted the positive consequences on the wellbeing of the occupants brought forward by availability of natural light, access to an aperture and view satisfaction. In the absence of such facilities occupants might experience psychological and physiological challenges, as well as a drop in productivity at the workplace.

The powerful role of nature and any unbuilt environment, and its elements emerged constantly throughout the research. Its role in architecture is recognised as a fundamental component on how the occupants perceive both the indoor and outdoor surroundings.

The direct effect of daylight glare on productivity is vague. This relationship in based on several external factors such as motivation, working conditions, emotional state, sinister personal problems, and ultimately, the degree of control on indoor environmental conditions.

The research indicates that the acceptance of discomfort glare does not influence the productivity and none of the participants suggested that the perceived glare influenced negatively or positively the productivity. In fact, the positive influence of the available daylight and view quality seem to counteract the potential negative influence of discomfort glare on productivity. This does not mean that there is no relationship between the perceived discomfort glare and productivity, but perhaps the methodology used was not suitable to establish such a relationship.

The measuring of the influence of discomfort glare on occupants is a complex and interdisciplinary approach that should be addressed by a manifold of pure and applied sciences. It is surely a cross-over between architecture through a good quality interior design layout, flexible enough to allowance for a comfortable home-office, combined with a psychological a positive state of mind and sense of well-being.

ACKNOWLEDGEMENTS

This study would not have been possible without the voluntary contribution of all fifty one participants. Their patience and perseverance to achieve the desired feedback cannot go unnoticed. Sincere gratitude is being expressed herewith.

The study was part of a larger research project as the final dissertation, submitted towards an M.Arch degree by the second author, at the University of Malta. All academic and technical support is hereby acknowledged.

REFERENCES

1. Ruck, N., Aschehoug, Ø, & Aydinli, S. (2000). Daylight buildings. A source book on daylighting systems and components.

2. Brebbia, C. A. (2007). Environmental health risk IV, Volume 11 of WIT transactions on biomedicine and health. WIT Press.

3. Boyce P., H. C. (2003). The benefits of daylight through windows. (). New York, USA.

4. National Statistics Office. (2020). Regional statistics MALTA 2020 EDITION. (). Valletta, Malta: National Statistics Office.

5. Borg, K., Buhagiar, V. (2011). Effects on daylight & thermal performance an experimental study on a public library. Paper presented at the 27th International Conference on Passive and Low Energy Architecture.

6. Altomeonte, S. (June, 2009). Daylight and the occupants. Paper presented at the 26th Conference on Passive and Low-Energy Architecture.

7. Hopkinson, R. G. (1972). Glare from daylighting in buildings. Applied Ergonomics, 3(4), 206-215.

8. Tuaycharoen, N., & Tregenza, P. R. (2007). View and discomfort glare from windows. Lighting Research & Technology, 39(2), 185-200.

9. Kent, M. (2016). Temporal effects in glare response.

10. Hellinga, H. (2013). Daylight and view: The influence of windows on the visual quality of indoor spaces

PLEA SANTIAGO 2022
Will Cities Survive?

Bioclimatic residential buildings strategies for tropical savanna climate, Brazil

Examples of heritage modernist houses in Goiania

LOYDE VIEIRA DE ABREU-HARBICH[1 2] LARISSA RODRIGUES ARAÚJO[2] KARLA EMMANUELA RIBEIRO HORA[2]

[1] University Presbyterian Mackenzie
[2] Federal University of Goiás

ABSTRACT: This study aimed to assess the relationship between thermal comfort and bioclimatic design adopted in examples of modernist residences in the city of Goiania, Brazil. The following methodological procedures were used to predict thermal sensations: a) climate description to understand the local climate background and the relationship between users and buildings; b) study case to describe all elements of the building envelope; c) users' features as anthropometric data, clothing preferences, and activities developed inside the residence; and d) three-dimensional building/modeling and simulations to report building behavior during the year. Three representative bioclimatic modernist houses were selected and four scenarios were analyzed: scenario 1, the original situation of the residence; scenario 2, removal of the double walls and stone cladding; scenario 3, removal of the brises soleil and balcony; and scenario 4, removal of the vegetation cover. The results highlight the importance of the thermal performance of the materials used in tropical houses, especially in strategies with high mass for cooling. Brises soleil can significantly influence energy gains, especially during the morning. The interior ambiance must be adequately distributed in a solar orientation.

KEYWORDS: Bioclimatic Modern Architecture Houses, Bioclimate Strategies, Thermal Comfort, Tropical Climate (Goiânia); Design Builder (Energyplus)

1. INTRODUCTION

In the historical context of architectural production, modernist architecture manifested in Brazil with a concern to adapt the building to the local reality, incorporating several characteristics, including climate control mechanisms that are related to the principles of bioclimatic architecture.

In 1920, Brazilian modernist architecture presents itself in a different way and with a desire to characterize each building and report it to the landscape [1]. Modernist brazilian architecture brings several features, including climate control mechanisms, such as solar and lighting control [2]. Some authors understand that this concern gradually fades away and elements such as fully glazed facades are incorporated into the projects, although there is initially a search for the physical adaptation of the building to the climate. Corbella and Yannas [3] also note that, for a short period from the 1930s onwards, architects resorted to the principles of modernism together with a concern for the environment, however, from the 1960s onwards, buildings began air conditioning uses.

Considering the importance of adapting buildings to the conditions of the climate in which they are inserted, this work aims to analyze the relationship between the principles and strategies of bioclimatic architecture and the design solutions adopted in examples of modernist residences in the city of Goiânia-GO. In Goiania, there are Three buildings were selected as object of study.

2. OBJECT OF STUDY

There are three moments of modern residential architecture: the first period, marked by the influence of Rio's rationalism, the second, considered a transition period, and the third, defined by the brutalist expression [4]. It can highlight that these moments did not follow a rigid sequence and there is a combination of Rio and São Paulo currents in some works due to the late manifestation of the modern movement in the city. The modernist language that took place in Goiania acquires an original feature and can be considered creative and mixed due to local limitations and adaptations [5]. The language of these modernist houses was summarized and distributed in a timeline (Fig. 1)

For this study, it was selected the most representative bioclimatic modernist house, Georthon Philocreon Residence. Figure 2 presents the bioclimatic strategies observed on this house (Figure 2).

Figure 1:
Timeline of Modernist Houses built in Goiania

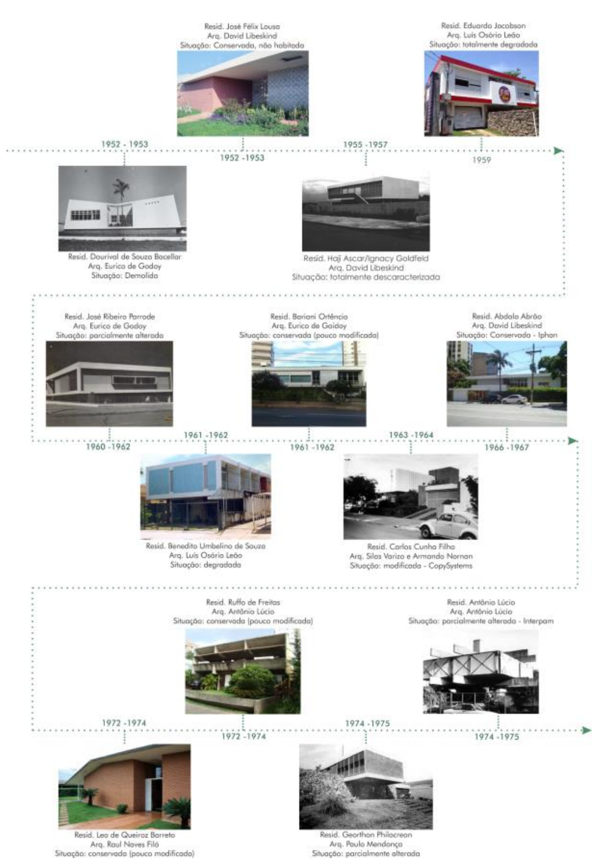
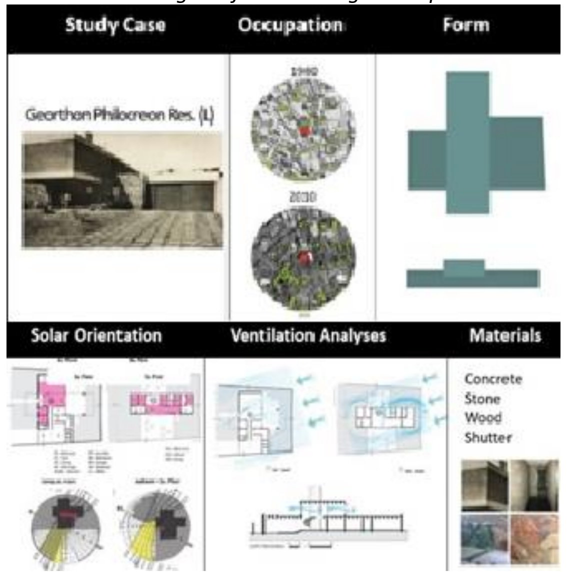


Figure 2:
Bioclimatic strategies of the building envelope



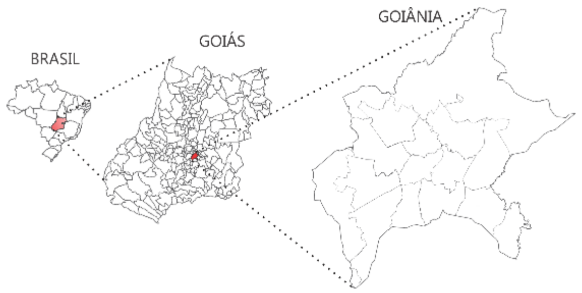
3. METHODOLOGY

The methodological procedures used on this study to predict thermal sensations were:

- Climate description to understand the local climate background and relation between users and buildings;
- Study case to describe all elements of the building envelope (Figure 3);
- Users' features as anthropometric data, clothing preferences, and activities developed inside was based on [6]
- Tree-Dimensional Building Modelling and Simulations to report building behavior during the year.

The city of Goiania (Figure 3) has a well-defined rainfall regime, configuring a dry season (May to October) and a rainy season (November to January). The months of February, March, and April have a reasonable rain intensity, characterizing a transition between periods. Relative humidity indices vary from 52% in August (the driest month of the year) and 82% from December to March [7]. The average wind velocity was 1.5 m/s and the predominant wind direction was southeast.

Figure 3:
Localization of Goiania, Brazil

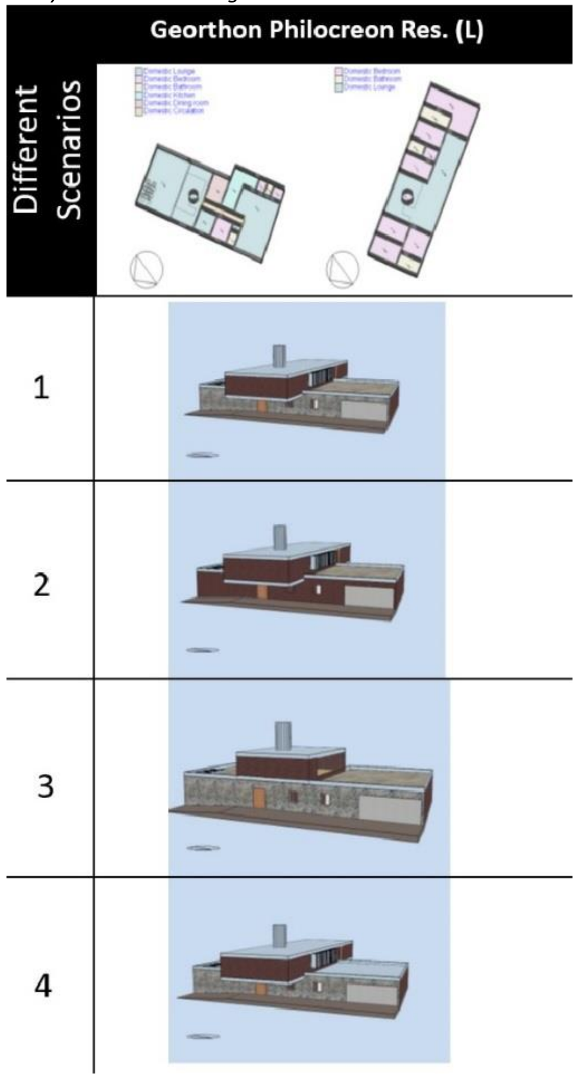


To evaluate the influence of bioclimatic strategies, it was selected 4 scenarios: - In scenario 1, the original situation of the residence; In scenario 2, the double walls were removed, and the stone cladding removed; In scenario 3, brises soleil and balcony have been removed; and in scenario 4, the vegetation cover was removed.

Input data were:

- Category: Residential Spaces.
- Configuration for operation under natural conditions only (cooling, heating, water heating, and mechanical systems will be disabled).
- Temperature: 24 °C (the window was opened when the indoor air temperature was equal to or higher than the set temperature and the indoor temperature was higher than the outdoor temperature);
- For other data, the program's default values were employed.

Figure 4:
Analysed house in Design Builder



After modeling, the materials for each building element must be configured, such as internal and external walls, floors, roofs, and openings, as table 1. They will also be configured as zones according to the use of each environment (living room, bedroom, kitchen, bathroom, or circulation) using the templates provided in the software.

After creating a scenario with the original situation (Scenario 1), the other scenarios were created by modifying the original file. The results obtained for the living and dining room areas of each residence during the simulation were collected; this is an extended stay resting place that is common to all homes and enables differentiation from the defined scenarios.

The data obtained in the four scenarios were tabulated and treated in spreadsheets to obtain clearer information regarding the influence of conditions on the performance of households. Of note, the purpose of the simulation was to verify the difference in operating temperature variations between the scenarios; thus, the scenarios were not supported in isolation.

Table 1
Variations in the composition of the walls and roofs for each residence

Residence	ID	Composition	Thickness	U* W/(m².K)	TC** kJ/(m².K)	Thermal Delay (h)
Georthon Philocreon (L)	External wall 1	Stone (100 mm); Cement render (25 mm); ceramic solid brick (100x60x220mm); Cement render (25mm) Stone (100 mm);	470 mm	1,93	501,36	8,2
	External wall 2	ceramic solid brick (100x60x220mm);	220 mm	2,53	352,13	5,62
	Roof 1	Ribbed Concrete (200mm);	500 mm	3,64	273,65	2,5
	Roof 1	Ribbed Concrete (500mm); Soil (100 mm); grass (50 mm)	650 mm	1,84	520,10	8,3

As part of the analysis, the adaptive comfort index of Auliciems [8] was used, which was the most suitable for use in Brazil by Pereira and Assis [9]. This index defines the neutral temperature (at which people feel comfortable) using the following equation:

$$TN = 0.314*TE + 17.6 \qquad \text{(Eq. 1)}$$

where TN is the neutral temperature and TE is the monthly mean outdoor temperature.

For the month of September, which has a monthly average temperature of 24.78 °C (obtained from the climate file used), the neutral temperature was 25.38 °C. As the comfort amplitude for the Auliciems model [8] is not defined, a variation of ± 2 °C in relation to the neutral temperature, it was adopted as the maximum temperature for comfort. Goiania has the greatest discomfort due to heat, and air temperatures are above the maximum comfort range in September.

3 RESULTS

Based on the architectural project, results of three-dimensional model of the building were reported in this section. Results for a percentage of occupied hours with the operative temperature ranger (PHFT) for each scenario during a year can be seen in Figure 5.

Results of PHFT show that Georthon Philocrean Residence has more than 8600 thermal comfort hours by year. It was observed that the solar protection can influence on thermal performance. As well, the use of high mass for cooling can brings more thermal comfort. It was observed that Although presence of bioclimatic strategies design on buildings, in tropical climate (savanna) the attendance of inertia mass for cooling is very important.

Figure 5:
Results for PHFT in different Scenarios by each study case

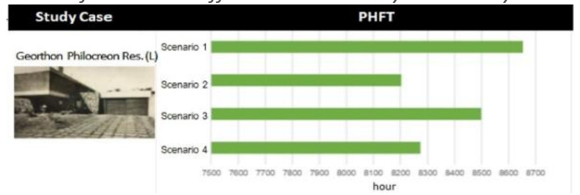
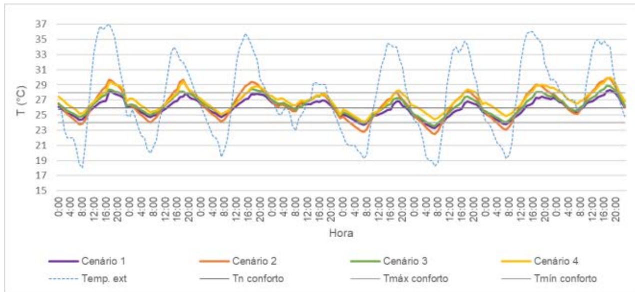


Fig. 6 summarizes results of operative temperature for first week of September (autumn season in Brazil) in different scenarios for each study case. It can observe that scenario 2 and 3, improving high mass inertia, bring more thermal comfort hour.

well, scenario 3, removing solar protect, has worst thermal performance for all cases. In scenario 4, removing vegetation, have thermal performance reduced due to vegetated cover.

Figure 6:
Results of thermo-simulations for modern residences in autumn season in Brazil



There was no significant difference between the temperatures of Scenarios 1 and 2. When the variation in operating temperature is compared between Scenarios 1 and 3, an increase of up to 2.7 ° C was found owing to the removal of the existing sun protection elements. For Scenario 4, the replacement of the fiber-cement covered by the vegetated covering favored a decrease of up to 1.8 ° C in the operating temperature, which could contribute to fewer periods with temperatures above the comfort range.

Comparing results to attendance of bioclimatic strategies for different studied housing with thermo-energetic simulation, it was observed the influence of thermal mass on thermal comfort conditions on Tropical Climate (savanna). These results confirmed Eli et al. [9] findings.

The design process of buildings from bioclimatic modernism considered knowledge of environmental principles and the analytical tools of today. It was confirmed results by Gonçalves et al [10].

The positive impact of external shading or correct orientation of windows in moderating internal temperature variations and, in the context of this analysis, keeping them within the pre-established comfort zone, with even better conditions when window apertures are opened up to 60%. This study is important to develop project guidelines appropriate for the nation's socio-cultural reality to reduce energy consumptions.

Although modernist architecture in Goiania considers bioclimatic strategies, during a warm wave, it is necessary the use of fans for provide thermal comfort inside. Buildings need to adopt to climate changes for reducing energy consumption, especially in Savanna tropical climates. These findings confirms Eli et al. [9] and Abreu-Harbich et al, [5].

4. CONCLUSIONS

Bioclimatic architecture seeks to develop the built environment in a way that suits the local climate, seeking comfort, energy efficiency and sustainability. In modern bioclimatic architecture is not explicit, although Brazilian modernism initiatives are manifested by the use of sunscreens and leaked elements during the 50's to 70's. a way to sensitize the student and designer about the first searches for energy efficiency and sustainability in housing. From these examples of implementation in the architectural project, it is possible to make an integration between the present and the future.

Even not fully contemplating the design guidelines, the analyzed residences present different approaches to adaptation to the climate and contribute with solutions that are compatible with the city of Goiania. To assess the level of thermal comfort and influence of materiality, it is necessary to conform in place and / or computer simulation. The advantages of this type of activity in the design process are: development of critical thinking about architectural and urban diversity in its time, culture and practice; creation of new climate-adapted design parameters; expansion of the design repertoire and reflection on the possibilities of applying different bioclimatic strategies in architectural design; understanding of the methods used to define bioclimatic in each climate. This activity can also be performed using different types of different buildings (school, commercial, institutional); in another architectural style; and in different cities. It is suggested that the activity be carried out in the Thermal Comfort and Architectural Design discipline. This method of analyzing case studies makes it possible to sensitize the student and designer to the dissemination of good design practices in thermal comfort, health and energy efficiency, as well as the application of bioclimatic in future projects.

ACKNOWLEDGEMENTS
This research was supported by Federal University of Goiás research grant PROCIDADE-UFG.

REFERENCES

1. Montaner, J. M. (2001). Depois do movimento moderno. Arquitetura da segunda metade do século XX. Barcelona: Gustavo Gili.
2. Tinem, N. (2006). Arquitetura Moderna Brasileira: a imagem como texto. Arquitextos, São Paulo, ano 06, n. 072.02, Vitruvius, maio 2006.
3. Corbella, O; Yannas, S..(2010) Em busca de uma arquitetura sustentável para os trópicos – conforto ambiental. Rio de Janeiro: Revan, 2003Silva Neto.
4. Caixeta, E. M. M. P.; Frota, J. A. D.; Badan, R.C.; Mahler, C. R.: Amaral, C. V. L. (2011). Arquitetura moderna em Goiânia: desafios e limites da documentação para a preservação. *In*: SEMINÁRIO DOCOMOMO BRASIL, 9. 2011. Anais... Brasília, jun. 2011. CAIXETA et al. 2011).
5.Abreu-Harbich, L. V.; Chaves, V.L.A.;. Brandstetter, M.C.G.O (2018). Evaluation of strategies that improve the thermal comfort and energy saving of a classroom of an institutional building in a tropical climate. *Building and Environment* 135: 257-268.
6. ABNT, ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15575: Edifícios Habitacionais até cinco pavimentos. Rio de Janeiro: ABNT, 2013
7. Abreu-Harbich; V. L.; Chaves. V. L. Identificação do ano climático de referência para Goiânia-Goiás. In: XVI Encontro Nacional de Tecnologia do Ambiente Construído, 16, 2016, São Paulo. Anais... São Paulo: ENTAC, 2016. p. 406-416. [in portuguese]
8. Auliciems A. Towards a psycho-physiological model of thermal perception. International Journal of Biometeorology, 25 (2) (1981), pp. 109-122
9. Eli, L.G.; Krelling, A.F.; Olinger, M.S. Melo, A.P.; Lamberts, R. Thermal performance of the residential building with mixed-mode and passive cooling strategies: The Brazilian context, Energy and Buildings, Volume 244, 2021, 111047, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2021.111047.
10. Gonçalves, J. C. S.; Dolce, M.; Mulfarth, R. C. K. ; Lima, E. G.; Ferreira, A. M. Revealing the thermal environmental quality of the high-density residential tall building from the Brazilian bioclimatic modernism: The case-study of Copan building. Energy & Buildings journal, v. 175, p. 17-29, 2018. Doi: https://doi.org/10.1016/j.enbuild.2018.06.054

A technical and energy performance approach for the construction and operation of a zero-energy renovation of a residential building in the Netherlands

THALEIA KONSTANTINOU [1] STELLA BOESS [2]

[1] Delft University of Technology / Faculty of Architecture and The Built Environment
[2] Delft University of Technology / Faculty of Industrial Design

ABSTRACT: Accounting for almost 40% of energy consumption in the European Union, the role of the existing building stock is instrumental in the energy transition and the goals for carbon neutrality of the built environment. An effective renovation plan must significantly improve the current energy performance towards a nearly zero-energy level. Nevertheless, renovation that addresses the energy performance of buildings is at a rate as low as 1%, with deep renovation being at 0.2%. The low rate can be attributed to the higher complexity and costs incurred due to the high number of retrofitted components and the integration of renewable energy sources, the many actors involved and barriers such as split incentives and availability of funds.
This paper discusses the process that led to a zero-energy renovation of a previously outdated post-war, mid-rise, tenement apartment building. This process included design, execution of the technical measures, energy contracting and monitoring. The aspects considered during this project focus on the technical solution, including the building envelope and services upgrade and the performance guarantee that made the project a successful business case. The results showed that the renovated building is zero-energy and the energy production overcompensate for the energy demand. The steps that were taken ensured a renovation concept development towards upscalability. Lessons learned during this project have enabled the involved stakeholder to extend the renovation concept to address various buildings types and performance goals.
KEYWORDS: zero-energy renovation, energy performance guarantee, building refurbishment

1. Introduction

Accounting for almost 40% of energy consumption in the European Union (Tsemekidi Tzeiranaki et al., 2020), the role of the existing building stock is instrumental in the energy transition and the goals for carbon neutrality of the built environment. To tackle this potential, the rate and depth of renovation need to increase (Artola et al., 2016). Today the annual renovation rate of the building stock varies from 0.4 to 1.2% in the Member States (European Commission, 2020). This rate will need at least to double to reach the EU's energy efficiency and climate objectives (European Commission, 2019). The low rate can be attributed to the higher complexity and costs incurred due to the high number of retrofitted components and the integration of renewable energy sources, as well as the many actors involved (Bystedt et al., 2016; D'Oca et al., 2018). Furthermore, the split incentive between the tenants who benefit from the energy savings and the landlords who do not have sufficient incentive to invest in improving the property (Atanasiu et al., 2014) is identified as one of the most long-lasting barriers.

An effective renovation plan must significantly improve the current energy performance towards a nearly zero-energy level. Zero-energy does not necessarily imply zero-carbon, as the carbon emissions also depend on the energy supply system on regional and national level (Galvin, 2022). A Zero Energy Building (ZEB) is a building with greatly reduced energy needs and/or carbon emissions, achieved through efficiency gains and renewable energy. ZEB can be referred to as a Zero Energy Building and Zero Emission Building. The first considers the energy consumed by a building in its day-to-day operation, and the second is the carbon emissions released into the environment as a result of its operation (D'Agostino & Mazzarella, 2019).

In both cases, to reduce the energy demand, zero-energy renovation needs to upgrade several building components to reach an improved performance. The integration of many components increases the complexity and the cost of those renovations. Energy performance contracts (EPCs) offer the option of performance guarantees which can reduce risks associated with complex projects. Given that they enable funding of energy renovations from energy cost savings, they successfully tackle upfront cost barriers for consumers (Bertoldi et al., 2021).

This paper discusses the process that led to a zero-energy renovation of a previously outdated post-war, mid-rise, tenement apartment building. The aspects considered during this project focus on the technical solution, including the building envelope and services upgrade, and the performance guarantee model that made the project a successful business case.

2. Method

2.1. Renovation design and execution

The objective of the project was to demonstrate the feasibility of a zero-energy renovation. The standard needed to achieve in this project was "Nul op de meter (Zero on the meter)", which means that the yearly average energy consumption is zero (RVO, 2016), including heating, domestic hot water (DHW) and appliances. Achieving zero-on-the-meter performance was also essential for the business case, as makes it possible to apply the "energy performance subsidy (EPV)" regulation (RVO, 2017), that allows for a fixed amount per m2, per month to be compensated to the building owner for the improved performance. The subsidy is not part of a rent increase.

The first concern is to include all the necessary measures to achieve the zero-energy goal and allow for the performance guarantee. Next to the selected technical upgrade interventions, the construction process is very important. It constitutes the proof that the renovation is feasible and applicable while the occupants are living in their dwellings. The planning needed to follow some basic principles in order for the construction process to be as little disturbing for the occupants as possible and of course, safe and efficient. Those attention points highlighted process issues to consider for the planning, such as that the residents cannot stay with no heating or warm water and that a maximum of five days of construction work inside each apartment is allowed.

Taking into account the above mentioned and the time needed for the manufacturing, transfer, and installation of the components, the construction team planned and successfully executed a detailed timeline for the renovation process for all 12 dwellings over 15 weeks. The renovation was completed in February 2018.

2.2. Energy calculations and Energy contract

Given the zero-energy objective, the energy demand and energy generation were central in the renovation's decision-making. Moreover, estimating the energy use was essential to determine the conditions of the energy contract.

The calculation was made through the tool Uniec[2] (Earth Energie Advies, 2017), which is an accredited software for calculating the Energy Performance Coefficient (EPC) in the Netherlands, defined by the NEN7120 building degree (NEN, 2017). The calculation method is a static calculation on the theoretical energy demand based on standardised inputs. The output of energy generated is calculated according to the Photovoltaic panels' specifications. This software was considered appropriate for the project, as it facilitated the communication between the design team and the building owner and occupants. Moreover, the calculation of the EPC and the benchmark value of 0,2 is the precondition to apply for the EPV.

2.3. Monitoring

A wide array of techniques is available for monitoring. Post-occupancy evaluation of a building can be done through surveys on comfort and perception of temperature and climate; qualitative methods such as diaries can be used to evaluate the usability of systems and building; and objective measurements can be taken regarding indoor environment in relation to the weather (Guerra-Santin & Tweed, 2015).

For the current research, a combination of existing methods was chosen. Temperature, CO2 levels, and humidity can be measured relatively straightforwardly and give a good indication of thermal comfort compared to norms and measured over more extended periods of time. Furthermore, a fine-grained dataset of indoor climate measurements provides rich data for analysis which can then be linked to clear instances of occupants' practices or difficulties in use (Guerra-Santin et al., 2017). This data also allows for a comparison with a simulation of the performance of the occupied building [source]. Finally, if occupants are well informed of the research, the use of sensors in the home does not have to lead to too much disruption.

In addition to the indoor climate measurements, interviews and walkthroughs were organised in occupant visits, where the data could be coupled with the preferences and practices of the residents and problematic issues in the buildings. This offers an occupant perspective and more in-depth information that will help formulate learnings for future projects.

Each of the ten dwellings was fitted with three monitoring devices [**Figure 1**]. These sensor boxes record and transmit the measurements for indoor temperature, levels of CO2, and humidity in 3-minute intervals. One of the three sensor boxes was placed in the living room, one in the kitchen, and one in the front room. Bedrooms where not monitored because the ethical approval for the study had to be obtained within a short time frame.

Figure 1: The monitoring boxes installed in the dwellings, developed by industrial partner OfficeVitae.

Next to this, the residents received a booklet that helped them reflect on their own thermal and climate comfort and practices pre-and post-renovation.

The present paper reports indicative results of a preliminary post-occupancy evaluation of the period until 2019.

3. Strategy to zero-energy renovation

3.1. Renovation solution

The main objective of the building envelope upgrade is to reduce the heat losses through the building elements. The high thermal resistance of the envelope, indicated by the values in Table 1, is essential to the heating demand. Combined with the Heat Recovery Ventilation, it allows for low-temperature heating sources (Wang, Ploskić, Song, & Holmberg, 2016).

The renovation resulted in excellent insulation and airtightness, featuring external insulation on the walls, new window frames with triple gazing , prefabricated insulated roof panels, photovoltaic (PV) panels.

As suggested by the national energy goals, the building is disconnected from the gas, which complies with the current energy policy. The heating and DHW is provided by the ground-source heat pump of COP6. The heat pump, water tank and heat-recovery ventilation unit are placed in prefabricated, insulated boxes located outside the apartments on a new, enlarged balcony. The building consortium partners provided the building owner with maintenance and energy performance guarantee.

3.1. Energy use and generation,

During the design phase, the project team calculated the energy demand as part of the building permit process and determined the energy performance guarantee. The energy calculations show a net energy surplus on an annual basis for standardised occupancy.

Table 1: *Overview of technical options of the Demonstrator and Scaler projects. The explanation column includes the reasons for deciding for different measures in the scaler project*

Wall	Rigid expanded polystyrene Plaster finishing U=0,16 W/Km2,	
Windows	u-PVC frames Triple glazed panes Uw=1 W/Km2, g=0,8	
Roof	Sandwich Insulation panels U=0,14 W/Km2	
Ground floor	Expanded polystyrene in granulated form blown crawling space U=0,28 W/Km2	
Balcony	Old balcony removed and replaced with new steel structure, on new foundations	
Entrance	New closed entrance	
Ventilation	Mechanical ventilation with heat recovery, up to 95%,	
Heating	Ground-to-water heat-pump COP 6.00 (one every 3 apartments)	
DHW	Ground-to-water heat-pump COP 3.00 (one every 3 apartments, one water buffer per apartment).	

For reference, earlier studies (Guerra-Santin et al., 2018) suggested that this type of dwellings are expected to consume on average approximately 2300kWh/yr for heating and DHW, and 2800 kWh/yr for appliances, with the possibility to reduce to 1600 kWh/yr, if they switch to high efficiency appliances. **Table 2** presents details on the energy use and production per dwelling. The total projected energy use of 3106 kWh/yr constitutes a 60% reduction from the 5100 kWh/yr reference energy use.

To reach the zero-energy standard, energy production on-site is needed. To this end, photovoltaic panels with a capacity of 300 Wp are installed, both on the south and the north sides of the roof. Given the roof area, each apartment receives 8 photovoltaic panels oriented to the South, resulting in a yield of 2,304 kWh to cover their household consumption of 1,800 kWh. One dwelling gets 2 panels on the South and 10 on the North. The remaining 80 panels on the north produce additional energy to ensure that the zero-energy objective is met.

Due to the excess of PV panels compared to the calculated energy demand, there will be a surplus of energy on building level. This energy can be saved for future years, when the PV output energy is reduced due to degeneration of the panels or the occurrence of colder or less sunny years. The risk of missing to compensate the energy demand is thus reduced.

Table 2: *Calculation of the energy use (with no cooling) and the energy generation with PV with 300Wp, per dwelling, per year.*

Area apartment (m2)	59
Energy use building services (kWh)	353
Energy useDHW (kWh)	487
Energy use - Building related (kWh)	840
Energy use - user related (kWh)	1800
15% reserve (kWh)	466
Total energy demand (kWh)	**3106**
Energy generated from PV - 8panels south (kWh)	2304
Energy generated from PV - collective panels north (kWh)	1230
Total energy generation (kWh)	**3534**

Those calculations allowed for a 25-year zero-energy performance contract to be agreed upon between the building services provider and the building owner. According to the agreement, the building services provider guarantees the maintenance of the systems and the energy demand for a fixed amount per dwelling.

Furthermore, to overcome the split-incentives barrier, the housing association signed a contract with each occupant for their energy use. The energy budget for space heating and DHW, guaranteed by the building services, is 966 kWh per year, per dwelling, which is 15% over the calculated demand (Table 2)

4. Post-occupancy evaluation

4.1. Energy use

After the building renovation completion, the performance monitoring continued, as part of the energy performance contract, between the building owner and the building services provider. **Table 3** provides an overview of the energy used for space heating and DHW and energy generation. Because there is one heat pump for every three, vertically-stacked apartments, the energy consumption metered by the heat pump is divided equally by 3 in the table.

The first observation is that the energy use in 3 out of 4 cases is higher than the 840 kWh per apartment predicted (**Table 2**). Since this heat pump consumption includes both space heating and DHW, we cannot separate it if this is building- or user-related. Nevertheless, the PV generation is also higher than predicted. As a result, and taking into account the contracted household electricity of 1800kWh, there is an energy surplus

Table 3: *Energy use and energy generation for the period 1-1-2019 until 31-12-2019, in kWh/year*

	Energy use – Space heating + DHW	Energy generated from PV	Energy use - user related energy contract	Energy surplus
1-G	852	3785	1800	**1133**
1-M	852	3807	1800	**1155**
1-T	852	3836	1800	**1184**
2-G	1427	3821	1800	**594**
2-M	1427	3856	1800	**629**
2-T	1427	3825	1800	**598**
3-G	1149	3127	1800	178
3-M	1149	3297	1800	348
3-T	1149	3827	1800	878
4-G	1511	3823	1800	**512**
4-M	1511	3790	1800	**479**
4-T	1511	3593	1800	**282**

4.2. User related energy for appliances

The user-related energy usage slightly exceeded their projected use of 1800kWh, but the solar panels for the heat pump consumption produced a surplus of energy. Energy usage data is unavailable from all houses because electricity is contracted separately with the energy company. An example of one household provided below, based on the household's energy bills for their personal energy use (appliances). It shows that energy yield comes close to energy use for the household's individual energy use, after renovation.

Table 4: the energy use and energy generation (in kWh) for June 2016- June 2019 for one household's personal appliances. The yield differs from Table 3 because only the PV for personal energy use are included.

	Jun2016 Jun2017	Jun2017 Jun2018	Jun2018 Jun2019
Energy use, off-peak	1509	1451	1262
Energy use, peak	1547	1178	785
Total energy use	3056	2629	2047
Energy yield, off-peak	-	457	480
Energy yield, peak	-	1093	1193
Total yield	-	1550	1673
Net energy use	**3056**	**1079**	**374**

The table shows the difference in that household's energy use before and after the renovation. The renovation took place during the winter of 2018. The household's energy use post-renovation still exceeds the yield by 374 kWh. However, the table does not yet reflect the full yield that can be expected for the resident's next energy use period. As mentioned above, this surpassed 1800 kWh in the first eight months of 2019. Additionally, the yield of the other set of solar panels, those for the building services, was higher than needed, adding to the surplus to be expected.

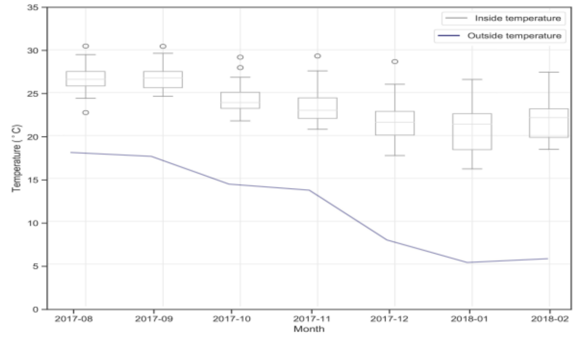
The resident's lower energy use over these three years (from 3056 kWh to 2629 kWh to 2047 kWh) can be explained by the refurbishment: insulation, switch to led lighting (residents received a gift set), efficient installations and switch to induction cooking.

4.3. Comfort, preferences and practices

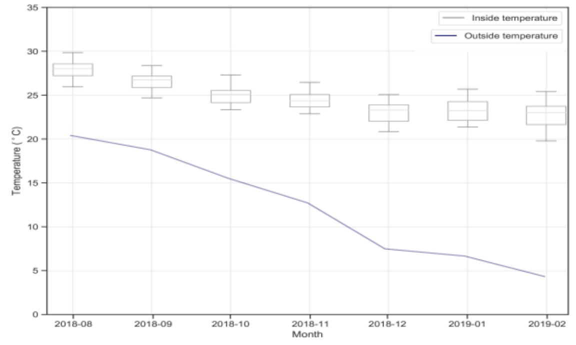
Both the CO2 levels and the temperature in the households have stabilised since the renovation of the building. Indoor air humidity has also decreased and stabilised between 30 to 60 %, reducing fungus and dampness in the ground floor apartments, which was an issue before the renovation. However, in two households, CO2 levels are measured that are too high for continued periods. Some of these issues could be resolved by changing the ventilation setting. The CO2 levels were significantly lowered after the residents were advised to change the setting.

The temperature of the households has stabilised significantly since the renovation. The data shows that the temperature rarely drops below 18oC in winter (**Figure 2**). However, the indoor temperatures in the top floor apartments reached more than 26oC above 25% of the time, including nights during June, July and August of 2019, with a maximum of 31oC. The summers of 2018 and 2019 were hot compared to average weather data. This led to an average temperature in households on all levels of 26oC during 21-25 of July 2019, with only one-degree cooler at night. Homes sometimes were 28 degrees warm at night. Short-term temperature peaks over 26oC also happened during other times of the year, mainly in the early evenings, after cooking and sun exposure in south-facing living rooms.

Many of the ten households monitored had bought additional heating devices for the winter. Although the temperatures were now much more stable, with drafts removed and all rooms heated evenly, some residents felt they would like a bedroom to be cooler or warmer than the rest of the home. Some felt that even a temperature of 22oC was too cool, while others would have preferred a temperature of around 20 degrees. A stable temperature is valued by all residents, although at different levels. In addition, they would also like to be able to change the temperature to their preferred level.



Before renovation



After renovation

Figure 2: Line and box plot: The period of July to January is taken for 2017-2018 (before renovation) and 2018-2019 (after renovation). A boxplot is made for each month to compare the relationship between indoor and outdoor temperature over time (graph by Heleen Oude Nijhuis and Rene van Egmond).

Overall, the residents reported high satisfaction with the renovated homes. The key points of satisfaction were the absence of fungus, drought and humidity in the homes post-renovation. The increased temperature stability was an additional point of satisfaction, as were lower peak indoor temperatures in summer than in pre-renovation. The aesthetic quality of the exterior of the building was also an essential point of satisfaction for the residents. The residents reported lower satisfaction and dissatisfaction with their limited ability to set the temperature at the desired level. The residents also reported low satisfaction with the user interfaces of the building services, such as the ventilation interface and the activities they needed to perform for maintenance on the ventilation filters. These aspects can potentially affect building performance in the long term.

5. CONCLUSION

The paper presented a zero-energy renovation concept applied to a multi-residential building of 12 apartments in the Netherlands. The concept addressed the technical aspects, including the building envelope and services upgrade and energy generation application through PV panels. Furthermore, it offered an energy performance guarantee to the building owner, who was able to provide an energy performance contract to the residents.

The combination of measures to reduce the energy demand and maximise the energy generation achieved and went beyond the zero-energy target. Even though some households exceeded the predicted energy demand of 840 kWh/yr, the PV yield exceeded the calculated production, resulting in an energy surplus. In this sense, the reduction in energy use was 100%.

Moreover, the energy performance contract resulted in a viable business case without increasing the rent after the renovation. This is a significant achievement, given that the increased costs for the building owner are one of the main barriers to implementing zero-energy renovation concepts. Energy performance contracts proved an effective way to implement a complex zero-energy renovation strategy and can be a tool for upscaling renovations.

6. ACKNOWLEDGEMENTS

The authors would like to thank the project partners, the building owner, and the residents for their collaboration and cooperation. The study reported in this paper is part of the EIT- Climate-KIC 2ndSKIN Demonstrator Project, executed in 2017-2019. Thanks also to Heleen Oude Nijhuis and Rene van Egmond for contributing to the data analysis.

7. REFERENCES

Artola, I., Rademaekers, K., Williams, R., & Yearwood, J. (2016). *Boosting Building Renovation: What potential and value for Europe?* http://trinomics.eu/project/building-renovation/

Atanasiu, B., Kontonasiou, E., & Mariottini, F. (2014). *Alleviating Fuel Poverty in the EU. Investing in home renovation, a sustainable and inclusive solution*.

Bertoldi, P., Economidou, M., Palermo, V., Boza-Kiss, B., & Todeschi, V. (2021). How to finance energy renovation of residential buildings: Review of current and emerging financing instruments in the EU. *WIREs Energy and Environment*, *10*(1), e384. https://doi.org/https://doi.org/10.1002/wene.384

Bystedt, A., Ostman, L., Knuts, M., Johansson, J., Westerlund, K., & Thorsen, H. (2016). Fast and simple - Cost efficient facade refurbishment. In J. Kurnitski (Ed.), *Sustainable Built Environment Tallinn and Helsinki Conference Sbe16 Build Green and Renovate Deep* (Vol. 96, pp. 779-787). Elsevier Science Bv. https://doi.org/10.1016/j.egypro.2016.09.140

D'Agostino, D., & Mazzarella, L. (2019). What is a Nearly zero energy building? Overview, implementation and comparison of definitions. *Journal of Building Engineering*, *21*, 200-212. https://doi.org/https://doi.org/10.1016/j.jobe.2018.10.019

D'Oca, S., Ferrante, A., Ferrer, C., Pernetti, R., Gralka, A., Sebastian, R., & Veld, P. O. (2018). Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects [Article]. *Buildings*, *8*(12), 25, Article 174. https://doi.org/10.3390/buildings8120174

Earth Energie Advies. (2017). *Uniec2*. In https://uniec2.nl/

European Commission. (2019). *The European Green Deal*. Brussels Retrieved from https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

European Commission. (2020). *A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives*. Brussels Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835

Galvin, R. (2022). Net-zero-energy buildings or zero-carbon energy systems? How best to decarbonize Germany's thermally inefficient 1950s-1970s-era apartments. *Journal of Building Engineering*, *54*, 104671. https://doi.org/https://doi.org/10.1016/j.jobe.2022.104671

Guerra-Santin, O., Boess, S., Konstantinou, T., Romero Herrera, N., Klein, T., & Silvester, S. (2017). Designing for residents: Building monitoring and co-creation in social housing renovation in the Netherlands. *Energy Research & Social Science*, *32*. https://doi.org/http://dx.doi.org/10.1016/j.erss.2017.03.009

Guerra-Santin, O., Bosch, H., Budde, P., Konstantinou, T., Boess, S., Klein, T., & Silvester, S. (2018). Considering user profiles and occupants' behaviour on a zero energy renovation strategy for multi-family housing in the Netherlands [journal article]. *Energy Efficiency*. https://doi.org/10.1007/s12053-018-9626-8

Guerra-Santin, O., & Tweed, C. A. (2015). In-use monitoring of buildings: An overview of data collection methods. *Energy and Buildings*, *93*, 189-207. https://doi.org/https://doi.org/10.1016/j.enbuild.2015.02.042

NEN7120+C2 Energieprestatie van gebouwen – Bepalingsmethode., (2017).

RVO. (2016). *Nul op de meter [Zero on the meter]*. Rijksdienst voor Ondernemend Nederland (RVO) Retrieved 4 Aug from https://www.rvo.nl/onderwerpen/technieken-beheer-en-innovatie-gebouwen/nul-op-de-meter

RVO. (2017). *Energieprestatievergoeding (EPV)*. Rijksdienst voor Ondernemend Nederland (RVO). Retrieved 04 Aug from https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/epv

Tsemekidi Tzeiranaki, S., Bertoldi, P., Paci, D., Castellazzi, L., Ribeiro Serrenho, T., Economidou, M., & Zangheri, P. (2020). *Energy Consumption and Energy Efficiency Trends in the EU-28, 2000-2018.* (ISBN 978-92-76-21074-0,).

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE URBAN DEVELOPMENT

DAY 01
14:15 — 15:45

CHAIR
MARGARITA GREENE

PAPERS
1609 / 1476 / 1556 / 1550 / 1357

6TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Vegetation as a mitigation strategy on Mediterranean context

Outdoor thermal comfort from simulated data

MARIA FERNANDA ARRIAGA-OSUNA[1] KAREN ESTRELLA MARTINEZ-TORRES[1] JULIO CESAR RINCÓN-MARTÍNEZ[1] MARCOS EDUARDO GONZÁLEZ-TREVIZO[1]

[1] Facultad de Ingeniería, Arquitectura y Diseño, Universidad Autónoma de Baja California (UABC), B.C. México.

ABSTRACT: The deterioration of the urban microclimate impacts the thermal comfort of the city's inhabitants. The urban heat island (UHI), which defines the differences in air temperature and urban-rural area, is the most studied urban climate phenomenon. The thermal environment induces adverse effects on human health, affecting psychological responses and cardiovascular functions and increasing human mortality. Shade trees are a passive strategy to mitigate the urban heat island phenomenon (UHI). Therefore, designing the optimal tree layout is essential to maximize thermal benefits. Based on a simulation in ENVI-met software, this research analyzes how the location and arrangement of trees influence outdoor microclimates and human thermal comfort in a residential neighborhood in Ensenada, Baja California, Mexico. The study focused on understanding the impacts of the location and distribution of trees on outdoor microclimates, the same tree species (Cupressus Forbessi) was used in the simulation scenarios. However, due to the tree size and limited space on residential sidewalks, scenarios with groups of more than two trees for each single-family home were not simulated. This study reveals that using individual tree arrangements improves the cooling benefits and thermal comfort. The best results were obtained for arranging a Cupressus Forbessi tree (3.0 m crown and 3.0 m tall), at a 7.0 m distance from each other.
KEYWORDS: Thermal Comfort, Shade Trees, Urban Heat Island, Residential Areas, ENVI-met.

1. INTRODUCTION

Urbanization has been increasing during the past few decades. According to recent demographic statistics from the United Nations, the global urbanization rate will reach 66% by 2050 (Bherwani, Singh, & Kumar, 2020; United Nations, 2015).

The urban heat island (UHI) defines surface and air temperature differences of up to 8°C between cities and surrounding suburban and rural areas. The causes of UHI have mainly attributed to four aspects of cities: land cover; construction fabric and its thermal and radiative attributes; the urban form; and the addition of heat energy by humans and their activities (Mills et al., 2022). It is the most significant and studied urban climatic phenomenon due to the fact that effects on thermal comfort have been identified. (Cilek et al., 2021; Perini et al., 2017). Furthermore, heatwaves affect human health, affecting psychological responses and cardiovascular functions and increasing human mortality (Antoniadis et al., 2020).

For this reason, several mitigation strategies have been implemented to reduce the UHI. Aflaki & Nuruzzaman mentioned that greenery is an effective strategy for mitigating UHI (Wonorahardjo et al., 2020). According to Nuruzzaman, (2015), green vegetation seems to be the most effective measure to encounter the UHI effect among all the mitigation strategies. Also, its effectiveness is well proven and widely accepted by experts.

In particular, trees and their cooling performance have been investigated in detail (Zhang et al., 2020). Numerical models consistently show that increased vegetation or tree coverage provides a cooling effect, but the extent of cooling for a given amount of vegetation varies. Those variations occur due to the climatic environment at different geographic locations, the size or the type of vegetation, and the building layout or wind corridor design (Zhao et al., 2018).

Hami et al., (2019) mention that the cooling potential of trees varies according to their characteristics: leaf area index, tree height, trunk height, crown height, and crown width.

In recent years high-resolution numerical simulation of surface–plant–air interactions as a tool to assist in planning decisions has experienced increased consideration as a method for estimating the environmental performance of urban space and the improvements that it will make to the outdoor environment (Bruse & Fleer, 1998; Li et al., 2019).

Based on ENVI-met simulation, this research aims to analyze the influence of tree location and arrangement on outdoor thermal comfort in the Mediterranean urban context. Comparing different tree-planting patterns reveals how to maximize cooling benefits in the study area and elsewhere with similar contexts.

2. METHODOLOGY

The study area is in one residential neighbourhood in the city of Ensenada B.C., Mexico (31°52'N; 116°37'W). In addition, a land surface temperature (LST) distribution from the Landsat 8 data was utilized to identify the UHI intensity (Figure 1).

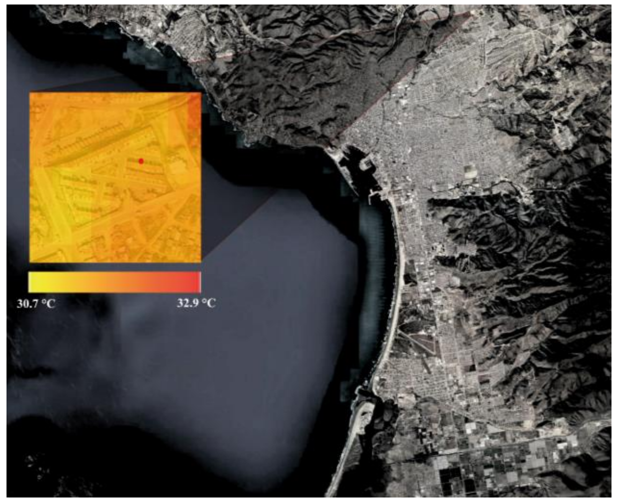


Figure 1: Image of Landsat 8. Acquisition date July 03, 2019.

According to the Köppen classification, the city's climate is Cold semi-arid Mediterranean (BSks). The place analyzed was a residential area with 16,948.63 m² and was characterized by a prototype of a minimal house. As shown in Figure 2, the methodological framework of the research was:

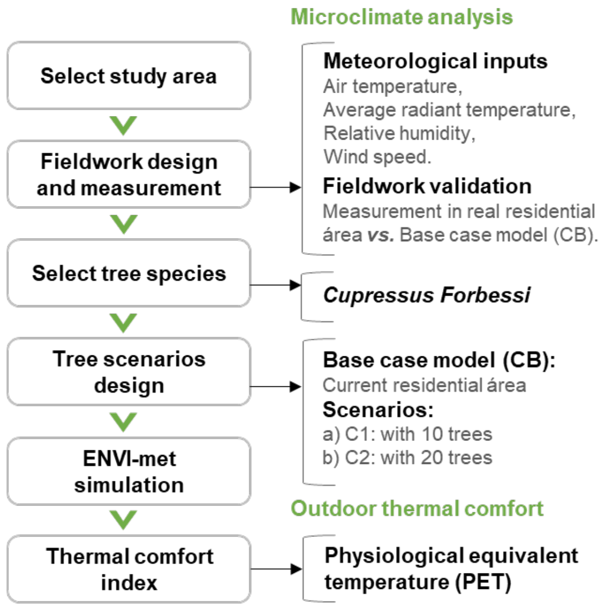


Figure 2. Methodology framework

After selecting the site, the meteorological data were obtained on-site to use as input parameters of the simulation in the ENVI-met software, obtained in monitoring campaigns with Data Loggers, HOBO Brand, that record temperature and humidity. Subsequently, the vegetation species was determined through its characterization to simulate the current situation of the site and different alternative scenarios, seeking a cooling effect to improve external thermal comfort. Finally, the ENVI-met output data allowed analyzing the site's thermal comfort. The index used to estimate thermal comfort was the Equivalent Physiological Temperature (PET).

2.1. Fieldwork design and measurement

An on-site monitoring campaign was performed to validate the accuracy of the numerical simulation results and obtain meteorological information with Data Loggers, that record air temperature and relative humidity data.

Data were collected to be simulated on October 4, 2020, that day presented high temperatures, low wind speed (~2 m/s), and clear skies. The monitored and simulated data (24 h) were used to validate the ENVI-met numerical model (Table 1).

Table 1. Tair comparison of monitoring and simulation on October 4, 2020

Air Temperature	Measurement	Base case (CB)
Min (°C)	19.9	20.0
Max (°C)	32.3	32.1
Media (°C)	25.63	25.6

In other studies with ENVI-met, the root mean squared error (RMSE) and mean absolute error (MAE) of air temperature were typically around 1–2°C (Zhao et al., 2018). In the validation of this study, the air temperature's mean square error (RMSE) and mean absolute error (MAE) were 0.21 and 0.19, respectively. In this sense, the simulated results were accurate concerning monitored data (Figure 3).

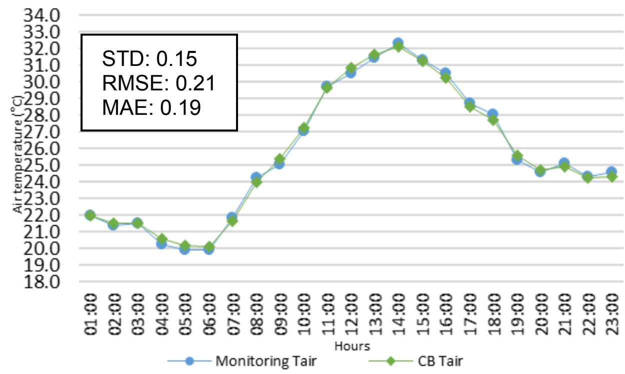


Figure 3. Adjustment of the monitored data and the simulator of October 4, 2020 at a pedestrian scale (1.50 m).

2.2. Simulation

The simulation was performed using ENVI-met software, a forecasting three-dimensional microclimate model designed to simulate complex interactions between surface, vegetation, and air in the urban environment (Tsoka et al., 2018). In ENVI-met, the vegetation is treated as a one-dimensional column with height-zp and the profile of leaf area density (LAD) is used to describe the amount and the distribution of leaves (Figure 4). The same concept is used inside the soil system: the distribution of roots is represented by the root area density (RAD) profile stretching from the surface down to the root depth –zr (Bruse, 2004).

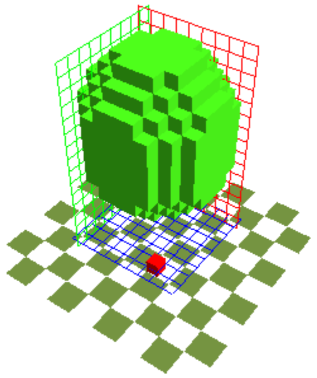


Figure 4. Tree in Albero module of ENVI-met.

The complete domain of the ENVI-met in this study area (GRID) was 50 × 50 × 30 m (x, y, z), with a vertical and horizontal grid resolution of 1.0 m. The research focused on understanding the location and distribution impacts of trees. The Cupressus Forbessi was the tree species used in the simulation scenarios (Table 2). First, a base case (CB) was simulated whit the current situation of the study area, and then two proposed scenarios were created considering vegetation species on the sidewalks in front of the properties.

Table 2. Summary of tree information

Tree name	Scientific name	Leaf type	Crown width	Tree height
Cypress	Cupressus forbesii	Evergreen	3.0 m	3.0 m

Note: Tree information was obtained from the web Gymnosperm Database. (https://www.conifers.org/cu/Cupressus_forbesii.php)

As seen in Figure 5, the configuration 1 (C1) featured an arrangement of trees at individual intervals of 7.0 m with a total of 10 trees; Configuration 2 (C2) presented a grouped arrangement (1.0 m of the distance between trunks) with two trees at 14.0 m of the distance between clusters and a total of 20 trees.

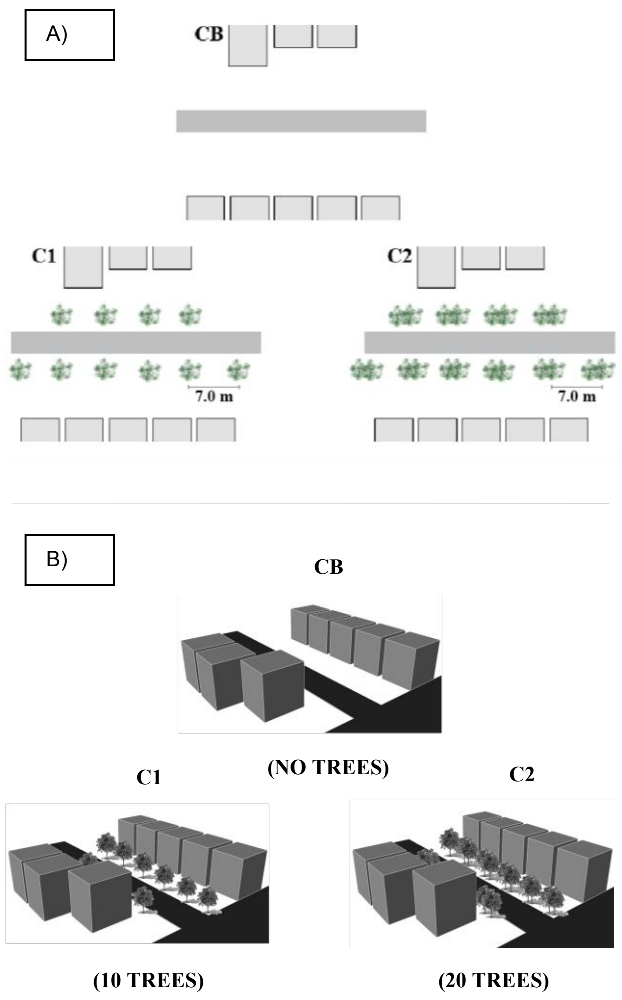


Figure 5: A) Simulation scenarios in 2D, B) Simulation scenarios in 3D.

3. RESULTS

Each scenario presented a different configuration of shading trees, which modified the microclimate of the study area in other aspects, such as Relative Humidity, Air Temperature and Average Radiant Temperature.

The *Cupressus Forbessi* species presented a predominant shade throughout the year, being an evergreen tree. The Cupressus forbessi species showed the ideal characteristics, such as foliage density and adequate dimensions for the study area. Regarding the PET, the C2 scenario was affected in most of the schedules when using groupings of two trees with the superimposed crown, since instead of decreasing the °C values, they increased them. This effect was attributed to wind obstruction and decreased speed m/s (Figure 6).

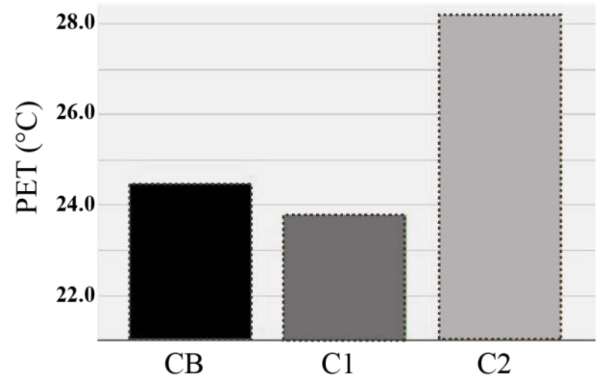


Figure 6: Comparison of means of the PET index

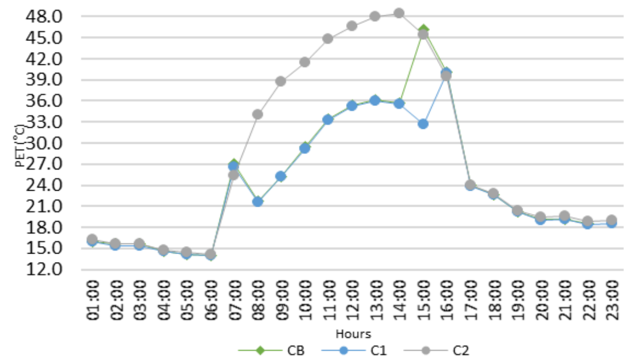


Figure 7. PET hourly on October 4, 2020.

Compared to the CB, at 15:00 (an hour with the highest PET °C), all scenarios decreased in °C. In scenario C1 the reduction was 13.49 °C; in C2, the drop was 0.7 °C. On the other hand, at 06:00 (the hour with the lowest PET °C), the °C remained in the same conditions as the CB (14.00 °C); Scenario C2 presented an increase of 0.23 °C (Table 3).

Table 3: PET hourly analysis

Date	Time	CB (° C)	C1 (° C)	C2 (° C)
04.10.2020	01:00	16.0	16.0	16.2
04.10.2020	02:00	15.6	15.4	15.6
04.10.2020	03:00	15.6	15.4	15.6
04.10.2020	04:00	14.6	14.6	14.8
04.10.2020	05:00	14.2	14.2	14.4
04.10.2020	06:00	14.0	14.0	14.2
04.10.2020	07:00	27.0	26.6	25.4
04.10.2020	08:00	21.8	21.6	34.0
04.10.2020	09:00	25.2	25.2	38.8
04.10.2020	10:00	29.4	29.2	41.5
04.10.2020	11:00	33.4	33.3	44.8
04.10.2020	12:00	35.4	35.3	46.7
04.10.2020	13:00	36.1	36.0	48.0
04.10.2020	14:00	35.7	35.6	48.4
04.10.2020	15:00	46.1	32.7	45.4
04.10.2020	16:00	40.1	39.9	39.5
04.10.2020	17:00	24.0	23.8	24.0
04.10.2020	18:00	22.6	22.6	22.8
04.10.2020	19:00	20.2	20.2	20.4
04.10.2020	20:00	19.2	19.0	19.4
04.10.2020	21:00	19.2	19.2	19.6
04.10.2020	22:00	18.6	18.4	18.8
04.10.2020	23:00	18.6	18.6	19.0

The CB scenario served to diagnose the current situation of the study area and determine the values used as study constants, that is, the urban geometry, material surfaces, the characteristics of the vegetation species, and the climatic conditions.

Observing Figure 8 and Figure 9, it is notable that the areas with the highest temperature in the study area were located to the North. The C1 (with 10 trees) is considered the best scenario since it presented the most significant decrease in °C during the warmest hour. Furthermore, it reduced or remained in the same conditions as the CB. The equality of conditions between scenarios was presented from 04:00 a.m. to 06:00 a.m. and at 11:00 p.m.

It is possible to observe temperature differences both in its minimum and maximum, observed mainly in the vegetation area, influenced by the shading effect.

Scenario C2 (with 20 trees) shows a predominance in the increase in temperature, specifically at 01:00, for the time interval of 04:00 - 06:00, from 08:00 - 14:00, and from 18:00 - 23:00. The temperature was maintained with values equal to CB, from 02:00 - 03:00 and at 17:00. The reduction was presented at 07:00 and from 15:00 - 16:00, particularly at 15:00 (critical hour of the CB) such reduction was 0.70 °C. At 06:00. there was a minimum value of 13.60 °C and a maximum of 16.37 °C, while at 15:00 the minimum value was 31.87 °C and the maximum was 54.20 °C.

Matzarakis & Mayer, (1996), introduced PET assessment classes to facilitate further interpretation of PET results. However, it is only valid for the assumed values of internal heat production (80 W) and thermal resistance of the clothing (0.9).

According to this classification, in scenario C1 on October 4, 2020, it was perceived at 06:00 a degree of psychological stress called slight cold stress, while moderate heat stress was perceived at 15:00

In scenario C2, on October 4, 2020, it was perceived at 06:00 a degree of psychological stress called Slight cold stress, while extreme heat stress was perceived at 15:00.

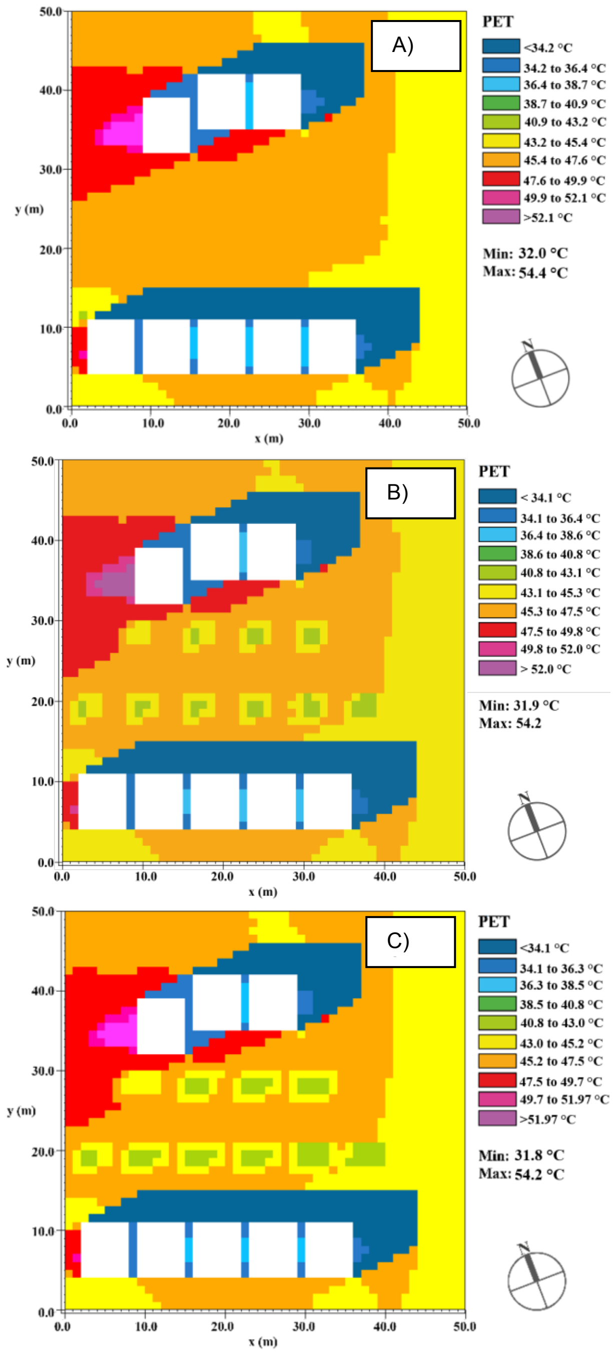


Figure 8: Map of October 04, 2020, to visualize the PET index at 15:00 in scenario CB, C1 and C2 at 1.50 m, simulated in ENVI-met.

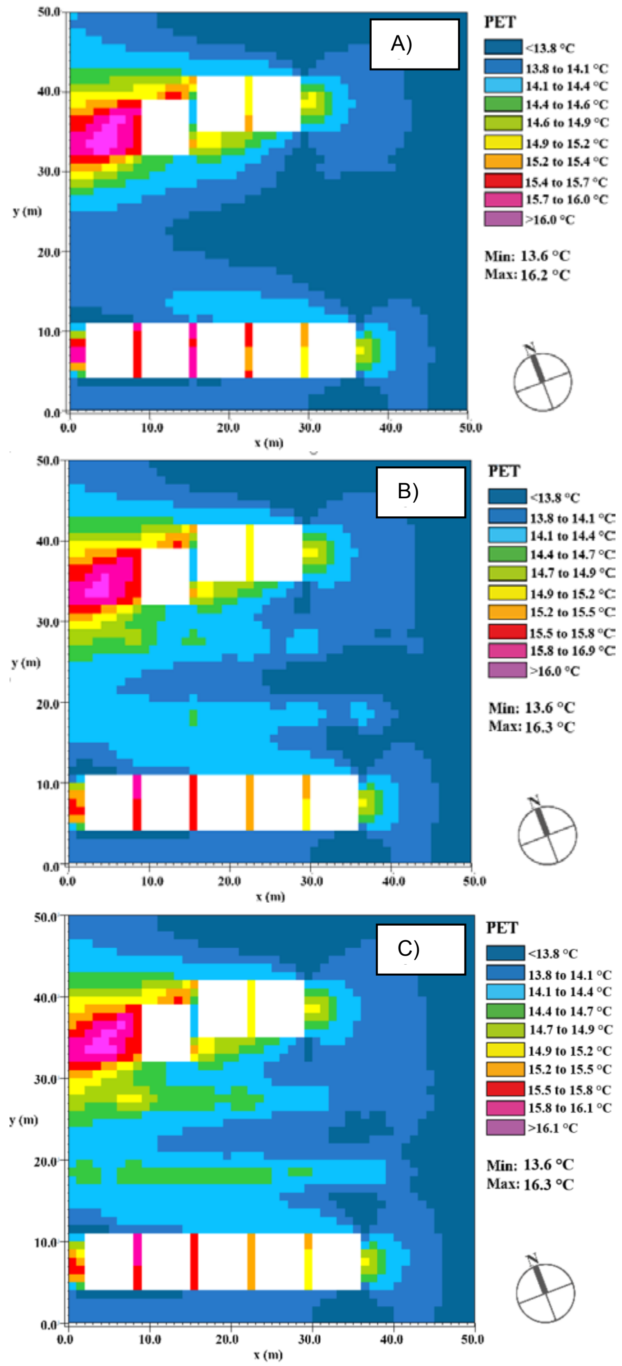


Figure 9. Map of October 04, 2020, to visualize the PET index at 06:00 in scenario CB, C1 and C2 at 1.50 m, simulated in ENVI-met.

4. CONCLUSION

Each city has a different climate and problems. The microclimatic alterations that urbanization causes affect the interior spaces of buildings and impact the thermal comfort of open spaces. Therefore, it is necessary to consider the vegetation species that will be used. It is also essential to define the optimal arrangement of green infrastructures in the urban environment to choose a positively adapted model to the needs.

This work explores the layout design of planting patterns and compares different locations. The number of trees reveals that using individual tree arrangements improves the cooling benefits and thermal comfort. The best results were obtained for arranging a tree (3.0 m crown and 3.0 m tall), such as *Cupressus Forbessi*, at 7.0 m distance from each other.

The simulation models of the present study demonstrated that tree locations and arrangements could modify outdoor microclimates and human thermal comfort. The research results reaffirm the quote by Santamouris et al., (2018) ''The right tree, in the right place'', since depending on the configuration, the mitigation effectiveness of °C varies.

It is essential to mention that similar studies should be carried out using various building designs in different seasons. The recommendations for the location and arrangement of trees in the residential area may not be effective in another climatic zone, just like other trees with different types of leaves, tree height, leaf area index (LAI), and crown size may recommend different results from this investigation.

REFERENCES

Antoniadis, D., Katsoulas, N., & Papanastasiou, D. (2020). Thermal environment of urban schoolyards: Current and future design with respect to children's thermal comfort. *Atmosphere*, *11*(11), 1–26. https://doi.org/10.3390/atmos11111144

Bherwani, H., Singh, A., & Kumar, R. (2020). Assessment methods of urban microclimate and its parameters: A critical review to take the research from lab to land. *Urban Climate*, *34*(May), 100690. https://doi.org/10.1016/j.uclim.2020.100690

Bruse, M. (2004). *ENVI-met 3.0: Updated Model Overview*. *March*, 1–12.

Bruse, M., & Fleer, H. (1998). Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling and Software*, *13*(3–4), 373–384. https://doi.org/10.1016/S1364-8152(98)00042-5

Cilek, M. U., Cilek, A., & Uslu, C. (2021). The effects of tree cover density on the urban heat islands in the city of adana. *Journal of Digital Landscape Architecture*, *2021*(6), 267–277. https://doi.org/10.14627/537705023

Hami, A., Abdi, B., Zarehaghi, D., & Maulan, S. Bin. (2019). Assessing the thermal comfort effects of green spaces: A systematic review of methods, parameters, and plants' attributes. *Sustainable Cities and Society*, *49*(May), 101634. https://doi.org/10.1016/j.scs.2019.101634

Li, X., Zhou, Y., Yu, S., Jia, G., Li, H., & Li, W. (2019). Urban heat island impacts on building energy consumption: A review of approaches and findings. *Energy*, *174*, 407–419. https://doi.org/10.1016/j.energy.2019.02.183

Matzarakis, A., & Mayer, H. (1996). Another kind enviromental stress thermal stress. *WHO Newsletter*, *18*, 7–10.

Mills, G., Stewart, I. D., & Niyogi, D. (2022). The origins of modern urban climate science: reflections on 'A numerical model of the urban heat island.' *Progress in Physical Geography*, *46*(4), 649–656. https://doi.org/10.1177/03091333221107212

Nuruzzaman, M. (2015). Urban Heat Island: Causes, Effects and Mitigation Measures - A Review. *International Journal of Environmental Monitoring and Analysis*, *3*(2), 67. https://doi.org/10.11648/j.ijema.20150302.15

Perini, K., Chokhachian, A., Dong, S., & Auer, T. (2017). Modeling and simulating urban outdoor comfort: Coupling ENVI-Met and TRNSYS by grasshopper. *Energy and Buildings*. https://doi.org/10.1016/j.enbuild.2017.07.061

Santamouris, M., Ban-Weiss, G., Osmond, P., Paolini, R., Synnefa, A., Cartalis, C., Muscio, A., Zinzi, M., Morakinyo, T. E., Ng, E., Tan, Z., Takebayashi, H., Sailor, D., Crank, P., Taha, H., Pisello, A. L., Rossi, F., Zhang, J., & Kolokotsa, D. (2018). Progress in Urban Greenery Mitigation Science – Assessment Methodologies Advanced Technologies and Impact on Cities. *Journal of Civil Engineering and Management*, *24*(8), 638–671. https://doi.org/10.3846/jcem.2018.6604

Tsoka, S., Tsikaloudaki, A., & Theodosiou, T. (2018). Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review. In *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2018.08.009

United Nations. (2015). *World Urbanization Prospects: The 2014 Revision*.

Wonorahardjo, S., Sutjahja, I. M., Mardiyati, Y., Andoni, H., Thomas, D., Achsani, R. A., & Steven, S. (2020). Characterising thermal behaviour of buildings and its effect on urban heat island in tropical areas. *International Journal of Energy and Environmental Engineering*, *11*(1), 129–142. https://doi.org/10.1007/s40095-019-00317-0

Zhang, J., Gou, Z., Zhang, F., & Shutter, L. (2020). A study of tree crown characteristics and their cooling effects in a subtropical city of Australia. *Ecological Engineering*, *158*(May), 106027. https://doi.org/10.1016/j.ecoleng.2020.106027

Zhao, Q., Sailor, D. J., & Wentz, E. A. (2018). Impact of tree locations and arrangements on outdoor microclimates and human thermal comfort in an urban residential environment. *Urban Forestry and Urban Greening*, *32*(March), 81–91. https://doi.org/10.1016/j.ufug.2018.03.022

PLEA SANTIAGO 2022
Will Cities Survive?

Urban materials for thermally liveable Madrid

A digital twin strategy to characterize developments

EMANUELA GIANCOLA[1] HELENA LÓPEZ[1] SILVIA SOUTULLO[1] M. NURIA SÁNCHEZ[1] ANA GAMARRA[1] ISRAEL HERRERA[1] LUIS ZARZALEJO[1] EMANUELE NABONI[2]

[1] Department of Energy, CIEMAT, 28040 Madrid, Spain
[2] University of Parma; Royal Danish Academy

ABSTRACT: This paper presents the measure, calibration and simulation strategy that will be used in a Spanish research project for fostering new material customized to Madrid sustainable goals. In particular, a very preliminary simulation result of an ad-hoc developed Building Performance Simulation tool is presented. It enables to appropriately simulate the effect of thermochromic hysteretic behaviour and its influence on energy use in buildings of an envelope with a commercial thermochromic coating in a simple test room space in Madrid. The general strategy will be used to evaluate mutual relations amongst relevant urban factors (microclimate, materials, typologies…) building energy performance, and outdoor thermal comfort with the crafting of a rationalized Grasshopper based digital workflow. The project will be performed in the thermally vulnerable areas of Madrid, which is an adequate city to analyse the problem of the Urban Heat Island, given its size and its Mediterranean climate with significant energy demands for heating in winter and for cooling in summer.
KEYWORDS: Parametric Design, Environmental Simulation Tools, Chromogenic Smart Materials, UHI.

1. INTRODUCTION

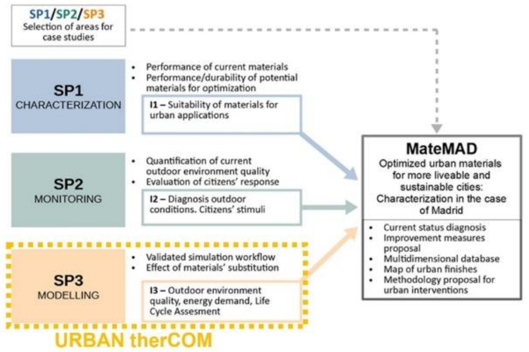
The world's population that lives in urban areas is expected to increase to 68% by 2050. [1]. Buildings are referred to as the sector needing solutions for a low-carbon future as they account for 36% of global final energy consumption and 39% of carbon dioxide emissions [2]. Moreover, the built environment is highly responsible for the development of the Urban Heat Island (UHI) phenomenon associated with global and local climate change which in turns have serious impact on the energy consumption of buildings and increase of atmospheric pollutants, negatively impacting health [3]. It is therefore of primary importance to concentrate studies on the design of the microclimate and the interactions between it and the urban materials [4], [5]. In this sense, there is a gap in the knowledge and research referred to: a) the characterization of urban materials in and their thermo-optical (TO) performance that mainly define their impact on urban environment; b) the monitoring of environmental parameters that affect liveability in public spaces and energy demand; c) the adequate tools to correctly simulate these interrelations, in Europe and especially in Spain.

1.1 mateMad Concept

Within this framework, the recent approved Spanish research coordinated project, mateMad, is based on the hypothesis that optimized materials, like chromogenic smart materials for urban surfaces can provide efficient solutions to the UHI effect. The project will be performed in thermally vulnerable areas of Madrid, which is an adequate city to analyse the problem of the UHI due to its size and its Mediterranean climate with significant energy demands for heating in winter and for cooling in summer.

The project addresses via a multidisciplinary approach combining the activities performed under three subprojects (Fig. 1): - Subproject 1 (SP1). Characterization of urban materials in multiple dimensions, the thermo-optical performance that mainly define their impact on urban environment and citizens' well-being. This approach is necessary to identify those materials potentially suitable to be considered in the optimization and to obtain reliable results from the simulations by the digital model of the cities. - Subproject 2 (SP2). Monitoring of environmental parameters that affect liveability in public spaces and energy demand, as well as the citizens' response to urban materials stimuli. This approach is necessary for the validation of the digital model of the city. - Subproject 3 (SP3), named URBAN therCOM, subject of this work. Modelling outdoor thermal comfort and energy demand in urban areas with a comprehensive digital workflow that implements mutual relationships amongst these two aspects and relevant urban factors, such as microclimate, materials and typologies. This approach is necessary to test and quantify the effect of substitution of urban materials on the liveability and sustainability of the cities in a digital environment.

Figure 1:
The multidisciplinary approach of the mateMad project strategy.



This paper presents the measure, calibration and simulation strategy that is used for fostering new material customized to Madrid sustainable goals. The strategy will be used to evaluate mutual relations amongst relevant urban factors, microclimate and materials customization in light of building energy performance, and outdoor thermal comfort. A Grasshopper (GH) [6] based digital workflow is used to complete the digital twin among areas of Madrid and simulation. In particular, the methodology adopted for the simulation approach and an ad-hoc developed BPS tool which enables to appropriately simulate the effect of thermochromics materials (TC) hysteretic behaviour and its influence on energy use in buildings is described. This is followed by a description of a demonstration case study, a simple test room space in Madrid. Finally, the main results are presented in the perspective of extending the developed BPS tool to be more generally applicable also to other facade technologies and to be more seamlessly integrated into the design process.

2. BACKGROUND

One of the main goals for the energy design of buildings is to adapt to the climatic conditions, reducing heat losses and attenuating thermal oscillations between outdoors and indoors [7]. The façade is considered the primary element that thermally connects the external and internal environments. Urban overheating is mainly caused by building materials that over-absorb heat. A mitigation strategy is to pay attention to the thermally absorbing urban materials and replace them with those featuring a greater rejection of sunlight radiation (shortwave) [8]. Reflective materials developed to decrease the surface temperature, contribute to minimising decrease their cooling demand [9].

2.1 Thermocromic materials (TC)

Most of the current research to reduce UHI is related to "cool" materials applied to horizontal surfaces characterized by a high solar reflectance to reduce solar energy absorbed [10], [11]. Consequently, there has been growing interest coatings such as chromogenic smart materials with a variable optical response to different seasons [12], adapting to climates with extreme summer and in winter temperatures.

In this context, thermochromic coating have been considered by many researchers as significant factors in determining surface and air temperatures in urban canyons by exploiting materials intrinsic good thermal-optic properties. [13]. The current state of the art of thermochromic materials has been summarized by [12] with specific attention to the possible application in the building sector.

Thermochromism is the feature of a functional material to vary reversibly its optical properties as a response to a temperature variation. When using TC materials in buildings as a passive system, their performance is highly dependent on the interaction between the material and the climatic conditions, allowing to achieve a passive smart envelope able to control solar gains.

Most of TC materials presents a hysteretic behaviour between the heating and cooling phase, meaning that the relationship between the variable optical properties and the temperature will follow a different path if the material is heated up or cooled down. The energy (activation energy) required to reverse the thermochromic phenomenon allowing a homogenous nucleation of the thermochromic transition determines the width of the hysteresis [14].

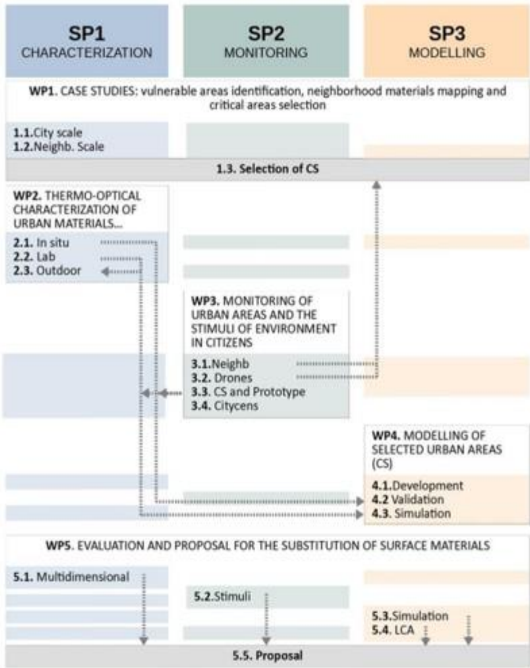
2.3 Simulation gap

In the energy simulation of buildings there has been little focus on the influence of the building envelope on the exterior and interior environment; simulation tools have usually dealt either with building or with outdoor simulation separately, mainly due to the limited ability of the current Building Performance Simulation tools (BPS) to evaluate these interrelationships. Determining the urban outdoor comfort characterized by different surface conformations such as the potential energy saving of thermochromic coatings when applied to building envelopes is still a challenge given the complexity of external spatial and temporal thermal fluxes. Just a few procedures have been adopted to simulate the dynamic behavior of thermochromic paints [15] [16]. Jianying and Xiong [17] modelled the dynamic optical properties of thermochromic paints using the Energy Management System (EMS) in EnergyPlus [18], so it changed accordingly to the surface temperature. For these reasons, it is necessary to create ad-hoc measures and customized simulation workflows to evaluate the influence of their impacts on outdoor and indoor. Such customized simulation tool workflows can help to achieve the target of Climate-neutral Cities with improved liveability and sustainability.

3. MEASURE, CALIBRATION AND SIMULATION STRATEGY

The mateMAD project strategy encompasses five steps as shown in the working plan scheme (Fig. 2).

Figure 2:
A schematic overview of strategy of the mateMad project.



The first step describes a procedure to select the urban areas where a greater impact is expected from the application of the project's hypotheses. The objective is the assessment of vulnerability within the city, on those aspects related to Climate Change, discomfort (such as overheating during the summer) and energy inefficiency of buildings and the urban fabric. Three scales of analysis are proposed for the identification of areas of specific interest: • Cityscale: to find the most vulnerable areas and their distribution within the city. • Neighbourhood scale: to assess the morphology, comfort conditions and materials. • Public space scale: the information generated in the previous step will allow the selection of at least two singular urban elements in a situation of thermal stress which will be analysed in detail as case studies.

The second step will be a detailed thermo-optical (TO) characterization of a wide range of surface urban materials. In the first stage, the experimental characterization will be performed in-situ for the vegetation and materials currently in use in pavements and façades. A second stage will address the empirical TO characterization of a wide set of commercial and innovative materials, including TC, for urban applications. The results of this step will provide input to the map of urban materials, to the validation of the developed simulation workflow and to the evaluation and proposal for the substitution of surface urban materials defined in the last step.

In the third step monitoring at four levels will be performed: neighbourhood, case study areas, outdoor tests, and citizens. The monitoring objectives at these four scales are different but interconnected. The information will be collected and analysed using different techniques: sensors and monitoring equipment (air temperature, relative humidity, solar radiation, air velocity, globe temperature, noise, illuminance, and air quality); electroencephalography and eye-tracking (for emotion detection) and citizens' surveys (for comfort evaluation and to promote citizen participation and awareness).

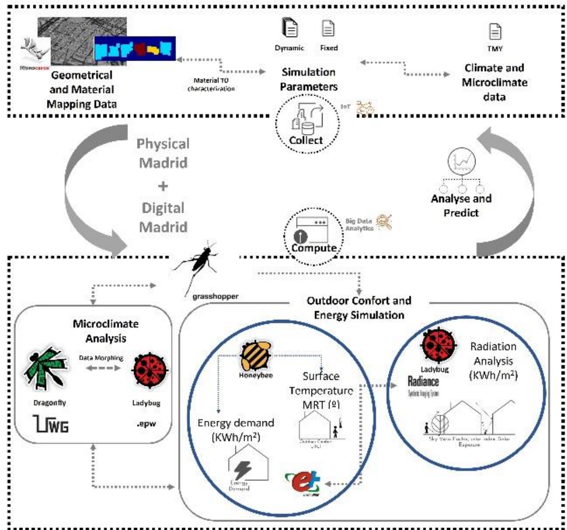
The aim of the fourth step is to provide a strategy and tools to evaluate mutual relations amongst relevant urban factors (microclimate, materials, typologies…), building energy performance and outdoor thermal comfort using existing evaluation tools in a single digital workflow. A series of existing and customised plugins, most of which are already in use and open source, will be integrated into a multi-parametric workflow based on a visual programming tool. Then, validation tests will be developed using simulated and experimental data.

The final step will prepare a complete and justified proposal for the substitution of surface materials in the case studies. This proposal will be based on the results of characterization of materials, as well as on the monitoring and modelling of urban areas obtained from previous steps. However, to achieve a reliable and useful proposal the assessment of the environmental impact of the materials along their life cycle will allow quantifying the environmental impacts for the selected materials and scenarios.

3.1 Simulation approach and workflow

The overview of the Grasshopper [6] based digital workflow used to digitally twin areas of Madrid and simulation is shown in (Fig. 3), where the connections amongst the different tools are highlighted. GH is a tool that allows the parametric management of geometrical information through Rhinoceros [19] providing a graphical user interface to scripting and Python programming language [20]. In this way the designer / modeller develops urban virtual model, interlinking various domains. The first step of the proposed simulation workflow will consist in creating an appropriate geometric representation of the urban area that will be investigated. This will be used for the determination of building energy demand as well as for simulating building surface temperatures.

Figure 3:
A schematic overview of simulation approach and workflow in GH of the URBAN therCOM (SP3) project.



The workflow relies on several plug-ins to allow the simulation of indoor and outdoor thermal field. Dragonfly [21] runs the Urban Weather Generator (UWG) tool [22], which estimates the hourly air temperature and relative humidity in the urban canopy starting from an existing weather file and generates a morphed weather file in the ".epw" format, compatible with many Building Energy Simulation tools [23]. On the other hand, Honeybee and Ladybug [24] take into account the interaction of the envelope with both the indoor and outdoor spaces: they calculate the energy demand for space heating and cooling based on the EnergyPlus [18] and Radiance [25] engine, also assessing the outdoor mean radiant temperature. Eventually, the workflow assesses the thermal comfort perceived by pedestrians through suitable metrics, i.e. the Mean Radiant Temperature (MRT) and the Universal Thermal Climate Index (UTCI). The main focus here is on urban-building shortwave heat exchanges reducing the current shortcomings in the evaluation of outdoor thermal comfort. Hence, a suitable comfort model will be addressing climatic conditions, urban environment, and physical characteristics. The second part will be to provide a unified approach for the real-time evaluation of the outdoor performance of tested materials evaluated in the project. This will include onsite physical characterization of factors affecting the wide range of transient performance as well as the inputting of measures data into the model.

The performance of the TC material and the influence of the hysteresis width on this performance are evaluated by means of a virtual experiment, simulating a reference office room, in which the TC envelope are integrated measuring the whole year´s performance relative to different domains of interest. The virtual building models in each physical domain are generated through an integrated approach by means of two add-ons HoneyBee and LadyBug [24]. In the case of the TC first, several simulations are run in Radiance to represent all possible effects of TC states on the visual domain. Look-up tables are generated automatically and fed into the thermal model of EnergyPlus [18], which combines the history-independent visual results according to the simulated temperatures. The control and set-up of the thermo-optical proprieties of the TC were carried out parametrically by the integration of the Energy Management System (EMS) of Energy Plus in HoneyBee (through Grasshopper).

The presented timestep-by-timestep simulation approach allows the variation of the thermo-optical properties of the TC material within the simulation runtime itself, which in turn implies precisely considering the thermal inertia of the building and its effects on the energy demands for heating and cooling.

4. RESULTS

4.1 Case study

As an example, a first approximation to the simulation environment is presented here. The variation of (a) hysteresis width and (b) transition temperature in a simple test room space in Madrid, whose location is characterized by semi-arid climatic conditions (Koppen-Geiger coefficient: Csa) with mild cool winters and hot summers, was considered as a case study. An enclosed office 3.6 m wide, 4.5 m deep and 2.7 m high was assumed as a case study. On one of the short walls, south oriented, is located a window 2.26 m wide and 1.5 m high, for a Window-to-Wall Ratio (WWR) of 35%. The case study was assumed to be part of an office block, flanked by two identical offices on two sides on the same floor and on the floor immediately above and below with the same thermal conditions on the third side on the same floor. All the horizontal and vertical internal partitions were therefore considered as adiabatic. The external opaque envelope has been modelled considering design values that meet the minimum construction and operational requirements regulated by the Spanish normative for the year 2006 [26]. The design data are shown in Table 1.

Table 1:
Design data of the building envelope. The limit values of the overall heat transfer coefficient of the building envelopes for 2006 normative requirements.

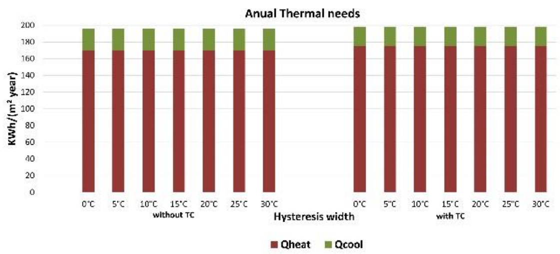
Constructive elements	U_{limit} 2006 W/m^{2}K)
Roof	0.38
Exterior wall	0.66
Ground floor	0.66
Partition wall	0.66
U window	1.43
g window	0.61
Window frame	2.20

To simulate the numerical model of TC coating, a commercial one with the following characteristics is used: τvis range between 0.68 and 0.06 (cold and hot state respectively); τsol range between 0.62 and 0.23 (cold and hot state respectively); transition temperature ranges between 26 °C and 71 °C; hysteresis width equal to 5 °C

4.2 Annual Thermal Needs

The paper shows some preliminary results on the annual thermal needs for heating and cooling for the simple test room space with and without TC coating in the envelope facing the south. To assess the energy performance of the building models, one TMY provided by the climatic database of the Energy Plus website [22] has been used.

Figure 4:
Annual results of energy demand relative to the case study with and without TC coating for the hysteresis width considered.



(Fig. 4) represents the thermal needs obtained for the case study with and without the TC coating, showing that the heating needs are much higher than the cooling needs. This is due to the climatic conditions of Madrid and the higher number of months of the heating period (9 months) in comparison with the cooling period (3 months). The application of the proposed TC coating on the south-oriented wall increased the heating demand by 3.1% while the cooling demand has been reduced by 12.7%. It is interesting to notice that TC hysteresis effect on the energy performance is negligible. There is a clear need for future works to test different TC technologies in different orientations and types of envelopes.

With this preliminary approach it was possible to test that the modelling strategy used reproduces the effect due to the use of the TC material. This last aspect represents a strength of the proposed integrated simulation approach, as a comprehensive evaluation of the performance of such material was not possible by means of currently available BPS tools, if not by introducing some simplifications in the analysis, with a consequent higher degree of inaccuracy in the final outcomes. Finally, the implementation in Grasshopper (GH) of this simulation strategy allows a high flexibility for its application. The only requirement is that of specifying the numerical model describing the behaviour of the adaptive component, which allows simulating both control strategies for active components and the intrinsic behaviour of passive adaptive component.

5. CONCLUSION

It is clear that urban surfaces have strong influence on the quality of the outdoor environment, the energy demand and the well-being of citizens and that thermo-optical properties are the key factors to define and control this influence. However, there is a gap in the knowledge and research referred to these topics in Europe and especially in Spain. The present work aims to advance to fill this gap, presenting a strategy adopted in the mateMAD project to optimize urban materials and validating their viability via experimental research, monitoring and simulation. As shown in this paper, the use of Parametric Design tools is a valid strategy for exploring solutions to environmental performance analysis of building integrating new kind of adaptive material in the envelope. The application of the proposed integrated simulation methodology to the case of an envelope with TC coating is therefore aimed at showing its possibilities and advantages, compared to currently available BPS tools. Specifically, the use of such methodology enabled: i) the correct modelling of peculiar material aspects, such as temperature dependency of optical properties and hysteresis; ii) the implementation of this model into the ad-hoc developed multi-physics simulation strategy for adaptive materials.

Although the methodology was tested for one specific case study, a similar approach can be used to investigate the variation of different design parameters (i.e. building orientation, building geometry, window-to-wall ratio, the thermal resistance of the external envelope, etc.), by means of the parametric user interface developed.

The preliminary results of this paper are used to test the simulation strategy of TC materials and are presented in the perspective of extending the developed BPS tool to be more generally applicable also to other façade technologies and to be more seamlessly integrated into the design process.

Future work and further investigation are needed to test and validate the strategy and the general digital workflow with real cases studies of Madrid through the information that will be acquired throughout the duration of the mateMad project. The comprehensive simulation workflow will depend on the performance of each component and the interaction between these components in the entire façade system and how the façade interacts with the internal/external environment creating specific outdoor microclimates.

This kind of strategy will be useful for planners and designers and will be support for assisting the public policymakers and regulators in decision taking processes.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude for the financial support from Grant PID2020-114873RA-C33 (URBAN-TherCOM Project) funded by MCIN/AEI/10.13039/501100011033.

REFERENCES

1. UN WUP, 2018. Population Division of the United Nations Department of Economic and Social Affairs (UN DESA). [Online], Available: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html [06 August 2022].
2. UN Environment and International Energy Agency. (2017). Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017. [Online], Available: https://www.worldgbc.org/sites/default/files/UNEP%20188_GABC_ en%20%28web%29.pdf. [06 August 2022].
3. Santamouris, M., Cartalis, C., Synnefa, A., Kolokotsa, D., (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings–a review, *Energy and Buildoings*, 98: p.119–124.
4. Naboni, E., Milella, A., Vadalà, R., Fiorito, F., (2020). On the localised climate change mitigation potential of building facades. *Energy and Buildings*, 224: p. 110284.
5. Mauree, D., Coccolo, S., Perera, A., Nik, V., Scartezzini, J.L., Naboni, E., et al., (2018). A new framework to evaluate urban design using urban microclimatic modeling in future climatic conditions. *Sustainability*, 10: p. 1134.
6. McNeel R. Grasshopper: algorithmic modeling for Rhino [Online], Available: http://www.grasshopper3d.com/ [06 August 2022].
7. Giancola, E., Soutullo, S., Olmedo, R., Heras, M.R., (2014). Evaluating rehabilitation of the social housing envelope: experimental assessment of thermal indoor improvements during actual operating conditions in dry hot climate, a case study. *Energy and Buildings*, 75: p. 264–271.
8. Croce, S., Vettorato, D., (2021). Urban surface uses for climate resilient and sustainable cities: A catalogue of solutions. *Sustainable Cities and Society*, 75: p. 103313.
9. Berardi, U., Garai, M., Morselli, T., (2020). Preparation and assessment of the potential energy savings of thermochromic and cool coatings considering inter-building effect. *Solar Energy*, 209: p. 493-504.
10. Santamouris, M., (2020). Recent progress on urban overheating and heat island research. integrated assessment of the energy, environmental, vulnerability and health impact synergies with the global climate change. *Energy and Buildings*, 207: p. 109482.
11. Wang, Y., Berardi, U., Akbari, H., (2016). Comparing the effects of urban heat island effect mitigation strategies in the city of Toronto. Energy Build. 114: p., 2–19.
12. Garshasbi, S., Santamouris, M., (2019). Using advanced thermochromic technologies in the built environment: Recent development and potential to decrease the energy consumption and fight urban overheating. *Solar Energ Mater Solar Cells*, 191: p. 21–32.
13. Rosso, F., Golasi, I., Castaldo, V.L., Piselli, C., Pisello, A.L., Salata, F., Ferrero, M., Cotana, F., de Lieto Vollaro, A., (2018). On the impact of innovative materials on outdoor thermal comfort of pedestrians in historical urban canyons, *Renewable Energy*, 118: p. 825-839.
14. Parkin, I.P., Binions, R., Piccirillo, C., Blackman, C.S., Manning, T.D., (2008). Thermochromic Coatings for Intelligent Architectural Glazing, *Journal of Nano Research*, 2: p. 1–20.
15. Park, B., Krarti, M., (2016). Energy performance analysis of variable reflectivity envelope systems for commercial buildings. *Energy Build.,* 124: p. 88–98.
16. Zheng, S., Yi, X., Shen, Q., Yang, H., (2015). Preparation of thermochromic coatings and their energy saving analysis. *Sol. Energy*, 112: p. 263–271.
17. Jianying, H., Xiong, B.Y., (2019). Adaptive thermochromic roof system: Assessment of performance under different climates. *Energy Build.,* 192: p. 1–14.
18. DOE. EnergyPlus Energy Simulation Software 2017. [Online], Available: https://energyplus.net [06 August 2022].
19. Rhinoceros, (n.d.). [Online], Available: https://www.rhino3d.com [06 August 2022].
20. Python, (n.d.), [Online], Available: https://www.python.org/ [06 August 2022].
21. Dragonfly (n.d.), [Online], Available: https://github.com/chriswmackey/Dragonfly [06 August 2022].
22. Urban Weather Generator (n.d.)., [Online], Available: https://urbanmicroclimate.scripts.mit.edu/uwg.php [06 August 2022].
23. Bueno, B., Norford, L., Hidalgo, J., Pigeon, G., (2012). The urban weather generator, *J. Build. Perform. Simul.*, 6 (4): p. 269–281, doi:10.1080/19401493.2012.718797.
24. Ladybug and Honeybee (n.d.), [Online], Available: http://www.grasshopper3d.com/group/ladybug [06 August 2022].
25. Radiance, (n.d.). [Online], Available: https://www.radiance-online.org [06 August 2022].
26. Spain. Technical Building Code. [Online] Available: https://www.codigotecnico.org/DocumentosCTE/AhorroEnergia.html [06 August 2022].

PLEA 2022 SANTIAGO
Will Cities Survive?

Evaluation of thermal performance of urban asphalt pavements with rubber incorporation

LUIZ FERNANDO KOWALSKI[1 2]; DAIANE CORAGEM AMANCIO[2]; JULIANA FERNANDES VIANA[2]; FELIPE PEREIRA DA SILVA[2]; IVONEI TEXEIRA[2 3]; ÉRICO MASIERO[1]

[1] Federal University of São Carlos (UFSCar)
[2]Adventist University of São Paulo (UNASP)
[3]University of Campinas (UNICAMP)

ABSTRACT: Modification of urban surfaces changes the microclimatic conditions of the cities. Besides, the mechanical performance properties of asphalt binders and mixtures can be enhanced by utilizing several modifiers, including Crumb Rubber (CR) and gilsonite. However, it is not known whether the addition of rubber can reduce heat storage on the pavements and eventually contribute to the mitigation of the Urban Heat Islands. Thus, this paper aims to compare the variation of surface and subsurface temperature between asphalt pavement with and without rubber incorporation. This research then consists of an experimental work and was divided into three main stages: characterization of the study object, collection of surface and subsurface temperature data and, finally, a comparative analysis between temperature data of two different types of pavements. Analysing both models, with and without rubber incorporation in the asphalt mixture, it was possible to notice that the conventional pavement presented the highest surface temperatures during the day. However, the greatest variation can be observed between subsurface temperatures, with a difference of approximately 2K. So, a hypothesis is that there is greater capacity of rubber pavement to store heat in the subsurface layers and potentially reduce the impact on the temperature of cities during the day.
KEYWORDS: Thermal Performance, Rubber, Pavement, Urban Heat Island

1. INTRODUCTION

The modification of urban surfaces changes the thermal comfort conditions of the cities, the energy performance of buildings and, consequently, has implications for human health.

In this context, the thermophysical properties of the surface and elements are important for heat retention of urban tissue and can be considered strategic instruments in the control of the microclimate of cities [1].

The application of cool surface materials can reduce the temperature of cities by 2 or 3°C according to the Global Cool Cities Alliance [2]. Even environmental certification systems, such as LEED, have incorporated the solar reflectance of materials as a scoring criterion [3].

Moreover, the adoption of such initiatives has been seen as a strategy to increase environmental quality and reduce impacts on microclimate from interventions in the urban environment [4].

In addition, to understand and analyze thermodynamic behavior of cool pavements, in various urban realities, it is essential that new strategies be adopted and incorporated into urban design to reduce the effects of Urban Heat Islands (UHI) [5].

Raising the albedo of sidewalks can reduce surface temperature, favoring comfort conditions for pedestrians [6].

In arid environments, cool sidewalks promoted a 25% reduction in air temperature in low-density urban areas, contributing in improving comfort condition and energy demand for cooling [7].

However, by disregarding shading elements and vegetation, it can increase the thermal load of urban canyon facades [8] [9].

Furthermore, the modification of pavement thermal properties and materials plays an important role in strategies to improve urban thermal conditions, such as the increase of thermal conductivity, emissivity, thermal capacity of paved roads [5,9].

An alternative would be the incorporation of rubber into pavements, as using rubber asphalt can improve the mechanical performance of asphalt mixture [10].

Besides, the mechanical performance properties of asphalt binders and mixtures can be enhanced by utilizing several modifiers, including Crumb Rubber (CR) and gilsonite [11].

However, it is not known whether the addition of rubber can reduce heat storage on the pavements and eventually contribute to the mitigation of the Urban Heat Islands.

Thus, this paper aims to compare the variation of surface and subsurface temperature between asphalt pavement with and without rubber incorporation.

2. MATERIALS AND METHOD

The research consists of an experimental work and is divided into three main stages:

- Characterization of pavement materials;
- Characterization of the study object;
- Collection of solar reflectance;
- Collection of surface and subsurface temperature data;
- Comparative analysis between the temperature data of two different types of pavements, with and without rubber incorporation.

First, two asphalt pavement plates were constructed, with an area of 1m², one of them with the incorporation of tire rubber. The layers of the floor were distributed as follows: 3cm of coating, 17cm of granular base and 18cm of sub-bed, all properly compacted. Figure 1 shows the study model.

Figure 1:
Plates of study model and experimental site.

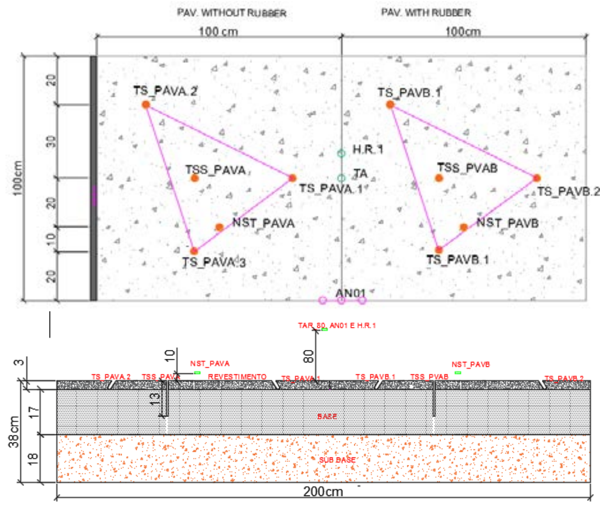
To carry out the construction and compaction of the prototypes, the technical standards listed in Table 1 were used.

Table 1:
Technical standards related to the execution process of each pavement layer

Layers	Description
a) Asphalt concrete surfacing, (CBUQ) Track C / Cold asphalt concrete surfacing with rubber polymers	DNIT 031/2006 ES
b) Bituminous Binding Priming	DER/SP ET-DE-P00/020
c) Bituminous waterproofing primer	DER/SP ET-DE-P00/019
d) BGS base, band C, CBR ≥ 100% and exp. ≤ 0,3%	DER/SP ET-DE-P00/008
e) Existing subgrade, scarified and compacted, CBR ≥ 8 %, exp. ≤ 0,2%	DER/SP ET-DE-P00/001
f) Subsurface and deep drains	DER/SP ET-DE-H00/014

Then, the solar reflectance of the pavements was collected with an ALTA II portable spectrometer, according to ASTM C1549-16 [12]. Finally, 10 sensors (thermocouple DS18b20, accuracy ±0,5K) were installed at three points on the surface of each model, a sensor in the base layer, located inside the floor and a sensor positioned at 10 cm high to collect the air temperature near the surface, as shown in Figure 2.

Figure 2:
Thermocouple positioning on the pavements



In addition, 2 HOBO Pro-V2 sensors were simultaneously installed to collect temperature and humidity data, in addition an anemometer (three cups with 75mm of diameter and ±0,2m/s accuracy) for the microclimatic characterization of the study site.

3. RESULTS

The results are presented in three main sections:

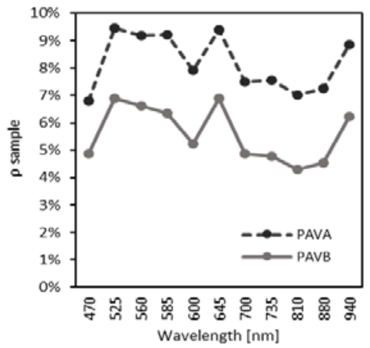
- Pavement albedos;
- Temperature gradient (Subsurface, surface and air) of both pavements;
- Comparative analysis between the pavements temperature with and without rubber incorporation.

3.1 Pavement albedo

Albedo may explain some of the pavement's temperature variation behavior, since it is an optical property related to the ability to reflect incident solar radiation. In this research, the pavements without and with rubber incorporation were measured, and presented, respectively, an albedo of 0.92 and 0.94.

In addition, for an analysis of the material in the visible and near infrared spectrum, the spectral reflectance data are presented in Figure 3.

Figure 3:
Spectral reflectance of the samples (ρ) with rubber incorporation (PAVB) and without incorporation (PAVA).



The spectral reflectance of the pavement without rubber is higher in both the visible and near infrared ranges.

However, the results represent a non-significant variation, considering the equipment error of ±10% [13].

Thus, in this work, the albedo was not the most significant property in reducing the model temperatures.

3.2 Temperature gradient between pavement layers

For the analysis of the temperature variation between layers, we considered: a subsurface layer (Tss) and two layers above the surface (Ts, Ta).

Figure 4 and Figure 5 show the average hourly temperatures, respectively, for the conventional pavement and for the pavement with rubber in the overlay.

Figure 4:
Average temperature of conventional pavement

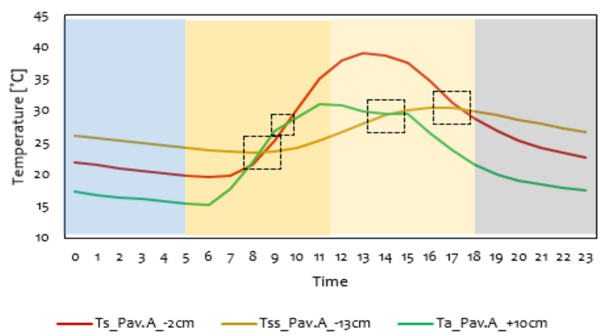
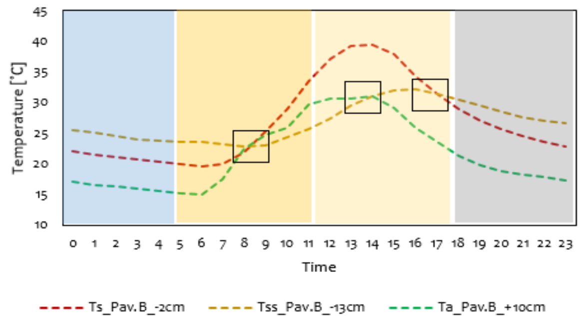


Figure 5:
Average temperature of pavements with rubber incorporation



When evaluating the temperature variation in periods of the day, that is, the early morning, the afternoon and the early evening, it is noted that the inflection points occur at different times.

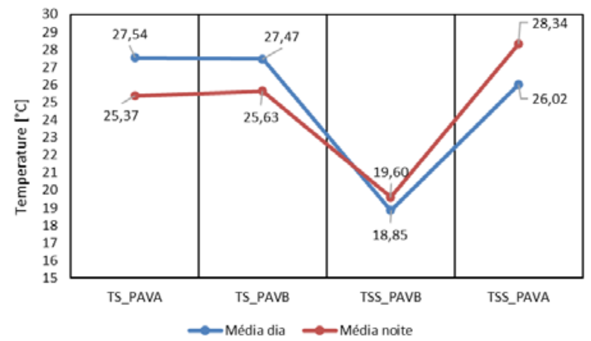
The conventional pavement and the one with rubber incorporation presented their maximum temperatures (Ta) at 11:00 a.m. and 2:00 p.m., respectively.

In addition, it is noted that the maximum surface temperature was recorded at the same time. However, the subsurface temperature of the pavement with rubber showed a greater temperature range (9.29˚C) compared to the conventional one (7.10˚C), indicating a greater capacity to store heat during the day.

3.3 Average temperature differences between pavements

The surface and subsurface temperature data of the conventional pavement (PAVA) and the one with rubber incorporation (PAVB), as well as the air temperature near the surface are presented in Figure 6.

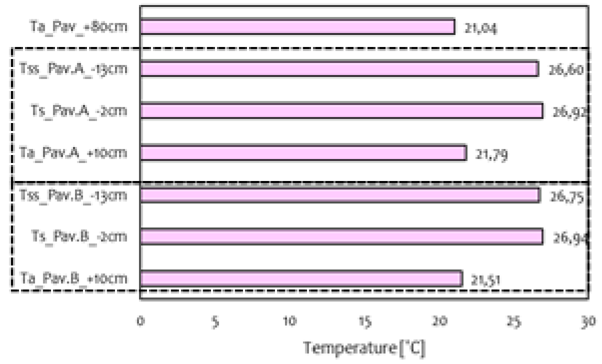
Figure 6:
Average surface and subsurface temperature of conventional pavement (PAVA) and with rubber incorporation (PAVB) during the day and at night.



The temperatures between the layers tend to vary through the losses that have occurred by heat conduction. Floors that have low thermal conductivity heat the surface but do not transfer heat in other layers of the floor instantly compared to a high conductivity floor [5].

Figure 7 shows the average temperatures for the period.

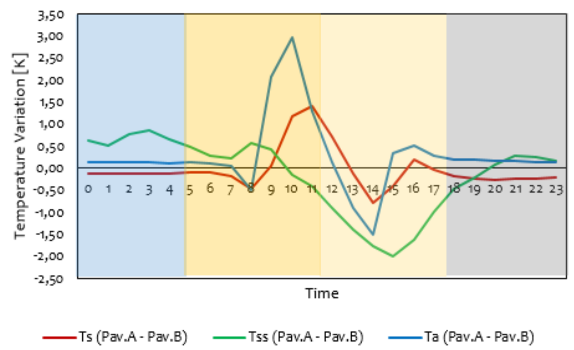
Figure 7:
Averages temperatures of the period



The daily average of the pavement layers does not present significant differences. Therefore, there is a need to analyze the behavior of the layers at different times of the day.

Therefore, the variation of surface temperature (Ts), subsurface temperature (Tss) and air temperature (Ta) between the conventional pavement and the one with rubber incorporation over 24 hours is presented in Figure 8.

Figure 8:
Temperatures variation between conventional pavement (PAVA) and with rubber incorporation (PAVB) for 24 hours.



The surface temperature of the rubber pavement was lower than the conventional pavement between 9am and 5pm (with a turning point at 2pm).

Consequently, between 10 AM and 7 PM, the rubber pavement had higher subsurface temperatures than the conventional pavement.

Finally, air temperature (Ta) was higher over the rubber pavement only between 12pm and 3pm. And in the rest of the time, it presented lower records, in relation to the conventional pavement.

4. CONCLUSION

Analysing both models, with and without tire rubber incorporation in the asphalt mixture, it was possible to notice that the conventional pavement presented the highest surface temperatures during the day.

However, the greatest variation can be observed between subsurface temperatures. The difference between the models was approximately 2K.

In addition, the subsurface layer of the rubber pavement had a higher heat storage capacity, which did not necessarily lead to a higher air temperature at night. This is due to the fact that it dissipates heat by conduction to the ground.

So, a hypothesis is that there is greater capacity of rubber pavement to store heat in the subsurface layers and potentially reduce the impact on the temperature of cities during the day.

Finally, it could be observed that the pavement with rubber incorporation presented lower surface temperatures during the day, due to its low thermal conductivity. However, a greater amplitude ends in the base layer, which allowed heat to be stored and dissipated to the ground during the night.

It is also recommended for future studies the measurement of heat flux between the layers of the pavement and an approach about the ageing process.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) Finance Code 001. Furthermore, the authors thank the support of Technological Nucleus of Engineering and Architecture (NUTEA), Adventist University of Sao Paulo (UNASP) and Federal University of Sao Carlos (UFSCar) for the development of this research.

REFERENCES

1. Ferreira, L. S and Duarte, D., (2019). Igawa, N. and H. Nakamura, (2001). Exploring the relationship between urban form, land surface temperature and vegetation indices in a subtropical megacity. *Urban Climate*, 27, p. 105-123.
2. Global Cool Cities Alliance - GCCA. *A practical guide to cool roofs and cool pavements*. Available at: https://www.coolrooftoolkit.org/wp-content/ pdfs/CoolRoofToolkit_Full.pdf. Accessed on 20th of june 2020.
3. Green Building Council – GBC. *Leadership in Energy and Environmental Design.* Available at: https://www.gbcbrasil.org.br/certificacoes/. Accessed on 2nd of june 2020.
4. Kowalski, L. F., Masiero, E. (2021). Envelhecimento de pavimentos de concreto pigmentado e consequências sobre o albedo. *Revista de Arquitetura IMED*, Passo Fundo, v. 10, n. 1, p. 126-147, janeiro-junho.

5. Li, H., (2016). *Pavement materials for heat Island mitigation: Design and management strategies.* Oxford: Elsevier.
6. Qin, Y. (2015). Urban canyon albedo and its implication on the use of reflective cool pavements. *Energy and Buildings*. n.96, p.86–94.
7. Aboelata, A. (2021). Reducing Outdoor Air Temperature, Improving Thermal Comfort, and Saving Buildings' Cooling Energy Demand in Arid Cities-Cool Paving Utilization. *Sustainable Cities and Society*, p. 102762.
8. Gonzalez, D. E. G. (2015). *Análise dos efeitos do albedo no microclima de cânions urbanos.* Curitiba, 175f. Dissertação (Mestrado). Programa de Pós-Graduação em Engenharia Civil. Universidade Tecnológica Federal do Paraná.
9. Zhu, S. and Mai, X., (2019). A review of using reflective pavement materials as mitigation tactics to counter the effects of urban heat island. *Advanced Composites and Hybrid Materials*, 2(3): p. 381-388.
10. Shu, Z., Wu, J., Li, S., Zhang, B., Yang, J., (2021). Road performance, thermal conductivity, and temperature distribution of steel slag rubber asphalt surface layer. *Journal of Renewable Materials,* 9(2): p. 365-380.
11. Ameli, A., Babagoli, R., Asadi, S., Norouzi, N., (2021). Investigation of the performance properties of asphalt binders and mixtures modified by Crumb Rubber and Gilsonite. *Construction and Building Materials*., 27912. Article number 122424
12. American Society for Testing and Materials (2016). *ASTM C1549-16: Standard test method for determination of solar reflectance near ambient temperature using a portable solar reflectometer*. Philadelphia.
13. Pereira, C. D., Marinoski, D. L., Lamberts, R., Güths, S., & Ghisi, E. (2017). Avaliação experimental do espectrômetro Alta II e sua aplicação na normatização brasileira. *Ambiente Construído*, 17(4), 197-213.

Can different vegetation influence on outdoor thermal comfort by cycling routes in tropical savanna climates?

LOYDE V. ABREU-HARBICH[1] JÚLIA W. S. RORIZ[2] KARLA E. R. HORA[2]

[1] Presbyterian Mackenzie University
[2] Federal University of Goias

ABSTRACT: This study aims to evaluate thermal improvement generated by different species planted linearly on sidewalks and cycle paths in Goiania - Go. It was carried out at two different areas of the cycle path at Universitaria Ave.: one with Palm trees by specie Guariroba (Syagrus oleracea (Mart.) Becc) and the other with trees by species Sibipiruna (Cenostigma pluviosum (DC) E. Gagmon & GP, Lewis) and Monguba (Pachira aquatica Aubl). Data collected were air temperature, relative humidity, globe temperature and wind speed during four sunny days at 8:00 am, 10:00 am, 12:00 pm, 2:00 pm, and 4:00 pm. Outdoor Thermal Comfort Index as PET and UTCI were calculated by Rayman software. It collected 148 questionaries surveys about thermal sensations. Results showed that the area with Sibipirunas trees brings more thermal comfort than Guariroba palm for cyclists. Thermal reduction in terms of PET was 11°c and UTCI was 8.5°c. Monbuba present can air humidify until 7.45%. It is concluded that tree distribution in cities is important for microclimate improvement. Morphological characteristics of trees and distribution of trees need to be observed during afforestation focused on the sustainable urban landscape.
KEYWORDS: forestry, outdoor thermal comfort, cycle path, Tropical Savanna Climate (Goiânia).

1. INTRODUCTION

It is necessary to re-establish healthy relationships between society and the natural environment through urban afforestation to promote a better quality of life, well-being, psychological and physical health. The benefits of vegetation to improve thermal comfort in tropical cities (hot climate) at the scale of urban design are attenuation of direct solar radiation, air temperature mitigation, increased air, and soil moisture, control of wind speed and direction, increase of fauna and flora biodiversity, soil stabilization and maintenance of precipitation cycles [1].

The work of thermoregulation of thermal comfort by plant specimens occurs due to the control of wind speed by the structure of the crown and stem, the attenuation of radiation by the tree crown and the evapotranspiration process [1, 2]. This occurs when excess water vapor is expelled by the stomata of plant leaves, which open and close, allowing the exchange of gases with the environment and thermoregulation temperatures. Several studies point to the benefits of road afforestation concerning the reduction of urban heat islands and the improvement of thermal comfort provided by plant specimens on sidewalks [2,3,4]

To encourage the use of bicycles as a means of transport in the city of Goiania, especially at a time when public transport is a worrying issue in terms of health due to the COVID-19 pandemic, cycle paths must promote adequate thermal comfort for the development of the activity. As the different plant specimens work in different ways in the environment, it is important to assess the thermal comfort provided by the shade of plant specimens (palm trees and trees) to pedestrians and cyclists in cities with a tropical savanna climate such as Goiania, Brazil.

This study aims to quantitatively evaluate the thermal improvement generated by three plant specimens of different species planted linearly for shading of cycle paths in Goiania, Brazil.

2. METHOD AND PROCEDURE

This is an experimental study that was developed in the following steps, based on the RUROS project (Rediscovering the Urban Realm and Open Spaces) [5]

a) Description of Local Climate;
b) Selection of study areas;
c) Meteorological data collected in selected study areas;
d) Analysis of Thermal Comfort;
e) Questionaries surveys by the thermal perception of cyclists and pedestrians

2.1 Local Climate

Goiania (16º 40 S; 49º 15 W; 749m) has a population estimated at 1.536.097 inhabitants. The climate of Goiania is defined by Köppen-Geiger [6] as Aw (Tropical with dry season). The seasons are well-defined rainfall regimes configuring a dry season (May to October) and a rainy season (November to January). The months of February, March, and April have a reasonable rain intensity, characterizing a transition between periods. Relative humidity indices vary from 52% in August (the driest month of the year) and 82% from December to March [7]. The average wind velocity was 1.5 m/s and the predominant wind direction was southeast.

2.2 Selection of study areas

In the selection of study area, the following criteria were observed: street or ave with more than 1 km in the same direction, to better observe the thermal benefits of the lane and sidewalks, have a grouping of specimens of species with potential for improvement, place of great circulation of pedestrians and cyclists and pedestrian safety. In this area, there is an intense circulation of cars, pedestrians and cyclists, due to the commercial area with Araújo Jorge Hospital, Faculties and other commerce.

In 2012, the municipality removed 34 trees and maintained Guariroba (*S. oleracea)*, three Sibipirunas (*C. pluviosum)* e one Monguba (*P. aquatica)* in the study area. As environmental compensations, there were planted species such as *Handroanthus sp.* (Ipês), *Lophanthera lactescent* Ducke (Lanterneiro), *Licanea tomentosa* (Benth.) Fritsch (Oitizeiro), *Lagerstroemia indica* (L.) Pers. (Resedá), *Sapindus saponaria* L. (Saboneteira) with approximate height of 2 m each. In 2022, these trees are not adults between 6 to 10 m. Figure 1 shows that tree cover reduced so much in the last 10 years.

Figure 2 shows two areas selected for this study case in Universitaria Ave, Eastern University Sector, Goiania, were selected (Figure 1). The width of Universitaria Ave is 11 m. The width of the central sidewalk´s in area 1 (with trees) is around 9.8 m and in area 2 (with palms), 4,8 m. The sidewalk´s width is 6.0 m. In Area 1, the arborization of cycle paths is composed of trees by different species. In area 2, the arborization of cycle paths is composed by different species of palm trees of a single species. In both selected areas, lateral sidewalks have less vegetation than the central sidewalks. The table shows how the features of trees in selected areas.

Figure 1:
Study area with trees and with trees in both areas (adopted Google Earth Pro)

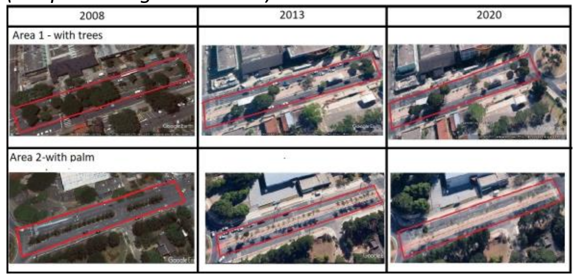


Figure 2:
Study area in Goiania, Brazil

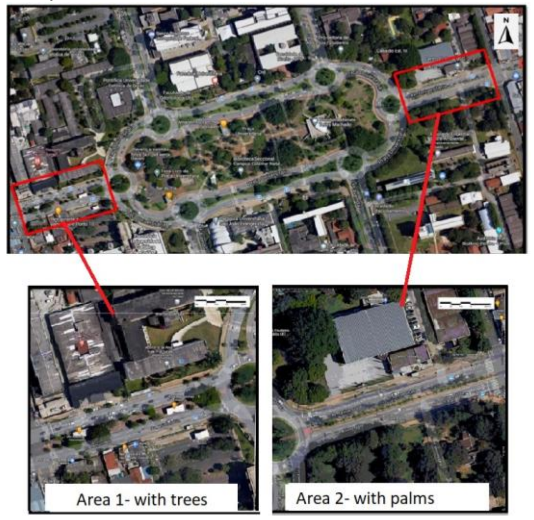


Table 1:
Features of trees in selected sites

	Features	Examples		
		Guariroba	Sibipituna	Monguba
TRUNK	high	14m	10m	9m
	Casca			
CROWN	Type	Stipe	Plagiotrópic	Ortotrópic sympodial
	Diameter	4m	12m	16m
LEAVES	Type	Pinade	Bipinate	Simple

2.3 Meteorological data collected

Meteorological data collected as air temperature, relative humidity, globe temperature, and wind velocity, were collected during four sunny summer days (March 1st, 2nd, 5th, and 6th, 2021) at 8 p.m, 10 p.m, 12:00 p.m and 4 a.m.

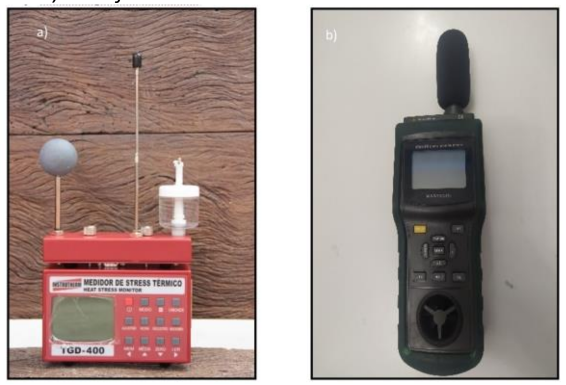
It selected 3 points to collect meteorological data in area 1 - with trees (figure 3) -, and 2 points in area 2 – with palms 4). The set points were at the shade of trees and sun, on cycle paths.

Figure 3:
Area 1- with trees

Figure 4:
Area 1- with plams

The equipment used was a Thermal Stress Meter (TGD-400 Instrutherm) and a Multifunctional (MS6300 Environment Multimeter) (Figure 5). The thermal stress meter recorded the following temperatures: wet bulb temperature (Tbu); dry bulb temperature (Tbs); globe temperature (Tg) which indicates the radiant temperature of the environment and others. The sphere of the thermal stress meter, originally in black, was replaced by another in gray, keeping the sensor in the center of the sphere to avoid interference in data collection under the sun.

Figure 5:
Used Equipment: a) stress meter (TGD-400 Instrutherm) and b) Multifuncional MS6300 Environment Multimeter



2.4 Analysis of Thermal Comfort

Used descriptive statistics to assess air temperature and relative measurement at each midpoint. From the mean radiant temperature, the temperature and the temperature of the Gray Globe were found, according to the following measure of sunlight by ISO 7726 (ASHRAE, 1998):

$$Tmr=\{(Tg+273)^4 + [(1,1x10^8 \times Va^{0,6})/(\varepsilon g \times D^{0,4})] \times (Tg - Ta)\}1/4 - 273 \quad (1)$$

where:
Trm = Mean Radiant Temperature (ºC);
Tg = Globe Temperature (ºC);
Va = Air velocity (m/s);
εg = emissivity
D = Globe diameter (m);
Ta = Air temperature (ºC).

Descriptive statistics used to assess air temperature and relative measurement at each midpoint. From the mean radiant temperature, the temperature and the temperature of the Gray Globe were found, according to the following measure of sunlight., 1998) and UTCI (Universal Thermal Climate Index) [8].

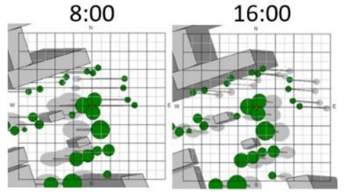
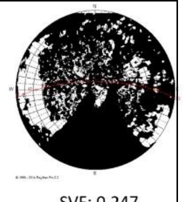
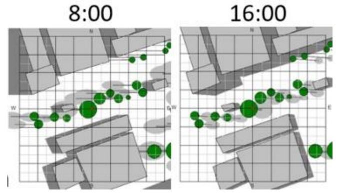
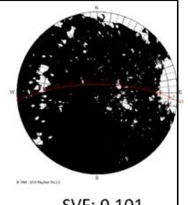
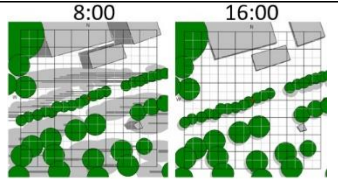
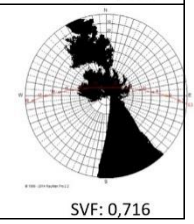
RayMan Pro software was used to quantify thermal comfort by these two indices [9]. The input climate variables were air temperature, relative air humidity, wind speed and Mean Radiant Temperature; and as personal variables, it was 0.6 Clo, based on the studies by Abreu-Harbich et al. (10) and sitting, 80W, and cycling, 200W, according to Lamberts et. (11). To compare the results of the UTCI indexes with the PET, Table 2 was used as thermal sensations are strengths in the classification of thermal sensations.

Table 2:
Thermal Sensations classification by PET e UTCI para Europa, Taiwan e Sao Paulo

Thermal Sensation	UTCI (ºC) [12]	PET para European (ºC PET)	PET para Taiwan (ºC PET)	PET para São Paulo
Very Cold	-13 a -27	<4	<14	
Cold	-13 a 0	4 an 8	14 an 18	<4
Cool	0 a 9	8 a 13	18 a 22	4 a 12
Slight Cool	9 an 18	13 an 18	22 a 26	12 an 18
Comfortable	18 a 26	18 a 23	26 a 30	18 a 26
Slight warm	26 a 32	23 a 29	30 a 34	26 a 31
Warm	32 a 38	29 a 35	34 a 38	31 a 43
Hot	38 a 46	35 a 41	38 a 42	>43
Very Hot	>46	>41	>42	

To calculate thermal comfort, it was used RayMan Software Pro. Figure 6 shows shade analyses and sky view factor of setpoints at shade. There is a large asphalt pavement in the front of area 1- with trees and a large area of planted grass and trees in front of area 2 – with palms.

Table 3:
Shade analyses and Sky View facto (SVF) of setpoint at a shade

	Shade Analysis	Sky View Factor
P1	8:00 16:00 	 SVF: 0,247
P2	8:00 16:00 	 SVF: 0,101
P4	8:00 16:00 	 SVF: 0,716

2.5 Questionaries surveys by the thermal perception of cyclists and pedestrians

It collected 148 questionaries surveys about thermal sensations and arborization preferences. The questionnaire survey had 16 questions about location perception, street aesthetics preferences, human variables (clothes and activities); thermal comfort perception and thermal comfort preferences. Respondents were between 18-48 years old and 65% of women.

3. RESULTS AND DISCUSSION

Figures 6,7 and 8 show the results of air temperature, relative humidity and mean radiant temperature for each set point in the selected area.

Figure 6:
Air temperature by set point areas (with trees and palm) in selected areas

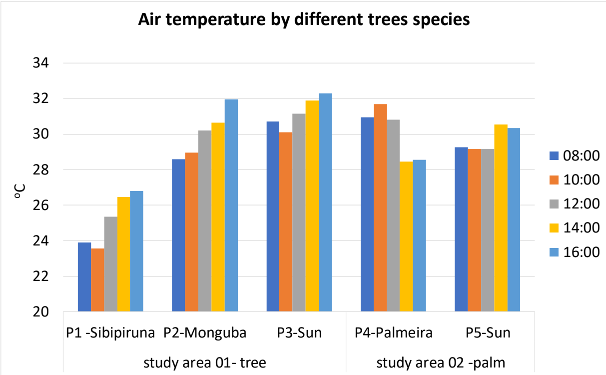


Figure 7:
Relative Humidity by set point areas (with trees and palm) in selected areas

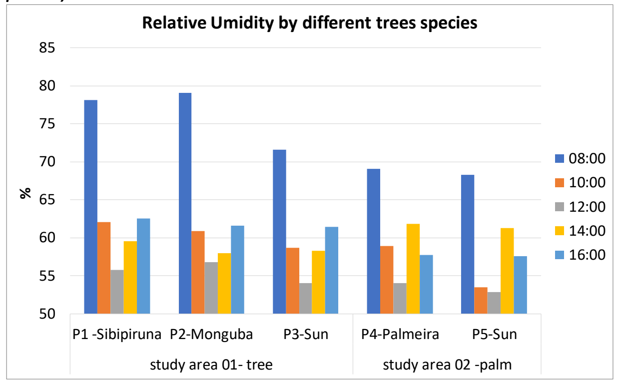


Figure 8:
Mean Radiant temperature by set point areas (with trees and palm) in selected areas

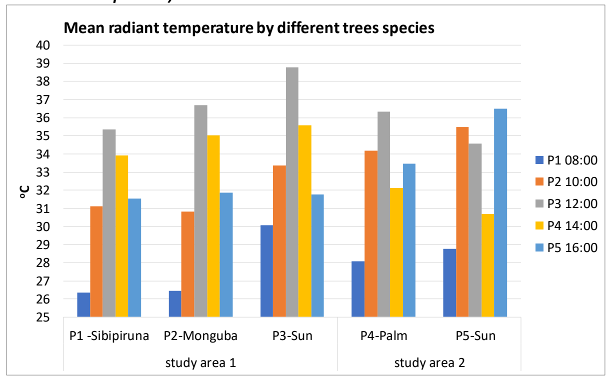
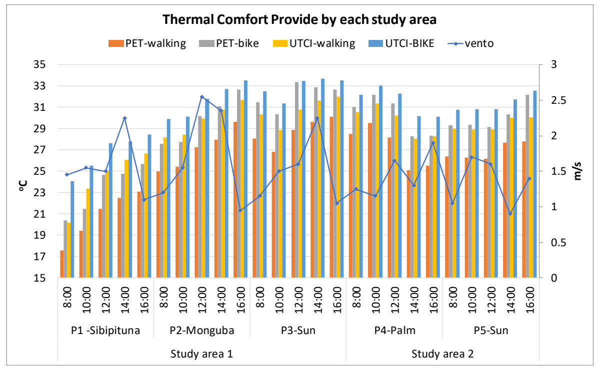


Figure 9 shows results of thermal comfort by each point in the selected area. It can observed that in Si

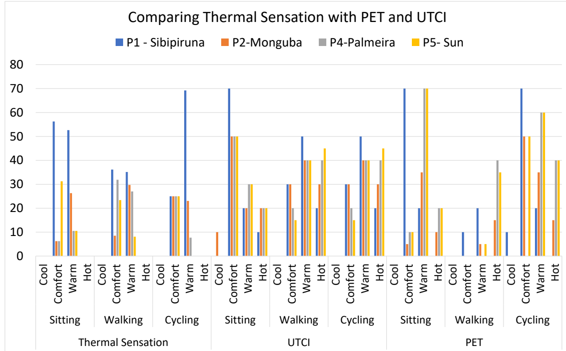
Figure 9:
PET and UTCI temperatures *by set point areas (with trees and palm) in selected areas*



Around 91% of respondents prefers to walking or cycling in street with trees and 7% in street with palms. Around 74% of respondents prefers aesthetics of street with only trees and 27% with only palms. Around 90% respondents answered that streets need more trees, but 6% prefers the actual situation. About arborization of University Ave, respondents answered that it is very good (8%), good (33%), adequate (44%), and inadequate (15%). Results show that most Brazilian pedestrians and cycles prefer to walk in the shade of trees and the aesthetic of the street brings well-being.

Figure 10 presents the comparison between thermal sensations, UTCI and PET. In situation sitting, P1-Sibipiruna, it brings 56% of thermal comfort and 70% for UTCI and PET. In situation walking, P1-Sibipiruna brings 36% of Thermal Sensation and 30% for UTCI and 10% for PET.

Figure 10:
Comparison between thermal sensation, UTCI and PET



Results show that the morphological characteristics among the analysed plant specimens generate different shading areas, distinctly influencing the microclimate and that they can significantly improve the thermal comfort for bike path users, up to Guarribooms, confirming the results of Shashua-bar (16), Abreu-Harbich et al (17) and Ribeiro (18).

The limitations found were regarding the date of data collection, the rainy season. It would be interesting to repeat this methodology during the dry season in the capital, between August and October, when the temperature is close to 40º C and the air humidity reaches less than 20%.

Results suggests that more pedestrian and cyclist need to answer this questionary to have a better correlation between thermal index. Also, a tridimensional studies for future scenario could be implemented on this study.

4. CONCLUSION

It is concluded that the Guariroba palm tree has a good capacity to provide shading on the cycle path and promote thermal comfort, but it is recommended whenever possible to plant trees instead of palm trees to reduce thermal stress on the cycle paths. Finally, it is concluded that: 1. The choice of species for planting in cities is essential for better thermal comfort for the population, due to the improvement of the microclimate, with the attenuation of temperature and increase in air humidity provided by trees and palms ; 2. That, depending on the space available for planting, there can be any of the various species of trees and that there is no space for them, it is perfectly possible to plant palm trees, in their most varied species, as there will also be an improvement in the microclimate .

REFERENCES

1. SANTAMOURIS, M. *Energy and climate in the urban built. London: James & James.* 2001
2. DACANAL, C.; LABAKI, L. C.; SILVA, T. M. L Vamos passear na Floresta! O conforto térmico em fragmentos florestais urbanos. Ambiente Construído, Porto Alegre, v. 10, n. 2, p. 115-132, abr./jun. 2010.
3. KETTERER, C.; MATZARAKIS, A.. *Human-biometeorological assessment of the urban heat island in a city with complex topography – The case of Stuttgart, Germany, Urban Climate*, Volume 10, Part 3, 2014.
4.RAHMAN, M. A., *et al Tree cooling effects and human thermal comfort under contrasting species and sites, Agricultural and Forest Meteorology*, Volume 287, 2020.
5. NIKOLOPOULOU, M. Designing open spaces in the urban environment: a bioclimatic
approach. Project RUROS. Aittiki, Grécia. Junho de 2004. ISBN 960.86907-2-2.
6. Kottek, M. et al. (2006). World Map of the Köppen-Geiger climate classification updated Meteorol. Z., 15**.**
7 Abreu-Harbich; V. L.; Chaves. V. L. Identificação do ano climático de referência para Goiânia-Goiás. In: XVI Encontro Nacional de Tecnologia do Ambiente Construído, 16, 2016, São Paulo. Anais... São Paulo: ENTAC, 2016. p. 406-416. [in portuguese]
8. BLAŽEJCZYK, P. et al. Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. Miscellanea Geographica. 2010; 14: 91-102.
9. MATZARAKIS, A; RUTZ, F.; MAYER, H. (2007) Modelling radiation fluxes in simple and complex environments – application of the RayMan model. In: Internation Journal of Biometeorology. V.51. pp. 323-334.
10. ABREU-HARBICH, Loyde. V.; CHAVES, V. L.A. ; BRANDSTETTER, M. C. G.O. . Evaluation of strategies that improve the thermal comfort and energy saving of a classroom of an institutional building in a tropical climate. Building and environment, v. 135, p. 257-268, 2018.
11. LAMBERTS, R. et al. Análise do procedimento de simulação da NBR15575 para avaliação do desempenho térmico de edificações residenciais. In: Ambiente Construído. Vol.14 n.4. Porto Alegre, out/Dez. 2014.12 Blažejczyk, 2010)
13 (MATZARAKIS, A.; MAYER, H.; IZIONMON, M. G. Applications of a Universal Thermal Iindex: physiological equivalent temperature. International Journal of
Biometeorology, v. 43, p. 76-84, 1999.
14 LIN, T. P., MATZARAKIS, A. Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. In:

Internacional Journal of Biometeorology. V.54. pp. 281-290. 2008.
15 Monteiro e Allucci 2009)
15. MONTEIRO, L. M.; ALUCCI, M. P. Proposal of an outdoor thermal comfort index for
subtropical urban areas. In: Passive & Low Energy Cooling for the Built Environment
Conference, 3, 2010, Rhodes Island, Greece. Proceedings... Rhodes Island: PALENCIA
2010.
16. SHASHUA-BAR, L.; POTCHTER, O.; BITAN, A. BOLTANSKY, D.; YAAKOV, Y. *Microclimate modeling of street tree species effects within the varied urban morphology in the Mediterranean city of Tel Aviv. In: International Journal of Climatology. Int. J. Climatol*. 30: 44–57. 2010.
17.ABREU-HARBICH, L. V.; LABAKI, L. C.; MATZARAKIS, A. *Effect of tree planting design and tree species on human thermal comfort in the tropics. In: Landscape and Urban Planning*, v.138, p.99-109, Jun 2015.
18. RIBEIRO, N. L. S. Atenuação solar e sombreamento produzido por espécies de palmeiras em área urbana. Faculdade de Engenharia Civil, Arquitetura e Urbanismo da Unicamp. (Dissertação). 107p. Campinas, 2018.

Evaluation of radiant temperatures of tree canopies and their effects on close surfaces

The influence of leaf colour pantones as a hypothesis of surface heat generation

THIAGO DOS SANTOS GARCIA [1] LUCILA CHEBEL LABAKI[1]

[1] UNICAMP: CAMPINAS STATE UNIVERSITY

ABSTRACT: One of the contributions to possible improvements in the quality of life in cities is the planning of urban afforestation that can result in environmental benefits. Afforestation on public sidewalks should be attentive to the choice of suitable species that do not obstruct the passage of passers-by and explore the air space without environmental interference, seeking to promote shaded areas that provide comfort to local users. Planting trees without planning, as well as causing negative ergonomic and spatial impacts, can promote adverse environmental effects. It is assumed, for example, that the increase in the surface temperature of masonry can occur by the reflected radiation of the crowns of the trees, when very close. In this sense, the objective of this work is to evaluate the surface temperatures caused by the reflected radiations of the leaves of the crowns of the trees of a group of species at certain distances, seeking to identify the impacts on nearby surfaces. The methodology applied to this research will include bibliographical review on the subject, establishment of criteria for selection of tree species to be evaluated, analysis of the compositions and spatial arrangements of arboreal individuals, as well as measurements in loco that measure by pyranometers the average irradiance over the treetops.
KEYWORDS: Urban thermal comfort; Urban afforestation; Radiant temperature; Thermal energy balance of vegetation; Solar radiation.

1. INTRODUCTION

The planning of urban afforestation can generate environmental benefits and, therefore, contribute to possible improvements in the quality of life in cities. Choosing the right location and tree species can provide better conditions for tree development, minimizing accident risks, reducing pruning needs, without causing damage to accessibility, for example. Currently, the ideal parameters for the afforestation of sidewalks on public roads are still being discussed. For planting trees on sidewalks, suitable species must be chosen that allow the trees to fully develop, exploring the available air space without causing interference and damage to other public equipment, buildings and pavement.

Based on existing concepts and theories about tree planting, questions such as: What are the correct planting parameters? What negative effects can the planting of trees, improperly, have on open spaces in cities? Thus, it is intended to evaluate the radiant temperatures and their effects on the canopy of tree species to identify the impacts, at certain distances, of the heat emitted on nearby surfaces, since it is known that the leaves of the trees have radiative properties that depend on the length. waves, also possessing properties of absorption, transmission and reflection of heat, through the pigments of these sheets.

Vegetation has been systematically used as a passive environmental conditioning strategy, integrating a set of bioclimatic strategies used by construction professionals. On the other hand, the great demand for urban land use leads to the emergence of new researches that seek different ways to bring vegetation to cities. (Matheus et al. 2015).

The characteristics of the immediate surroundings directly interfere with thermal comfort; therefore, the behavior of arboreal individuals in the microclimate varies according to the type, size, age, period of the year and forms of disposition in urban enclosures (Labaki, 2010).

Transmission through leaves depends on their structure and thickness. According to the thickness (varying for each sheet) the sheets tend to have the same optical and thermal properties (Shinzato, 2009).

According to Bartelink (1998), the availability of radiation is one of the main forces responsible for the growth of trees in forests. According to Govind et al. (2013), the canopy radiative transfer mechanism is probably the most important biophysical process that drives mass energy exchanges between the biosphere and the atmosphere.

Shinzato (2009) describes that the occupancy balance of a leaf is due to its position in the canopy, being, therefore, an extremely variable parameter. It should be considered that, in addition to the position, age and the proposal a in the processes of transformation, reflection and transmission.

Rahman et al. (2016) describe that urban trees regulate their thermal environment, mainly through canopies. It is observed, in one of the studies, shown in Figure 3, that it occurs according to the differences in temperatures with the 3 times, as a function of the amount of transmission received during the long day. The study also reported that, at night, the surface temperature increases by 0.5ºC, and inside the canopy, there is an average reduction of 0.85ºC in relation to the long surface of the whole day.

“Green” infrastructures consist of living natural surfaces, composed of vegetation; can be implemented through green areas, roofs and walls, urban forests, among others. the vegetation promotes cooling by its ability to absorb solar radiation in the visible range, by shading and the promotion of latent heat fluxes, associated with evapotranspiration processes of plants and the presence of moisture. Its use also favors the reduction of air pollution rates. and carbon sequestration (Ferreira & Pereira & Labaki, 2020, pp 239).

2. OBJETIVES AND JUSTIFICATION

The objective of this work is to identify whether the radiation emitted by the leaves of certain types of trees contributes to the increase in the temperature of elements of facades close to these crowns.

2.1 Methodology

The research methodology is structured in stages. The first part comprises a bibliographic survey of the specific literature on the subject, based on the method known as Systematic Literature Review (SLR). The criteria for bibliographic selections will be the use of databases, such as Scopus, Elsevier, Scielo, Ambiente Construcdo Magazine, among others, as well as reputable journals and books related to the topic under discussion. These searches will be carried out using registered terminologies (keywords) referring to the topics covered. The inclusion criteria for the studies found will be, particularly, concerning some type of thermal impact caused by urban vegetation on nearby surfaces (facades in general).

Still in the bibliographic research, it is necessary to carry out a definition of selection criteria for the tree species to be studied, analyzing the individual thermal characteristics of each one, an analysis of the composition and spatial arrangement of the tree individuals in the study structures to be defined.

Currently, in some Brazilian cities, city halls provide informative catalogs about planting tree species considered ideal for cities. These manuals suggest parameters for planting on sidewalks/sidewalks public, but they only deal with aspects related to crown pruning and types of roots that may eventually obstruct the passages, and even suggest the typological format that the crowns should have, as shown in Figure 1:

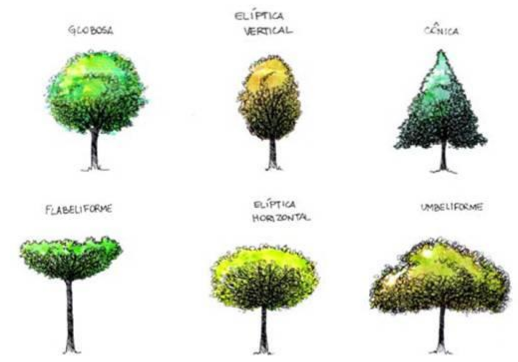


Figure 1: Canopy architecture typology. Source: Technical manual on urban afforestation.

The methodological construction to be suggested for this research is the creation of a database that catalogs the species according to the emission of thermal radiation by the leaves of the crowns of the species that will be evaluated, suggesting ideal distances, so that the supposed reflected radiation and emitted by leaves, do not change the temperature of nearby surfaces. Figure 2 shows some drawings of road profiles, which insert urban trees without considering the thermal impact. Such standards, as a rule, aim only to provide a solution for shading and traffic on the sidewalks, neglecting the necessary distance criteria from the facade.

Figure 2: Canopy architecture typology

The second methodological step of this work concerns the choice of location to carry out the measurements. The initial proposal is to choose a location in the region between Campinas and the lower Mogiana region, but this discussion should be better evaluated according to the costs necessary to carry out this research. For the measurements of the amount of radiation emitted by the leaves of the crowns, it is proposed sensors, called pyranometers, equipment designed for use with vegetation, which also evaluates the amount of solar energy under trees, through the collection of solarimetric data. It will be necessary to choose certain treetops close to adjacent vertical surfaces, using a compass to identify the direction of true north, subtracting the local magnetic declination for that crown from magnetic north. A sensor to measure relative humidity and air temperature, a sensor for wind speed and wind direction should also be added. This instrumental set should be used in two possible ways: through a metal structure fixedly mounted on trees or by means of a drone.

In addition, a thermographic camera will be used to acquire infrared images, in order to demonstrate in a more didactic way the amount of heat emitted by the leaves of the trees. The thermographic camera filters infrared rays through a specific lens, usually made of germanium, built into the camera itself. All images generated by the camera will be transferred, organized, stored, electronically post-processed, through computer programs for the analysis of thermal images, where reports will be generated detailing the results collected in loco.

2.2 Measurements

After the bibliographic surveys of this initial stage, the next stage will be the analysis of the radiation emitted by some species of urban trees. Along with this next step, a container model will be developed that can simulate a small-scale built environment. The idea is to create a mobile environment that can be installed over the crowns, thus enabling thermographic measurements of these crowns, so that the results of the emissivities obtained can be analyzed.

A thermographic camera will be used to acquire infrared images, in order to demonstrate in a more didactic way the amount of heat emitted by the leaves of the trees. The thermographic camera filters infrared rays through a specific lens, usually made of germanium, built into the camera itself. All images generated by the camera will be transferred, organized, stored, electronically post-processed, through computer programs for thermal image analysis, where reports will be generated detailing the results collected in loco, as shown in Figure 3.

Figure 3: Thermographic image result in vegetables.

Figure 4 demonstrates a possibility of visual study that could be produced in this research. The idea is to clarify if there is any interference from the reflections of the leaves of the crowns in environments close to these trees and the possible solutions suggested to solve the problems, when they exist.

Figure 4: Hypothesis of an object of study

After all the methodological development, it is intended to answer whether the amount of radiation emitted by leaves of treetops is capable of influencing the increase in temperature of surfaces close to these crowns and, if so, what is the best solution to propose. . For this possible answer, a simplified table is proposed that determines the correct position of planting certain tree species in cities.

2.4 Initial Measurements

The research methodology is structured in stages. First, it is important to inform you that this research is in its initial stage. The methods and results to be presented below are still hypothetical and this research will still undergo a more refined evaluation process. The initial idea of the project was initially to develop a closed and thermally insulated container to understand if there is any relationship of heat accretion between the distances of a tree canopy. For the initial measurements, tests with a pyranometer have not yet been performed, this will be carried out in the next stage of this research.

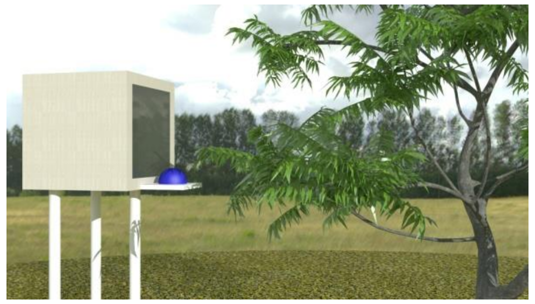


Figure 5: Virtual representation of the prototype.

Figure 5 demonstrates a prototype whose idea would be to have a thermometer on the inside of the box and a pyranometer on the outside, where the extracted results would be the ambient temperature inside the box and the amount of radiation emitted, both results obtained by the heat emitted from the cups. of trees.
In practice, largely due to the period of the pandemic, the solution for the development of the initial prototype was a much more simplified model, this being a styrofoam box, sealed with a plastic film, having inside a Digital Thermo-Hygrothermal thermometer with sensor. external, ASKO brand, model AK28new, as shown in figure 6.

Figure 6: Simplified prototype.

With the assembly of the prototype, the first conceptual measurements of this project began.

Two trees were chosen for a pilot test in a square in the city of Mogi Mirim-SP, whose species are popularly called “Gold Rain” Tree, whose scientific name is Lophantera lactescens and “Astrapeia” whose scientific name is Dombeya. wallichii respectively. The location and the day of this measurement showed an air temperature of 32ºC and an air velocity of practically zero (0m/s).
For the initial measurements, three points with different distances were chosen. In figure 7, it is observed that the first point has a distance of 2 meters in relation to the tree canopy, when the second point is 1 meter away and in the last point, the prototype is very close to the canopy.
The measurements took place on July 25, 2021 between 2:00 pm and 2:40 pm.

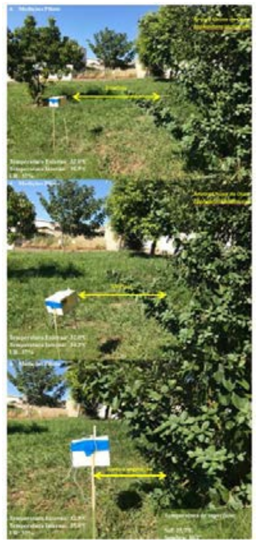


Figure 7: Prototype applied in loco for initial measurements on the species Lophantera lactescens.

Figures 7 and 8 show the arrangement between the prototype and the vegetation, indicating the three measurements, which varied between 2 meters and 30 cm.

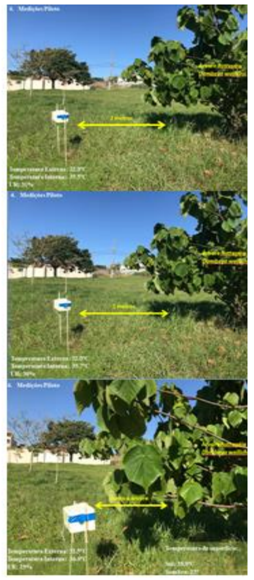


Figure 8: Prototype applied in loco for initial measurements on the species Dombeya wallichii.

3. PARTIALS RESULTS

The first results with an adapted prototype showed that there are possibilities that the hypotheses raised for this research may have true relationships.
Comparing the results between the two selected trees, it was observed that the smaller the distance between the box and the canopy surfaces, the higher the internal temperature of the box.

The results referring to the increase in heat of Lophantera lactescens showed higher thermal amplitudes, with a total amplitude of 2.5ºC, while Dombeya wallichii presented a smaller and more homogeneous thermal amplitude, with a total difference of 0.5ºC, according to the results shown in Figure 9 .

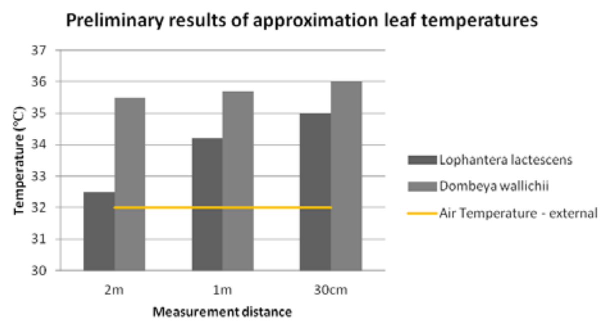


Figure 9: Partial results of the first measurements.

For this stage of the research, the canopy albedo capacity is not yet being evaluated and measured.

3. CONCLUSION

The main hypothesis presented is that properties present in the leaves collaborate with the increase in temperatures of surfaces close to the crowns, as a function of the radiant heat of the leaves. If this is proven by other measurement methods, we should rethink the planting of urban trees, respecting certain distances from these in relation to the facades of buildings.
The lack of ergonomic discussion of tree planting may be omitting problems of heat addition in urban areas is still widespread, and may be masking more accurate results on heat islands in cities, because when tree planting solutions are prescribed in urban, the recommendations are related only to the shadows generated on the ground, but there are no urban discussions about the possibility of radiating the heat generated by the leaves of the crowns.

Another hypothesis is that, if the first hypothesis is confirmed, the amount of radiation may result not only in the size of the leaves, but also in their thickness, density and the variation of the leaf pantones according to their plant age, however this is still part of future doctors in the next stage of this research.

ACKNOWLEDGEMENTS

I thank the University of Campinas for the opportunity to allow a complex research.

REFERENCES

BARTELINK, H. H. Radiation interception by forest trees: a simulation study on effects of stand density and foliage clustering on absorption and transmission. ELSEVIER. Ecological Modelling, 105. Págs.: 213-225. Wageningen, Holanda. 1998.
GOVIND, A. GUYON, D. ROUJEAN, J. RAGUENES, N. Y. KUMARI, J. PISEK, Jan. WIGNERON, Jean-Pierr. Effects of canopy architectural parameterizations on the modeling of radiative transfer mechanism. ELSEVIER. Ecological Modelling, 251. Págs.: 114-126. Toulouse, França. 2013.
MATHEUS, C. C. F. D. N. MORELLI, D. O. LABAKI, L. C. Desempenho térmico de envoltórias vegetada em edificações no sudeste brasileiro. Ambiente Construído, Vol. 16. n. 1. , pág.: 71-81, Porto Alegre, 2015.
RAHMAN, M. MOSER, A. R. T. SHINZATO, P. O Impacto da vegetação nos microclimas urbanos. Universidade de São Paulo, Faculdade de Arquitetura e Urbanismo. Tese de Doutorado, FAUUSP. 2009.
FERREIRA, F.L. PEREIRA, E.B. LABAKI, L.C. Land surface temperature associated factors in urban areas: local climate zones and spectral characteristics. Ambiente Construído. 2020. P. 239.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE BUILDINGS AND TECHNOLOGY

DAY 01
14:15 — 15:45

CHAIR
SUSEL BIONDI

PAPERS
1397 / 1390 / 1166 / 1638

7TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Integration of sustainability tools and Building Information Modelling in the early stages of design

ILEANA BERGES-ALVAREZ[1], JORGE MUÑOZ-FIERRO[1], SEBASTIAN GIRALDI[2], LAURA MARIN-RESTREPO[1,3]

[1] Department of Building Science, University of Bío-Bío, Chile
[2] GBIM Consulting, BIM Services for Architecture, Engineering and Construction, Chile
[3] Architecture et Climat, LAB, Université catholique de Louvain, Belgium

ABSTRACT: Decisions in the early stages of design are the ones that generate the greatest environmental, economic, and social impacts in projects of the built environment. It has been identified that the professionals involved in these stages usually have difficulties in understanding and using life cycle analysis tools. For this reason, this paper looks to develop an integration between the database of the Abaco-Chile sustainability tool and Building Information Modelling and evaluate its effectiveness to aid decision making. Entry data and sustainability criteria to evaluate were collected (GHG emissions, incorporated energy, and unit economic cost), the integration was proposed with the flow: Abaco-Chile, Revit, Excel, and ten experts evaluated the sustainability through a case study that analyses three masonry wall design options, using the current (just Abaco-Chile) and the proposed workflow. Finally, the integration was evaluated through a survey in terms of time, applicability, scalability, and ease of understanding. The results show that the proposed integration allows designers to quickly assess the environmental and economic impact of different design options and facilitate understanding in reading results compared to the current workflow.
KEYWORDS: Building Information Modelling, Sustainable buildings, Sustainability Tools, Architectural Design.

1. INTRODUCTION

In the building sector, the decisions in the early stages of design have the highest impact on sustainability, which is why one of the greatest challenges for designers is the incorporation of environmental criteria in the initial stages [1, 2]. There are different methods to evaluate the economic and environmental impact of buildings throughout their life cycle, like the Life Cycle Evaluation and Cost Cycle Evaluation. However, these are time-consuming [3, 4, 5], and highly specialised.

To facilitate this complex process, a variety of software suites and calculators have been developed worldwide to evaluate the sustainability of buildings [6]. In Chile, the Abaco-Chile tool comprehensively evaluates construction projects, considering environmental parameters and economic and social costs, from its design to construction on its web platform [7, 8]. It has a database based on Ecoinvent 3.0 adapted to the Chilean energy matrix [7, 9]. However, it is a standalone online platform, not directly connected with the design process, requiring the manual introduction of data to perform the evaluations.

Building Information Modelling (BIM) is considered an emerging technology. It is a methodology that seeks, within a collaborative context, to manage information throughout the project's life cycle [10]. In recent years, BIM started to be studied in the sustainability area. Different approaches have been proposed to reduce the manual loading of data and aid the reading of results by non-experts in the field [4, 10]. However, there are still certain limitations [4, 11, 12]: (a) Interoperability between tools, where data transfer between them requires a lot of time and effort; (b) Loss of information and errors in the transfer from one tool to another, (c) Incorporation of sustainability criteria at later stages of the design process; and (d) Complexity in data interpretation.

This research aims to develop an integration between a sustainability tool, the Abaco-Chile database, and the BIM workflow for the early stages of design and to evaluate their effectiveness.

2. MATERIALS AND METHODS

A non-experimental correlational quantitative methodology was used. As the proposal is a workflow, it is considered that it can be applied at a global scale. In this case, a Chilean database was taken as a reference so that the application context is limited to the domestic scale.

The work was done in three stages. First, the workflow was developed to connect a local database (Abaco-Chile) with design software (Autodesk Revit). Then, a group of ten experts in the area evaluated the sustainability (environmental and economic) in the early stages of design of a case study, analysing three wall construction system options through the current method (manual measurements and calculations in Abaco-Chile), and the proposed workflow, to make an informed decision about the system to use. Finally, the effectiveness of the integration proposed in terms of (a) Time, (b) Applicability, (c) Ease of understanding, and (d) Scalability was evaluated through a survey to the experts. The evaluation was made using 11 closed questions, analysed following the Likert scale and three open questions.

2.1 Proposed Integration between the Sustainability Tool and BIM

A semi-automatic integration was proposed, which considers: Data Collection, Calculation, and Display. To implement the integration, the sustainable tool used was Abaco-Chile. Autodesk Revit was used as the design software within the BIM environment. The Add-in for Revit UniBIM and Microsoft Excel supported the data exchange. The details of the proposed integration are reported as a result of this research, in section 3.1.

2.2 Environmental and Economic Evaluation

A case study was taken to evaluate its environmental and economic impact, using the current workflow method and the semi-automatic integration proposed. A group of ten experts with previous experience in architectural design and in using Abaco-Chile was asked to apply the workflows on the case study to determine the environmental and economic impact of the solutions, and from this, to select the final material solution.

2.2.1 Current Workflow

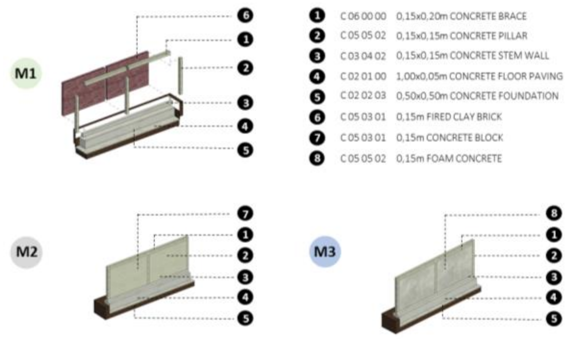
In the current workflow: (1) The volumes are obtained manually through design software or spreadsheets; and then (2) This information is input into Abaco-Chile, where the different materials the construction systems have, are chosen, and the environmental and economic impact calculations are made, as shown in Figure 1.

Figure 1:
Current Method for the Sustainability Evaluation.

2.2.2 Case Study

The case study comprises three construction system options of 6.00 x 2.60 m walls with a width of 0.15 m, plus foundations of 6.00 x 0.50 m. These include a foundation, braces, pillars, a (structural) stem wall, and (non-structural) concrete floor paving, differentiated only by the masonry material. The first wall (M1) has fired clay brick; the second (M2), concrete blocks; and the third (M3), foam concrete, as shown in Figure 2. The solutions (M1-M3) were defined according to the typical construction materials in Chile and their availability in Abaco-Chile.

Figure 2:
Case study. Design options of external wall construction systems.



2.3 Validation

The effectiveness of the proposed integration was validated in terms of (a) Time, (b) Applicability, (c) Ease of understanding, and (d) Scalability through a survey carried out among the experts participating in the test.

The survey was adapted from Van Eldik et al. [3], leaving the 14 questions listed in Table 1. These were divided into four categories (a-d). The first two questions referred to the time involved, were measured from 1 (a lot) to 5 (very little). Questions 3 to 11 were measured with scores from 1 (strongly agree) to 5 (strongly disagree). The last 3 are open questions for general opinions.

The tool's effectiveness was estimated by comparing the results obtained with the current method and those with the one proposed through the Likert Scale analysis [13]. In it, the attitude of those surveyed regarding both methods was evaluated, placing the answers from a very unfavourable attitude (1 point in each question) to a favourable attitude (5 points in each question). The scores were added by category and in total per participant. Finally, an average score including the answers from all participants was calculated. The scores were transformed into percentages to facilitate comparison, with the lowest possible value equal to 0% and the highest possible value equal to 100%.

Table 1:
Survey Questions made to the Group of Experts.

	Question
(a)	Time
	Bearing in mind the entire design process, do you consider that the time that is usually needed to evaluate the sustainability of a project is…
(Q1)	… with the current method
(Q2)	… with the proposed method
(b)	Applicability
(Q3)	The current method can be easily adapted
(Q4)	The proposed method can be easily adapted
(Q5)	The current method is flexible to evaluate different design options
(Q6)	The proposed method is flexible to evaluate different design options
(c)	Ease of Understanding
(Q7)	The results of the current method are quick and easy to understand and interpret
(Q8)	The results of the proposed method are quick and easy to understand and interpret
(Q9)	The proposed method allows making designers more aware of sustainability than the current method
(d)	Scalability
(Q10)	The current method can be easily applied to different projects
(Q11)	The proposed method can be easily applied to different projects
(e)	Open Questions
(Q12)	What limitations and strengths do you see in the current method?
(Q13)	What limitations and strengths do you see in the proposed method?
(Q14)	Which aspects of the proposed method would you highlight, compared to the current one?

3. RESULTS

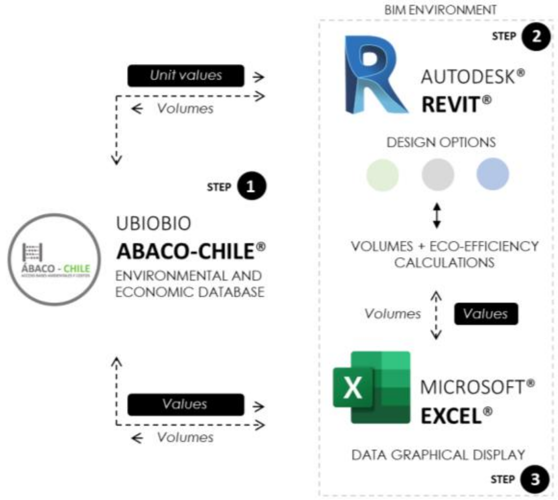
3.1 Proposed integration

A semi-automatic integration was developed between Abaco-Chile and the BIM environment in three steps, as shown in Figure 3: (1) Data Collection, (2) Integration with the Model and Calculations, (3) Display. First, the information needed to calculate the environmental and economic indicators in the BIM model was taken from the Abaco-Chile database. Then, data were incorporated in the model in Autodesk Revit by creating non-native parameters, from which quantification tables were generated with the Abaco-Chile data, the volume in cubic meters and the calculations needed to evaluate the environmental impacts and economic costs of each material. Finally, using the UniBIM Add-in, the data was exported to Excel, and the graphical results were generated.

3.1.1 Data Collection

The goal of this stage was to collect the necessary data from the Abaco-Chile database to make the environmental and economic evaluation in the BIM environment.

Figure 3:
Integration between Abaco-Chile and BIM.



The database gathers the impact of the different materials during their entire life cycle. For this study, only the initial stages, from the extraction of the raw material, its transportation to the factory, the manufacturing of the material, the transportation to the worksite, and its construction, were considered (Stages A1-A5, as per UNE EN 15978:2012). From the environmental indicators in the database, the decision was made to evaluate the contained energy (MJ) and the GHG emissions ($KgCO_2eq$), as these are the variables present in most available materials. The unit cost data were used for the economic impact (Chilean Pesos).

3.1.2 Integration with the Model and Calculations

The collected data had to be integrated into the BIM model to evaluate the project's impacts. To start the process, each element of the construction system was modelled through the design options, and the related materials were assigned along with their assembly code (as per Abaco-Chile) in the properties of the element in Autodesk Revit 2021. Then, two non-native project parameters of the type of project and shared grouped within the properties of Green Buildings were generated, called "Unit GHG Emissions ($KgCO_2eq$)" and "Contained Energy (MJ)". With these parameters, the data taken in the previous section on each material was manually uploaded. The economic costs were input in the "Identity Data" and "Costs" sections.

Then, the planning tables were generated for each element, where the volume (m^3), the unit values, and total values of the environmental and economic indicators are detailed. To calculate the totals, new fields were generated within the properties of the table, using parameters calculated within the common work of the standard number, such as those of the following equation (1):

$$\text{Total} = (\text{Volume}_{component} * \text{Unit value}_{indicator}) / 1 \text{ (volume measurement unit)} \quad (1)$$

Where $\text{Volume}_{component}$ – volume/area that each component occupies (m^3/m^2);
$\text{Unit value}_{indicator}$ – GHG Emissions ($kgCo_2$-eq), Contained Energy (MJ), Cost ($).

Once the necessary information was obtained, the tables created in Revit were imported to Excel using the UniBIM Table 1.5 Add-in to format the display of the results.

3.1.3 Display

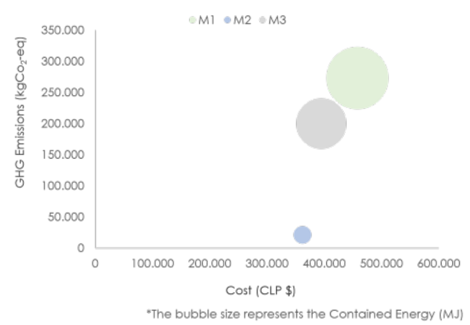
A dynamic display was chosen to aid in understanding the relationship among the sustainability impacts of the different design options. In the proposed method, Microsoft Excel is used to generate the different graphs.

Starting from exporting the information made in the previous point, an Excel spreadsheet was obtained for each table. A consolidated table with all the information was generated to facilitate the process. A bubble graph was created, which allowed comparing the environmental and economic costs of all the design options.

3.2 Case Study Evaluation

The experts evaluated the case study using the current and the proposed method to gather later their opinions of the analysis made. Figure 4 shows an example of the comparative figure used to make the decisions.

Figure 4:
Visual comparison of the environmental and economic costs of all the design options.



3.3 Validation

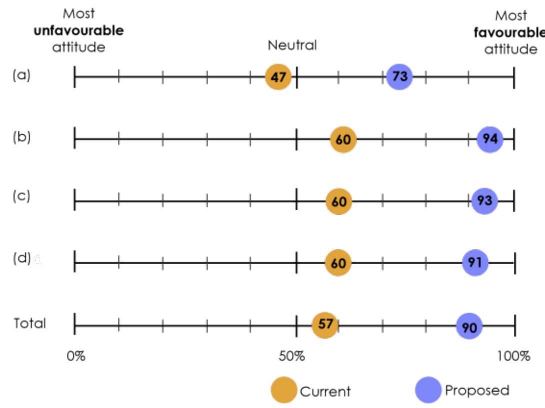
There was a response rate of 90% from the evaluation requested from the experts. In Table 2 and Figure 5, it is seen that all the questions related to the proposed method (Q2, Q4, Q6, Q8, Q9, and Q11) had the highest number of answers linked to favourable attitudes compared to the current method.

Table 2:
Results of the Survey to the Group of Experts.

		1	2	3	4	5
(a)	(Q1) *	22%	33%	33%	11%	0%
	(Q2) *	0%	11%	22%	56%	11%
(b)	(Q3)	11%	22%	22%	33%	11%
	(Q4)	0%	0%	0%	22%	78%
	(Q5)	22%	11%	33%	22%	11%
	(Q6)	0%	0%	0%	33%	67%
(c)	(Q7)	11%	11%	56%	11%	11%
	(Q8)	0%	0%	11%	22%	67%
	(Q9)	0%	0%	0%	22%	78%
(d)	(Q10)	0%	44%	22%	22%	11%
	(Q11)	0%	0%	0%	44%	56%

*Where 1 (a lot) to 5 (very little) for the other questions, 1 (strongly disagree) to 5 (strongly agree).

Figure 5:
Results of the Survey to the Group of Experts by Category, using the Likert Scale. The lighter colour shows the attitude to the current method, while the darker colour corresponds to the attitude to the proposed method.



3.3.1 (a) Time

55% of those surveyed felt that the time required to analyse a project with the current method is quite or very long (Q1). According to the Likert Scale, the current method scored 2.3 points (47%), while the proposed one (Q2) got 3.7 (73%), with 5 being the maximum (very favourable attitude) and 1 being the minimum (very unfavourable attitude).

3.3.2 (b) Applicability

As for applicability, 44% agreed or strongly agreed that the current method is readily adaptable (Q3), while 33% felt it flexible enough to integrate other design options (Q5). In the same section, those surveyed stated they agreed or strongly agreed in 100% of the cases about adaptability and flexibility when considering the proposed method (Q4 and Q6). The current method scored 6 points (60%), from a minimum of 2 and a maximum of 10. On the other hand, the proposed method scored 9.4 (94%) out of 10.

PLEA STGO 2022
WILL CITIES SURVIVE?
SUSTAINABLE BUILDINGS AND TECHNOLOGY

3.3.3 (c) Ease of Understanding

In this section, 22% agreed or strongly agreed about the ease and speed of understanding and interpreting the data with the current method, while 56% neither agreed nor disagreed (Q7). On the other hand, in the proposed method, the positive responses rose to 89% (Q8). When asked about comparing both methods to evaluate sustainability, 100% manifested agreeing or strongly agreeing in an increase of contribution by the designers over the current method (Q9). The Likert Scale evaluation confirmed the favourable attitude of those surveyed towards the proposed method, scoring 9.3 (93%) out of a possible 10. The current method scored 4.8 (48%), with 2 being the minimum.

3.3.4 (d) Scalability

Finally, for Scalability, 33% considered that the current method is easily scalable to other projects (Q10). Meanwhile, 100% of those surveyed agreed or strongly agreed with the scalability of the proposed method (Q11). Concerning the Likert Scale, the current method scored 3 (60%) points, while the proposed method 4.6 (91%), with a minimum of 1 and a maximum of 5.

3.3.5 (e) Open Questions

According to the open questions, half of those surveyed identified that the current tool is built on an old programming level, has limitations in terms of ease in use, and lacks flexibility for changes and the repetition of processes. They felt that the evaluation process of alternatives or large-scale projects takes a long time and that it is not very visual. They also understand that knowledge or experience on the topic is needed to easily and quickly understand the results. The experts agreed that the strength of the current tool is its database (Q12). Most of those surveyed mentioned that the proposed integration covers most of the limitations of the current method. However, they highlighted that it still lacks development at a programming level to integrate the indicators more fluently and in an automated fashion. They found that the proposal has potential, like the possibility of working in an integrated and collaborative way in the design and sustainability indicators at early stages, facilitating their inclusion in the workflow, and flexibility and versatility when it comes to evaluating different variations and projects, as well as speed in obtaining volumes, ease to visualise and interpret the results, all of this supporting the decision-making process. They also felt that once it has a repertoire of indicators loaded in the integration, the method will be more automated and thus quicker (Q12 and Q14).

Overall, the analysis using the Likert Scale (Figure 4) shows that, for the current method, the responses are slightly above the midpoint of the scale, with a score of 14.3 (57%) out of 25, which indicates a position that ranges from neutral to unfavourable. On the other hand, the proposed method scored 27 points (90%), with 30 being the maximum, reflecting a very favourable attitude of those surveyed regarding the current method.

4. DISCUSSION

The results show that the integration developed between the Abaco-Chile database and BIM: (a) Reduces the time required by designers to make sustainability evaluations compared to the current method; (b) Is flexible to evaluate different design variations; (c) Speeds up and aids the visualisation of the results to make decisions based on sustainability criteria at early stages of design; and (d) Can be easily applied to different projects.

Similarly, Crippa et al. [12] developed and validated integration between ArchiCAD19 and SimaPro8 to evaluate different types of walls, concluding that the framework impacts the mitigation of problems related to sustainability in the industry. Jalaei et al. [14] linked Autodesk Revit, Microsoft Excel, and Athena Impact Estimator to evaluate the sustainability of buildings in the early stages. They mentioned that the proposal was easy to use, allowed reducing the time to obtain calculations and helped to minimise errors caused by manual input. Correspondingly, the present study recognises the use of a local database and a simple workflow that take advantage of frequently used tools for designers. Van Eldik et al. [3] integrated a Dutch database and BIM for infrastructure projects in the early design stages, demonstrating that this method increases sustainability awareness in the design team. This topic is a growing need in the construction industry. For this reason, our research points out to bring complex but necessary tools closer to the people who make the critical decisions in project design.

Moreover, today's technological advances and new challenges lead designers to incorporate automation into their workflows, changing their mindset and approaching the design process in a completely new way. Architects and designers are no longer passive users of tools but instead emerge with a more active role in customisation and leveraging data. Our study sought to make this evident, showing that the tools are there to be used in new ways. Data can be accessed in a structured, orderly manner and be an input for the design.

We developed an integration between a Sustainability Tool and BIM in this research and implemented it using Abaco-Chile, Revit and Excel. This is one of many possible solutions that is improvable, but that allows showing that it is possible to empower designers and bring information closer to the users where decisions with greater impact on the project life cycle can be made. Besides, it is an example of the potential of Abaco-Chile as a local database and platform which can continue to nurture several developments in the area.

Although the results suggest that the integration proposed in this study is valuable to help designers in decision making in the early stages of design, it still has some limitations, namely: (1) There is no automation for data transfer between the BIM software and the database; (2) The integration does not consider the different levels of development (LOD) of the projects; (3) It only addresses the sustainability indicators of Contained Energy, GHG Emissions, and Unit Cost; (4) The database used, Abaco-Chile, still has a limited amount of material resources, while the unit cost values have been out of date since 2018; and (5) Its application was limited to the Chilean context, on using a domestic database. These limitations are an opportunity for future research, including developing an automated integration between the Chilean sustainability indicators database and BIM, broadening the scope of integration for higher levels of detail above LOD 100, and including more sustainability indicators.

5. CONCLUSION

Through this study, BIM is recognised as a potential tool to study the sustainability of projects in the construction industry during their early stages. The proposed integration between the Abaco-Chile database sustainability tool and BIM allows designers to quickly evaluate the economic and environmental impact of different design options, as well as to facilitate the reading of the results for those who are not experts in the area, allowing making better decisions at early stages of design, contributing to the sustainability of buildings. The integration can be improved and complemented to be used by architects and designers in a context such as Chile, using the local database Abaco-Chile, or adapted to other contexts and data sources.

ACKNOWLEDGEMENTS

The authors would like to thank the entire group of experts who took part in this work.

REFERENCES

1. Liu, Y., van Nederveen, S., Wu, C., & Hertogh, M. (2018). Sustainable Infrastructure Design Framework through Integration of Rating Systems and Building Information Modeling. *Advances in Civil Engineering, 2018*. https://doi.org/10.1155/2018/818353

2. Mercader Moyano, M., Camporeale, P., & Cózar-Cózar, E. (2019). Environmental impact assessment by means of indicators. *Revista Hábitat Sustentable*, 78–93

3. Van Eldik, M. A., Vahdatikhaki, F., dos Santos, J. M. O., Visser, M., & Doree, A. (2020). BIM-based environmental impact assessment for infrastructure design projects. Automation in Construction, 120. https://doi.org/10.1016/j.autcon.2020.103379

4. Safari, K., & AzariJafari, H. (2021). Challenges and opportunities for integrating BIM and LCA: Methodological choices and framework development. *Sustainable Cities and Society*, *67*, 102728. https://doi.org/10.1016/j.scs.2021.102728

5. Santos, R., Costa, A. A., & Grilo, A. (2017). Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015. *Automation in Construction*, *80*, 118–136. https://doi.org/10.1016/j.autcon.2017.03.005

6. Najjar, M. K., Figueiredo, K., Evangelista, A. C. J., Hammad, A. W. A., Tam, V. W. Y., & Haddad, A. (2019). Life cycle assessment methodology integrated with BIM as a decision-making tool at early-stages of building design. *International Journal of Construction Management*, 1–15. https://doi.org/10.1080/15623599.2019.1637098

7. Muñoz, C., Vega, M., Rocha, A., Cereceda, G., Molina, A., & González, P. (2020). Eco-efficiency Tool for Decreasing Environmental Load in the Life Cycle of Buildings - ABACO - Chile. In *IOP Conference Series: Earth and Environmental Science* (Vol. 503). Institute of Physics Publishing. https://doi.org/10.1088/1755-1315/503/1/012013

8. Kairies-Alvarado, D., Muñoz-Sanguinetti, C., & Martínez-Rocamora, A. (2021). Contribution of energy efficiency standards to life-cycle carbon footprint reduction in public buildings in Chile. Energy and Buildings, 236. https://doi.org/10.1016/j.enbuild.2021.110797

9. Wiche, P., & Rodríguez, B. (2020). Alternativas Metodológicas de Calculadoras de Huella de Carbono.

10. Hollberg, A., Genova, G., & Habert, G. (2020). Evaluation of BIM-based LCA results for building design. *Automation in Construction*, *109*(September 2019), 102972. https://doi.org/10.1016/j.autcon.2019.102972

11. Bueno, C., & Fabricio, M. M. (2018). Comparative analysis between a complete LCA study and results from a BIM-LCA plug-in. *Automation in Construction*, *90*(January 2016), 188–200. https://doi.org/10.1016/j.autcon.2018.02.028

12. Crippa, J., Boeing, L. C., Caparelli, A. P. A., da Costa, M. do R. de M. M., Scheer, S., Araujo, A. M. F., & Bem, D. (2018). A BIM–LCA integration technique to embodied carbon estimation applied on wall systems in Brazil. *Built Environment Project and Asset Management*, *8*(5), 491–503. https://doi.org/10.1108/BEPAM-10-2017-0093

13. Hernández Sampieri, R., Fernández Collado, C., & Baptista Lucio, M. del P. (2014). *Metodología de la investigación*. (McGRAW-HILL / Interamericana editores S.A. de C.V, Ed.) (Sexta edición.)

14. Jalaei, F. (2013). Integrating building information modelling with sustainability to design building projects at the conceptual stage, (2010), 273–280. https://doi.org/10.1007/s12273-013-0120-0

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE BUILDINGS AND TECHNOLOGY

PLEA SANTIAGO 2022
Will Cities Survive?

Development of an artificial neural network prediction model for reducing particulate matter (PM2.5) in school facility

KIM, TAE WON[1] CHOI, YOUNG JAE[1] BYUN, JAE YOON[1] MOON, JIN WOO[1]

[1] Department of Architecture and Building Science, Chung-Ang Univ, South Korea

ABSTRACT: High concentration of particulate matter can be critical to those with vulnerable immunity. Especially, its importance is all the more noticeable in school facility as it has higher particulate matter production rate and requires occupants' long-term concentration. However, since there are practical problems for occupants to control air quality in real-time, effective air conditioning control measures must be prepared to manage such. Thus, this paper developed artificial neural network based prediction model capable of automatically controlling indoor air quality in school facility. Learning data used for development were obtained by establishing Mock-up chamber and simulation model, and the prediction model's performance evaluation showed high accuracy of Cv(RMSE) being 8.40%. Prediction model is expected to be used for real-time prediction based control after its installation in ventilation management algorithm.
KEYWORDS: Fine particulate matter, Prediction model, Indoor air quality

1. INTRODUCTION

International Agency for Research on Cancer under World Health Organization (WHO) specified particulate matter as group 1 carcinogenic material in 2013[1]. Particulate matter under 2.5 µg radius, also known as PM2.5, is known to be 5th most fatal death risk factors in 2015[2] and indoors infiltrated by high concentration of PM2.5 are reported to be more critical to those with vulnerable immune systems such as children and elderly, causing asthma[3] and lung cancer[4-5]. Children of age under 13, who requires more amount of respiration per unit weight during their growing period, are especially more sensitive to the source of pollution[6-7].

The main sources of these indoor particulate matter are inflows from fenestration, ventilation systems and infiltration, and pollutants emitted from indoor activities, building components and furniture[8]. Also, as pollution level is known to be dependant to gas and micro-organism pollutants inside the building, it can be controlled by efficient operation of air conditioning systems inside the building[9]. Hence, school facilities, which shows distinctiveness of requiring long-term attention and has higher particulate matter occurrence rate due to occupants' activities inside, need ventilation through controlled air conditioning. Practically, however, there presents several problems for school managers to operate air conditioning and give lessons at the same time. Thus, there presents need for development of preemtive responding real-time particulate matter prediction model, and relevant research are being conducted.

Studies regarding particulate matter prediction model can be divided to one, mathematical modelling based on concentration analysis theory and two, development of prediction model using artificial intelligence, and majority of them focusses on outdoor particulate matter prediction, leading to research for indoor particulate matter prediction being relatively inadequate. As for mathematical modelling based on concentration analysis theory, Kim (2018) mathematically modelized indoor particulate matter concentration formation to control ventilation and air purification, and selected constants that affected indoor particulate matter concentration through derivation of major influencing factors. Highly accurate results of average error of 5% and maximum error of 17% could be achieved after comparing with field data[10]. Yeo (2019) applied mathematically modelized prediction models to actual field for comparative evaluation. Correlation result with R2 being approximately 0.8 higher has been achieved as a result[11]. Prediction model based on concentration analysis theory shows high accuracy in regard to spaces that can be applied. However, various experiments must be practiced in advance and shows very low prediction accuracy for particulate matter occurring due to occupants' activities. Research for development of prediction model using artificial intelligence mainly focused on comparing performance of models learned based on sequence data using various learning algorithms. Lagesse (2020) developed indoor PM2.5 concentration prediction model using Regression Model, Artificial neural network (ANN), and Long Short Term Memory(LSTM). As a result, LSTM model's RMSE (Root Mean Square Error) was 1.73, showing superior result to Regression Model and ANN[12]. Several research to develop indoor particulate matter prediction model using LSTM other than above has been executed but there are only few cases that conducted control using such.

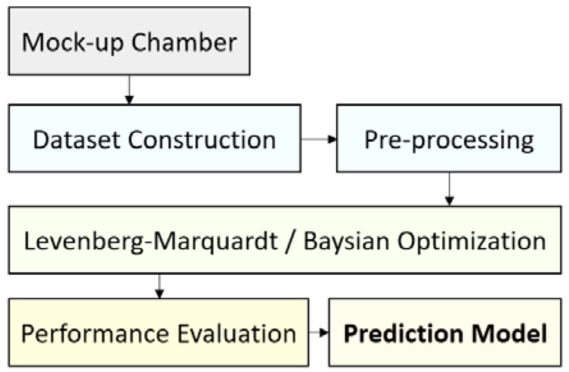
For other cases of prediction model development using artificial intelligence, studies aiming to improve comprehensive air quality were majority. Amado and Dela Cruz (2018) tested accuracy and practicality of machine learning based prediction model for air quality evaluation and control[13], and Tagliabue et al. (2021) applied data collected from IoT (Internet of Things) network inside educational facility to prediction model and used it to control indoor air quality[14].

Therefore, this paper developed indoor particulate matter prediction model for indoor air quality improvements in school facilities based on artificial neural network capable of real-time learning and optimized control.

2. INDOOR PARTICULATE MATTER PREDICTION MODEL DEVELOPMENT

ANN, one of Machine Learning's supervised learning algorithms, consists of Input Layer, Hidden Layer, and Output Layer. Each layer is composed of Node, and possesses Weight and Bias based on perceptron structure[15-16]. This study established Mock-up chamber to obtain learning data set. Also, for the purpose of regression, developed prediction model that sets factors which contribute to indoor particulate matter density formation as input variable using artificial neural network and predicted PM2.5 concentration as output variable.

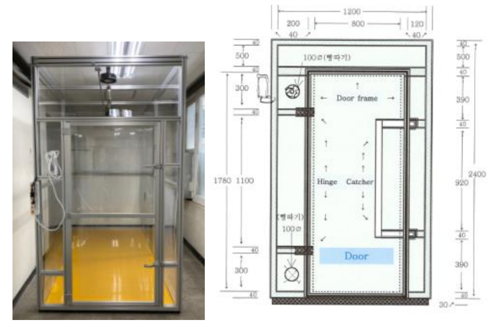
Figure 1:
Flow chart of predictive model development



2.1 Mock-up chamber establishment

A Mock-up chamber capable of particulate matter production and measurement was built develop indoor particulate matter initial prediction model. Major components are particulate matter producer that can insert particulate matter from the front side, measuring compartment capable of real-time measurement via Arduino sensor, Supply Fan, Return Fan, and control compartment which consist of external air inlet adjustment damper. Especially, control compartment can be Linear controlled through PWM (Pulse Width Modulation), Hepa Filter has been attached to Supply Fan, Pre-Filter attached to Return Fan and Exhaust so that conditions can be equal to previous air conditioner. Wall surface has been finished with uninterruptable acrylic panel to prevent adsorption due to static electricity. Precise information is as Table 1. Arizona Dust, testing dust used for formal experiments in ISO, has been used as particles for rendering particulate matter.

Table 1:
Chamber summary

		Content
Structure	Volume (m3)	3.225 ㎡×2.04M≒6.6 ㎥
	Floor area (m2)	≒3.225 ㎡ (W×D mm)
	Size	1290(W)×2500(D)×1980(H) (mm)
	Material	Aluminum profile + Acrylic (no blackout)
	Door	800(W)×30(D)×1780(H) (mm)
		
Control unit	Power	220 V AC, single phase Total power ≤ 1.0 kW/h
	Supply fan	Two: Square fan, 150⌀ (220 V AC, single phase)
	Return fan	Two: 170⌀, PC control communication (24 V DC)
	Lighting	LED ramp (2 each)

2.2 Establishing and preprocessing prediction model learning data

Prediction model must select variable that has high correlation between input and output variable, learning data applied with various scenarios improve prediction performance. For indoor PM2.5 prediction, 11 Data with high correlation to particulate matter density formation have been selected as input variable through preceding research as shown in Table 2. Chamber experiment has been conducted to acquire PM2.5 concentration reduction process data for a total 7 scenarios by applying 3 air volumes (Strong, medium, and weak) to 3 operation modes: OFF when particulate matter dispersed inside reached 400 $\mu g/m^3$, External air inlet, and Internal circulation. To unify scale and objectify importance of each variable, collected data has undergone preprocessing via Normalization and ratio of 60% Training data, 20% Validation data, and 20% Test data has been allocated.

Table 2:
Prediction model input variable

Category	Variables
Indoor	Temperature, relative humidity, PM2.5 concentration, CO2 concentration, PM2.5 concentration change
Outdoor	Temperature, relative humidity, PM2.5 concentration, CO2 concentration
System	Operation mode, wind volume

2.3 Prediction model optimization and performance evaluation

Artificial neural network prediction model has been developed using Levenberg-Marquardt learning algorithm used most universally for nonlinear function optimization problem and Bayesian Optimization strategy capable of stochastically obtaining Input through correlation[17]. 1~8 Hidden layers, 10~80 Neurons, learning rate 0.01, 0.001, 0.0001 have been set for Hyper-parameter search range. Above mentioned 11 data were entered for input layer, and PM2.5 concentration after 1 minute is printed out as output layer. Learning proceeded to minimalize MSE (Mean Square Error) through Back propagation.

Developed prediction model consists of 6 hidden layers and 56, 56, 56, 51, 64, and 67 neurons were set for each hidden layer(Figure 2). Prediction accuracy were evaluated by producing RMSE (Root Mean Square Error) and Cv(RMSE) (Coefficient of Variation of the Root Mean Square Error) for correct answer and prediction of Test data. Both indicators suggest the closer to 0 they get, the higher their prediction accuracy is. After commencing prediction for Test data, it showed high accuracy with RMSE 0.0052 $\mu g/m^3$ and Cv(RMSE) 8.40%(Figure 3).

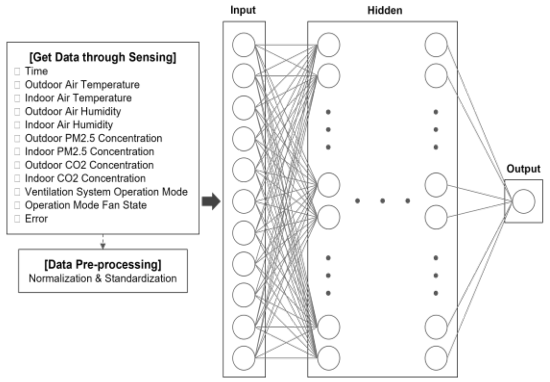


Figure 2:
Proposed ANN model structure

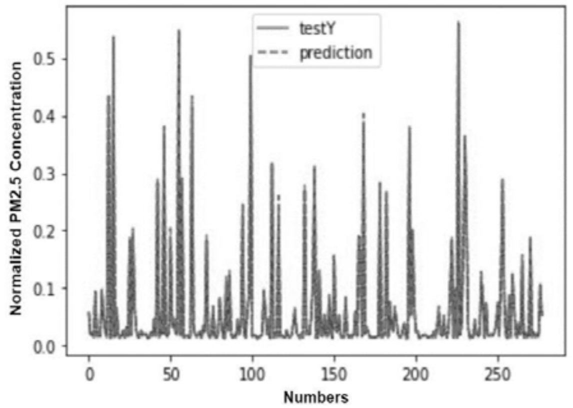


Figure 3:
Proposed model performance on test data.

3. CONCLUSION

This paper developed artificial neural network based indoor PM2.5 prediction model and evaluated its performance to improve indoor air quality of school facilities. Since prediction model developed through establishment and optimization of learning data using Mock-up showed high accuracy of Cv(RMSE) being 8.40%, it serving the purpose of prediction model is plausible. However, as it has only gone through learnings under limited conditions, there is possibility of its accuracy proving to be below expectancy if applied to actual site. Therefore, further studies aim to continuously collect actual survey data from school facilities currently under progress and commence additional learning and correction of prediction model. Additionally, by applying to optimal ventilation control algorithm, such model is expected to be developed into more versatile model for various environments, capable of not only real-time prediction based control but also real-time learning.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT, MOE) and (No. 2019M3E7A1113090).

REFERENCES

1. Centre international de Recherche sur le Cancer, Lyon, France. 2013. IARC evaluation of the carcinogenicity of outdoor air pollution. IARC Monograph 109, Outdoor Air Pollution, 7-18.
2. Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V. 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015, Lancet Vol 389 (2017), 1907–1918.
3 Brauer, M., Hoek, G., Smit, H.A., de Jongste, J.C., Gerritsen, J., Postma, D.S., Kerkhof, M., Brunekreef, B., 2007. Air pollution and development of asthma, allergy and infections in a birth cohort. European Respiratory Journal, 29, 879–888.
4. Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, J. Am. Med. Assoc. 287,1132–1141.
5. Jung, J.W., Lee, H.K. 2004. Dust concentration in an elementary classroom due to student activity. Korean Society for Atmospheric Environment 2004 Spring Conference, 253-254.
6. Park, S., Park, T., Park, S., Kim, Y., Kwon, M., Jung, J., Lee, C. 2018. Levels of the concentration of PM10 and PM2.5 in elementary school classroom at Yeongwol county. Journal of Odor and Indoor Environment, 17(1), 11-17.
7. Landrigan, P. J. 1998. Environment hazards for children in USA. International Journal of Occupational Medicine Environmental Health, Vol.11, No.2, 189-194.
8. Lee, B. H., Yee, S. W., Kang, D. H., Yeo, M. S., Kim, K. W. 2017. Multi-zone simulation of outdoor particle penetration and transport in a multi-story building. In Building Simulation, Vol 10, No 4, 525-534.
9. Fermo, Paola et al. 2021. Improving indoor air quality through an air purifier able to reduce aerosol particulate matter (PM) and volatile organic compounds (VOCs): Experimental results. Environmental Research, 197 (2021) 111131.
10. Kim, J.H. 2018. Ventilation and filtration control strategy considering indoor and outdoor particle environmental conditions of apartment building. Seoul National University Doctoral Thesis.
11. Yeo, M.S., Kim, J.H. 2019. Prediction of indoor fine dust incidence through analysis of indoor activities in day care center. Magazine of the SAREK 48(12), 44-50.
12. Lagesse, B. et al. 2020. Predicting PM2.5 in well-mixed indoor air for a large office building using regression and artificial neural network models. Environmental Science & Technology, 54, 23, 15320-15328.
13. Amado, Timothy M., Dela Cruz, Jennifer C. 2018. Development of machine learning-based predictive models for air quality monitoring and characterization. IEEE Region 10 Conference.
14. Tagliabue, Lavinia Chiara et al. 2021. Data driven indoor air quality prediction in educational facilities based on IoT network. Energy and Buildings 236 (2021) 110782.
15. Choi, E.J. et al. 2020. Development of occupant pose classification model using deep neural network for personalized thermal conditioning. Energies 2020, 13(1), 45.
16. Choi, Y.J., Choi, E.J., Cho, H.U., Moon, J.W. 2021. Development of an indoor particulate matter (PM2.5) prediction model for improving school indoor air quality environment. KIEAE Journal, Vol. 21, 35-40.
17. MacKay, D.J.C., 1992. Bayesian Interpolation, Neural Computation, 4(3): p. 415–447.

PLEA SANTIAGO 2022

Will Cities Survive?

A dynamic feedforward control strategy for energy-efficient building system operation

Xia Chen [1] Xiaoye Cai [2] Alexander Kümpel [2] Dirk Müller [2] Philipp Geyer [1]

[1] Institute for Sustainable Building Systems, Leibniz University Hannover, Germany
[2] Institute for Energy Efficient Buildings and Indoor Climate, RWTH Aachen University, Germany

ABSTRACT: The development of current building energy system operation has benefited from: 1. Informational support from the optimal design through simulation or first-principles models; 2. System load and energy prediction through machine learning (ML). Through the literature review, we note that in current control strategies and optimization algorithms, most of them rely on receiving information from real-time feedback or using only predictive signals based on ML data fitting. They do not fully utilize dynamic building information. In other words, embedding dynamic prior knowledge from building system characteristics simultaneously for system control draws less attention. In this context, we propose an engineer-friendly control strategy framework. The framework is integrated with a feedforward loop that embedded a dynamic building environment with leading and lagging system information involved: The simulation combined with system characteristic information is imported to the ML predictive algorithms. ML generates step-ahead information by rolling-window feed-in of simulation output to minimize the errors of its forecasting predecessor in a loop and achieve an overall optimal. We tested it in a case for heating system control with typical control strategies, which shows our framework owns a further energy-saving potential of 15%.

KEYWORDS: Machine Learning, Control Strategy Optimization, First-principles Model, Building Performance Simulation, Energy Efficiency

1. INTRODUCTION

The challenge of climate change shapes the shared goal of decarbonatization and sustainability globally. As the building sector consumes up to 30-45% of global energy with the growing trend (Zhong et al., 2021), efforts in building system fine control and management are recognized to contain considerable potential in saving energy (Junker et al., 2018; Mariano-Hernández et al., 2021). In this context, research regarding building control strategy development in Building Energy Management Systems (BEMS) is drawing attention recently. They are classified into two major distinct categories: *Rule-based Controls (RBC)* and *Model Predictive Control (MPC)* (Péan et al., 2019).

RBC with "if-then" trigger rules serves flexibility objectives with substantial performance in load shifting, peak shaving, cost reduction by energy price response, etc. (Bae et al., 2021). The set-point is usually tracked with a traditional PID controller (Madani et al., 2013); however, due to its manual predefined rules/policies, it is less flexible to anticipate optimization with changing external conditions. With the recent boom of artificial intelligence (AI) and the decrease of computation resources cost, MPC surmounts RBC by performance and flexibility for its ability of future behavior estimation, which in the most case benefited by using machine learning (ML) algorithms (Mariano-Hernández et al., 2021; Mendoza-Serrano & Chmielewski, 2014) with its strength of implicit pattern learning ability. In this context, MPC strategies are developed for further improvement via its process-based estimation of defining a specific objective function for minimization (Drgoňa et al., 2020). It is designed to project the future system's behavior and optimize current operation accordingly.

Meanwhile, the flourishing of AI has led to new algorithm adoption of reinforcement learning (RL) based on maximizing the set reward function under environmental constraints (Sutton & Barto, 2018), which has yielded promising results in research (Zhang et al., 2018). RL inherits the strength of ML in well integrating implicit learning factors to deal with external condition changing; however, its modeling process requires reprogramming by different environments, and the model itself is in a black box state, making it less engineer-friendly for deployment and interpretation.

If we carefully inspect the advantages of RL compared to MPC, the former learns implicit relationships of interactive consequences between environment and agent action in a consistent rolling time frame. Whereas MPC strategies based on the ML model merely emphasize the future information input for optimization (Péan et al., 2019). In our opinion, dynamic control is a continuous process requires leading (future) and also lagging (historical) information simultaneously. In this context, prior knowledge embedded with lagging information remains underappreciated. For example, a lagging signal known as autocorrelation in the field of time-domain signal analysis has been shown effective in extracting pattern information (Fulcher, 2018). In this study, we set an objective for research by involving: 1. past behavioral patterns as ML additional inputs via methods, i.e., differencing, and 2. Combined ML with prior knowledge embedded simulation, to improve BEMS performance in the aspect of energy-saving and flexibility.

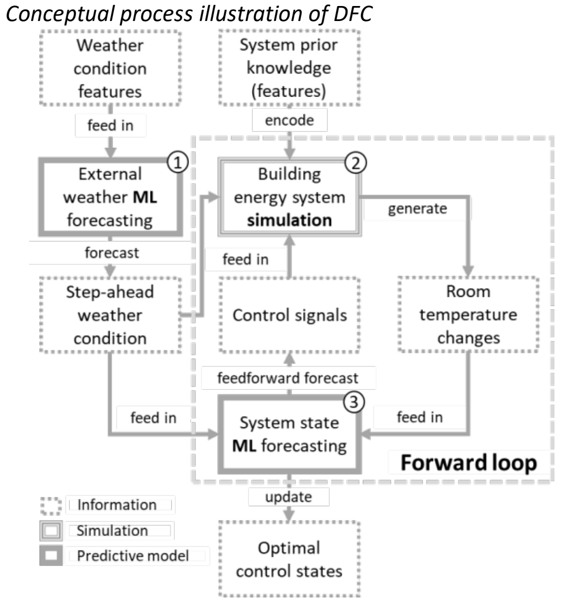
To address the abovementioned issues, we propose an engineer-friendly, dynamic feedforward control strategy (DFC) framework for BEMS by integrating ML forecasting and physics-based simulation. It carries the advantages of understanding historical/future patterns to ensure performance in system control while operating in advanced energy-efficient behavior.

The remainder of this paper is organized as follows: Section 2 introduces necessary theories and methods for developing forward strategy; Section 3 describes the setup of a case study with benchmark strategies; the result is discussed in Section 4; Section 5 outlines the limitations and future work; Section 6 concludes the paper.

2. METHODOLOGY

A general process illustration of the DFC strategy is presented schematically in Figure 1. The core of this strategy is to train an ML model for capturing the dynamic relationship between time-domain features of external weather conditions, indoor temperature changes, and system control states.

Figure 1:
Conceptual process illustration of DFC



Note: DFC strategy consists of two predictive models, including one for external weather prediction (left) and another (bottom) for capturing dynamic behavior between system status and in-/external conditions. It operates in a simulation-involved loop.

2.1 Physical-based simulation: Modelica

To complete the desired strategy framework, we apply the building performance simulation (BPS) in Modelica - an open-source modelling language that supports equation-based and object-oriented modelling approaches (Fritzson & Engelson, 1998). The model is based on thermal network models, in which thermal system behaviors are represented with resistances and capacitances of an electrical system based on the analogy of both systems. The German Guideline (VDI 6007-1, 2012) introduces a two-element building model considering internal thermal masses and outer walls, and this model has been evaluated (Lauster et al., 2014). Based on this, (Lauster et al., 2015) introduced the three-elements model by considering one more element for the floor plate. Furthermore, the four-elements model is published in the Modelica library *AixLib* (Müller & et al., 2016): by considering excitations from the exterior wall, interior wall, floor plate, and roof to enable a finer resolution of the dynamic building system behavior. For multiple use cases, this model can be parameterized based on the corresponding databases.

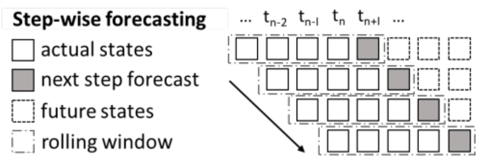
2.2 Machine learning model: boosting algorithm

To ensure the ML model recognizes implicit dynamics in time-series data in the state-of-the-art, reviews (Chakraborty & Elzarka, 2019; Chou & Tran, 2018) point out two current prominent advanced algorithm families applied in our domain: neural networks (NNs) and boosting algorithms. Since NNs usually require case-based network structure design, fine-tuning in features of neural nodes, layers, and activation functions to guarantee decent performance, boosting algorithms own the advantage of being "off-the-shelf" without extensive preprocessing or tuning required to perform accurately with generalization flexibility (Tyralis & Papacharalampous, 2021). In this study, we select Light Gradient Boosting Machine (LightGBM) as our ML models. Further insight and an open-source implementation in detail are available in the original paper (Guolin Ke et al., 2017).

2.3 Strategy framework

DFC strategy is implemented as step-ahead (stepwise) time-series forecasting, as shown in Figure 2. Dynamics is the keyword of this strategy, which means the objective of this strategy is flexible under different input conditions. For this purpose, a feedforward process is introduced to enable predictive models (ML models) to learn the dynamic relationships between system states and other time-domain features in a range of certain time frames. We designate this system state forecasting model as the target model.

Figure 2:
Semantic illustration of stepwise time-series forecasting with a rolling window

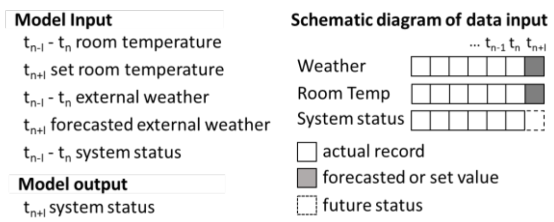


Note: t_n stands for the time step. The rolling window means that with the ongoing time, the predive model takes the current state and a certain number of past states as input to forecast the next step. It learns the dynamic relationship in a time-series sequential window.

The core mindset to implementing a feedforward process is to combine the forecasted weather information (Model 1, Figure 1) with the physical-based simulation (Model 2, Figure 1) to obtain the synchronous correspondence between future weather conditions, indoor temperature (setpoint), and system control state (from Model 3, Figure 1). These relationships are fed into the system state forecasting target model (Model 3, Figure 1), thus completing the feedforward loop.

Furthermore, we design the data input structure to ensure that the target model captures the dynamics of the indoor temperature variation in association with time-domain features in an implicit pattern, as presented in Figure 3. The indoor thermodynamic behavior usually has hysteresis effects on external weather conditions and internal load changes, from which the energy-saving potential arises. The target model is designed to access feedforward (leading) and historical (lagging) information within a time-rolling window to make each step of the control strategy optimal with the consideration of consistency.

Figure 3:
Data input/ output structure of the target model



Finally, by combining all components together, the proposed framework pseudo-code is organized as follows:

Input: $\{(\boldsymbol{x_i}, \boldsymbol{T_i})\}_1^n$, in total $\boldsymbol{n}$ sequential set of building information features $\boldsymbol{x_i}$ (building feature, historical load, weather condition, etc.) with forecasted temperature $\boldsymbol{T_i}$, a differentiable loss function $\boldsymbol{L(T, F(x))}$, number of iterations $\boldsymbol{M}$.

Algorithm:

For $\boldsymbol{i = 1}$ to $\boldsymbol{n}$:

If the forecasted temperature in the next $\boldsymbol{M}$ steps doesn't fulfill the comfort standard, initialize model with a constant value:

$$F_0(x) = \arg\min_{\gamma} \sum_{i=1}^{M} L(T_i, \gamma) \quad (1)$$

For $\boldsymbol{m = 1}$ to $\boldsymbol{M}$:

a. Feed $\boldsymbol{F_{m-1}(x)}$ into simulation to get the system states output and consequential temperature $(\boldsymbol{S_m(x_i)}, \boldsymbol{F_m(x_i)})$.
b. Compute pseudo-residuals: the difference between temperature standard and intermediate predicted temperature:
$$r_m = -\left[\frac{\partial L(T_i, F(x_i))}{\partial F(x_i)}\right]_{F(x)=F_{m-1}(x)} \quad (2)$$
c. Fit a regression tree to the $\boldsymbol{r_m}$ values and create terminal regions $\boldsymbol{R_{j,m}}$ for $\mathbf{j} = \mathbf{1}, \dots, \boldsymbol{J_m}$
d. Compute multiplier $\boldsymbol{\gamma_{j,m}}$ by:
$$\gamma_{j,m} = \arg\min_{\gamma} \sum_{x_i \in R_{j,m}} L(T_i,\ F_{m-1}(x_i) + \gamma) \quad (3)$$
e. Update the model with forecasted temperature:
$$F_m(x) = F_{m-1}(x) + \nu \sum_{j=1}^{J_m} \gamma_{j,m} \quad (4)$$

Output: control state sequential $\{(\boldsymbol{S_M(x_i)})\}_{i-1}^{n}$

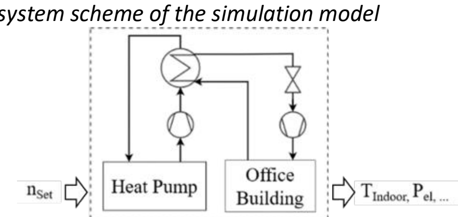
In summary, the novelty, and the performance improvement of the DFC strategy come from the embedding of physical information dynamically into the objective function in the data-driven process, which means that the DFC enable:

- Recognition of encoded building physical information from simulation output data by the ML model.
- Combining historical indoor temperature changes and states, training the relationship between future weather and system states through weather leading information combined with simulation.
- Dynamic pattern learning from lagging input of external weather conditions, indoor temperature, and system states information, thus optimizing system control states.

3. CASE DESCRIPTION

In the case study, we simulate a typical office building in Modelica with the standard of the passive house (Tian et al., 2018). The model handles solar radiation and internal gains, which contain the emitted heat from occupants, equipment, and lighting. The database parameterizing the office building was validated and has been used in several works (Mork et al., 2022; Niederau et al., 2021). The office area is 1675 m² (parameters in Table 1), equipped with space heaters and a Viessmann heat pump with nominal power of 18,5 kW (scheme in Figure 4). Models and data are accessible in *AixLib*.

Figure 4:
The system scheme of the simulation model



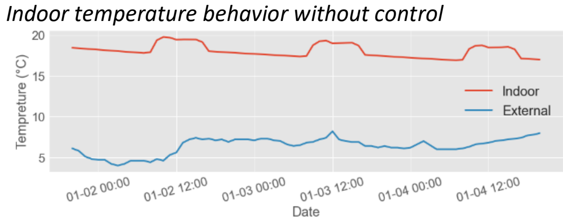
Note: $\boldsymbol{n_{set}}$: Relative rotational speed of compressor in the heat pump; $\boldsymbol{T_{Indoor}}$: indoor temperature; $\boldsymbol{P_{el}}$: electrical power.

Table 1:
Parameters of the office building simulation with passive house standard

Parameter	Value	Unit
Resistances of exterior walls	$1.41 \cdot 10^{-4}$	K/W
Heat capacities of exterior walls	$4.93 \cdot 10^{8}$	J/K
Resistances of floor plate	$1 \cdot 10^{-3}$	K/W
Resistances of roof	$1 \cdot 10^{-3}$	K/W
Resistances of interior wall	$1.3 \cdot 10^{-4}$	K/W

In this simulation, we define two rules for the comfort objective in temperature: *IF day (7 AM – 6 PM), THEN the temperature setpoint is 21°C; IF night, THEN the temperature setpoint is 19°C.* The simulation is set under the weather condition of Aachen, Germany. The simulated behavior of indoor temperature is presented in Figure 5.

Figure 5:
Indoor temperature behavior without control



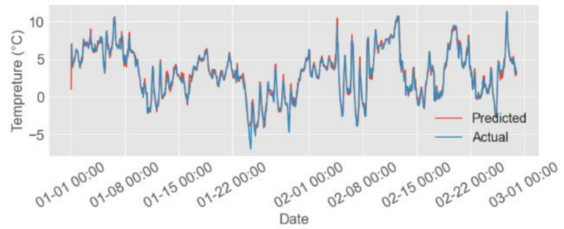
Based on the set scenario, we implement the desired feedforward strategy (DFC) mentioned in section 2 for fulfilling the comfort objective. To evaluate DFC, we compare it with two Reference Control (RC1 and RC2): RC1 is based on a proportional-integral-derivative controller (PID). A PID employs a responsive correction to a control function in real-time and hence the PID-based control aims at reducing the difference between the set indoor temperature and the measured value. RC2 features predictive control, which uses leading signals by simulation: When the indoor temperature is below the set temperature, by cumulative increasing *nSet* in 0.05 step length until the room temperature fulfills the comfort objective. All predictive strategies are applied in 10-minute time-step granularity.

RC2 and DFC strategies require the feed-in of future signals for process estimation. We used historical Aachen weather with features presented in Table 2 with lagging signals of features, and trained the ML model for one-step-ahead (as in Figure 2) external weather condition prediction with a rolling window. The result (plotted in Figure 6) shows high accuracy (0.9896 coefficient of determination, or R squared). The one step ahead output of air temperature is then merged into MPC strategy and DFC strategy model training and control (as in Figure 3).

Table 2:
Weather features

Input feature	Description
temp	Air temperature (℃)
dew	Dew point (℃)
hum	Relative humidity (%)
pres	Atmospheric pressure (hPa)
winds	Wind speed (m/s)

Figure 6:
Weather forecasting result



4. RESULTS

Table 3 shows a quantitative comparison of energy consumption within three strategies, while Figure 7 plots them in *nSet*, *indoor temperature,* and *heat pump coefficient of performance (COP)*, respectively.

Figure 7:
Comparison of performance results in different strategies.

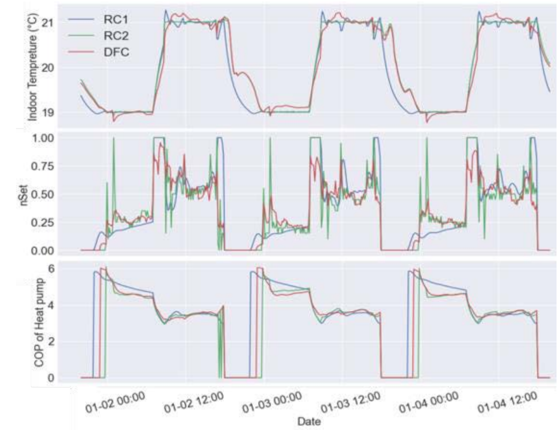


Table 3:
Comparison of electrical energy consumption in different strategies

Strategy	Energy consumption
RC1 (PID-based)	0.305 kWh/day per m²
RC2 (predictive)	0.273 kWh/day per m²
DFC	**0.251** kWh/day per m²

Note: Calculated based on the daily average from Figure 7.

The quantitative result shows that compared to RC2 and DFC, RC1 performs the least efficient control. We conclude the reason from the subfigure of *nSet* in Figure 7: With no future signal feed-in for process optimization, the PID-based RC1 causes oscillation at the temperature set point against temperature changes. Furthermore, because of its real-time response to temperature changes, a stable temperature curve is observed during daylight. The cost of this fine regulation results in a large amount of energy consumption by keeping the compressor running with oscillation to maintain the temperature above the minimum setting.

Compared to the RC1 control, RC2 performs in a more promising behavior with 10.5% lower energy consumption. The difference is that RC2 utilizes predictive leading signals of indoor temperature to regulate the energy system in less oscillation behavior and total energy consumption. However, RC2 has more spikes in regulation *(nSet)*.

The DFC strategy fulfills the comfort objective with a further advantage in energy-efficient control: 17.7% reduced energy consumption. Due to combined information from lagging and leading signals, DFC comprehends dynamic time-domain behaviors well and produces smoother control states with less overshooting. In return, the temperature curve is not strictly aligned with the standard with ±0.5°C fluctuation. The reason for this phenomenon is two-fold: the unpunished temperature overshooting behavior in the algorithm, and the accumulated inaccuracy of signals because of two ML models involved DFC strategy, including one for external weather prediction (Model 1 in Figure 1), and another for capturing dynamic behavior between weather, indoor temperature, and energy system states (Model 3 in Figure 1).

The highlight of the DFC is a new control pattern observed in Figure 7: Before the set temperature changes in the morning, we observed the DFC start the regulation in the time between RC1 and RC2. It means that the DFC strategy learns dynamic relationships among time-domain features in-depth by rolling stepwise training from physics-informed simulation. Furthermore, compared to RC1 or RC2, the DFC strategy tends to decompose a substantial change (upward or downward spike) into two to multiple small spikes. By taking both lagging and leading information into account, the strategy raises small spikes to preheat the room with continuous control sequence to ensure indoor temperature changes within the set frame.

5. DISCUSSION

This section discusses the strategy adaptability, limitation, and future development prospect.

DFC strategy is designed to fill the gap in the current MPC-based strategy by combining the physical-based simulation and data-driven models. The general framework design aims to fully utilize the domain knowledge (building characteristics) encoded in the simulation model and the implicit pattern (time-domain dynamic relationships) recognition ability of ML. *More specifically, it makes the prior-knowledge validation accessible in the loop of the data-driven optimizing process.* This mindset is applicable in general engineering domains. Within the scope of BEMS control optimization, we've proved its effectiveness with good interpretability. In this aspect, we encourage investigations in different scenarios to validate its performance robustness.

In this study, the setup scenario with external weather conditions, indoor temperature, and system status in the framework is relatively simple. DFC has the same potential as MPC to be extended in complex scenarios to achieve control strategies under different objectives, such as minimization of cost, CO_2 intensity, non-renewable primary energy, etc. by customizing the objective function.

Although the strategy shows advantages from an energy-saving perspective, the process of model training requires efforts in case-based simulation modeling. In this context, the trade-off investigation between modeling detail and performance is necessary. Future works in constructing a general simulation framework for a certain type of buildings to fit a broader range of application scenarios are meaningful.

6. CONCLUSION

In this study, based on current limitations in BEMS control strategies, we proposed a dynamic feedforward strategy to achieve stepwise rolling predictive system control, which contains two novelties: *integration of physical-based simulation with engineer-friendly ML models*, and *utilization of leading and lagging indicators with physics-informed information*, to conduct consistent and energy-efficient control signals. The designed case shows that the proposed strategy outperforms PID-controller and MPC-based reference strategy in terms of BEMS control and optimization. Under the general trend of digitalization and data-driven model application, the domain knowledge integration from the perspective of informed ML methods should raise further attention within our community to contribute to the objective of sustainable development.

ACKNOWLEDGEMENTS

We thank Yusheng, Chen for useful discussions. We acknowledge the German Research Foundation (DFG) support for funding the project under grant GE 1652/3-2 in the Researcher Unit FOR 2363.

REFERENCES

1. Bae, Y., Bhattacharya, S., Cui, B., Lee, S., Li, Y., Zhang, L., Im, P., Adetola, V., Vrabie, D., Leach, M., & others (2021). Sensor impacts on building and HVAC controls: A critical review for building energy performance. *Advances in Applied Energy*, *4*, 100068.
2. Chakraborty, D., & Elzarka, H. (2019). Advanced machine learning techniques for building performance simulation: a comparative analysis. *Journal of Building Performance Simulation*, *12*(2), 193–207.
3. Chou, J.‑S., & Tran, D.‑S. (2018). Forecasting energy consumption time series using machine learning techniques based on usage patterns of residential householders. *Energy*, *165*, 709–726. https://doi.org/10.1016/j.energy.2018.09.144
4. Clarke, J. (2007). *Energy simulation in building design*. Routledge.
5. Déqué, F., Ollivier, F., & Poblador, A. (2000). Grey boxes used to represent buildings with a minimum number of geometric and thermal parameters. *Energy and Buildings*, *31*(1), 29–35.
6. Drgoňa, J., Arroyo, J., Figueroa, I. C., Blum, D., Arendt, K., Kim, D., Ollé, E. P., Oravec, J., Wetter, M., Vrabie, D. L., & others (2020). All you need to know about model predictive control for buildings. *Annual Reviews in Control*, *50*, 190–232.
7. Fritzson, P., & Engelson, V. (1998). Modelica—A unified object-oriented language for system modeling and simulation. In *European Conference on Object-Oriented Programming.* Symposium conducted at the meeting of Springer.
8. Fulcher, B. D. (2018). Feature-based time-series analysis. In *Feature engineering for machine learning and data analytics* (pp. 87–116). CRC Press.
9. Requirements on methods of calculation to thermal and energy simulation of buildings and plants - Buildings;35.240.70, Düsseldorf (2001).
10. Calculation of transient thermal response of rooms and buildings - Modelling of rooms;91.140.10, Düsseldorf (2012).
11. Guolin Ke, Qi Meng, Thomas Finley, Taifeng Wang, Wei Chen, Weidong Ma, Qiwei Ye, & Tie-Yan Liu (2017). LightGBM: A Highly Efficient Gradient Boosting Decision Tree.
12. Junker, R. G., Azar, A. G., Lopes, R. A., Lindberg, K. B., Reynders, G., Relan, R., & Madsen, H. (2018). Characterizing the energy flexibility of buildings and districts. *Applied Energy*, *225*, 175–182. https://doi.org/10.1016/j.apenergy.2018.05.037
13. Lauster, M., Fuchs, M., Huber, M., Remmen, P., Streblow, R., & Müller, D. (2015). Adaptive thermal building models and methods for scalable simulations of multiple buildings using Modelica. In *the 14th International IBPSA Conference*.
14. Lauster, M., Teichmann, J., Fuchs, M., Streblow, R., & Mueller, D. (2014). Low order thermal network models for dynamic simulations of buildings on city district scale. *Building and Environment*, *73*, 223–231.
15. Madani, H., Claesson, J., & Lundqvist, P. (2013). A descriptive and comparative analysis of three common control techniques for an on/off controlled Ground Source Heat Pump (GSHP) system. *Energy and Buildings*, *65*, 1–9. https://doi.org/10.1016/j.enbuild.2013.05.006
16. Mariano-Hernández, D., Hernández-Callejo, L., Zorita-Lamadrid, A., Duque-Pérez, O., & Santos García, F. (2021). A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis. *Journal of Building Engineering*, *33*, 101692. https://doi.org/10.1016/j.jobe.2020.101692
17. Mendoza-Serrano, D. I., & Chmielewski, D. J. (2014). Smart grid coordination in building HVAC systems: EMPC and the impact of forecasting. *Journal of Process Control*, *24*(8), 1301–1310.
18. Mork, M., Xhonneux, A., & Müller, D. (2022). Nonlinear Distributed Model Predictive Control for multi-zone building energy systems. *Energy and Buildings*, *264*, 112066.
19. Müller, D., & et al. (2016). AixLib-An open-source modelica library within the IEA-EBC annex 60 framework. *BauSIM*, *20162016*, 3–9.
20. Niederau, J., Fink, J., & Lauster, M. (2021). Connecting Dynamic Heat Demands of Buildings with Borehole Heat Exchanger Simulations for Realistic Monitoring and Forecast. *Advances in Geosciences*, *56*, 45–56.
21. Péan, T. Q., Salom, J., & Costa-Castelló, R. (2019). Review of control strategies for improving the energy flexibility provided by heat pump systems in buildings. *Journal of Process Control*, *74*, 35–49. https://doi.org/10.1016/j.jprocont.2018.03.006
22. Robinson, D. (2012). *Computer modelling for sustainable urban design: Physical principles, methods and applications*. Routledge.
23. Sutton, R. S., & Barto, A. G. (2018). *Reinforcement learning: An introduction*. MIT Press.
24. Tian, Z., Zhang, X., Jin, X., Zhou, X., Si, B., & Shi, X. (2018). Towards adoption of building energy simulation and optimization for passive building design: A survey and a review. *Energy and Buildings*, *158*, 1306–1316. https://doi.org/10.1016/j.enbuild.2017.11.022
25. Tyralis, H., & Papacharalampous, G. (2021). Boosting algorithms in energy research: a systematic review. *Neural Computing and Applications*, *33*(21), 14101–14117. https://doi.org/10.1007/s00521-021-05995-8
26. Zhang, Z., Chong, A., Pan, Y., Zhang, C., Lu, S., & Lam, K. P. (2018). A deep reinforcement learning approach to using whole building energy model for hvac optimal control. In *2018 Building Performance Analysis Conference and SimBuild*.
27. Zhong, X., Hu, M., Deetman, S., Rodrigues, J. F. D., Lin, H.‑X., Tukker, A., & Behrens, P. (2021). The evolution and future perspectives of energy intensity in the global building sector 1971-2060. *Journal of Cleaner Production*, *305*, 127098.

Energy renovation towards Net-Zero carbon emission buildings

A case study in Sweden

RICARDO BERNARDO[1] RAFAEL PIZARRO[1]

[1] Division of Energy and Building Design, Lund University, Sweden

ABSTRACT: The European Union has set the goal to be the first climate neutral continent by 2050. Sweden aims at reaching that goal by 2045. 23 Swedish pioneer municipalities - together accounting for 40% of Sweden's population – are even more ambitious and aim for that goal by 2030. Globally, buildings and the construction sector account for almost 40% of global greenhouse gas emissions. Currently, roughly three quarters of buildings in the EU are not energy efficient, yet 85-95% of today's buildings will still be in use in 2050. Therefore, to reach our climate goals, the existing building stock needs to be significantly upgraded. Despite this, there is a lack of demonstrated cost-effective energy renovation solutions in Sweden that leads to yearly net-zero carbon emission buildings. This paper describes an energy renovation concept for residential multi-family buildings. The concept is based on prefabricated multifunctional façade elements with added insulation and integrated systems for ventilation, heat recovery and renewable energy. Within this study, a life-cycle analysis is carried out to investigate the possibility of achieving a net-zero carbon emission building after renovation. The main results show that, depending on the definition and assumptions, the renovation concept leads to net-zero carbon.
KEYWORDS: Energy, Renovation, Carbon neutral buildings, Life-cycle analysis

1. INTRODUCTION

To wisely use the greenhouse gas emissions that we have left to emit is probably the biggest challenge of our generation. The ambition taken by 23 cities in Sweden, within the Viable Cities programme, to reach climate neutrality in 2030 is among the most ambitious in the world [1]. Although it is well known that to decarbonize our cities the existing building stock needs deep intervention, there is a lack of demonstrated cost-effective energy renovation solutions in Sweden that leads to yearly net-zero carbon emission buildings.

Several projects in Sweden have dealt with deep energy-efficient renovations using prefabrication. Within the IEA research project Annex 50 "Prefabricated Systems for Low Energy Building Renewal", demonstration projects were carried out, which showed potential to meet economy and energy efficiency goals with multifunctional façade solutions [2]. An integrated heating system and a newly developed active solar energy system were applied to an apartment building [2]. Some projects also considered economic and environmental impacts. For example, the EU-funded "RetroKit" project developed and demonstrated in three pilot projects (Spain, Germany and Sweden), multifunctional, modular and low-cost prefabricated modules [3], [4]. Another example is the project "Industrial Energy Efficient Retrofitting of Resident Buildings in Cold Climates", also known as "E2Rebuild", which carried out seven demonstrations in Germany (2), Finland, France, Sweden, the Netherlands, and England [5]. This project showed significant energy savings in all demonstrations. All but two used a prefabricated wooden stud facade, which was mounted on the outside or replaced the existing facade. Several aspects were analysed in the project such as social sustainability, life cycle analysis, energy saving, and economics. The conclusion from the project was that it is possible to reduce carbon dioxide emissions from a building through an energy and cost-effective renovation without risking the indoor environment or social aspects during the construction process [5].

This study builds on a previous research project, that theoretically investigated a cost-effective and large-scale applicable concept for façade renovation of Swedish multi-family buildings based on prefabricated multifunctional facade elements, including added insulation with integrated systems for ventilation, heat recovery and renewable energy [6], [7]. The proposed façade elements are illustrated in Figure 1. These are to be installed on the outside of the building envelope. The existing exhaust ventilation ducts are reused, and new supply air ducts are integrated into the façade modules within the insulation. The ventilation system includes an air handling unit with heat recovery on the roof that effectively decreases the energy use for the ventilation air and increases thermal comfort indoors. The suggested construction for the façade elements is based on wood studs with insulation.

Results from this project showed that, under certain conditions, the energy renovation concept could lead to a net-zero energy building in a cost-effective manner [8]. The greatest advantages of prefabricated façade solutions include reduced renovation time and fewer disturbances to the tenants. Often the tenants do not need to be evacuated during the renovation as the work is mostly carried out on the outside. Such results are in line with previous related projects.

However, the previous investigation focused on the energy use accounted for during operation; carbon emission from materials used during the renovation was not investigated. While there has been much focus on reducing operational energy use in new buildings, the same cannot be stated regarding climate impact from the building production/renovation phase. Recent studies show that building production accounts for 20-85% of the total climate impact in new construction, depending on the choice of the analysis time-period and energy use [9]. Although energy efficiency is important, reducing emission from building material and processes is very relevant and impacts CO_2 in the atmosphere when we need it the most – right now.

This study investigates whether the proposed renovation concept can lead to net-zero carbon emission buildings, illustrated by a case-study in Sweden.

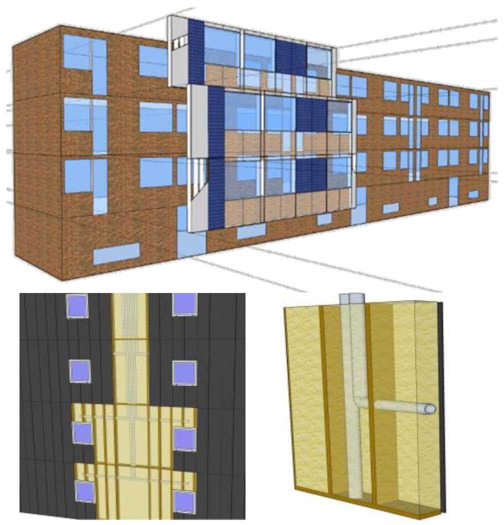


Figure 1. Concept visualization of the prefabricated façade modules, including added insulation, supply air ducts, and heat recovery.

2. METHODS

2.1 Case-study building and previous studies

The case-study building is a multi-family building representative of the construction boom during the post-war period in the 1960s and 1970s. During this period the need for housing was very high, leading to the use of some level of prefabrication in building construction. These buildings generally present high energy use and poor thermal comfort. Moreover, 50 years have passed since they were built, and a large share of these buildings need renovation due to wear and tear. This poses a good opportunity to carry out an energy renovation as well. The selected case-study is a real building consisting of 105 apartments distributed by nine floors and a total of 9235 m^2 of heated floor area. This high-rise building typology was chosen for this analysis as the fraction of roof to heated floor area is lower than smaller low-rise buildings. This decreases the available space for installing photovoltaics per floor area, which may limit the possibility of reaching carbon neutrality. Moreover, since supply air ducts are placed within the façade modules and led to each apartment, heat losses from supply air are larger due to longer duct paths to the apartments at the ground floor. This case-study is, in other words, a "worst-case scenario" for the present analysis.

Within the scope of previous studies, the renovation concept was investigated in terms of energy performance during operation and costs [6]–[8]. The energy use of the building was modelled using the software IDA-ICE, see Figure 2 [10]. Previous results showed that the specific energy use (heating, domestic hot water, and property electricity) could be reduced from 142 kWh/m^2/y before renovation to 62 kWh/m^2/y after renovation (Figure 3) [6]. If considered that the building was in need of an "anyway" renovation of the façade and roof due to wear and tear, and that such costs could be discounted from the energy renovation, the life cycle cost analysis showed that the renovation would be profitable [8].

Figure 2. Illustration of the building model in IDA-ICE.

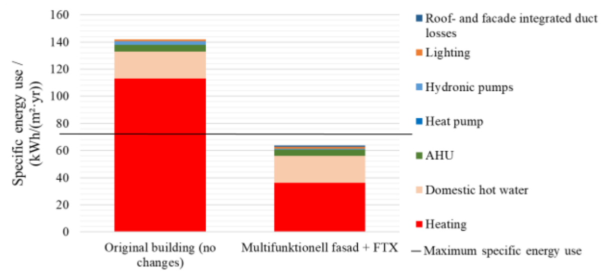


Figure 3. Specific energy use before and after renovation investigated in a previous study [6].

2.2 Life-cycle analysis

The renovation concept reduces the building energy use and therefore its climate impact during operation but increases the climate impact during the construction stage due to added materials, transportation, and installation work. Therefore, it is relevant to investigate the climate impact of the proposed renovation concept and what the requirements are to achieve a net-zero carbon building after renovation. There are several carbon-neutral definitions for new buildings such as "Zero Emission Buildings" by The Research Centre on Zero Emission Buildings, "Carbon Neutral Buildings" by White Arkitekter, and "NollCO₂" by The Swedish Green Building Council [11]–[13]. There is however no current definition commonly applied to renovation in Sweden.

The Swedish construction sector's Environmental Calculation Tool [14] was used for the calculations, and System Advisor Model for solar electricity production [15]. The $NollCO_2$ method from the Swedish Green Building Council was the definition of net-zero carbon building used within this renovation case-study. According to this definition, the life-cycle analysis (LCA) accounts for climate compensation measures (offsets) beyond the building's system boundary, i.e., sold electricity to the grid. As a sensitivity analysis, the LCA was also carried out without accounting for such climate compensation.

The LCA followed a commonly used approach: definition of goal and scope; inventory; calculation of climate impact; interpretation of results [16]. Calculations were based on global warming potential accounting only for CO_2 emissions following the standard EN 15978 that describes the life cycle stages of a building. According to the carbon neutral definition by $NollCO_2$, module C "end of life" and module D "impacts outside the system boundary" are excluded from the analysis. Furthermore, water use was excluded from the LCA, and it was assumed that no additional renovation was needed within the analysed time-period 2020-2050. Other relevant assumptions within LCA are the following:

- A1-A3: Environmental Performance Declarations (EPD) for each material were accessed by the national database included in the Swedish construction sector's Environmental Calculation Tool [14]. No EPD was available for the specially designed ventilation system with supply air ducts within the prefabricated façade elements and the air handling unit (heat exchanger). Its global warming potential was estimated based on the weight of all materials of the ventilation system: length of ventilation ducts, number of elbows and joints, air diffusers and air handling unit [6].
- Stage A4: default transport scenarios for materials in Sweden ranging between 150-400 km by diesel truck and 40 km from local distributor to construction site, depending on the material;
- Stage A5: generic data for "site operations" for new buildings within the Nordic countries including soil waste, construction wood waste, metal waste, other construction waste, diesel and electricity use on-site. Since such activities are significantly less extensive within renovation, it was assumed that 25% of the generic data value would be reasonable. Most probably, such an assumption is still over-dimensioned [17].

The most relevant consideration that stands out from this LCA is the assumption by the $NollCO_2$ method that excess solar electricity delivered to the electric grid compensates (offsets) the climate impact of the building's life cycle. The climate impact of delivering renewable electricity to Nordpool's Nordic electricity market is considered equivalent to the avoided greenhouse gas emissions (GHG) of fossil electricity production that are part of the market's electricity mix. As part of the $NollCO_2$ method, it is considered that solar electricity can be purchased at a lower price than the most expensive electricity in the market, which is coal power. Solar electricity is therefore sold instead of coal power in Nordpool. Coal power was produced during all hours of 2019 and could therefore always be replaced by solar power produced along the year. While it can be debatable whether this may always be the case in the future, statistics show that it was the case during 2019. According to $NollCO_2$, this also means that the climate compensation value of renewable electricity in Nordpool can be always considered the same during the whole year since coal power is always being replaced, and an average value during the year can be used. The estimated CO_2 intensity from electricity supply technologies of coal power from IPCC (2014) was 820 gCO_2e/kWh (Table A.III.2 [18]). The estimated life cycle-based CO_2 intensity of solar power production was 41 gCO_2e/kWh (Table A.III.2 [18]). This means the climate compensation effect of delivering solar electricity to the grid is the difference between those two values: -779 gCO_2e/kWh (Table 1). This is a key-aspect for this analysis.

Another important assumption is the period of validity. According to EU's Green Deal, Europe should be climate neutral by 2050. Therefore, $NollCO_2$ assumes all climate impact of energy use to be reduced linearly until then. $NollCO_2$ methodology was created to be implemented in new buildings. Within this project, it was investigated the impact of such methodology in a renovation case study.

Solar electricity production and property electricity energy use were estimated hourly using the System Advisor Model [15] and IDA-ICE [10], respectively. This made it possible to investigate the annual percentage of solar electricity production consumed on-site (avoids climate impact of electricity use) and delivered to the grid (climate compensation).

Table 1. Global warming potential of energy use during operation, installation of photovoltaics, and climate compensation of solar electricity sold to the grid.

Inputs	NollCO2 methodology
District heating (gCO2e/kWh)	60 [19]
Electricity use (gCO2e/kWh)	22 [19]
Installation of photovoltaics (gCO2e/kWh)	41 [18]
Climate compensation of solar electricity delivered to the grid (gCO2e/kWh)	-779 [19]

3. RESULTS

The LCA results show that, when climate compensation measures are considered according to the $NollCO_2$ method from the Swedish Green Building Council, it is possible to achieve a net-zero carbon building by implementing the proposed renovation concept with photovoltaics on the roof of the case-study building. When climate compensation measures - as defined in $NollCO_2$ - are not considered at all, the goal of net-zero carbon emissions was not reached. Even without photovoltaics, the accumulated global warming potential of the renovated building was significantly reduced by 50% compared to not carrying out any energy renovation at all. Without accounting for climate compensation measures, the climate impact after renovation including the installation of photovoltaics was reduced by 44%. The renovation and installation of photovoltaics increase the climate impact of the building during the product and construction stages (A1-A5.1) with approximately 10 $kgCO_2e/m^2$ but contribute to decrease the environmental impact during operation by -143 $kgCO_{2e}/m^2$. These results are illustrated in Table 2 and Figure 4.

The fraction of annual solar electricity production estimated to be consumed on-site was 23% and its climate impact was accounted for by avoided emissions from the Swedish electricity mix. The climate impact of the remaining 77% was either disregarded or accounted for as climate compensation measures replacing coal production in the electricity market. The photovoltaic installation was optimized regarding its tilt from horizontal, azimuth, and ground coverage ratio. Its size was determined to offset the accumulated climate impact of the building resulting in net-zero carbon during the study period. The total occupied roof area was roughly 68%, with a ground coverage ratio of the solar cells of 50%. Table 3 describes the PV design parameters.

Regarding the production stage, the distribution of A1-A5.1 are illustrated in Figure 5. Photovoltaics contribute to the second largest share of carbon emissions, 35% of total within A1-A5.1.

Table 2. LCA results for the several investigated scenarios.

Cumulative climate impact by year 2050	($kgCO2e/m^2/y$)
Without energy renovation measures	143
With energy renovation measures without PV	71
With energy renovation measures with PV	0
With energy renovation measures with PV but no compensation	80

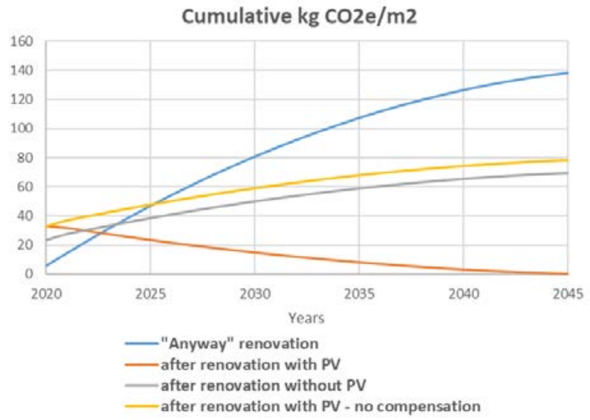


Figure 4. Cumulative emissions accounting for climate compensation measures according to NollCO2 assumptions.

Table 3. Design parameters of the PV system.

Parameter PV design	Value
Tilt (°)	35
Self-shading between rows	Yes
Production (kWh/kWp/y)	890
Total peak power (kWp)	81
Fraction of occupied roof area (%)	68
PV cell area (m^2)	395
Ground coverage ratio	0.5

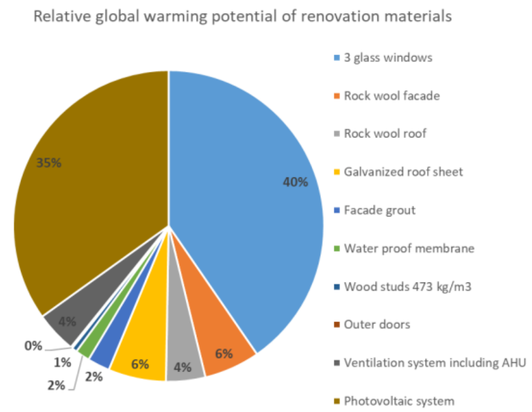


Figure 5. Relative global warming potential of renovation materials in stage A1-A5.1.

4. DISCUSSION

There is currently no definition of net-zero carbon building renovation. Therefore, an existing definition for new buildings was used. NollCO_2 methodology was therefore adapted to this renovation case-study which means that not all criteria were used, such as limits for A1-A3 categories. It is important to point out that the NollCO_2 assumption that excess solar electricity sent to the grid is accounted for with climate compensation for replacing coal is determinant to the results. This greatly favours maximizing the installation of photovoltaics and excess in production since the climate compensation is high. Interestingly, this is normally contrary to cost-effective design of PV systems in Sweden where exceeding self-consumption is counterproductive to profitability.

Considering the Swedish electricity mix, PV does not offset its own GWP when no climate compensation is awarded for excess production sent to the grid. The conclusion would change if: the climate impact of the electricity mix is higher; the level of self-consumption increases; the assumed climate impact of PV is lower, such as *green PV* produced in Europe.

The design of the renovation concept to reach a net-zero carbon building is significantly dependent on the definition of carbon neutrality that is used. NollCO_2 methodology favours the use of PV but does not account for biogenic carbon, for example. Other definitions based on different criteria would probably influence the proposed renovation design, especially regarding building materials, which illustrates the relevance of the choice of the definition.

5. CONCLUSION

This paper describes an energy renovation concept for existing multi-family buildings towards carbon neutrality. The concept was theoretically investigated in a case-study in Sweden focusing on the life cycle analysis (LCA).

LCA results showed that it is possible to reach a net-zero carbon building after renovation and according to the carbon neutral definition that was used. One important requirement is that climate compensation for excess solar electricity sent to the grid needs to be accounted for. The definition that was used greatly benefits large PV installations for overproduction and consequent electricity delivery to the electric grid. According to the definition, this implies a strong positive environmental impact in the LCA since coal electricity production is replaced by renewable electricity. Even for this case-study consisting of a high-rise multi-family building with limited roof space, there was enough roof space for the required PV to reach net-zero carbon. Integrating PV in the façade modules with lower annual performance was therefore not required.

The decrease of the environmental impact during operation due to the renovation far exceeds the added climate impact during the construction stage. Without photovoltaics, the accumulated global warming potential of the renovated building was significantly reduced by 50% compared to not carrying out any energy renovation at all, from 143 to 71 kgCO_2e/m^2/y. This points out the climate benefits of energy renovations, which are in line with previous studies.

Future work includes the need of a definition for energy renovations that leads to net-zero carbon buildings. In addition, a full-scale demonstration of the renovation concept is recommended as a next step.

ACKNOWLEDGEMENTS

This study was funded by The Swedish Energy Agency under the grant number 2020-004162.

Åsa Wahlström and Karin Farsäter at Lund University are acknowledged for the technical contributes to the LCA calculation.

REFERENCES

[1] 'Viable Cities', Viable Cities, Sep. 2021. https://en.viablecities.se (accessed Feb. 16, 2020).

[2] N. Brelih, 'IEA ECBCS Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings', Build Up, Apr. 11, 2012. https://www.buildup.eu/en/explore/links/iea-ecbcs-annex-50-prefabricated-systems-low-energy-renovation-residential-buildings (accessed Feb. 16, 2020).

[3] A. Fytrou-Moschopoulou, 'RetroKit project', Build Up, Aug. 07, 2017. https://www.buildup.eu/en/explore/links/retrokit-project-0 (accessed Sep. 20, 2021).

[4] 'Final Report Summary - RETROKIT (RetroKit - Toolboxes for systemic retrofitting) | FP7 | CORDIS | European Commission'. https://cordis.europa.eu/project/id/314229/reporting (accessed Sep. 20, 2021).

[5] 'E2REBUILD | Smartcities Information System'. https://smartcities-infosystem.eu/sites-projects/projects/e2rebuild (accessed Feb. 16, 2020).

[6] A. Hadzimuratovic and M. Swedmark, 'Study of active technologies for prefabricated multi-active facade elements for energy renovation of multi-family buildings', 2016, Accessed: Sep. 29, 2021. [Online]. Available: http://lup.lub.lu.se/student-papers/record/8884169

[7] S. Gosztonyi, M. Stefanowicz, R. Bernardo, and Å. Blomsterberg, 'Multi-active façade for Swedish multi-family homes renovation: Evaluating the potentials of passive design measures', Journal of Facade Design and Engineering, vol. 5, no. 1, pp. 7–22, 2017, doi: 10.7480/jfde.2017.1.1425.

[8] R. Sundling, S. Olander, P. Wallentén, S. Burke, R. Bernardo, and Å. Blomsterberg, 'Lifecycle profit analysis of prefabricated multi-active façades', International Journal of Building Pathology and Adaptation, vol. 37, no. 5, pp. 565–578, Jan. 2019, doi: 10.1108/IJBPA-12-2018-0109.

[9] C. Liljenström et al., 'Byggandets klimatpåverkan - Livscykelberäkning av klimatpåverkan och energianvändning för ett nyproducerat energieffektivt flerbostadshus i betong', Svenska Miljöinstitutet, NR B 2217, 2015. [Online]. Available: https://www.ivl.se/download/18.343dc99d14e8bb0f58b76c4/1445517730807/B2217_ME.pdf

[10] 'IDA ICE - Simulation Software | EQUA'. https://www.equa.se/en/ida-ice (accessed Apr. 12, 2022).

[11] 'ZEB Definitions'. http://www.zeb.no/index.php/en/about-zeb/zeb-definitions (accessed Apr. 12, 2022).

[12] 'Carbon Neutral Buildings – Creating Value Through Architecture', White Arkitekter. https://whitearkitekter.com/carbon-neutral-buildings-creating-value-through-architecture/ (accessed Apr. 12, 2022).

[13] 'NollCO2', Sweden Green Building Council. https://www.sgbc.se/certifiering/nollco2/ (accessed Apr. 12, 2022).

[14] 'Byggsektorns miljöberäkningsverktyg'. https://www.ivl.se/projektwebbar/byggsektorns-miljoberakningsverktyg.html (accessed Apr. 12, 2022).

[15] 'Home - System Advisor Model (SAM)'. https://sam.nrel.gov/ (accessed Sep. 22, 2021).

[16] 'Så här görs en LCA', Boverket. https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/livscykelanalys/sahar-gors-en-lca/ (accessed Sep. 21, 2021).

[17] 'World's fastest Building Life Cycle Assessment software - One Click LCA'. https://www.oneclicklca.com/ (accessed Apr. 12, 2022).

[18] Intergovernmental Panel on Climate Change, Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2014. doi: 10.1017/CBO9781107415416.

[19] 'Manualer och ramverk för NollCO2', Sweden Green Building Council. https://www.sgbc.se/certifiering/nollco2/anvandarstod-for-nollco2/manualer-och-ramverk-for-nollco2/ (accessed Sep. 22, 2021).

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 01
14:15 — 15:45

CHAIR
CAROLINA GANEM

PAPERS
1306 / 1493 / 1356 / 1260 / 1323

8TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Potentials of passive housing design in emerging countries with Mediterranean climate

Latest results and design recommendations for Central Chile

ERNST MÜLLER[1]

[1]University of Kassel (Germany), School of Architecture
(Fachbereich Architektur, Stadtplanung, Landschaftsplanung); ernstm@uni-kassel.de / Mueller.Ernst@gmail.com

ABSTRACT: Latin American emerging countries like Chile with their growing economy and energy use present new challenges for ecological and social sustainability. Sustainable passive and solar housing, including passive cooling and passive solar heating, is a promising strategy to improve thermal comfort in the Mediterranean climate of Central Chile with its hot and dry summers and cool, but relatively sunny winters. The evaluation of thermal building behaviour is based on extended parametric studies with a test year for Central Chile, prepared with an own methodology. Hourly thermal simulations were realized for a reference room and complete houses. Correlations between thermal simulations and adapted building code calculations were established and crucial building parameters identified. Analysis permitted systematic design recommendations for building elements and passive houses in a Mediterranean climate. The latest results and design proposals for simple and advanced passive houses show that it's possible to significantly improve the thermal comfort conditions in economically accessible dwellings with locally viable technology. Passive design proposals really present an interesting long-term strategy for sustainable housing based on solar energy. The approach of advanced research methods to develop simple flexible concepts is extendable to other Latin and emerging countries and thus can contribute to sustainable development.
KEYWORDS: solar architecture, passive design, thermal comfort, thermal simulation, sustainable building

1. INTRODUCTION

Latin American emerging countries like Chile with their growing population, economy and energy use present new challenges for ecological and social sustainability. Worldwide noticeable climate change makes this an even more urgent task. Sustainable passive and solar housing, including passive cooling and passive solar heating here, is a promising strategy to improve thermal comfort in the Mediterranean climate of Central Chile in the southern hemisphere with its hot and dry summers and cool, but relatively sunny winters. German style "Passive Houses", meaning extremely low energy consumption in a moderate to cold climate zone there, with high tech solutions including automated computational control of effective heating and heat recovery systems, ventilation and shading in sealed houses with extreme levels of insulation on all external surfaces, would hardly be viable in Chile, other Latin American or poorer European Mediterranean countries in the foreseeable future for cultural (e.g. combined indoor-outdoor living style) and economic reasons combined with the technical and economic problems of maintenance.

Some interesting work on the "next steps" of thermal improvement, especially for social housing in Chile, exists (e.g. [1], [2]). The objective of this research is to go much further with a systematic evaluation on how far you can advance with a long-term passive design strategy and which level of thermal design improvements and technology will be necessary for thermal comfort. The potentials of passive design need to be analyzed comparing the efficiency of potentially conflicting strategies to resolve comfort problems with heat and cold.

The latest results of the author's participation in an international scientific cooperation and the research for his PhD-thesis will offer some answers.

2. METHODOLOGY

The solutions for sustainable passive housing depend on the specific climatic, social and economical conditions of the target group and region. Accordingly, the investigation was based on the concept of applying advanced methods of research in order to develop simple and flexible concepts and tools for the design of passive houses, which can be easily adapted for the implementation under varying conditions later.

The evaluation of thermal building behaviour is based on extensive parametric studies on "passive" housing design, i.e. without non-renewable energy use for thermal purposes. The thermal simulations were realized with a test year for Central Chile with methodology [3] where original hourly climate data for Santiago de Chile were combined according to monthly mean reference values.

The evaluation of thermal building behaviour is now based on a significantly increased number of simulations (in comparison to [5]) for extensive parametric studies with the thermal simulation program DEROB-LTH, both for a reference room (>1100 cases) and for complete (passive) houses (>100 houses). Mean daily degree-hours of heat Gh26o (max. comfort level 26°C) for the hot period (December - February) and mean daily degree-hours of cold Gh19o (min. comfort level 19°C) for the cold period (May - September) could be calculated in (Kh/d) from simulation results of hourly interior operative temperatures. Therefore, in comparison to previous versions, an extended range of building elements, passive climatization strategies and building parameters can be combined and analyzed to propose optimized design strategies and recommendations.

Parallel to the thermal simulations, classic building code calculations were adapted and applied: simple building characteristics were calculated according to (German versions of) ISO or European building codes ([4] and related ones); necessary characteristic values and correction factors were determined with special thermal simulations; special simple models for passive design aspects, which are not considered in the building codes (e.g. night ventilation), were established. This way, the calculation methods originally created for the description of thermal behaviour in winter and the determination of energy needs were adapted for the new climate zone and extended to identify and determine size independent crucial building parameters for passive and solar houses with free-floating temperatures in the cold and hot period here: gains-to-loss ratio GL (dimensionless); time constant τ (tau) (h); utilization factor η (eta) (dimensionless). Helpfully, these also permit a better understanding of design optimization for mathematically minded designers, engineers and building physicists. As PLEA has a mainly architectural focus, I will concentrate my analysis here on building elements and thermal management like shading and ventilation options.

3. RESULTS

3.1 Simulations with a reference room

Each data point in examples (Fig. 1) and (Fig. 2) represents the thermal characteristics of a reference room considering its construction and thermal management (shading and ventilation). The correlation functions for the hot and cold period connect the building code calculations for each case from simulation.

The "excess-gains-to-loss ratio" GL_{exc} for the hot period ("summer") calculates the relative size of heat gains that are harmful to thermal comfort compared to thermal losses; it should be as low as possible.

(Fig. 1) shows very good correlation and proves that good to perfect comfort conditions can be obtained with a large spectrum of designs (lower left corner), but a large time constant alone (in well insulated, heavy designs) is not sufficient. A combination with a small GL_{exc} from effective shading and appropriate ventilation is essential for summer comfort.

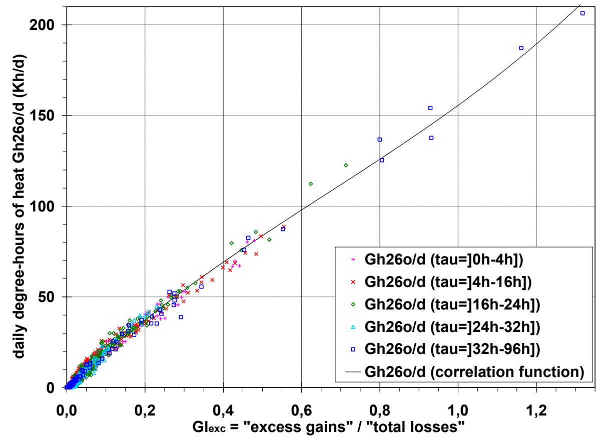


Figure 1: Correlation for hot period (December - February) indicating range of time constant tau

The "effective-gains-to-loss ratio" GL_{eff} for the cold period ("winter") calculates the relative size of heat gains that are useful for thermal comfort compared to thermal losses; it should be as close as possible to 1.

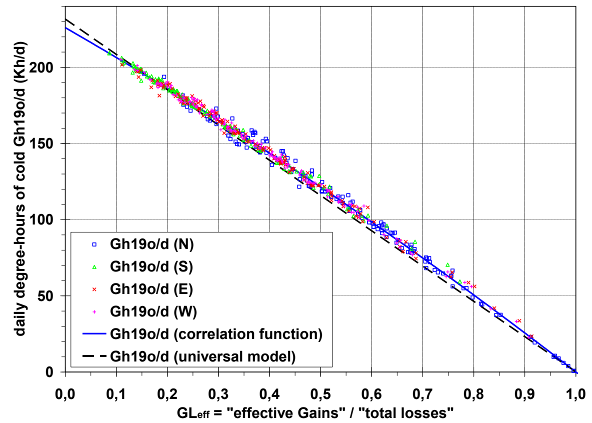


Figure 2: Correlation for cold period (May - September) indicating main window orientation N-S-E-W

(Fig. 2) shows very good correlation and proves that good to perfect comfort conditions can be obtained only with a small subset of designs with: northern orientation of main windows to the sun, very low heat losses and optimized solar gains, effectively used through high thermal capacity and large time constant.

A second "universal model" is included in (Fig. 2): it shows an interesting linear connection (with slightly reduced correlation) between the daily degree-hours of cold for the outside air in the cold period (231.6Kh/d for $GL_{eff} = 0$), i.e. the climate, and obvious Gh19o/d = 0 for $GL_{eff} = 1$ (for mathematical reasons), so that it could easily be drawn for similar climate zones or considering some climate change in the future.

Additionally these simulation results allowed extending the analysis of design parameters as in [5] for the hottest and coldest months, now for hot and cold periods with a wider range of design options. In the following figures some new examples are presented:

The efficiency of passive cooling strategies is shown and analyzed in (Fig. 3), depending on construction type and respective thermal mass (mean value for North and East orientation as West is very similar and South of little relevance for problems in summer): the curves show the process of improving the design from low to optimized thermal quality for different basic building types.

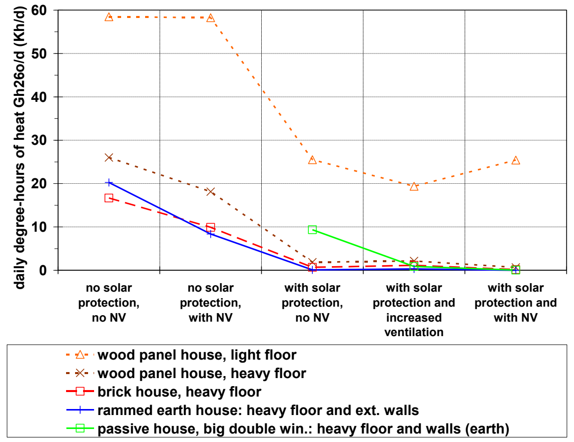


Figure 3: Efficiency of passive cooling strategies, depending on construction and thermal mass, mean value for North and East orientation; for hot period (December - February)

Wood panel houses with a wooden floor and only minimal 80mm of ceiling insulation, typical for economic constructions in Chile or even better than older ones, present the highest levels of thermal comfort problems in summer for all variants as they lack thermal capacity, so that night ventilation (NV) does not work; solar protection with simple curtains however can improve thermal comfort even in this case. The addition of thermal capacity with a heavy floor for the light house or even more with heavy walls of brick or rammed earth results in significant thermal improvement for all variants and makes night ventilation an efficient strategy because night temperatures are low in the dry summer of this climate zone. Thermal mass combined with adequate ventilation and shading can resolve summer comfort problems here without any expensive high tech equipment or materials.

Thermal comfort conditions in winter present more demanding problems: the efficiency of increased direct solar gains as the simplest design strategy for the cold period is shown in (Fig. 4) and (Fig. 5). Northern orientation of direct gain windows offers the best potential due to the better availability of solar radiation (see Fig. 2).

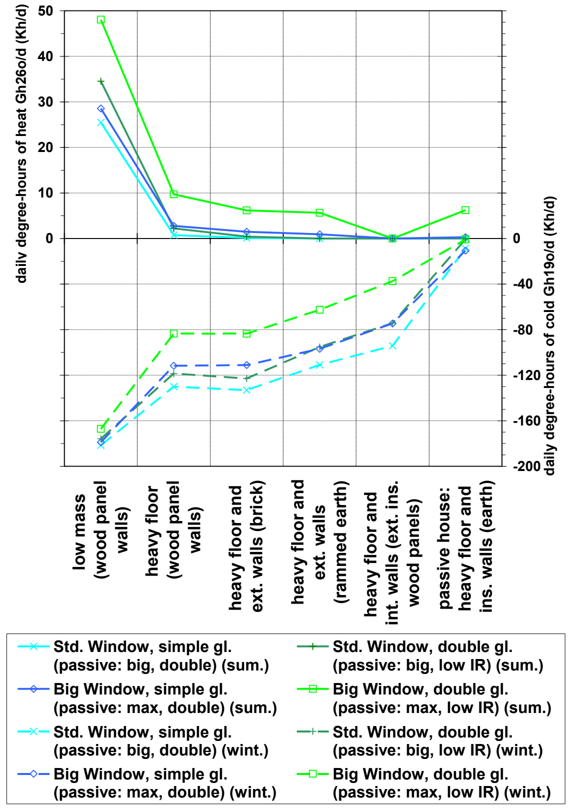


Figure 4: Efficiency of increased direct solar gains for different N window types and depending on thermal mass; for hot (December – February, "summer") and cold period (May – September, "winter")

Insulation levels in (Fig. 4) are basic and limited to a ceiling insulation of 80mm except 150mm for the passive proposal, 70mm for insulated wood panel walls and 100mm for the passive proposal walls of rammed earth. Thermal mass is increased step by step as indicated. Just as in summer, you get the worst problems in winter by a large margin without thermal mass and no matter how big or good windows are; even big double glazed windows are practically useless. With thermal mass from a heavy floor and eventually heavy walls you are rewarded with considerably reduced thermal problems in summer and winter. Now the improvements of window size and quality have a considerable positive effect on thermal comfort in winter; however, big resp. max. windows with low thermal losses can cause problems in summer if they are not compensated by further improved solar protection. The passive proposals with high thermal mass and improved insulation levels are good and big (not max.) low IR emissivity windows are best for summer and winter comfort combined, but the difference in winter to cheaper, big or max. size, double glazed windows is small.

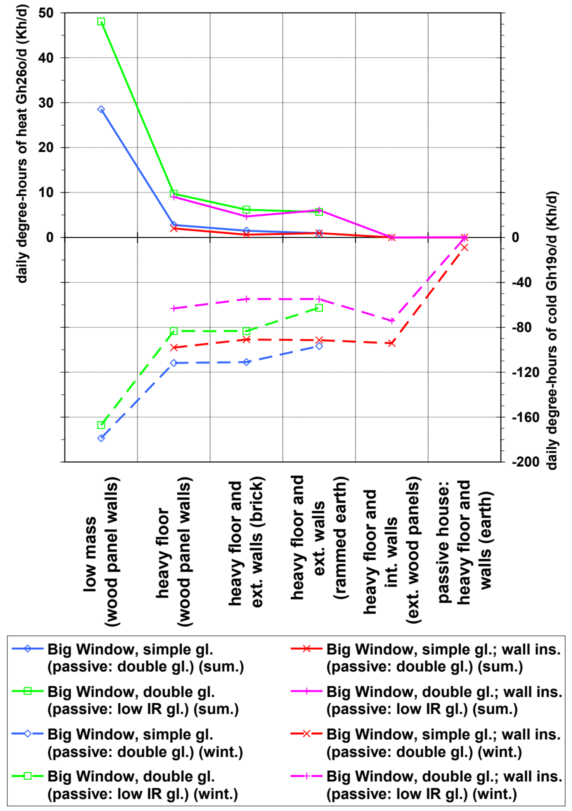


Figure 5: Efficiency of increased direct solar gains for big N window of different types (glazing) with improved wall insulation and depending on thermal mass; for hot (December – February, "summer") and cold period (May – September, "winter")

Based on these results, (Fig. 5) considers only design options with (just) big windows for direct solar gain and insulated walls for reduced thermal losses in winter: thermal comfort still varies widely with thermal mass and window quality. Where indicated for the series, wall insulation for wood panels is 70mm, for rammed earth 26mm and 100mm for the rammed earth walls of the passive proposals. The thermal behaviour in summer follows the already shown importance of thermal capacity and - to a minor degree - simple glazed windows show less problems than double glazed ones; with heavy floors and insulated / heavy walls thermal problems in summer disappear. Comparing the winter series, the positive effect of reduced thermal losses in the sequence "simple window > simple window with wall insulation > improved window (without insulation) > improved window with wall insulation" is clearly shown. Here, "simple window" means simple glazing for all design alternatives except passive with double glazing; "improved window" means double glazing for all design alternatives except passive with low IR emissivity glazing. Moreover it's clearly shown that in winter improved windows are more important and efficient than additional wall insulation because they present the surfaces with highest losses; the combination of both is obviously the best design proposal. These priorities remain valid for all the materials and thermal mass alternatives considered here.

It is important to resume that simple and still affordable passive proposals can resolve thermal problems, both in summer with efficient night ventilation and solar protection and in winter with minimized heat losses and direct solar gains.

3.2 Simulations and comparison of design options for complete houses and their thermal behaviour

Another series of hourly thermal simulations was realized and comfort conditions were analyzed for complete houses, considering the most interesting parameter combinations ranging from conventional "normal" designs to thermally improved and passive design proposals with varying strategies in (Fig. 10) and (Fig. 11).

The design graphs of the house were generated directly with the simulation program and show its geometric model in (Fig. 6) to (Fig. 9) for the latitude, date and hour indicated in the graph (15th of July representing the coldest month), seen from the sun's position (orange/red: walls and floor seen from inside/outside, blue: windows, yellow: shading elements including shading effect of thick walls made of rammed earth - at least 430mm thick depending on external insulation with the windows in the centre). Roof surfaces are not shown, so that the interior distribution of rooms and windows on the opposite side of the house remain visible.

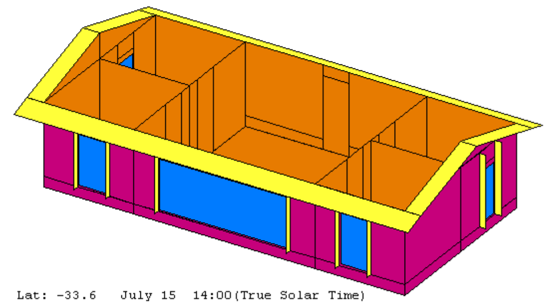


Figure 6: Standard rammed earth house with shading (always shown here without roof from sun's position, front: north side; representing coldest month)

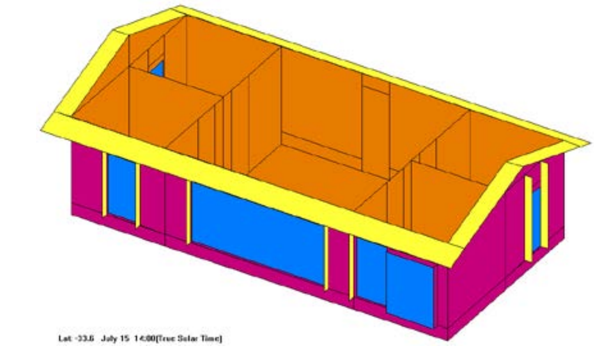


Figure 7: Passive house, rammed earth with shading: with Trombe wall on right side for bedroom

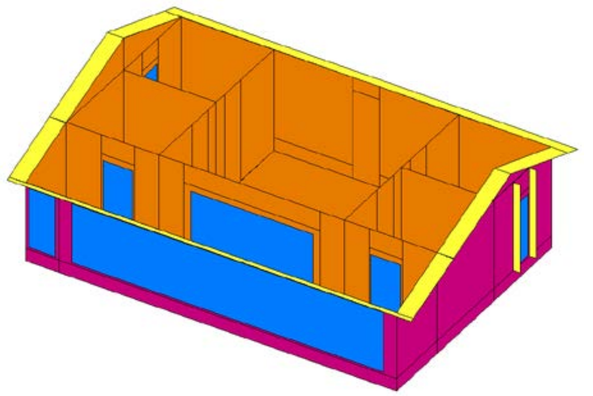


Figure 8: Passive house, rammed earth with shading: with winter garden in front on the north side

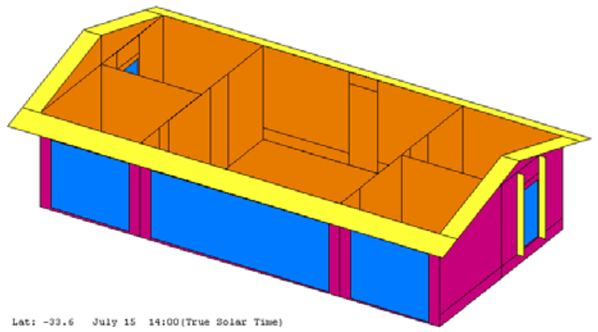


Figure 9: Passive house, rammed earth with shading: optimized for direct solar gains in winter

The simulation results presented in (Fig. 10) and (Fig. 11) are for the living room (the big centre one) and the bedroom in front seen on the right side; both have windows on the same main façade with its orientation as indicated for the houses.

(Fig. 10) offers an overview of the range of design options and proposals in four groups (separated by green bars):

Conventional "normal" designs with arbitrary orientation (as usual in Chilean reality) and no fixed shading present heavy thermal comfort problems both in the hot and cold period: the first group of light houses presents the worst problems in summer, the second with brick walls improves summer problems a bit due to thermal capacity, but maintains severe thermal comfort problems in winter. Due to their lack of shading and proper ventilation strategies and excessive heat losses in winter these serve as a reference and starting point for the following improvements.

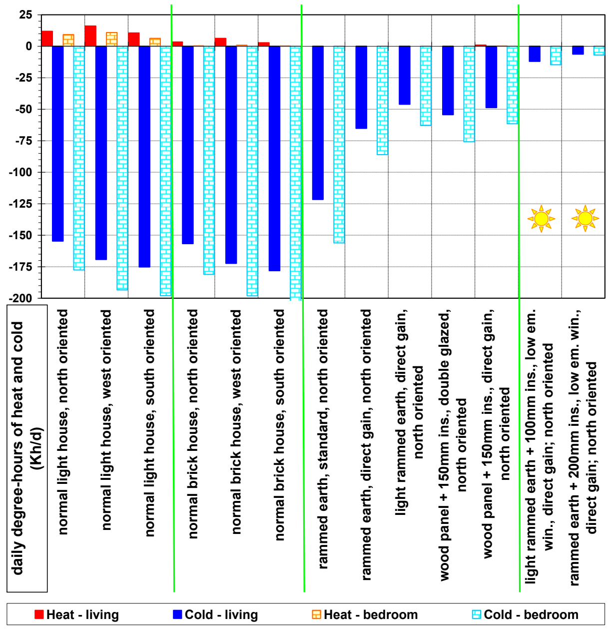


Figure 10: Thermal quality of normal, improved and passive houses: for hot (>0) and cold period (<0)

Simple design modifications for different basic construction materials in the third, improved group with better thermal capacity, proper north orientation and fixed / mobile solar protection can resolve summer problems. Comfort conditions in winter can be improved with reduced heat losses and increased solar gains combined with proper orientation and thermal capacity.

Finally, passive design options with perfect conditions in summer and practically perfect conditions in winter are proposed. They are based on optimized thermal insulation in walls, roof and windows combined with efficiently used direct solar gains.

(Fig. 11) permits analyzing the efficiency of different solar gain strategies for light and heavy houses: all improved wood panel houses (except the normal one) in the first group have 150mm wall and ceiling insulation, heavy interior walls and floor, night ventilation (NV) as indicated and advancing improvements from left to right, but only double glazing has a considerable effect, whereas increases in solar gains from an attached winter garden or bigger "direct gain" windows have little additional effect due to a still lacking thermal capacity. This deficiency is underscored by small indications of overheating in summer for direct gain here.

The two groups with earth walls and no additional wall insulation (!) show the effectiveness of direct solar gains in these simple solar houses, where "light rammed earth" maintains a very high thermal capacity but improves on heat losses with its lower density material.

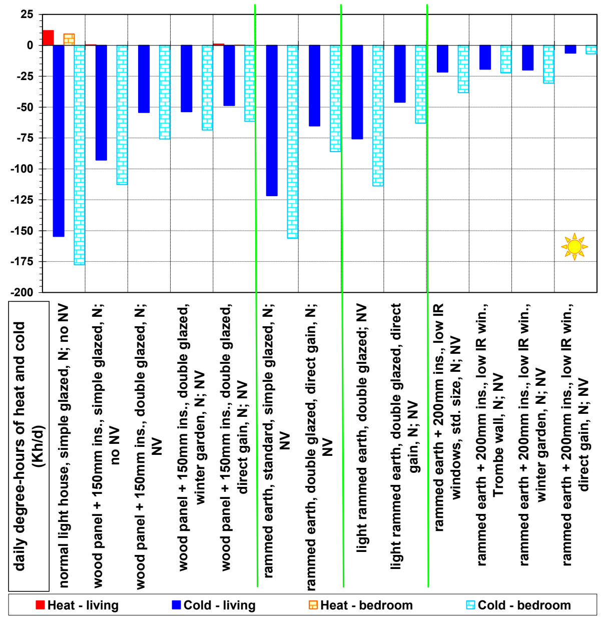


Figure 11: Efficiency of solar gain strategies for light and heavy houses: normal to passive/solar for hot period (>0) and cold period (<0)

The last group with earth walls plus 200mm of external insulation and high quality, low IR emissivity windows shows the positive effect of minimized heat losses in winter. High thermal capacity permits efficient use of solar gains from a Trombe wall or an attached winter garden, but direct solar gains clearly represent the most efficient strategy and at the same time the simplest design proposal for a comfortable passive house.

3.3 Challenges and possibilities for dissemination

Sustainability in the housing sector has three main and equally important dimensions:

- ecologic sustainability: energy efficiency and use of renewable energies, low emissions, but also low-impact building materials;
- economic sustainability: cost of construction, maintenance and energy, local economic development; and - often neglected -
- social sustainability: effective access and participation for all people, not only the (economically) privileged.

All design proposals are technologically viable for Chile and other countries of comparable economic level, but - intentionally - many improved and all passive design proposals go beyond the "next step" of thermal improvement and development in the housing sector as discussed for example in [1] and [2]. A strategy for the dissemination and effective implementation of these innovative proposals still requires a lot of effort for investigation, constructive improvements, extension of design proposals to other regional climate zones and pilot projects etc. but also inclusion in university curricula in engineering, architecture and building physics. Another important element will be "extension" in the sense of the Latin American university concept, meaning information and training ('capacitación' in Spanish) offered and directed to people and organizations beyond the universities for the benefit of the society as a whole. This will be essential to create, improve and organize the economic, legal and social conditions for dissemination.

4. CONCLUSIONS

The analysis here offers clear priorities and long-time perspectives for thermal improvement with passive strategies. The detailed design proposals for simple and advanced solar and passive houses prove that it is possible to improve significantly the thermal comfort conditions in economically accessible dwellings with locally viable technologies in a Mediterranean climate. The methodological approach of advanced research to develop simple and flexible design concepts is extendable to other regions, contributing to sustainable development.

ACKNOWLEDGEMENTS

The initial phase of this investigation was possible thanks to the participation in an international research project at Kassel University with financing from German DFG and GTZ. The original hourly climate data for Santiago were obtained thanks to the cooperation of the National Centre for the Environment CENMA from measurements of the National Environmental Commission CONAMA, both in Santiago de Chile. The thermal simulation program DEROB-LTH could be used thanks to the cooperation with Lund University (Sweden) for the author's PhD.

REFERENCES

1. Bustamante, Waldo et. al., (2009). Eficiencia energética en vivienda social: un desafío posible. In *Camino al Bicentenario Propuestas para Chile*.
2. Bustamante, Waldo, (2009). Guía de Diseño para la Eficiencia Energética en la Vivienda Social; Ministerio de Vivienda y Urbanismo, Santiago de Chile, 2009.
3. Müller, Ernst, (2001). Development of a Test Reference Year on a Limited Data Base for Simulations on Passive Heating and Cooling in Chile, *Building Simulation 2001*, Rio de Janeiro.
4. E DIN EN ISO 13790, 1999. Thermal performance of buildings - Calculation of energy use for heating (ISO/DIS 13790: 1999); German version prEN 13790: 1999.
5. Müller, Ernst, (2002). Manual de diseño para viviendas con climatización pasiva, *Building Research Institute, University of Kassel*. (Manual for the design of passive houses; in Spanish)

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA 2022 SANTIAGO
Will Cities Survive?

Passive design optimization towards Nearly Zero Energy building requirements

Operational performance of a low energy office building in a continental semi-arid climate.

MICAELA D'AMANZO [1], SOLEDAD ANDREONI, VIRGINIA MONTIEL [1], ALICIA BETMAN [1] AND CAROLINA GANEM [1, 2]

[1] Instituto de Ambiente, Hábitat y Energía. Consejo Nac. de Investigaciones Científicas y Técnicas INAHE – CONICET.
[2] Facultad de Artes y Diseño. Universidad Nacional de Cuyo FAD-UNCUYO.

ABSTRACT: Greenhouse gas emissions reductions in buildingsby cutting energy demand and increasing energy efficiency turns up as a possible response path to Climate Change. Nearly Net Zero Energy Buildings (nZEB) also integrate renewable energy (RE) technologies integrated in architectural design pursuing a nearly zero balance between energy demand and energy production. The present study investigates the operational performance of a low energy office building in a continental semi-arid climate, and the integration of passive and active design strategies to meet nZEB requirements. It focuses on the study of the thermal and energy performance of the building under summer conditions. Environmental measurements were performed during the year 2021. Meanwhile, ER generation data was collected. A simulation model was developed in Energy Plus software. Results show that the lack of adequate solar protections favours the overheating of the interior spaces during the hours in which the solar radiation falls directly on the façade. Regarding energy demand, there is a high consumption of electricity for the air conditioning to maintain indoor thermal comfort. The model was run improving the passive strategies of night ventilative cooling and solar protection. A consumption lower than 30 kWh/m²/year was achieved through the passive design optimization proposal meeting nZEB requirements.
KEYWORDS: nZEB, office building, passive strategies, sustainability.

1. INTRODUCTION

With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with high confidence that human-induced climate change is the main driver of these changes. Some recent hot extremes observed over the past decade would have been extremely unlikely to occur without human influence on the climate system. [1]

According with Becchio et al. (2016) concerning the building sector, greenhouse gas emissions could be reduced by around 90% by 2050 compared to 1990.And, the most immediate and cost-effective way of achieving this target is through a combination of cutting energy demand in buildings through increased energy efficiency and a wider integration of renewable technologies. [2]Regional and local studies also report reductions between that might reach 90% in theory. [3, 4] The reduction percentage varies mainly with materiality, typology and orientation, assuming an active user is operating correctly passive and active strategies integrated the building.

In the light of this situation, nearly Zero Energy Buildings (nZEB) turn up as a possible response path, especially in countries where the socio-economic context and the policy framework are not adequate for Zero Energy Buildings (ZEB).

The use of adaptive comfort models for nZEB can significantly reduce energy consumption and make it easier to achieve annual energy neutrality. [5] Previous research suggest that in continental semi dry areas, characterized by cold winters, hot summers, and a large number of clear sky days, it is necessary to adopt compromise solutions that combine blockage of the solar resource in summer with guarantee of full access in winter.[6] These climates are specially challenging because of their temperature's daily variations that can reach gaps of 20°C, especially in the mid seasons. Therefore, the need of solar radiation blockage varies several times within a single day.

Energy consumption is linked to comfort standards, considering sustainability in determining the interior climate of buildings and, consequently, preferring available low-energy solutions.[7] These requirements are met by nZEB buildings, which have a high performance in terms of energy efficiency. Also, the annual consumption of primary energy is supplied in a very significant way by energy from renewable sources, whether produced on site or nearby.

Energy consumption for heating and cooling is usually the most compromised in buildings, so the reviewed literature proposes achieving savings in nZEBs between 25% and 50%, limiting energy consumption to 30 kWh/m2/year.[8] Local research's findings show that in the case that insulation, solar protection and night ventilative cooling passive strategies were integrated to the building and used correctly, a reduction in summer energy consumption for space conditioning can be reduced from up to 60%. [3]

The present study investigates the operational performance of a low energy office building in continental semi-arid climate, and the integration of passive design strategies to meet nZEB requirements. It focuses on the study of the thermal and energy performance of the building under summer conditions.

2. METHODOLOGY

2.1 Case study.

A low energy office building has been chosen as case study due to its potential to achieve nZEB requirements. It is locatedin Godoy Cruz, Mendoza, in central-western Argentina (32º 93' South Latitude, 68º50' West Longitude and 750masl). Mendoza has adry temperate cold climate (Bwk) accordingto the Köppen-Geiger classification [9].

The monthly mean temperatures in winter are 0.8°C (min) and 15.7°C (max) and in summer 17.4°C(min) and 32.3°C (max). With large thermal daily variations, from 10°C to 20°C. Mean relative humidity in summer is 63 % and in winter is 49%. Global solar radiation according to the surface orientation in winter –July in the South Hemisphere- is 10.2 MJ/m^2 and in summer -January- is 26.1 MJ/m^2. The predominant winds are from the southwest and west with 30% of calm days within a year. Annual rainfall is approximately 200 mm.

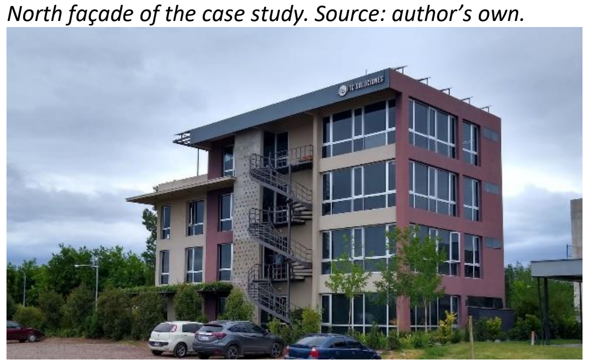
The building is located in a technological pole with medium height neighboring buildings. The built area of 1,069.57 m^2 is developed in 4 levels with a ground floor of 300 m^2. Its design integrates an efficient envelope and the production of renewable energy from photovoltaic panels on the roof, connected to the external grid. Figure 1.

The opaque envelope is composedbybrick walls (0.20m thick), a reinforced concrete (RC) structure and a thermal envelope with an insulation component. The structural RC floor slabs (0.20m thick) have interior plasterboard ceilings with glass wool insulation. Floor finishes are of *porcellanato*. The interior wallsare made of plasterboard with glass wool. Fenestration is a double 6+9+6 glazing system. The roof is made of galvanized steelwith injected polyurethane (0.05m thick).

The thermal transmittance(U) of the building envelopeelements are;

- Structural RC floor slabs = 2,27 W/m^2k
- Brickwall + EIFs = 0,43 W/m^2k
- Double glazing system= 1,96 W/m^2k

Figure 1:
North façade of the case study. Source: author's own.



2.2 Monitoring:

On-site measurements collect data allowing the quantification of the building's thermal performance. They provide information about air and surface temperatures and environmental humidity. [10]

Environmental measurements were performed during the year 2021 in summer (January), fall (April), winter (July) and spring (October). In each period of 30 days, the occupation level was registered. For this work, the summer period corresponding to the month of January was analyzed.

The indoor and outdoor thermal parameters including air temperature(°C), relative humidity (RH), and horizontal solar radiation were measured.

Horizontal solar radiation was recorded in the research center located nearby with a pyranometer KIPP & ZONEN CM5. The pyranometer is located in a roof away from shadows and horizontal obstacles and records data every minute.

Air temperature and relative humidity were recorded with 11 micro-data loggersONSET HOBO U10. They were located away from elements with mass and hung at a height of 2m from the floor. 1 data logger was placed in the exterior to measure microclimatic conditions (Figure 2); and the rest was distributed in the four floors in offices with different orientations and different plan configurations (open plan office or individual office – BOX A) to record interior temperatures Figure 3.

The interval for data collection was set at 15' and the information was processed with the HOBO ware pro and Excel programs.

Figure 2:
Exterior data logger location. Source: author's own.

Figure 3:
Interior data logger location. Source: author's own.

Note: From left to right: a- Open plan office oriented North; b- Individual office (BOX A) oriented Northwest.

2.3 RE consumption and production:

Energy consumption data of the buildingwas collected from the electricity network monthly bills.

Regarding renewable energy production on site, the building has an installation of a photovoltaic plant SMA Solar technology AG, with an installed power of 25,75 kWp.

In this case, data was collected in real time through the page www.sunnyportal.com [11].

As the building is connected to the electricity network on-grid, the local regulation establishes the injection of the generated energy directly through theinverter to the grid; and took the electricity demand through the network.Therefore,the building has installed a two-way electricity meter.

REproduction onsite accounts for the 30 % of the total annual energy consumption and equals 40 kWh/m^2.

Highly efficient equipment LG MULTI V Water IV is used to air-condition the office building. This compact water source cooling system has a lightweight outdoor unit that allows flexible installation. It also has a high efficiency inverter scroll compressor with frequency range from 15Hz to 150Hz. It improves performance with low vibration and reduced noise.

2.4 Thermal and energy simulation

A simulation model was performedin Open studio application v.2.9.1 and developed in Energy Plus v.9.2 software [12]

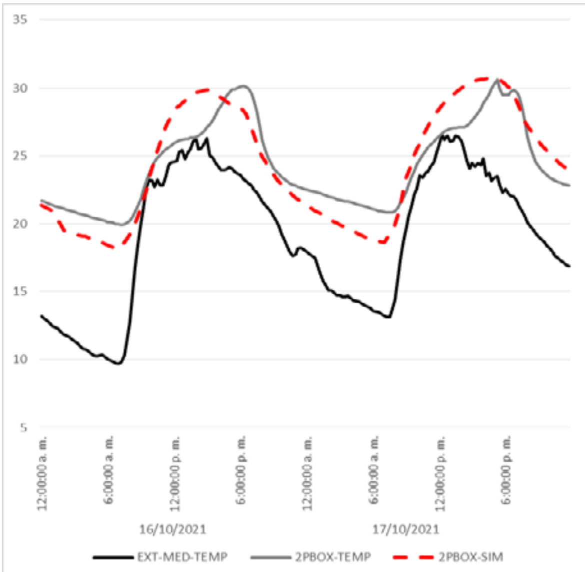
The building was divided into 25 thermal zones, distinguishing the four floors and orientations of the existing offices.In this work two interior spaces on the 2nd floor were studied: the individual office calledBOX Aoriented towards the North-West andthe open plan office of the 2nd floor. Figure 3.

A weather file was created with the following measured values: Global radiation on horizontal surface (measured with Kipp & Zonen pyranometer). Dry bulb air temperature and relative humidity (measured with Hobo data loggers).

Diffuse Radiation on horizontal surface was calculated with the Isotropic Diffuse Model.

The model was validated with onsite measurements taken in an intermediate season (spring) and non-occupied days. This allowed a high level of correspondence between the physical model and interior measures taken on site. Measured and simulated temperatures are shown in Figure 4, average temperatures adjust around 2°C. The correlation between measured and simulated data has an R^2 equal to 0.88.

Figure 4:
Model validation. Source: author's elaboration.



The actual air conditioning system was modeled as Multi-split Variable Refrigerant Flow (VRF) Air Conditioning (AC) systems with the HVAC Template module of EnergyPlus; a design coefficient of 1.2 was used for sizing HVAC through simulation of typical days for summer and winter.

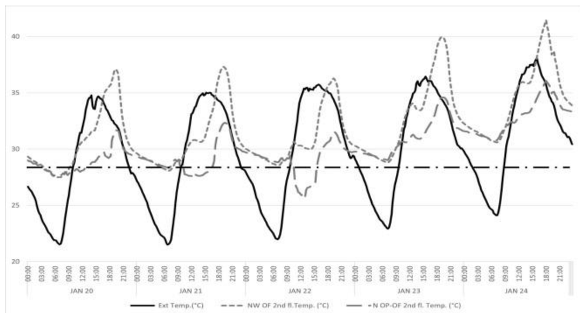
3. RESULTS

In the summer period (January for the Southern Hemisphere), offices tend to overheat. The interior temperatures equal or exceed the exterior temperature, which, together with the interior RH (around 55%), results in an uncomfortable interior environment. Therefore, it's essential the use of auxiliary energy to achieve comfortable temperatures between recommended in the ranges between18°C to 25°C for winter and 20°C to 27°C for summer.[13]

In Figure 5, the comparison between the temperatures registered outside and the temperatures registered inside is presented in a period of 5 days for the case of the individual office BOX A oriented towards the North-West and the open plan office, both located on the 2nd floor.

Figure 5 also shows the potential for nocturnal cooling that is being wastedbecausewindows are closed during the night. One of the reasons for that relates to insecurity, and also to avoid dust. It is interesting to propose an alternative solution as outdoor temperatures at night are lower than the interior ones up to 10 °C. Likewise, the lack of adequate solar protections favours the overheating of the interior spaces during the hours in which the solar radiation falls directly on the façade.

Figure 5:
In Situ measurements Source: authors' elaboration.

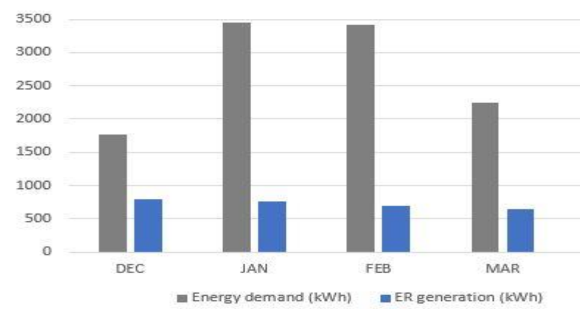


Note: Comparison between the outside temperatures (black plain) and the temperatures of the two interior spaces in the 2nd floor: theBOX A oriented towards the North-West (grey dots) and the open plan office (gray slashes)

The operation of the building is commonly called "mixed-mode", allowing users to switch on/off of the air conditioning system, depending on their comfort perception. Regarding energy demand, the building needs a high consumption of electricity to maintain indoor thermal comfort. Even though the building has its own production of electrical energy by a photovoltaic energy system, it does not cover the full requirement. Figure 6 shows the registered electrical energy demand and generation during the summer season. It is important to take into account that, even though 30% of the energy demand is covered by RE, most of the interior spaces are in uncomfortable conditions during the occupation hours.

If all spaces were in use and within the comfort parameters, the energy requirement will rise to 45 kWh/m^{2}and the energy demand covered by RE will be reduced to 20%. Therefore, it is crucial to implement passive night cooling and daytime solar control measures to reduce artificial air conditioning requirements.

Figure 6:
Electrical energy demand and generation during summer season 2020-2021. Source: author's elaboration from www.sunnyportal.com and surveys.



3.1Passive design optimization proposal

The model was run improving the passive strategies of the building. The use of night ventilative cooling, and the integration of solar protections in windows, in order to adapt the envelope to the microclimatic conditions and achieve a higher thermal and energy performance according to nZEB requirements.

Solar protection systems consist of devices integrated into the architecture that totally or partially prevent the arrival of solar radiation through opaque or translucent elements inside a space with the aim of avoiding overheating. External character designs have higher performance than internal ones.

To evaluate the efficiency of the external solar protection devices, 6 proposals were based on the solar inclination value of 82° for 12 am solar hour for the summer condition in the city of Mendoza: 3 proposals Type A: horizontal multiple overhangs and 3 proposals Type B: vertical multiple fins,were combined according to the sun protection method, shape, size, and depth. The selection was based in Cho (2014) methodology. [14] Subsequently, through the energy modeling process Energy Plus the sun protection algorithm was used, obtaining as a result the performance value of each proposed sun protection. (See figure 7 and Table 1).

Figure 7:
Study of characteristics of horizontal and vertical overhangs proposals. Source: author's elaboration.

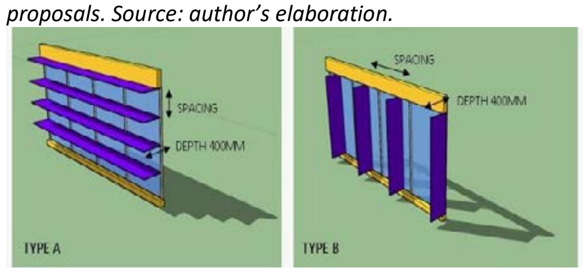
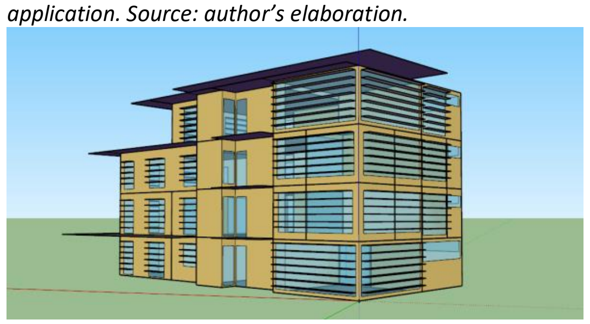


Table 1:
Comparative of outside surface windows, analyzing solar fraction run periodto theoverhangs proposals in open plan and box office located in 2nd floor. Source: author's elaboration.

EXTERNAL SHADING TYPES	BASELINE	CONFIGURATION		OUTSIDE SURFACE SOLAR FRACTION			
		DEPTH (mm)	SPACING (mm)	V2 BOX N	V1 BOX W	V3 OP N	V6 OP E
BASE				0.274	0.302	0.040	0.124
TYPE A : HORIZONTAL MULTIPLE OVERHANGS	A04	400	400	0.011	0.070	0.021	0.079
	A06	400	600	0.016	0.101	0.027	0.092
	A08	400	800	0.030	0.133	0.031	0.099
TYPE B: VERTICAL MULTIPLE FINS	B04	400	400	0.065	0.157	0.025	0.092
	B06	400	600	0.084	0.210	0.029	0.105
	B08	400	800	0.104	0.235	0.032	0.111

The characteristics of the optimal proposal consist of horizontal multiple overhangs (Type A04), with a depth of 0.40 cm, width of the window, and a spacing of 0.40 cm, located on the northeast and northwest facade of the building. See Figure 8

Figure 8:
North view overhangs optimization in Open studio application. Source: author's elaboration.



The night ventilative cooling proposal was performed by a ventilative simple model- Wind and Stack Open Area- in Energy plus software. In which the natural ventilation flow rate can be controlled by an opening schedule of the window fraction open area and through the specification of maximum and minimum temperatures. There were incorporated variables of windows opening through building management systems, cooling, and heating schedule.

Minimizing the energy demand of the building is an important step to achieve high energy performance building like nZEB. The results of the thermo-energy simulation with the improvements in the passive strategies (night ventilative cooling and solar protection) showed a decrease in temperature in the affected sectors and with more spaces with temperatures within the comfort range.

Figures 9 and 10 show the comparison between outdoor temperature and indoor temperatures of the individual office oriented towards the North-West – BOX A- and the open plan office, both in the 2nd floor.

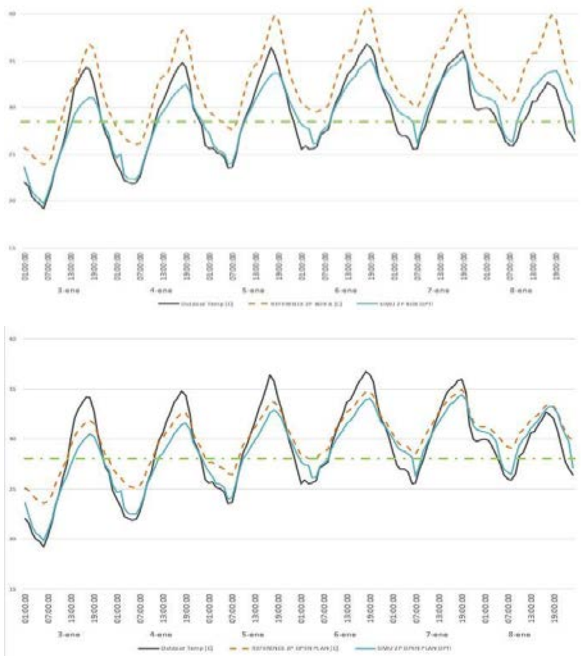
A 10°C reduction in the indoor temperature of the BOX A office is observed, which represents a lower energy requirement for cooling. See Figure 9. On the other hand, the open plan office presents a difference of 5°C below the reference building. See Figure 10.

The results of the thermal performance of the reference building are shown compared to the thermal performance after the incorporation of the proposed improvements in a free running mode. These results show the importance of the use of sun protections to the north-west, as it is the most unfavorable orientation in summer in Mendoza.

Concerning the comparison between zones in the 2nd floor, we can affirm that the lack of crossed ventilation in the individual office, BOX A, caused an inferior indoor comfort condition than the one registered in the Open plan office.

Even though interior comfort is not achieved completely by the incorporation of the proposed passive strategies, in the hypothetical situation in which all spaces were in use and within comfort parameters at the same time, the energy requirement would be reduced to 28 kWh/m^2.

Figures 9 and 10:



Note: Comparison between the outside temperatures (black plain) and the temperatures of the two interior spaces in the 2nd floor after and before optimization proposals: the Box A office oriented to the North-West and open plan office (gray slashes) Source: authors' elaboration.

4. CONCLUSIONS

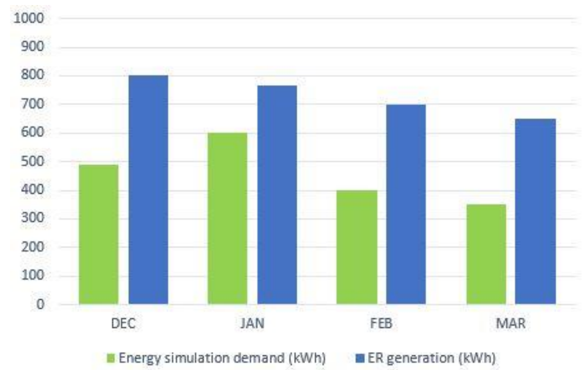
The presented paper shows the operational performance of a low energy office building in a continental semi-arid climate.

The monitoring of the thermal and energy parameters under summer conditions evidence the necessity of the optimization of the existing architecture through passive design strategies. The night ventilative cooling strategy and solar protection integration in North and West facades were proposed and evaluated.

Results are conclusive: according to the collected data, the building consumes 40 kWh/m^2. This consumption responds to a mixed-mode in which only some spaces are within comfort ranges, as they are being used. If all spaces were in comfort, consumption was estimated to rise to 45 kWh/m^2. And, if the proposed passive strategies were implemented, consumption will drastically reduce to 28 kWh/m^2, considering that all spaces are in comfort, corresponding 19 kWh/m^2 for heating and 9 kWh/m^2 for cooling.

Figure 11 shows that the inclusion of a high efficient air conditioning equipment to account for comfort in working hours, and the RE production onsite results in an optimal combination in which the building has turned from energy consumer to energy producer as it injects to the energy network more energy that it need for operating.

Figure 11:
Improved building electrical energy demand (simulated) and generation during summer season period. Source: author's elaboration.



A consumption lower than 30 kWh/m^2/year was achieved through the passive design optimization proposal meeting nZEB requirements, consequently between 60% and 80% of the energy demand will be covered by RE in summer.

ACKNOWLEDGEMENTS

Authors would like to thank the National Research Council of Argentina CONICET for founding their PhD scholarships and PIP 11220200101711CO; and to the ANPCYT – FONCYT for funding PICT 2019-2752.

REFERENCES

[1] IPCC, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf.
[2] C. Becchio, S.P. Corgnati, C. Delmastro, V. Fabi, P. Lombardi, The role of nearly-zero energy buildings in the transition towards Post-Carbon Cities, Sustain. Cities Soc. 27 (2016) 324–337. doi:10.1016/j.scs.2016.08.005.
[3] Ganem, C. (2006) Rehabilitación ambiental de la envolvente de viviendas. El caso de Mendoza. Tesis Doctoral. Barcelona: Universidad Politécnica de Cataluña.
[4] Pérez Fargallo, A., Calama Rodríguez, J. M., Flores Alés, V. (2016). Comparativa de resultados de rehabilitación energética para viviendas en función del grado de mejora. Informes de la Construcción, 68 (541):e134, doi: http://dx.doi.org/10.3989/ic.15.048.
[5] M. Piderit, F. Vivanco, G. van Moeseke, S. Attia, Net Zero Buildings—A Framework for an Integrated Policy in Chile, Sustainability. 11 (2019) 1494. doi:10.3390/su11051494.
[6] M.A. Cantón, C. Ganem, G. Barea, J.F. Llano, Courtyards as a passive strategy in semi dry areas. Assessment of summer energy and thermal conditions in a refurbished school building, Renew. Energy. 69 (2014) 437–446. doi:10.1016/j.renene.2014.03.065.
[7] J.F. Nicol, M.A. Humphreys, Adaptive thermal comfort and sustainable thermal standards for buildings, Energy Build. 34 (2002) 563–572. doi:10.1016/S0378-7788(02)00006-3.
[8] M. D'Amanzo, M.V. Mercado, C. Ganem-Karlen, 10 preguntas de los edificios energía cero: revisión del estado del arte, Rev. Hábitat Sustentable. 10 (2020) 24–41. doi:10.22320/07190700.2020.10.02.02.
[9] M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World map of the Köppen-Geiger climate classification updated, Meteorol. Zeitschrift. 15 (2006) 259–263. doi:10.1127/0941-2948/2006/0130.
[10] Centro de Investigación en Tecnologías de la Construcción, Universidad del BíoBío, Citec UBB (2012). *Manual de Diseño Pasivo y Eficiencia Energética en Edificios Públicos*. Santiago de Chile: Sociedad Impresora R&R Ltda.
[11] SMA Solar Technology AG (2022).https://www.sunnyportal.com/
[12] D.B. Crawley, L.K. Lawrie, C.O. Pedersen, F.C. Winkelmann, EnergyPlus : Energy simulation program, ASHRAE J. 42 (2000) 49–56.
[13] Givoni, Baruch. Comfort, climate analysis and building design guidelines. *Energy and buildings* 18.1 (1992): 11-23.
[14] Cho, Jinkyun, ChangwooYoo, and Yundeok Kim. "Viability of exterior shading devices for high-rise residential buildings: Case study for cooling energy saving and economic feasibility analysis." *Energy and Buildings* 82 (2014): 771-785

PLEA SANTIAGO 2022
Will Cities Survive?

Net Zero Energy Buildings

Analysis of passive strategies for building retrofits in central-southern Chile

ANDREA VALENZUELA-FLORES[1] ROXANA GUIÑEZ-VIVEROS[1] DANIEL BEDOYA-VÁSQUEZ[1] ROMINA TOLEDO-PICCARDO[1]

[1] Universidad del Bío Bío, Chile

ABSTRACT: To achieve carbon neutrality, Chile established, as its goal by 2050, that all its buildings must operate with net-zero carbon or nZEB performance. However, Chile does not have a Thermal Conditioning Standard for non-residential buildings. It only has the Standardized Terms of Reference (TDRe, in Spanish), which establish energy efficiency parameters for public buildings. The goal of this research is to evaluate three thermal envelope solutions and passive architectural design strategies, to retrofit an office building located in the city of Concepción, with the purpose of identifying envelope solutions or strategies that generate the greatest impact on the energy consumption and thermal comfort of the building, to later analyze the resulting performances with international level nZEB criteria. The results of the research indicate that passive design strategies generate a greater impact on thermal comfort and on the reduction of energy consumption than thermal envelope strategies. It is concluded that to reach the goals set out in Chile by 2050, having an Energy Efficiency and Environmental Comfort Standard applied to buildings, which includes nZEB performance criteria with a passive and active approach, is essential.
KEYWORDS: net-zero energy building, envelope performance, retrofitting, passivhaus, energy efficiency.

1. INTRODUCTION

The impact buildings have on Greenhouse Gas (GHG) emissions and energy consumption, around the world, increases by 1% to 2% every year [1]. In Chile, the building sector accounts for over 23% of total energy consumption [2].

In the COP21 – Paris Summit, an agreement was reached to speed up and intensify actions needed for a sustainable future with low carbon emissions (Di Pietro, 2017). For this, the European Union (EU) established as a goal by 2020, that all new buildings will have to be net-zero energy buildings (nZEB) [3].

In terms of GHG emissions, the Chilean policy sets the following mid and long-term goals for buildings: 2035 Goal, contributing to commitments of the COP21 National Determined Contribution (NDC), and a GHG emissions mitigation plan applied for the energy sector; and the 2050 Goal, where GHG emissions of the Chilean energy sector are coherent with limits internationally defined by science. 100% of new buildings comply with the Standards of the Organization for Economic Cooperation and Development (OECD) for efficient construction and have smart energy management and control systems [4][5].

Currently, Chile does not have obligatory Thermal Conditioning Standards for the building sector. The General Urbanism and Construction Ordinance (OGUC, in Spanish) only establishes obligatory standards for the residential sector, as such, high-performance standards for commercial or private buildings are voluntary. Although the application of Energy Efficiency Standards, such as the Standardized Terms of Reference of the Public Works Ministry (MOP) in public buildings (TDRe), energy efficiency labeling in housing, and sustainability certifications for buildings have been promoted, these measures have not been successful in the building sector due to a lack of legislative regulation [6][7][8].

Hence, it is necessary to create specific standards to increase comfort, save energy, and reduce carbon emissions generated by the construction sector. On the other hand, the current building code (TDRe) is outdated and must be aligned with the nZEB approach [9][7].

The International Energy Consumption Recommendations for nZEB in the building sector, indicate that for a climate zone that is similar to central-southern Chile, energy needs are for consumptions that range between 20 and 30 kWh/(m2/year) of net primary energy, with a primary energy use of 80-90kWh/(m2/year), normally covered by 60 kWh/(m2/year) from onsite renewable sources [10]. Piderit et al (2019), in their article "Net Zero Buildings: A framework for an integrated policy in Chile", suggest two approaches to evaluate nZEB performance in Chile, with energy efficiency goals of 15-25 kWh/m2y for buildings with a technological approach, and 15-45 kWh/m2y for buildings with a low technological or passive approach [9].

The purpose of this article is to evaluate three thermal envelope solutions and passive design strategies to retrofit an office building, in order to identify the strategies or solutions that generate the greatest impact on energy consumption and the thermal comfort of buildings.

The research was made using a warehouse-type building in the city of Concepción, where passive design strategies were added in its retrofit to turn it into offices with an nZEB approach. Experimental-type methodology was used, with energy consumption and thermal performance simulations in the DesignBuilder software.

Later, the results were compared with the recommended energy consumption for nZEB in the international building sector, to determine whether the strategies defined for the Concepción case could help in the definition of Standards for nZEB buildings in Chile, in the future.

2. METHODOLOGY

The methodology used is divided into two stages. Stage 1 is the analysis of the geometry in the site being intervened, while Stage 2 is retrofitting using passive design strategies. A case study was chosen, where the stages were analyzed under three thermal envelope solutions as independent variables. First, the local TDRe Standard as a base case, corresponding to the 6SL "Coastal South" climate area of Chile, and second, two envelope solutions that comply with the Standards of the Passivhaus European Certification System. The former corresponds to a building located in Santiago, Chile, and the latter, a building located in Bologna, Italy.

Each thermal transmittance value simulated for each surface, and its respective coding system, which is the name laid out in the graphs, was specified (Table 1).

As analysis methodology, the 3 envelope solutions were combined with the solutions' 3 glazing types, to determine the optimal combination.

Table 1: Maximum thermal transmittance (U) in W/m²K for the three thermal envelope solutions.

Solution	U Walls	U Roof	U Windows	SHGC
Solution 1 – TDRe	0.60	0.40	2.20	0.56
Solution 2 Passivhaus Chile	0.30	0.15	0.70	0.51
Solution 3 Passivhaus Bologna	0.22	0.10	0.70	0.48

The building's occupation conditions were supposed for both stages. This considers office use, based on an occupation load of 10 m²/person. Regarding use, occupation times were defined from Monday to Friday, from 7 am to 7 pm, with an occupation percentage of 100% throughout the year with the exception of February, which was considered as the holiday period, with a maximum occupation of 50%.

The loads for office equipment were supposed with a power density of 4.5 W/m² and electrical lighting with a power density of 15 W/m².

The ventilation flows indicated in ASHRAE 62.1 for a minimum airflow for office spaces were used, considering 2.5 L/s-person and 0.3 L/s/m², for the adaptive thermal comfort analysis under free oscillation.

2.1 Stage 1: Base case

First, an architectural survey was made of the building. This was a building without internal divisions, with a rectangular floor plan of 9.90m north to south, and 10.47m east to west, a minimum height of 3.20m, and a gable roof with a maximum height of 5.81m (Fig.1).

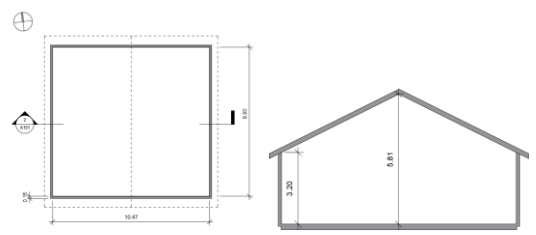


Figure 1: Floor plan and architectural section of base case.

2.2 Stage 2: Retrofitting using passive design strategies

For the office retrofitting design process, passive architectural design strategies were used considering the analyzed climate. The thermal envelope variables were analyzed under the three thermal envelope solutions, using the methodology described in number 2.1. The following passive design strategies were used considering the climate conditions of the location.

a) Central distribution of floor plan and orientation of work areas to the west and south (Fig. 2, yellow). A central glass partition is generated to obtain solar gains in winter on the north façade, and direct gains on the east façade (Fig. 3) due to the blocking of the north façade by an adjoining building (Fig. 4, letter a). To avoid overheating of the building in summer, horizontal solar protections to the north are designed (Fig. 4), and horizontal and vertical ones to the East (Fig. 5).

b) For the mixed-use air-conditioning system with natural ventilation, a time frame of 7 am to 7 pm was used, a range where it is possible to activate natural ventilation, as long as ventilation control temperature criteria are followed. 3 air renewals per hour (ac/h) were used on activating natural ventilation.

Note: Mixed-use air-conditioning was only analyzed for the energy consumption simulation. All the thermal comfort analysis was done under free oscillation, with the flows expressed in point "b".

c) Natural ventilation control temperatures: A minimum outdoor temperature of 12°C and a maximum of 30°C were considered. Indoors, a minimum temperature of 24°C was considered.

For the analysis of total energy consumption of Stage 2, two analysis scenarios were defined regarding artificial lighting.

Scenario 1: Lighting power density 15W/m^2.
Scenario 2: Lighting power density 7.5 W/m^2, corresponding to efficient lighting.

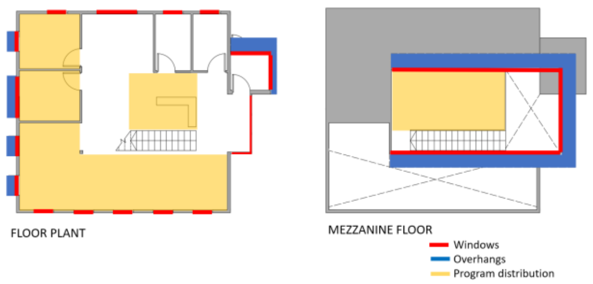


Figure 2: Architectural floor plan of retrofitted case

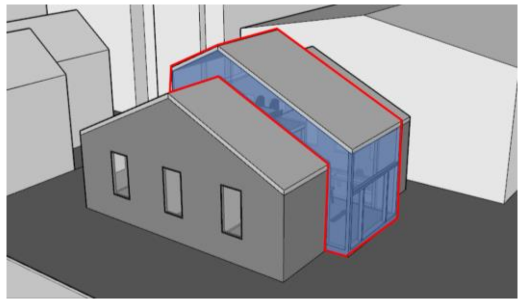


Figure 3: Proposed case intervention layout

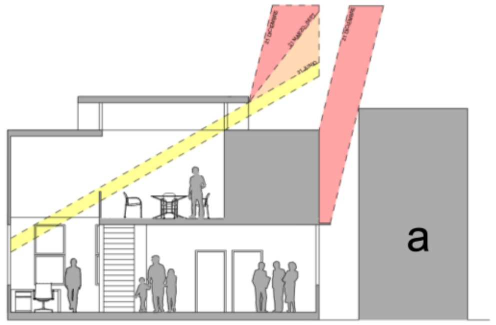


Figure 4: Improved case with north-facing solar protections setup (December 21st)

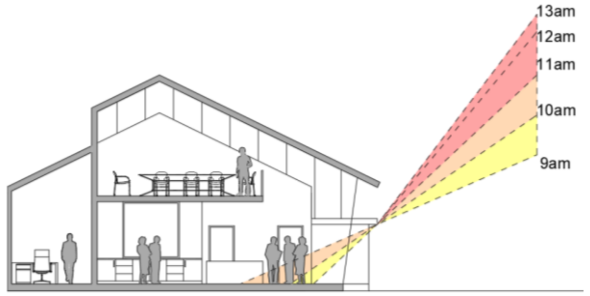


Figure 5: Improved case with east-facing solar protections setup (March 21st/September 21st)

2.3 Reading of the Results

The results were analyzed considering the building's total energy consumption in kWh/m^2 per year, and the energy consumption is broken down by use in kWh/m^2, in order to analyze the variation considering the combination of the thermal envelope solutions for the two stages and later, comparatively analyzing the standardized consumption for buildings with an nZEB approach in the world.

In addition, the results were analyzed considering the percentage of hours per year that the space is within the adaptive thermal comfort model of the ASHRAE 55 Standard of 2017, to determine the effect of the low consumption from air-conditioning on the occupants' wellbeing.

3. RESULTS

The highest total energy consumption per year of Stage 1, is that of Solution 1: TDRe Standard with a total of 67.4 kWh/m^2, while the lowest consumption is from the combination of Solution 3: Passivhaus Bologna, with the glazing of Solution 1: TDRe Standard, with a consumption of 57.1 kWh/m^2 (Fig. 6).

The variation between Solution 2: Passivhaus Chile and Solution 3: Passivhaus Bologna, is 1.2 kWh/m^2 (Fig. 6).

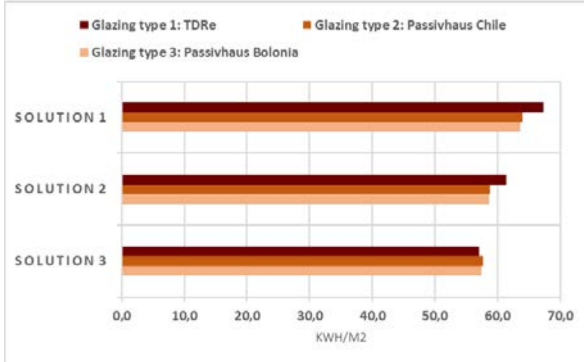


Figure 6: Total energy consumption of Stage 1 in kWh/m^2 per year, with combinations of the three chosen thermal envelope solutions

where 1 - Standard 1 - TDRe;
2 -Standard 2 - Passivhaus Chile;
3 -Standard 3 - Passivhaus Bologna;
W - Wall transmittance;
R - Roof transmittance.

The lowest consumption of Stage 2 was solution 3: Passivhaus Bologna; while the highest consumption of Stage 1 is Solution 1: TDRe Standard, with the result being a total energy consumption reduction of 24.8 kWh/m^2 a year (Fig. 7).

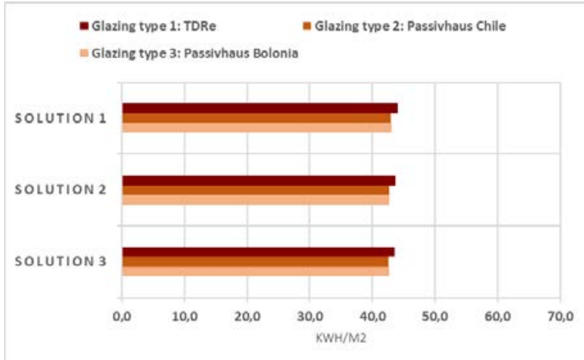


Figure 7: Total energy consumption of Stage 2 in kWh/m^2 per year, with combinations of the three chosen thermal envelope solutions.

For the change of lighting technology, the trend between the standards remains, but a consumption reduction of around 10 kWh/m^2 per year is generated, compared to Stage 2 (Fig. 8).

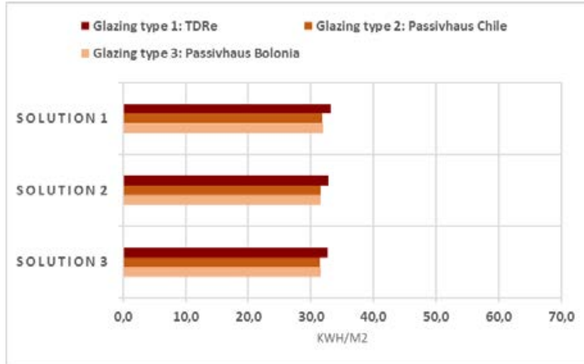


Figure 8: Total energy consumption of Stage 2 in kWh/m^2 per year, with combinations of the three chosen thermal envelope solutions, plus a change of lighting for LED technology.

The energy consumption for lighting represents the highest consumption for the two stages and for the three thermal envelope solutions. Stage 1 has the highest consumption values for cooling, while Stage 2 reduces consumption for cooling and increases demand for heating (Fig. 9).

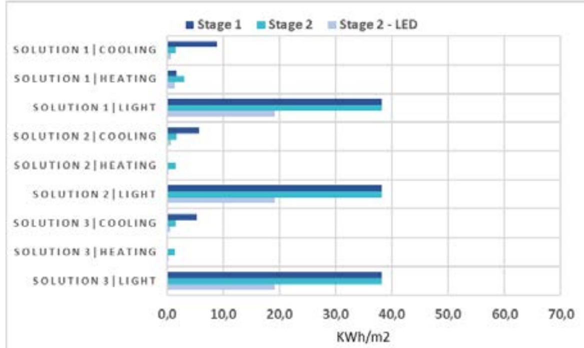


Figure 9: Energy consumption broken down by use in kWh/m^2 per year, with combinations of the three chosen thermal envelope solutions, plus a change of lighting for LED technology.

The energy consumption of all the thermal envelope solutions for Stage 2 has a maximum variation of 1.4 kW/h, while for Stage 1 there is a maximum variation of 10 kWh/m^2 (Fig. 10).

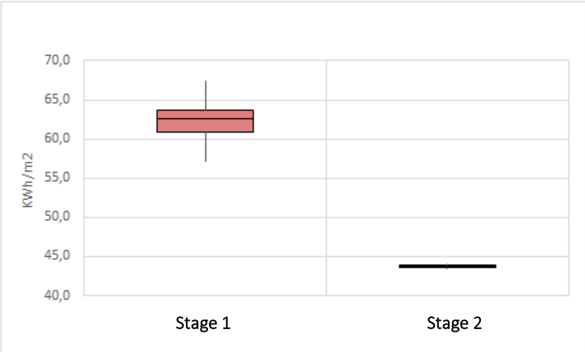


Figure 10: Variation of total energy consumption of the building in kWh/m² per year, considering the thermal transmittances iterated in the 3 standards, for Stage 1 (base case) and Stage 2 (retrofitting with passive strategies).

Performance under the adaptive thermal comfort model of Stage 1 has an oscillation between 39.2% of the hours of comfort per year, with solution 1: TDRe, and 48.3% corresponding to Solution 3: Passivhaus Bologna, with 31.7% under the acceptable range of 80% of hours of comfort per year.

However, for Stage 2, under free oscillation, the building reaches a percentage of hours of comfort per year of between 79% of hours per year in Solution 1: TDRe Solution, and 87.9% of hours per year under Solution 3: Passivhaus Bologna, with LED lights (Fig. 11).

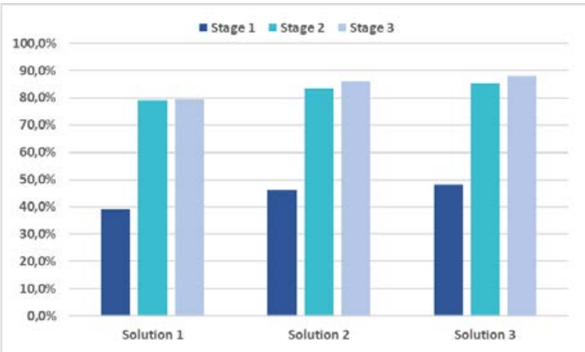


Figure 11: Percentage of hours of comfort per year under the ASHRAE 55 of 2017 Adaptive Thermal Comfort Model, comparison between the three thermal envelope solutions of Stage 1 and Stage 2.

4. DISCUSSION

On analyzing the results of Stage 1, a minimum total energy consumption of 57.1 kWh/m² per year was reached, applying Solution 3: Passivhaus Bologna. Within the nZEB Standards reviewed with a low technology or passive approach, these are 12.1 kWh/m² per year above the maximum nZEB requirement [9]. This shows that, if there is a high thermal transmittance performance of the envelope, passive design strategies need to be applied to reach a true consumption reduction considering nZEB. However, the building with a high thermal envelope performance (Solution 3) can reach a reduction of around 10.3 kWh/m² per year, compared with the energy consumption of Solution 1 TDRe, without applying passive strategies.

On applying passive strategies to the building's retrofitting design, combined with the thermal envelope solutions, a total energy consumption per year is achieved, of 42.6 kWh/m², close to the maximum range of 45 kWh/m² per year of the nZEB seen for buildings with a low technology or passive approach [9]. Meanwhile, there is a very low variation (around 3%) between the thermal envelope solutions chosen (all within the nZEB approach). This is due to the application of passive design strategies in architectural design, which allows analyzing the low influence that the requirement of the Thermal Transmittance Standards has when there are passive design strategies.

The energy consumption is reduced by 25% just by changing lighting to LED technology (compared to Stage 2 without a change), reaching a consumption that oscillates between 31 and 32 kWh/m² per year. All the analyzed thermal envelope solutions, including the TDRe, are within the nZEB Standards seen with a low technology or passive approach and close the maximum nZEB energy consumption value for buildings with a technological approach (25 kWh/m² per year)[9]. With this being the strategy applied for most new buildings built in Chile, its application is appropriate for retrofitting processes.

The thermal comfort analysis allows studying the suitability of applying passive design strategies in the buildings, as the difference between Stage 1 and Stage 2 is approximately 40% of hours per year in comfort, mainly reaching 80% of hours per year in comfort for an optimal behavior of the space. However, the TDRe Standard only reaches the 80% level within the Adaptive Thermal Comfort Model when lighting strategies are applied. Stage 2, with a change in lighting, is just 1% under the expected levels (80% of hours of comfort per year).

The variation between thermal envelope solutions again provides a low variation, of around 5% of annual hours, retaining the linear increase trend following the analyzed standard.

5. CONCLUSION

Starting from the analysis of the 3 thermal envelope solutions applied to the building for Stage 1: Base Case, and Stage 2: Retrofitting with Passive Design Strategies, the conclusions are the following:

1.- Passive design strategies, adjusted to the building's climate context, generate greater impact in terms of thermal comfort and energy consumption reduction than the thermal envelope strategies under the chosen envelope solutions.

This allows validating the importance of incorporating climate-related strategies in the design processes.

2.- Including passive design strategies in retrofitting processes can reduce the performance requirements of the thermal envelope. Within this scenario, the TDRe Standard can reach the standards of buildings with an nZEB approach, if suitable strategies are included.

3.- The consumption recorded for the building retrofitted with passive design strategies fits the reference consumption for nZEBs proposed in the article "Net Zero Buildings: a framework for an integrated policy in Chile" (15-45 kWH/m²y for buildings with a low technology or passive approach), which is why nZEB Standards can be reached with the energy efficiency and environmental comfort parameters of the TDRe.

4.- To reach the goals proposed by Chile regarding the nZEB, the requirement of an Energy Efficiency and Environmental Comfort Standard applied to public and private buildings is key, along with performance criteria that come close to nZEB buildings with a passive and active approach.

Ventilation must be analyzed with calibrated wind speed and direction data, as the impact of a constant flow (as made in this research) within the scheduled natural ventilation can alter the performance in thermal comfort.

For future research, it is suggested to incorporate the cost analysis of passive strategies and construction elements under the analyzed Thermal Transmittance Standards, aiming at determining the impact of design decisions on the project cost under the nZEB approach. On the other hand, the methodology used in the research can be replicated, as long as the specific needs of each case study are considered in terms of passive strategies conditioned to the climate and urban context of its location.

ACKNOWLEDGEMENTS

Special thanks are given to Laura Marín Restrepo Ph.D. and Alexis Pérez Fargallo Ph.D., Professors from the Sustainable Habitat and Energy Efficiency Master's Program at the University of Bio-Bio, Concepción.

REFERENCES

1. International Energy Agency. (2017). *Energy Technology Perspectives 2017 - Executive Summary. International Energy Agency (IEA) Publications*. Retrieved from https://webstore.iea.org/download/summary/237?fileName=English-ETP-2017-ES.pdf
2. National Energy Commission. (2017). Anuario Estadístico de Energía 2017 [Annual Energy Statistics 2017], 164. Retrieved from https://www.cne.cl/wp-content/uploads/2018/06/AnuarioCNE2018.pdf
3. Collado, N., Himpe, E., González, D., & Rueda, L. (2019). Retos para una definición de " Edificios de consumo energético casi nulo " Challenges for a definition of Nearly Zero Energy Buildings, *34*, 321–329.
4. P, D. N. (2014). Plan Nacional De. *Plan Nacional de Adaptación al Cambio Climático*, 60.
5. Ministerio de Energía. (2014). Energía 2050 Política Energética de Chile. *Ministerio de Energía Gobierno de Chile*. Retrieved from http://eae.mma.gob.cl/uploads/D03_Politica_Energetica_de__Chile_2050_Anteproyecto2.pdf
6. Trebilcock, M., Soto-Muñoz, J., & Piggot-Navarrete, J. (2020). Evaluation of thermal comfort standards in office buildings of Chile: Thermal sensation and preference assessment. *Building and Environment*, *183*, 107158. https://doi.org/10.1016/j.buildenv.2020.107158
7. Pérez-Fargallo, A., Pulido-Arcas, J. A., Rubio-Bellido, C., Trebilcock, M., Piderit, B., & Attia, S. (2018). Development of a new adaptive comfort model for low-income housing in the central south of Chile. *Energy and Buildings*, *178*, 94–106. https://doi.org/10.1016/j.enbuild.2018.08.030
8. Pérez-Fargallo, A., Rubio-Bellido, C., Pulido-Arcas, J. A., Gallego-Maya, I., & Guevara-García, F. J. (2018). Influence of adaptive comfort models on energy improvement for housing in cold areas. *Sustainability (Switzerland)*, *10*(3), 1–15. https://doi.org/10.3390/su10030859
9. Piderit, M. B., Vivanco, F., van Moeseke, G., & Attia, S. (2019). Net-zero buildings-A framework for an integrated policy in Chile. *Sustainability (Switzerland)*, *11*(5), 1–18. https://doi.org/10.3390/su11051494

10. Comisión Europea. (2016). Recomendación (UE) 2016/1318 de la Comisión de 29 de julio de 2016 sobre las directrices para promover los edificios de consumo de energía casi nulo y las mejores prácticas para garantizar que antes de que finalice 2020 todos los edificios nuevos sean edi. *Diario Oficial de La Unión Europea*, *9*, 46–57.

PLEA SANTIAGO 2022
Will Cities Survive?

An innovative environmental test chamber for testing passive cooling prototypes

A new methodology for research and pedagogical applications

OMAR AL-HASSAWI[1] DAVID DRAKE[1]

[1] Washington State University

ABSTRACT: This paper reports on the design, construction, and commissioning of an off-grid, solar powered, cost-effective environmental test chamber built inside a standard shipping container. The described chamber is capable of replicating a broad range of outdoor conditions to evaluate reduced-scale prototypes of passive cooling systems. In contrast to other evaluation methods, use of the chamber does not require software skills associated with computer simulation and avoids costs and extended data collection times needed to test prototypes at full scale. Commissioning and preliminary test data show a high correlation with data sets collected from full-scale prototype evaluation. The chamber was designed for integration with design pedagogy as well as faculty research and is currently being used as part of a grant-funded course sequence to test innovative passive cooling devices developed by student design teams.

KEYWORDS: Environmental Test Chamber, Passive Downdraft Cooling, Passive Cooling, Reduced-Scale Prototypes

1. INTRODUCTION

Barring an alternative, energy demand for space cooling is projected to double by 2050, driven by accelerating urbanization, especially in hot and warm climates [1- 2]. Currently, buildings account for 60% of global electricity consumption, 18% of which is due to active mechanical air conditioning systems. If widely adopted, passive cooling systems can play an important role in building decarbonization.

Compared with active mechanical systems, passive systems use little to no electricity, relying instead on the natural flow of sensible and latent heat from smaller, warmer spaces to larger, cooler heat sinks, such as the atmosphere and earth. Examples of passive cooling systems include: downdraft evaporative cooling towers, which transfer heat to the atmosphere through convection and evaporation, and earth tubes, which transfer heat to the earth through conduction.

Contemporary passive cooling projects such as Zion National Park Visitor Centre in Springdale, Utah, the Torrent Research Centre in Ahmedabad, India, and the courtyards at Princess Nora University in Riyadh, Saudi Arabia, have all proved to be efficient, cost-effective, and comfortable [3-5]. Given these successes, and the thousand-year history of use of passive cooling systems in the hottest regions of the planet, it's surprising that passive cooling systems haven't been more widely adopted [6].

This may be due to lack of familiarity with passive cooling systems not only in architectural practice, but in academic research and design pedagogy as well, coupled with widespread misperceptions of inefficacy. Integration of passive cooling system research and development into design curriculum can promote familiarity and correct misperceptions, leading to wider adoption of passive systems as future architects and researchers move into practice. Unfortunately, existing methods for investigating passive cooling models, such as computer simulation and full-scale prototyping, come with significant drawbacks in terms of cost, practicality, and approachability.

Computational Fluid Dynamics (CFD) simulation software relies on simplified digital models to simulate fluid flows. Rapid output and graphical display simplify comparison of multiple design iterations [7-8]. On the other hand, the learning curve to reach proficiency is steep, and CFD software does not have the ability to analyse system's operational shortcomings.

Construction of full-scale physical prototypes, with construction materials and test location calibrated to accurately represent system performance and operation, allows performance to be tested under actual environmental conditions, and operational issues to be recognized and rectified. However, rapid iteration of designs and exploration of a variety of solutions is impractical. In addition, full-scale prototyping requires considerable time, costs, and construction experience. Data collection can also be cost-prohibitive and data collection timeframe is constrained by environmental conditions [9-11].

Investigating reduced-scale physical prototypes permits a broad view of operational issues while allowing for rapid iteration of designs [12]. However, this approach requires a controlled environment. Design and construction of an effective environmental test chamber, even for reduced-scale models, can be more cost-prohibitive than construction of full-scale prototypes. Where laboratory space is at a premium, installing a permanent indoor environmental chamber may be impractical.

This paper reports design, construction, and commissioning of an off-grid, solar powered, cost-effective environmental test chamber for testing passive cooling system prototypes at reduced scale. The chamber is built primarily from donated components, including a standard shipping container used for the outer shell. Now commissioned, the chamber is playing an active and ongoing role in building science and design pedagogy, as well as faculty research. Our experience suggests hands-on exploration of unfamiliar systems is resulting in deeper student engagement and optimal learning outcomes.

2. DESIGN METHODOLOGY

Chamber design was constrained by an available construction budget of $10,000 USD, supplemented with in-kind donations of equipment and materials, including: a standard 6.10 m (20') shipping container; EPS geofoam panels 152 mm (6") thick; 3480 Watt PV array with inverter and 2400 amp-hour battery bank; and 12,000 BTU mini-split heat pump. The available chamber site was an outdoor concrete pad lacking onsite access to grid electricity.

These constraints and resources resulted in a schematic design using the shipping container as the chamber exterior shell, with the PV array and battery bank supplying chamber electrical needs. A system of continuous interior insulation employing geofoam panels was designed to boost efficiency of chamber environmental controls and moderate heat exchange with the outside. Light gauge galvanized sheet steel was selected as an economical material to clad interior surfaces, minimizing friction and turbulence, as well as reducing emissions for the chamber's potential secondary application in IAQ testing. The mini-split heat pump provides heating, cooling, and dehumidification on the inside.

Designing an effective chamber within these budgetary and resource constraints required satisfying a complex set of competing criteria. These included: A) maximization of prototype scale reduction for cost and design iteration efficiencies outlined above; B) maximization of test run times within the limits of battery storage and solar recharge capacities; C) accurate and repeatable control of operational parameters allowing collection of reliable data; and D) use of existing full-scale prototype datasets to calibrate data from reduced-scale prototypes. Other criteria include adaption to other building science applications, and chamber portability.

Because comparison between prior full-scale investigations and planned reduced-scale investigations requires maintaining the same volumetric flow rate at the inlet for both prototypes, air velocity was a critical design parameter.

$$Q = v \times A \qquad (1)$$

where Q – Volumetric flow rate (ft^3/min)
v - air velocity in chamber test section (fpm);
A - cross sectional area through test side (ft^2).

From Equation (1), it is clear the reduced-scale prototypes' smaller inlet vertical surface area of flow (A) requires an increase in flow velocity (v) to hold volumetric flow rate (Q) constant. Therefore, the effective lower boundary for scale reduction can be derived using Equation (2):

$$C = v / v' \qquad (2)$$

where C - scale factor;
v - air velocity from full-scale testing (fpm);
v' - air velocity inside the test chamber established through the CFD analysis (fpm).

Based on a review of wind tunnel design literature [13-14], we determined maximization of chamber air velocities (and thus maximum scale reduction) could be achieved with an array of high-volume, high-velocity fans circulating air in a closed-loop raceway (Fig. 1).

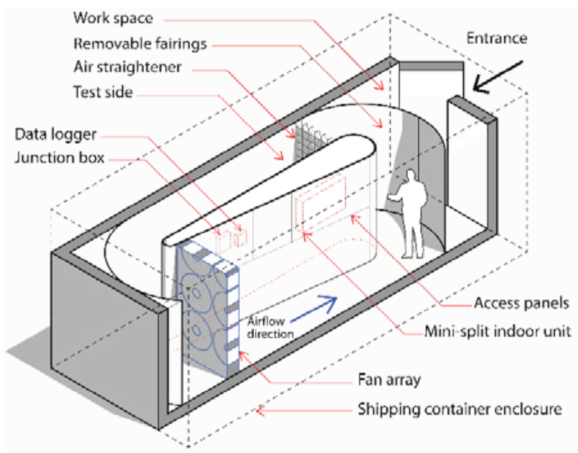


Figure 1: 3D Diagram explaining the test chamber overall design.

Budget and chamber size constraints resulted in specification of a six-fan array, moving 807 m^3 of air per minute (28,500 cfm), at 4.62 kW total electrical load. Solar resources during late spring and summer allow daily test runs of approximately two hours, which was judged adequate for initial testing.

Design of the chamber raceway, including fan placement, corner fairing radii, and centre divider sectional geometry, was refined through an iterative series of Computational Fluid Dynamics (CFD) simulations, using the Autodesk CFD 2019 platform coupled with Autodesk Revit as the 3D modelling tool. More than 15 variations were examined with design goals being maximization of air velocity and minimization of turbulence on the test side of the divider, as well as overall ease-of-construction.

Modelling focused on the geometry surrounding the air flow path. Software default values were used to assign materials to 3D objects, including rigid Styrofoam insulation for the enclosure, plywood for the air straightener, and air for the interior void. The fan array material was customized, using fan curves supplied by the manufacturer. Closed-loop air movement was generated through fan-initiated air flow on the supply side. An assigned static pressure of zero on the return side kept air cycling in the chamber. An automated mesh was generated for all simulation options with an average mesh count of approximately 400,000 cells. Fig. 2 shows plan views taken from three iterations in this series, leading to preferred iteration 'C'.

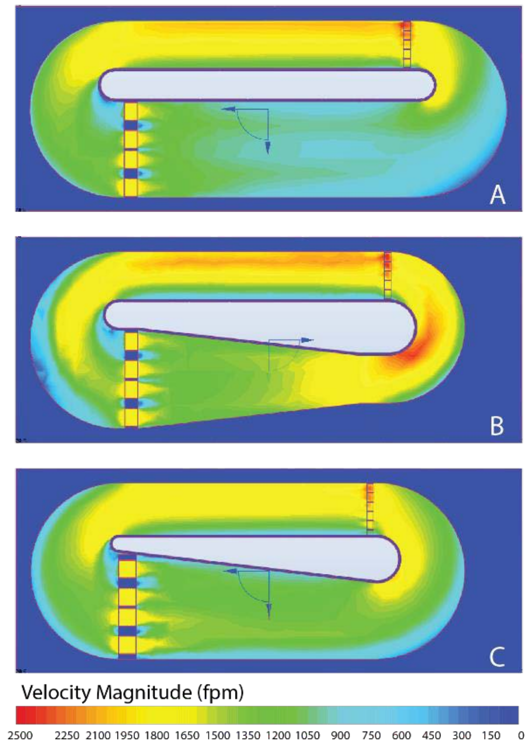


Figure 2: CFD simulation results plan views for three variations with 'C' as the preferred iteration.

Iteration 'C' has a test section measuring 2.0 m x 0.6 m x 3.0 m (6'-10" x 2'-0" x 10'-0") (H x W x D), with counter-clockwise air flow channelled by corner fairings around a centre divider. The divider is tapered in horizontal cross section to restrict airflow and increase velocity in the chamber test section. As illustrated in iteration 'C' the air flow path widens at the test section exit, resulting in velocity decrease, before air re-enters the fan array and begins a new cycle (Fig. 2).

Previous investigations by one of us of full-scale prototypes established useful parameters for calibrating chamber operations with reduced-scale prototypes. Measured outdoor air velocities during full-scale prototype investigations ranged from 4.8-12.9 km/h (260 - 705 fpm), with an average of 8 kph (440 fpm). CFD simulations give a maximum test-side air velocity of 33 kph (1805 fpm). Therefore, from Equation (2), calculated scale factor is 0.24, or ratio of 1:4.1. We assumed actual air velocity in the test chamber would be lower than predicted, due to sources of turbulence and friction not captured by the CFD simulation, and chose 1:3 as a conservative ratio for reduced-scale models.

3. CONSTRUCTION METHODOLOGY

Construction of the chamber took place between January and September 2021. Orientation of the chamber's long axis is optimized for PV generation within the constraints of the site conditions. The chamber system also includes an auxiliary 'doghouse' shed, which houses the battery bank and inverter and provides a mounting surface for four of the 12 PV panels. Fig. 3 is an overall image of the chamber taken from the northeast corner.

Figure 3: Overall image of the completed chamber taken from the northeast corner.

Centre divider and corner fairings are framed with light gauge steel studs, tubular cardboard concrete forms, 19mm (0.75") plywood, and clad with 0.7mm (22g.) galvanized sheet steel. Chamber insulation and steel cladding sheets are attached using polyurethane construction adhesive. To minimize friction and turbulence, the indoor mini-split unit, data logger, and electrical service panel are mounted inside the centre divider, and all cladding seams are sealed using aluminium HVAC tape.

Removable fairings on the door side of the container allow access to the chamber, and three weather-proof ports provide entry for electrical, data, water supply, and mini-split coolant lines.

A system of standard slotted strut channels and connectors, chosen for ease of construction and cost effectiveness, is used for the interior fan array frame and the angled PV mounting frames on the chamber roof. Fig. 4 shows the chamber and doghouse interior during construction and commissioning.

Figure 4: Photos taken during construction and commissioning of the chamber. A- doghouse interior, B- removable fairing on the door side. C- fan array facing the supply side. D- 1:3 prototype model placed in the test side.

4. CALIBRATION METHODOLOGY

A 1:3 reduced-scale model of the full-scale single-stage downdraft cooling tower used in the previous study was constructed with a shaft cross section area of 0.16 m^2 (1.75 ft^2). Materials and the direct evaporative cooling system were scaled down but otherwise identical to those of the full-sized prototype. These include polyisocyanurate insulation boards, metal angles, plywood, and misting nozzles.

The Onset Computer Corporation data acquisition system was identical to that used for full-scale investigations, including an RX3002-00-01 Data Logger with weatherproof enclosure rated for outdoor use. The logger has a time accuracy of ± 8 seconds per month in 0° to 40°C (32°F to 104°F) range. One RXMOD-A1 4-channel Analogue Module was installed, then the four sensors outlined in Table 1 were attached to the logger.

Table 1: Data acquisition sensors attached to data logger

Sensor Type	Quantity	Accuracy and Range
S-THB-M008 temperature/ relative humidity (RH) smart sensor	2	Temperature: ± 0.21°C (0.38°F). 0° to 50°C (32° - 122°F) RH: ±2.5%. 10% - 90%
T-DCI-F300-1C3 air velocity analogue sensor	2	± 5% of reading at + 0.15 m/s (+ 30 fpm)

One set of Temp/RH and air velocity sensors was located at the outlet and the other set was located at the tower inlet. Outlet sensors were placed inside an insulated box to protect the sensors and properly capture the air variables exiting the tower. Fig. 5 illustrates the placement of the model in relation to the sensors in the test side in the chamber.

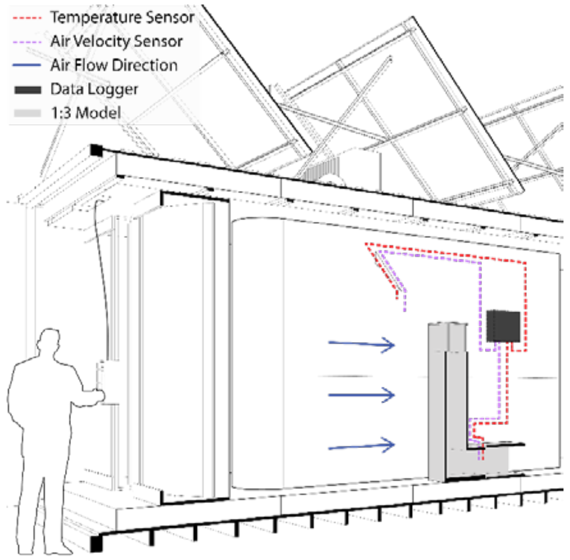


Figure 5: Section perspective indicating sensor and prototype locations in test side of the chamber.

Calibration was based on datasets for cooling via direct evaporation, provided by a misting system. The reduced-scale misting system used a single nozzle with maximum flow rate of 2.6 l/hr (0.7 g/hr), compared to the full-scale system, which used up to three nozzles for a total maximum flow rate of 8.0 l/hr (2.1 gal/hr).

Tables 2 and 3 outline data collected from full-scale investigation over four days or 27 hours of operation using 30 second logging intervals averaged every five minutes for a total of 317 data collection samples. Table 2 lists the ambient conditions whereas Table 3 lists conditions at tower outlet during hours of operation. Overall, outlet conditions from one mister operating averaged 12°C (23°F) in temperature drops, 15% rise in relative humidity, and 0.9 m/s (182 fpm) in air velocity.

Table 2: Average ambient conditions collected during full-scale investigation: Temperature (T), relative humidity (RH), and wind speed (V_{in})

Date	T - °C (°F)	RH - %	V_{in} -m/s (fpm)
June 14, 2017	39 (103)	4	1.758 (346)
June 15, 2017	42 (107)	5	1.580 (311)
June 18, 2017	43 (110)	9	2.310 (455)
June 21, 2017	46 (115)	10	3.360 (662)
AVERAGE	**43 (109)**	**7**	**2.250 (444)**

Table 3: Average conditions at tower outlet collected during full-scale investigation: Temperature drops (ΔT), relative humidity rise (ΔRH), and air velocity (V_{out})

Date	ΔT - °C (°F)	ΔRH - %	V_{out} -m/s (fpm)
June 14, 2017	12 (23)	15	0.823 (162)
June 15, 2017	17 (32)	25	0.823 (162)
June 18, 2017	11 (21)	13	0.935 (184)
June 21, 2017	9 (16)	7	1.123 (221)
AVERAGE	**12 (23)**	**15**	**0.925 (182)**

5. RESULTS

Chamber commissioning: Test runs began mid-September 2021, occurring once a week on average until the end of November 2021. Logging intervals were set to 30 seconds. All chamber systems functioned as designed, with some limitations:

1. Battery capacity and winter recharge times severely limit test durations, requiring modification to allow auxiliary recharging from an exterior electrical receptacle on a nearby building.
2. Operation in below freezing conditions requires considerable preheating for the chamber to reach test temperatures, exceeded battery storage if the mini-split heat pump is used as the sole heating source. Use of a propane construction heater for preheating is effective and rapid, although not ideal from a carbon footprint or indoor air quality perspective.
3. Build-up of waste heat from air circulation fans and system turbulence requires chamber venting to maintain desired test temperatures at steady-state. Currently, venting is accomplished through opening one of the insulated chamber doors and shifting door-side corner fairings to create a small gap of 5 cm (2”). Future modifications to the chamber will add a thermostatically-controlled vent fan to the system.

Characterization of temperature and relative humidity levels: A steady-state design temperature of up to 49°C (120°F) and 8% RH was maintained using the venting technique described above.

Characterization of air velocity (chamber empty): In contrast to expectations, measured air velocity in the chamber exceeded CFD predictions, reaching 45 kph (2460 fpm) in the test section. In principle, this allows a scale reduction factor of 1:5 or greater, however, chamber operation with a model in place significantly reduces air velocity.

Characterization of air velocity (model in place): Maximum air velocity at the tower model inlet was nearly identical to CFD analysis predictions with the model: 31 kph (1,680 fpm) versus 30 km/h (1,650 fpm). Velocity at the tower outlet was far lower: 5.5 kph (300 fpm). Velocity at outlet remained essentially constant, regardless of velocity at inlet. This means volumetric flow rates at tower outlet averaged 8.5 m^3/min (300 cfm) compared to 37.5 m^3/min (1325 cfm) at full-scale.

Characterization of model operation on chamber temperature and relative humidity levels: With the mister running at the top of the tower, the chamber remained within ± 1°C (± 2°F) of the steady-state temperature and RH levels would increase and stabilize at approximately 15%.

Preliminary results from prototype operation: Data was collected five times with mister running for 30 – 35 minutes each time for a total of approximately 3 hours of operation. Temperature drops at tower outlet averaged 7°C (12°F) which is 2°C (4°F) lower than the average low from full-scale operations. This ΔT remained consistent despite variation in chamber temperatures representing ambient conditions. RH levels at the outlet increased by an average of 15 – 20 % which was identical to full-scale results.

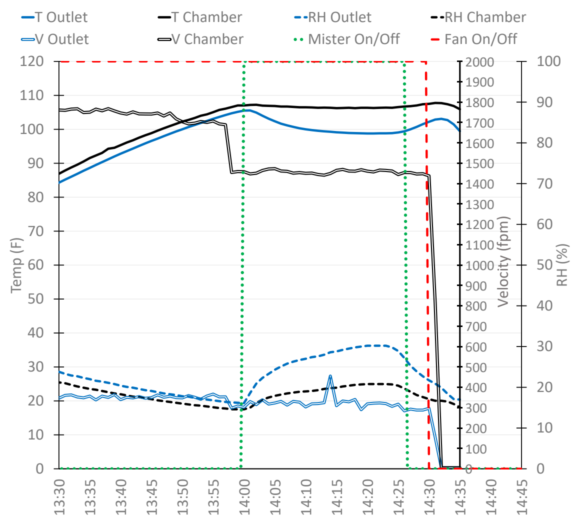


Figure 6: Data collection when misters operating inside the chamber for 30 minutes on October 01, 2021.

Figure 6 graphs data from chamber operation on October 01, 2021, with ambient conditions set to 42°C (107°F), relative humidity levels at 15%, and air velocities set to 26.5 kph (1450 fpm). Operating the mister for 30 minutes resulted in outlet temperatures of 36°C (97°F) or a ΔT of 6°C (10°F) and RH levels of 30%. Air velocities at outlet averaged 5.8 kph (320 fpm) despite changing fan speeds, likely due to the small size of the inlet resulting in air flowing around the outside of the tower. Further tests and calibration are ongoing.

Use of chamber in faculty research: more tests need to be conducted to answer several research questions including: modifications required to increase temperature drops as well as air velocities at outlet of the single-stage tower prototype; impacts of adding more misting nozzles on the outlet as well as chamber conditions in comparison to data from full-scale experiments; and performance impacts of innovations such as multi-stage cooling systems on downdraft cooling outlet conditions.

Use of chamber in design pedagogy: The chamber was used to test passive cooling system designs developed by student teams, as part of courses funded by a VentureWell Faculty Grant to teach entrepreneurial approaches to sustainability. Teams used digital modelling and simulation tools to test performance of multiple iterations and narrow designs for construction of reduced-scale physical prototypes using our school's fabrication labs. The teams then evaluated the prototypes using the chamber described above, comparing results from physical testing to digital models and simulations. Beyond the course, successful teams will receive additional funding to continue developing and commercializing their innovations.

6. CONCLUSION

Chamber construction was completed within budget and with minimal initial design modifications. Results from commissioning, characterization, and initial calibration are promising, as is the use of the chamber as a hands-on teaching tool to develop familiarity with passive cooling systems amongst future architects. Operational shortcoming of the chamber as constructed have been identified and specific modifications, including power venting, auxiliary power supply, and addition of an air straightener, have been designed, with implementation expected to be complete prior to the end of August 2022.

ACKNOWLEDGEMENTS

This research would have not been possible without the funding from the Lemelson Foundation and the School of Design and Construction (SDC) who awarded us with the VentureWell Faculty Grant and the SDC Seed Grant respectively. The researchers also wish to thank the SDC for donation of the solar array system, the rigid geofoam insulation, the split-type heat pump, and the shipping container. Finally, we wish to acknowledge input and effort throughout the project from: Colter Nubson, Nathan Albrecht, Anguel Atanassov, Ryan Smith, Tom Jobson, David Thiessen, Miles Pepper, and Scott Hanson.

REFERENCES

1. IEA. (2018). *The future of cooling: Opportunities for energy-efficient air conditioning*. *2018 OECD/IEA*. [online], Available: https://webstore.iea.org/the-future-of-cooling
2. Architecture 2030. (2019). Why the Building Sector? [online], Available: https://architecture2030.org/
3. Mead, D., Baptista, B., & Corney, A. (2013). Net zero energy through passive downdraft ventilation: the design & operation of the Conrad N. Hilton Foundation. In *BESS-SB13 CALIFORNIA: Advancing Towards Net Zero* (pp. 217–223). Pomona, California, U.S.A.
4. Schiano-Phan, R. (2012). Post-occupancy evaluation of non-domestic buildings using passive downdraught evaporative cooling in south-west USA. *Architectural Science Review*, *55*(4), 320–340.
5. Thomas, L., & Baird, G. (2006). Post-occupancy evaluation of passive downdraft evaporative cooling and air-conditioned buildings at Torrent Research Centre, Ahmedabad, India. In *Proceedings of the 40th Annual Conference of the Architectural Science Association ANZAScA* (pp. 97–104).
6. Cook, J. (1989). *Passive Cooling*. *Solar heat technologies*. Cambridge, Mass.: MIT Press.
7. Calautit, J. K., Hughes, B. R., Chaudhry, H. N., & Ghani, S. A. (2013). CFD analysis of a heat transfer device integrated wind tower system for hot and dry climate. *Applied Energy*, *112*, 576–591.
8. Kang, D., & Strand, R. K. (2013). Modeling of simultaneous heat and mass transfer within passive down-draft evaporative cooling (PDEC) towers with spray in FLUENT. *Energy and Buildings*, *62*, 196–209.
9. Duong, S., Craven, R., Garner, S., & Idem, S. (2018). A novel evaporative cooling tower constructed from an inflatable fabric duct. *Science and Technology for the Built Environment*, *24*(8), 908–918.
10. Givoni, B. (1997). Performance of the "shower" cooling tower in different climates. *Renewable Energy*, *10*(2–3), 173–178.
11. Pearlmutter, D., Erell, E., & Etzion, Y. (2008). A multi-stage down-draft evaporative cool tower for semi-enclosed spaces: Experiments with a water spraying system. *Solar Energy*, *82*(5), 430–440.
12. Chiesa, G., & Grosso, M. (2015). Direct evaporative passive cooling of building. A comparison amid simplified simulation models based on experimental data. *Building and Environment*, *94*, 263–272.
13. Calautit, J. K., Chaudhry, H. N., Hughes, B. R., & Sim, L. F. (2014). A validated design methodology for a closed-loop subsonic wind tunnel. *Journal of Wind Engineering and Industrial Aerodynamics*, *125*, 180–194.
14. de Almeida, O., de Miranda, F. C., Ferreira Neto, O., & Saad, F. G. (2018). Low subsonic wind tunnel - Design and construction. *Journal of Aerospace Technology and Management*, *10*, 1–20.

The complex challenge of sustainable architectural design

Assessing climate change impact on passive strategies and buildings' opportunities for adaptation. A case study

CAROLINA GANEM [1, 2] AND GUSTAVO BAREA [1]

[1] Instituto de Ambiente, Hábitat y Energía. Consejo Nac. de Investigaciones Científicas y Técnicas INAHE – CONICET.
[2] Facultad de Artes y Diseño. Universidad Nacional de Cuyo FAD-UNCUYO.

ABSTRACT: As a response to the last century energy crisis, passive strategies have been an interesting approach. Nevertheless, there are limits to passive design. And these limits will be greater constraints to the maintenance of Indoor building temperatures within acceptable parameters in the future, even with the complementary use of auxiliary energy. The objective of this paper is to assess climate change impact on passive strategies for IPCC's Representative Concentration Pathway (RCP) and to identify buildings' opportunities for adaptation to new climatic conditions. The performed dynamic simulation analyses on a case study shows a clear tendency to the increment of cooling loads and a reduction of the heating requirement. Moreover, when heating and cooling needs are added in a single figure it is interesting to analyse the whole energy consumption trends. In the study case, as well as similar constructions, total energy consumption present a maximum variation of less than 10% when compared with the worst-case scenario 4: RCP 8.5 (2100). Even though these figures look alike, there is a significant change in the source. Today, energy consumption for heating (natural gas) accounts for 57.5% of the total. While, in the worst-case scenario 4: RCP 8.5 (2100, energy consumption for cooling (electricity) predominates with 77.8% of the total.

KEYWORDS: climate change, extreme climate, passive strategies, buildings' adaptation opportunities.

1. INTRODUCTION

World population has reached to 7.753 billion in 2020 [1]. The combination of the projected population and economic growth together with climate change results in placing greater stress on vital resources in the future if there is a continuation of the business as usual scenario.

According to the Intergovernmental Panel on Climate Change - IPCC [2] and the International Energy Agency - IEA [3] around two-thirds of global primary energy demand is attributed to urban areas, inducing 75% of global direct energy-related GHG emissions. In the near future urban areas will be the main emissions sources of intensive heat energy and all kinds of environmental pollution, with an important impact on micro-, meso- and maybe even global climatic changes which will result in a reduction in the quality of life.

In this context, the residential and commercial buildings sector is responsible for approximately 30% to 40% of total global energy demand and one third of global GHG emissions. Energy use for cooling in buildings has doubled from 2000 to the present, making it the fastest growing end use in buildings. [4]

Most contemporary authors agree that the building stock is inexorably aging, composed of 75% buildings built before 1990, and the replacement of existing building stock by new (environmentally sound) construction is in the order of 1.2% per year. [5-9]

This situation leads to the assumption that, in the case that current regulations consider adequate standards for new buildings, the negative impacts due to energy consumption and polluting emissions in cities from the existing building stock will continue and the overall situation would be little reduced. It is important to keep in mind that in a decades-long perspective, the remaining buildings of the twentieth century will cause most of the environmental impacts in cities.

For this reason, improvements to the existing building stock will be the only way in which the benefits of energy efficiency will be made available to the majority of the population, and absolute reductions in domestic energy use and carbon emissions can be achieved. Increasing energy efficiency is the fastest and cheapest way to meet the challenges of energy security, the environment and the economy. This fact leaves an important course of action towards the refurbishment of existing buildings, and this is a very complex task.

Another difficulty to overcome is related to passive design as we know it. As a response to last century energy crisis, passive strategies have been an interesting approach. With the aim of displacing fossil fuels for space conditioning and lighting, the architectural design of the building itself, -e.g.

orientation, shape and materiality- plays a major role in capturing, storing and distributing wind and solar energy.

But, there are limits to passive design today, and these limits will be greater constrains to the maintenance of interior temperatures within acceptable parameters in future more extreme climatic conditions, even with the complementary use of auxiliary energy.

Extreme hot climates will become even hotter and the possibilities of using passive strategies will be further reduced. The use of renewable energy as a primary response to extreme weather conditions will be a constant in many regions of the world, and passive design criteria, in these cases, will be an accompanying factor in reducing energy demand.

However, there will be nuances and, in complex climates with significant daily and seasonal temperature variations, passive design still presents itself as a viable alternative in the future. [10-13] The consideration of dynamic forward projections, will allow for flexibility and adaptation to climate change, as opposed to the static simplification of current passive design recommendations.

In the case of temperate-continental climates, throughout the 20th century and specifically since the energy crisis of the 1970s, research into passive or low-energy strategies that contribute to the thermal conditioning of buildings in winter has been a priority. Well into the 21st century, the urban heat island is a well-known and sufficiently studied phenomenon, which, together with the prospective climate scenarios proposed by the IPCC for the next 50-100 years, redirects the disciplinary field to give priority to research on the thermal and energy situation of buildings in summer.

These changes not only imply a sustained increase in temperature values, but also a change in the relationship between daily maximum and minimum temperatures, which were the methodological basis for the application of passive cooling strategies such as night-time ventilation. In other words, an effective and massive assessment of the current condition of existing buildings and their likely future behaviour is necessary in order to reorient energy efficiency and passive cooling strategies. Only in this way will it be possible to make accurate recommendations from academia to decision-making bodies for the implementation of public policies that will ensure the resilience of our cities throughout the 21st century (in line with the estimated useful life of buildings).

In the 5th Assessment Report, IPCC defined 4 emission scenarios; the so-called Representative Concentration Pathways (RCPs), which take into account the effects of 20th century policies in mitigating climate change. See Table 1.

Table 1.
Four new emission scenarios. 5th IPCC Report. [14]

Scenarios	Radiative Forcing (RF)	RF Tendency	CO_2 in 2100
RCP 2.6	2.6 W/m²	decreasing	421 ppm
RCP 4.5	4.5 W/m²	stabilizing	538 ppm
RCP 6.0	6.0 W/m²	stabilizing	670 ppm
RCP 8.5	8.5 W/m²	increasing	936 ppm

A key question is whether a particular energy-optimised design under the present climate and use conditions, would remain energy-optimised in the future emission scenarios.

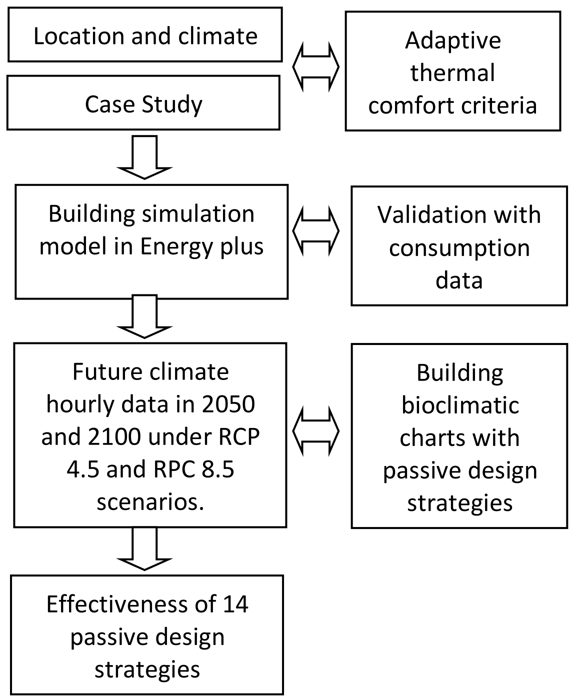
The objective of this paper is to assess climate change impact on passive strategies for IPCC's Representative Concentration Pathway (RCP) and to identify buildings' opportunities for adaptation to future extreme climatic conditions.

2. METHODOLOGY

The methodological framework for this study is presented in Figure 1.

In specific, Section 2.1 describes briefly the location under study and its climate. Section 2.2 describes building characteristics, configuration of the building simulation model in Energy Plus, its validation and thermal comfort criteria. The Bio-Climatic Chart and selection of viable passive design strategies for buildings are detailed in Section 2.3. And Section 2.4 deals with future climate hourly building simulation under IPCC's RCP 4.5 and RPC 8.5 scenarios.

Figure 1.
Methodological framework.



2.1 Location under study and climate

A consolidated neighbourhood in the Metropolitan area of Mendoza, Argentina (South Latitude -33° 9', West Longitude 69° 15', Elevation 1.950 masl) was chosen for this research.

Mendoza has a in a continental temperate cold desert climate with important daily and annual variations. According with the classification of Koeppen [15], Mendoza has a climate Bwk. See Table 2 for temperature and radiation data.

Table 2:
Climate data for Mendoza, Argentina. [16]

Annual values	
Maximum mean temperature	24.5 °C
Minimum mean temperature	9.6 °C
Mean temperature	16.5 °C
Global horizontal irradiance	18.4 MJ/m²
Relative humidity	56%
Relative heliophany	63%
July	
Maximum mean temperature	15.7 °C
Minimum mean temperature	0.8 °C
Mean temperature	7.3 °C
Global horizontal irradiance	10.2 MJ/m²
Relative humidity	63%
Relative heliophany	58%
January	
Maximum mean temperature	32.3 °C
Minimum mean temperature	17.4 °C
Mean temperature	24.9 °C
Global horizontal irradiance	26.1 MJ/m²
Relative humidity	49%
Relative heliophany	66%
Heating degree-days (Tb = 18 °C)	1384 °C
Cooling degree-days (Tb = 23 °C)	215 °C

2.2 Building characteristics, configuration of the building simulation model, and thermal comfort criteria

As a case study, a detached single-family house was chosen. See Table 3 for its main characteristics.

Table 3.
Case study main characteristics.

FORM	Perimeter	68 m
	Useful area	170 m²
	Volume	425 m³
ENVELOPE	Opaque Walls	94 m²
	Windows	80 m²
	Roofs	170 m²
COMPACTNESS COEFFICIENT		2
THERMAL TRANSMITTANCE	Walls (N, E, O)	2.41 W/m²°K
	Wall (S)	0.64 W/m²°K
	Windows	3.20 W/m²°K
	Roof	0.41 W/m²°K
Overall U VALUE		2.10 W/m²°K

Methodology follows the recommendations of the International Energy Agency (IEA) in its Annex 21 "Thermal Response Test" [17] that develops the concept of a "Performance Assessment Method" (PAM). A PAM is a guide to evaluate the building performance through the energy simulation of a building, which requires the establishment of a basic design case, the calibration of the model, the evaluation of the boundary conditions, the identification of problems, the generation of possible solutions and their evaluation. In this research, dynamic simulations were performed with Energy Plus v.9.5.0 software [18] Simplifications and assumptions in the virtual model followed ASHRAE 90.1 [19]

The simulated energy consumption results were compared with historical onsite energy consumption measurements from 2015 to 2019. The averaged measured energy consumption for heating and cooling allowed a reliable reference to calibrate the physical model in Energy Plus.

Table 4 shows the adjustment values achieved with the Energy Plus software, for a winter thermostat at 20°C and summer set at 26°C. Temperatures were set according to adaptive comfort criteria for free-running buildings in which heating and cooling systems are turned on and off when needed. [20]. The setting has a difference between measurements and simulation of 1.16 kWh/m² year in winter, and of 0.79 kWh/m² year in summer.

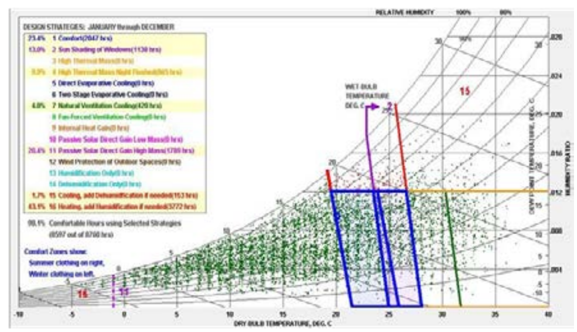
Table 4.
Simulation validation.

	Measurement kWh/m² year	Simulation kWh/m² year	Validation kWh/m² year
Heating	25.70	24.55	1.16
Cooling	17.36	18.15	0.79

2.3 Building Bio-Climatic Chart and selection of viable passive design strategies.

According to the Bio-climatic chart, Mendoza is within comfort temperatures 1641 hours a year, which is equivalent to only 68 days a year.

Figure 2.
Bio-Climatic Chart of Mendoza. [21]



Thermal Inertia is suggested as adequate to couple with the high thermal amplitude on winter.

High thermal mass + passive solar gain account for 4.012 more hours with temperatures within comfort ranges a year. This is equivalent to 167 days a year.

Sun Protection and Nocturnal Ventilation in summer are adequate strategies to regain internal comfort in 2.178 hours a year. That is 91 more days a year.

Today, with the correct use of the suggested passive strategies it is possible to reach the equivalent to 326 days in comfort in the city of Mendoza. It must be taken into account that hours are add up in order to have an impression of how important passive design is in this latitudes, but, hours in comfort are unevenly distributed each day. That is most days have some hours in comfort and some hours which temperatures are under or over the comfort range. See Table 5 for details of the effectiveness of each passive strategy.

2.4 Future climate hourly building simulation.

IPCC's RCP scenarios are the initial conditions and inputs for the General Circulation Models (GCMs) to forecast the climate change and obtain future climatic outputs.

A GCM is a complex system of computer programs that numerically represent the physical processes, and to a lesser extent chemical and biological, that occurs in the atmosphere, oceans, cryosphere and the earth's surface and in a very simplified form of the biosphere. It is the most reliable tool currently available to simulate the climate system and its variations.

Currently, the GCMs simulate the weather considering a three-dimensional grid on Earth with a general horizontal resolution of between 60 and 200 km^2, and up to 60 vertical levels in the atmosphere and similarly in the ocean. It has been verified that these models are capable of simulating the global characteristics of the climate and its changes recorded in the recent past.

One of the biggest limitations of the MCGs is that they do not always make an adequate representation of the climate at the regional level due to their low horizontal resolution. This particularly affects regions that have strong topographical accidents or thermal contrasts.

In the case of Mendoza, Argentina, this is a source of errors in the simulation of the climate in the entire Andean area and its surroundings due to the impossibility of adequately representing the Los Andes mountain range in models with low spatial resolution.

The problem of the low resolution of the GCMs can be addressed with the use of higher-resolution regional climate models (RCM) that, due to their computational demand, are usually limited to a certain region. As the regional climate is in permanent connection with that of the rest of the planet, this approach makes sense if the simulation of the regional climate that the RCM performs, incorporates information from a GCM. The strategy used is to feed the boundary conditions of the RCM cross-linking, every certain time step, with the GCM outputs, a process known as 'nesting'. [22-23]

To assess the impact of climate change on passive strategies, a model within 24 available alternatives in 3CN CIMA [24] database and from the World Climate Research Program - WCRP [25] was selected. The global model CNRM-CM5 RCP8.5 turned out the most suitable for Mendoza.

Climatic conditions for future scenarios according to the 5th IPCC where generated to subsequently perform dynamic simulation of thermal-energetic behavior of the building for future climate change conditions.

3. RESULTS AND DISCUSSION

3.1 Climate change impact on passive strategies

Fourteen passive strategies feasible to be used in continental temperate cold desert climates were studied under today's climate and in four IPCC RCP future scenarios: RCP 4.5 (2050 and 2100) and RCP 8.5 (2050 and 2100).

Table 5 shows how the different climate change projected scenarios could impact on these 14 passive strategies effectiveness.

In Table 5 notice that:

- Hours in comfort in a free running building will be incremented almost a 20% from 1641 hours to 1917 hours in the worst case scenario (find these information in the first line in Table 5).
- In a continental temperate cold desert climate, high thermal mass is important today, and it still will be important in many years perspective. High thermal mass associated with night ventilation in summer will increment its importance (marked with a green single line box).
- Sun shading of windows and cooling with dehumidification will be crucial in a years' perspective in summer (marked with red dotted boxes). Sun shading of windows will rise from 1211 hours to 1892 hours in the worst case scenario. And cooling need will increase dramatically from 175 hours to 1386 hours in the worst case scenario.
- In winter, passive strategies such as passive solar direct gain with low or high mass (marked with a blue double line box) will lose importance as climate will be warmer.

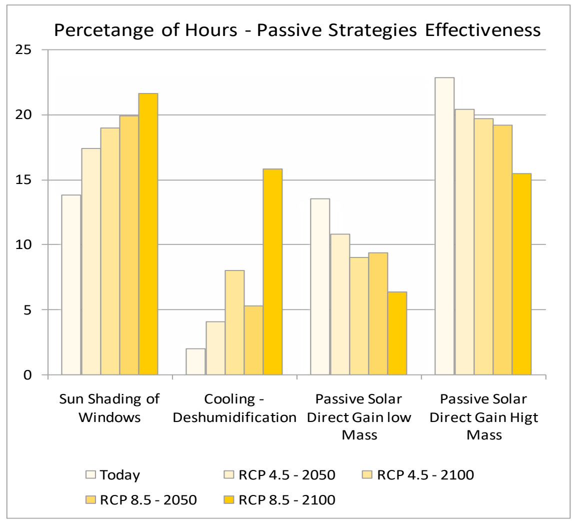
Figure 3 shows graphically the projected increment under the four future scenarios of the two main summer strategies (sun shading of windows and cooling); and the projected decrease of the two main winter strategies today (Passive Solar direct gain with high and low mass).

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Table 5. Passive strategies effectiveness in different Climate Change Scenarios.

Passive Strategies	Today		RCP 4.5				RCP 8.5			
			2050		2100		2050		2100	
	%	Hrs	%	Hrs	%	Hrs	%	Hrs	%	Hrs
1 Comfort	18.7	**1641**	22.4	**1966**	21.9	**1917**	22.2	**1946**	21.9	**1917**
2 Sun Shading of Windows	13.8	**1211**	17.4	**1523**	19	**1665**	19.9	**1564**	21.6	**1892**
3 High Thermal Mass	9.4	**825**	11	**965**	10.8	**943**	10.8	**946**	9.4	**825**
4 High Thermal Mass Night Flushed	11	**967**	15.1	**1319**	14.7	**1292**	14.6	**1280**	13.7	**1198**
5 Direct Evaporative Cooling	9.3	**814**	11.8	**1030**	10.8	**944**	11.4	**999**	9.7	**847**
6 Two-Stage Evaporative Cooling	10.4	**908**	13.6	**1190**	13	**1136**	12.7	**1113**	11.6	**1014**
7 Natural Ventilation Cooling	4.9	**430**	4.7	**415**	4.9	**425**	4.8	**422**	4.3	**376**
8 Fan-Forced Ventilation Cooling	2.7	**239**	3.1	**271**	3	**266**	3	**265**	2.8	**249**
9 Internal heat gain	32.1	**2810**	30.5	**2671**	28.4	**2485**	29.4	**2574**	25.1	**2198**
10 Passive Solar Direct Gain low Mass	13.5	**1186**	10.8	**989**	9	**789**	9.4	**827**	6.4	**558**
11 Passive Solar Direct Gain Higt Mass	22.8	**2001**	20.4	**1877**	19.7	**1727**	19.2	**1678**	15.5	**1360**
12 Dehumidification Only	2.4	**212**	3.2	**277**	4.4	**388**	4	**347**	5.6	**493**
13 Cooling, add Deshumidification if needed	2	**175**	4.1	**362**	8	**703**	5.3	**468**	15.8	**1386**
14 Heating, add Humidification if needed	19.5	**1707**	14.3	**1256**	12.4	**1082**	14.5	**1271**	9.8	**860**

Figure 3.
Percentage of hours in a year where the different passive strategies are recommended for the city of Mendoza in RCP 4.5 and RCP 8.5 (2050 and 2100)



3.2 Case Study –opportunities for adaptation

Based on the obtained results for the Metropolitan Area of Mendoza, the impact of climate change on urban microclimate and expected changes in energy consumption of buildings during the next century, will present new challenges. The heat waves with respect to the present will be more extensive and are estimated to be incremented in 115 more days by 2050. The previous analyses on passive strategies show a clear tendency to the increment of cooling loads and a reduction of the heating requirement.

-Scenario 1: The current situation (2020). Results are consistent with consumptions registered in the study case (heating = 25.7 kWh/m^2year and cooling = 17.36 kWh/m^2year). Heating represents the 57.5% and cooling 42.5%.

- Scenario 2: CRP 4.5 (2050).This scenario in a time horizon in the near future of interest for adaptation policies, corresponds to moderate emissions that stabilize around 2075. Heating represents the 40.6% and cooling 59.4%.

- Scenario 3: CRP 8.5 (2050).This scenario in a time horizon in the near future of interest for adaptation policies. Corresponds to the extreme case in which emissions will continue to grow with current trends until the end of the century to stabilize in 2200. Heating represents the 34% and cooling 66%

- Scenario 4: CRP 8.5 (2100).This scenario in a time horizon in the far future informative on the long term. Its simulation is justified because it did not stabilize in the near future time horizon. Heating represents the 22.2% and cooling 77.8%.

4. CONCLUSIONS

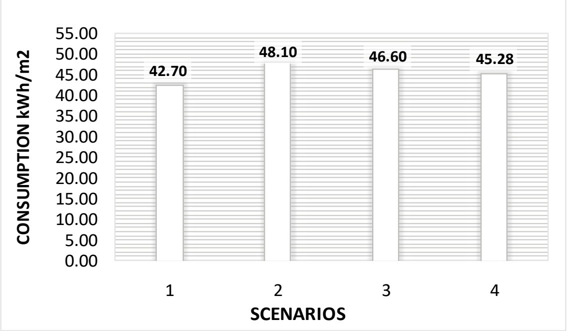
This paper addressed climate change impact on passive strategies and buildings' opportunities for adaptation in different IPCC's RCP extreme future conditions, in a continental temperate cold desert climate with important daily and annual variations.

It is a contribution to a relevant question in passive and low energy architecture: Would today's energy-optimised design remain energy-optimised in the future emission scenarios?

One of the main arguments placed retrofit and new designs in the hot spot for the reduction of carbon emissions, been existing buildings responsible for most emissions in cities in a decade perspective. Therefore, architectural design has a double jeopardy: building must perform today also and be able to adapt in future climatic scenarios, so it is highly important to acknowledge the main tendencies and take into account the big picture.

It is interesting to notice that, in the case under study, when heating and cooling needs are added in a single figure the whole energy consumption present a variation of less than 10% (comparing today with the worst-case scenario) See Figure 4.

Figure 4.
Total energy consumption results for each climate change scenario. (RCP 4.5 and RCP 8.5 (2050 /2100)



It is important to take into account that even though consumptions seem similar and variations are perceived as low between scenarios, the main aspect to discuss is in the use of the energy required. In the current situation prevails energy consumption for heating with 57.5% of the total, mainly covered by using natural gas as auxiliary energy (Net to primary energy conversion factor = 1.25).

While, in the worst scenario, predominates energy consumption for cooling with 77.8% of the total, mainly covered by using electricity (air conditioning split units (Coefficient Of Performance COP = 3, type A. Net to primary energy conversion factor 3.30).

Therefore, it is important that design today has the ability in its DNA to adapt not only to temperature changes that might occur but also to the type of energy that might be needed.

ACKNOWLEDGEMENTS

Authors would like to thank the National Research Council of Argentina CONICET for founding PIP 11220200101711CO; and to the ANPCYT – FONCYT for funding PICT 2019-2752.

REFERENCES

1. The World Bank, (2021). [Online] Available: https://data.worldbank.org/indicator/SP.POP.TOTL.[May 2022].
2. IPCC - Intergovernmental Panel on Climate Change, (2018). *Global Warming of 1.5°C. An IPCC Special Report*.
3. IEA - International Energy Agency, (2018). World Energy Outlook 2018. [Online] Available: https://www.iea.org/weo/ [May 2022].
4. Ganem C, Barea G, Andreoni S., (2020). Assessing Buildings' Adaptation to Climate Change. In *35th PLEA Conference. Sustainable Architecture and Urban Design. Planning Post Carbon Cities*. A Coruña, Spain, September 1-3.
5. Owe, Bele, y Johnston"Directory of Energy Efficient Housing."(1996) London: Chartered Institute of Housing Ed.
6. Boontra y Thijssen (1997) *Solar Energy in Building Renovation*. International Energy Agency – IEA. Solar Heating and Cooling Programme. Task 20. London: James & James.
7. Voss, K. (2000) *Solar energy in building renovation – results and experience of international demonstration buildings.* Building and Environment, 32: p. 291-302.
8. Vilches, A., Garcia-Martinez, A., Sanchez-Montanes, B. (2017) *Life cycle assessment (LCA) of building refurbishment: a literature review*. Energy Build, 135: p. 286–301.
9. European Commission, European Construction Sector Observatory. *Analytical report on improving resource efficiency*. [Online] https://ec.europa.eu/growth/sectors/construction/observatory_en [May 2022].
10. Tettey, U., Dodoo, A., Gustavsson, L. (2017) *Energy use implications of different design strategies for multi-storey residential buildings under future climates.* Energy 138: p.846- 860.
11. Liu, S., Ting Kwok, Y., Ka-Lun Lau, K., Ouyang, W., Ng, E. (2020) *Effectiveness of passive design strategies in responding to future climate change for residential buildings in hot and humid Hong Kong.* Energy and Buildings 228: p. 110469.
12. Pajek , L., Kosir, M. (2021) *Strategy for achieving long-term energy efficiency of European single-family buildings through passive climate adaptation*. Applied Energy 297: p. 117-116.
13. Ganem, C. and Barea, G. (2021) *A methodology for assessing the impact of climate change on building energy consumption*. In: Palme, M., Salvati, A. (eds) Urban Micro climate Modelling for Comfort and Energy Studies. Springer.
14. IPCC- Intergovernmental Panel on Climate Change. (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Geneva, Switzerland.
15. Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. (2006). World Map of the Köppen-Geiger climate classification updated. *MeteorologischeZeitschrift* 15(3): p.259-263.
16. Servicio Meteorológico Nacional – Fuerza Aérea Argentina. [Online] https://www.smn.gob.ar/ [May 2022]
17. World Climate Research Program - WCRP, (2021). *Coupled Model Inter-comparison Project 5 (CMIP5)*. [Online] Available: https://esgf17node.llnl.gov/projects/ cmip5/ [May 2022].
18. Crawley DB, Lawrie LK, Pedersen CO, Winkelman FC, (2000). *EnergyPlus: Energy Simulation Program*. ASHRAE Journal.
19. ANSI/ASHRAE/IES(2016) Standard 90.1-2010.*Performance Rating Method Reference Manual.*
20. Nicol, F. (2017) *Temperature and adaptive comfort in heated, cooled and free-running dwellings*, Building Research & Information 45: p. 730-744
21. ANSI/ASHRAE (2020) Standard 55-2004. Thermal environmental conditions for human occupancy.
22. Nuñez, M. N., Solman, S., Cabré, M.,Rolla, A. (2005) *Estimación de escenarios regionales de cambio climático mediante el uso de modelos climáticos regionales.* Informe Final. UBA.
23. Solman, S., Pessacg, N. (2012) *Evaluating uncertainties in Regional Climate simulations over South America at the seasonal scale*. Clim. Dyn.39: p.59–76.22.
24. 3CN CIMA-FCEN-UBA. (2014). *Informe: Los estudios de los cambios climáticos observados en el clima presente y proyectados a futuro en la República Argentina.* [Online] Available: http://3cn.cima.fcen.uba.ar/3cn_informe.php [May 2022].
25. Aosta et al. (2015). *Cambio Climático en Argentina: Tendencias y Proyecciones*. Secretaría de Ambiente y Desarrollo Sustentable de la Nación. Argentina.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

ARCHITECTURE FOR HEALTH AND WELL-BEING

DAY 01
14:15 — 15:45

CHAIR
ISABEL RIVERA

PAPERS
1665 / 1471 / 1110 / 1663 / 1416

9TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022

Will Cities Survive?

Humanizing Social Housing

A case study of indoor environmental quality in San Pedro de la Costa, Chile

MARÍA ISABEL RIVERA[1-3], FRANCISCO DE LA BARRERA[2-3], CAMILA BARRAZA[3], CARLA DURÁN[3], JORGE PAVEZ[3] & ANDREA MARTÍNEZ[1-3]

[1] Departamento de Arquitectura, Facultad de Arquitectura, Urbanismo y Geografía, Universidad de Concepción, Chile
[2] Departamento de Geografía, Facultad de Arquitectura, Urbanismo y Geografía, Universidad de Concepción, Chile
[3] Centre for Sustainable Urban Development (CEDEUS), Chile

ABSTRACT: The health crisis, of the COVID-19 pandemic has exacerbated the problems of overcrowding and poor construction quality of social housing in Chile develop by the State, impacting thermal comfort, indoor air quality, and energy poverty. This article analyzes the factors that help explain these deficiencies' origin through a case study in the Biobío Region in Southern Chile. The objective is to evaluate physical environmental parameters like indoor temperature and relative humidity, from a local community through fieldwork measurements during the summer and winter seasons. In addition, identified relationships between users' perceptions of their indoor environment experiences during the pandemic, with those measure parameters from a total of 260 survey questionnaire responses. The aim is to advance our knowledge and understanding through empirical studies of indoor environmental quality of social housing developed by the State and the different adaptive measurements residents take to find comfort. Results confirm previous research findings of more than 15 years ago. Of poor indoor environments, social housing residents are exposed to, the urgent need for the State to improve current standards and construction quality to improve people's quality of life, health and well-being

KEYWORDS Thermal Comfort, Social Housing, Energy Poverty, Housing Policy, and IEQ

1. INTRODUCTION

The poor quality in terms of habitability and energy poverty of social housing in Chile is a situation largely diagnosed and evidenced, even prior to the COVID-19 pandemic [1-3]. Deficient construction codes and the lack of local standards for indoor environmental quality (from here on IEQ), intensifies the risk and transmission of infectious diseases, such as influenza and the new virus SARS-CoV-2. In addition, overcrowding in social housing is characterized by its small average size (50-60 m^2) [540-660 ft^2]. The problem is large, which implies large-scale solutions.

From 1990 to 2018 in Chile, the government has delivered 3.8 million social homes through housing subsidies. In the same period, 1.3 million partial subsidies were given to improve some aspects of existing housing quality, with a small fraction destined to improve the constructive quality of walls and ceilings [4]. This funding aimed to incorporate insulation in the envelope and enhance the thermal performance of dwellings and thus, make comfortable indoor temperatures, which can reduce heating demand. The reduction of heating demand can reduce outdoor pollution emissions of particulate matter (PM2.5) associated with wood burning and other indoor air pollution from open gas furnaces, both widespread household heating systems in Southern Chile.

The poor air quality of many southern cities of Chile facilitates the spread of infectious diseases, particularly for vulnerable groups such as children and the elderly, which has caused the death of 12,228 people in 2018 [5].

The acknowledgment of this severe problem results in plans oriented to reduce emissions of fine particulate matter in the most polluted cities. This stimulates subsidies for improving deprived houses. However, they failed when their focus was only on reducing emissions through the optimizations of appliances and fuels, but not resolving the essence of the problem, which is to improve people's comfort, energy efficiency and indoor quality of homes.

Under this scenario, a transdisciplinary group including researchers, practitioners, and residents has worked for over two years to evaluate and identify the gaps between existing IEQ conditions in social homes from comfort thresholds established in international standards. The group critically analyze the State's alternatives to improve comfort and energy efficiency, and then recognize the challenges of profound urban sustainability and propose solutions.

This article analyzes the factors of thermal comfort, indoor air quality, and energy poverty that help explain these deficiencies' origin through a case study in the Biobío Region in Southern Chile. The objective is to measure environmental stressors and their perceptions during the pandemic. Physical environmental parameters included indoor temperature and relative humidity, and outdoor particulate matter (PM2.5 & PM10) from a local community through fieldwork measurements during the summer and winter seasons. Users' perceptions of their indoor environment experiences focused on the pandemic effects. The aim is to advance our knowledge and understanding through empirical studies of indoor environmental quality of social housing developed by the State.

2. METHODOLOGY

2.1 Field Site Selection

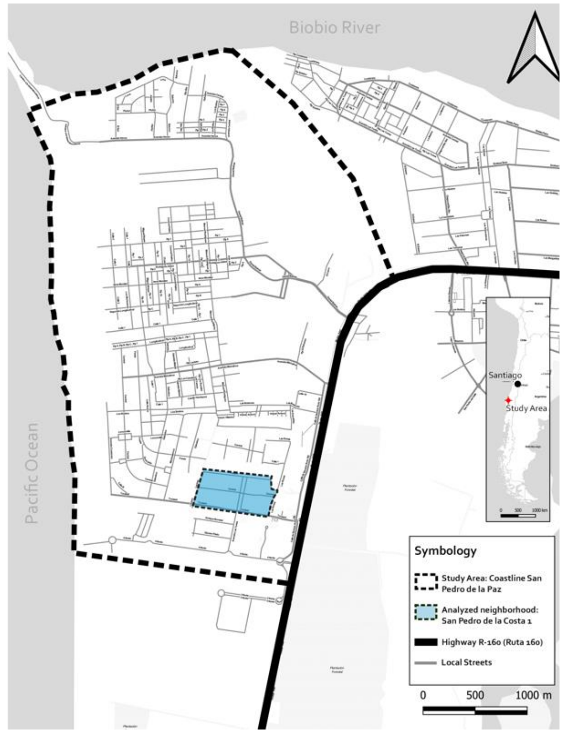
The study was carried out through fieldwork measurements in the neighborhood of San Pedro de la Costa Stage I (SPdlC from its Spanish acronym), in the west side of the commune of San Pedro de la Paz, part of the metropolitan area of Concepción, Chile. Climate conditions for Concepción and San Pedro de la Paz, based on the Köppen Classification System, are temperate (Csb), with cold, mild winters and mild dry summers. From historical weather data from Climate Consultant 6.0–2018, the range of annual average temperature in Concepción is 13°C (55.4°F), an annual average minimum of 8°C (46.4°F), an annual average maximum of 18°C (64.4°F). The maximum temperature can reach up to 28°C (83°F) during the summer months (December through March) and the low temperature can reach -2°C (28°F) during winter (June through September). Relative humidity averages can range between 58% and 90%.

2.2 Case Study

SPdlC Stage I was built in 2005 and included 850 homes on 162,509 m^2 [40.16 acres] distributed with 46% in residential usage, 39.35% for roads and streets, 9.37% for green spaces, and 5.36% for essential services. The neighborhood structure includes open spaces and squares, main urban roads, a diversity of essential services, and a mixture of residential and industrial zoning areas, see Figure 2. Currently, the neighborhood has a population of approximately 11,000 inhabitants, with a population density in the order of 232-359 inhabitants per hectare, concentrating high levels of overcrowding (11.6-19.4%) [6].

Figure 1:

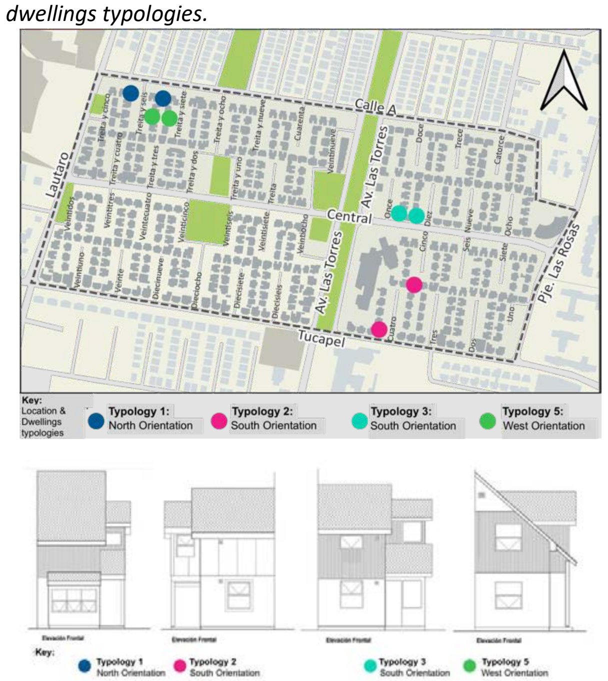
Case Study site location of the neighborhood San Pedro de la Costa I.



Note: Area in blue is the analyzed neighborhood of San Pedro de la Costa I. Source: CEDEUS.

Figure 2:

SPdlC neighborhood structure layout & distribution of dwellings typologies.



Note: Main elevation of the front façade of the four out of five main typologies of attached units commonly found at San Pedro de la Costa I. Source: CEDEUS.

The houses built were part of the Housing Program called "Dynamic Social Housing without

Debt" (Vivienda Social Dinámica Sin Deuda VSDSD from its Spanish acronym). This program eliminated credit assuming that families had a little debt capacity, and because there is no payment obligation, resources are used for the completion of their homes. The program employs the concept of "progressive housing" (Vivienda Progresiva for its Spanish term), in which the homeowners are responsible for at least 36% of the construction. This includes extending the square area, finishing indoor detailing and making spaces habitable and comfortable depending on owners' needs. Securing the success of this policy is put onto homeowners instead of the State, lacking tools and support from the government [7].

SPdIC Stage I project includes five housing typologies, of two stories each, some detached homes and other attached homes, as seen in Figure 2. The original square area of the housing started at 32m^2 [344 ft^2], putting a great deal of responsibility on the owners to upgrade and improve through various housing extensions to a least 50m^2 [54ft^2].

The area of the original house in its first stage has an average of 35 m^{2,} and it can reach between 50 to 60 m^2 through various stages of home extensions pre-considered in the original design. The houses were built with the 1st stage of the Thermal Regulation (2001), which considered insulation only in the roof. The construction of the initial home considers the following construction elements:

Table 1:
Housing construction building envelope materials and element composition.

Element	Composition	Insultation Material
Exterior Wall	**Level 1:** Brick with cement stucco on both side	None
	Level 2: Metal studs with OSB panel and drywall-sheetrock	None
Roof	Wood studs with drywall-sheetrock	Mineral wool
Floor	Cement slab with ceramic tiles	None
Windows	Single glazed pane, with aluminum frame and low emissivity	
Doors	Wood, poor airtightness	

Note: Collected data from envelope checklist. Source: CEDEUS.

2.3 Data Collection

Ethical and responsible conduct research

Approval was obtained by the Institutional Review Board (IRB) for research involving human subjects, from the Universidad de Concepción, prior to the start of data collection.

Measurement of environmental parameters.

Fieldwork measurements of indoor and outdoor environmental parameters were collected in two campaigns: 1) winter 2019 (July-August) in 16 homes, and 2) summer 2020 (January-February) in 8 homes. *ibuttons* sensors were used to collect ambient air temperature, and relative humidity every 10 minutes at the height of 1.1 m (3.6 ft) with a resolution of 0.065 degrees and ±0.5ºC accuracy for indoor and outdoor measurements. Various studies have used *ibuttons* temperature sensors in fieldwork to gather perceptions of users and physical parameters. As an example, the study by Venter et al. (2019) indicates that they are useful in studies related to health since they can represent the perception of people [8]. Sarricolea et al. (2008) focused on Urban Heat Island (UHI), where they complement fixed and mobile temperature measurement stations. In addition, the impact of green spaces through the use of vegetation and its distribution on mitigating UHI has been evaluated using ibuttoms in previous studies [9, 10].

Figure 3:
Location of ibuttoms indoors and outdoors.

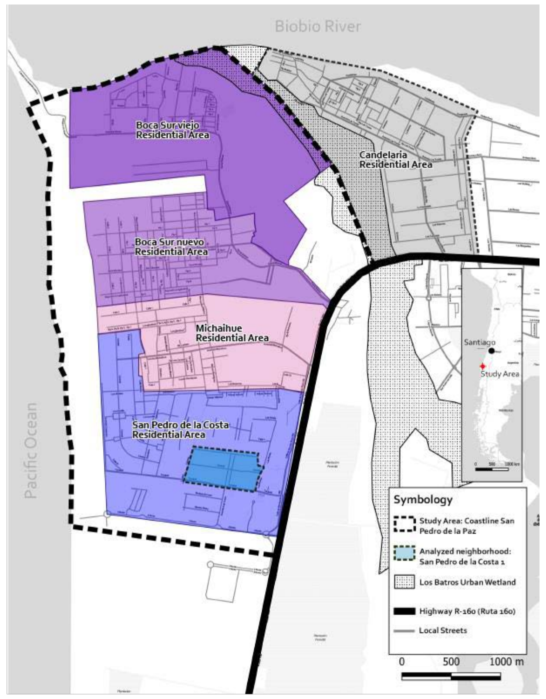
Source: CEDEUS.

Survey Questionnaire

In order to gain users' perceptions and experiences of their homes' indoor environment during the pandemic, a total of 216 survey responses were collected in the neighborhoods of the study area: Coastline of San Pedro de la Paz, as seen in Figure 4. The questionnaire contemplated a self-application technique through a web online survey and interview-based by phone. A subsample of 66 responses analyzed for the neighborhood of San Pedro de la Costa I for this paper see Figure 4. The aim of the survey called: *"Covid-19: What is happening in my neighborhood",* was to investigate the perceptions of the inhabitants in various areas that affect the quality of urban life, such as walkability, mobility, indoor thermal comfort of homes, and citizen participation and the relationship with state institutions. The questionnaire had 70 questions with an average length of 15 minutes each.

For one month, the survey was conducted in Spanish to adults older than 18 years old for men and women residents in the Coastline of San Pedro de la Paz. The thermal comfort section of the questionnaire asked questions about the resident's type of heating system used during winter, economic difficulties for heating during the pandemic, and perception of thermal sensation in winter.

Figure 4:
Neighborhoods involved in the survey responses of the study area: Coastline of San Pedro de la Paz.



Note: Five different *Neighborhoods* participated in the questionnaire as highlighted in different colors. The area in blue is the sub-sample of 66 survey responses analyzed for the neighborhood of San Pedro de la Costa I. Source: CEDEUS.

3. RESULTS

3.1 Deficiency constructive quality of the housing envelope

Poor airtightness was found in homes analyzed, leading to energy loss to the outside. Openings, like broken windows or holes in the building envelope due to poor construction detailing, it was estimated 4 air changes per hour (ACH) due to infiltrations in the wall cavities. Cold surface temperatures promote external condensation and mold growth inside the envelope and in indoor spaces, affecting construction materials and their residents' health and well-being. From field assessments, these dwellings present: discontinuous or non-insulated material, with single glassed windows and doors with little airtightness causing high thermal transmittance, heat losses caused by air infiltrations in winter, and overheating in summer, affecting directly residents' indoor comfort conditions.

3.2 Deficiency IEQ affecting comfort, health, and well-being

Data reveal minimal differences between indoor and outdoor air temperature in winter, with low indoor temperatures in many cases not higher than 5˚C than outdoor temperatures. From survey responses, 85% declared being cold most of the time in their homes. More than 56% declared having difficulties paying their heating, increasing up to 85% for those with low income (< CLP 150.000 (Chilean pesos)) [approximately < 200.00 USD] versus 75% for middle-low income ($150.000-350.000 CLP) [approx. 200-450.00 USD].

Table 2:
Summary of outdoor and indoor air temperature measurements for Winter and Summer Season.

		Minimum		Maximum		Average		STDA	
		Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoor
Summer	North	9.47	18.16	33.23	27.73	18.99	22.25	4.92	1.63
	South	10.72	15.84	35.55	24.85	18.70	24.85	4.64	1.65
	West	10.27	16.01	26.29	28.59	17.37	20.39	3.50	2.41
Winter	North	0.83	8.29	31.27	24.20	12.33	16.06	5.03	2.47
	South	1.85	8.15	25.66	29.74	11.24	16.95	3.56	3.22
	West	1.54	8.20	25.46	25.04	10.99	13.14	3.68	2.36

Note: Data was collected from three different main façade orientation (north, south and west orientation) and home typologies. Temperature values are in degree Celsius (°C). Source: CEDEUS.

From preliminary observational fieldwork in the original 850 social housing project of stage 1 (SPdC 1), it is possible to identify that 95.2% (810 homes) have altered their original construction design. In other words, only 40 dwellings (4.7%) retain their original structure. Due to the existing modifications that these social housings currently have, a diagnostic fieldwork evaluation of a subsample of 106 was visited. The latter resulted from a pre-evaluation of dwelling's conditions that did not have major modifications to the original design and could potentially get regularized. Thus, homeowners could apply to a new program developed by the government to retrofit existing building envelopes to improve thermal and energy performance through the installation of wall insulation.

During fieldwork, qualitative observational data was also gathered through a technical checklist requested by the Municipality San Pedro de la Paz, Public Works Department. In addition, notes of construction materiality, envelope conditions, housing extensions, and documented photography during in walk-in inside homes.

Multiple forensic pathologies were identified, as shown in Table 3**,** classified into three categories: Dwelling construction materiality, self-construction solutions and irregular house extensions, and material & usage weathering**.**

From the 106 visits, an average of 4 to 5 people lived in each dwelling. Approximately 90% of the houses have shared bedrooms, in which more than three people live inside, between 9 to 12 m^2 [97 to 130 ft^2]. It was observed that the main reasons for house extensions is to increase the number of bedrooms and to increase social areas such as the kitchen or living room.

3.3 Perception of inhabitants and experiences of dwelling's indoor environment

Demographically the results characterize a population of low income of less than $500,000 CLP (65%) Chilean Pesos [approximately 613.00 USD], where 43% receive less than $350,000 CLP the latter being a figure equivalent to the country's monthly minimum salary [approx. 430.00 USD] in comparison to the minimum wage in US, approx. 1,250.00.

Households are mainly inhabited by four or fewer people representing 48% of the survey responses, and 20% of dwellings have two or more families.

When asked about how they lived in the past winter (2020), 85% stated that they were cold in their homes and felt colder than in the previous winter (2019). Of the responses, 29% are cold always or almost always. The percentage of these responses was higher in households with lower incomes. Thus, households with incomes below $150,000 CPL felt cold 97%, in 52% experienced it always or almost always. Meanwhile, where the income is between $150,000 to $350,000 CPL, 95% of households were cold, and 33% experienced it always or almost always. These figures tend to decrease as income increases.

When asked to identify the most important problem inside their homes, 35% identified that being cold was the most important problem, fallow by crowdedness at their homes with 31%, and 16% indicated the lack of direct sunlight in their patio the third most common problem. The lower the income, the higher the identification of cold thermal sensation experiences inside their homes as the most significant.

In addition, from the survey responses, more than half (56%) of residents declared having difficulties heat-up their homes during winter, a result that increases to 85% among those with less than $150,000 CLP monthly salary and 75% within the range of $150-350.000 CLP. Thus, decreasing successively with higher incomes.

Among the houses without extensions, the main problem is the lack of space, while in those with extensions, it is the cold thermal sensation. On the other hand, the cold is the main problem identified in houses with up to four people, while with five or more people, the main problem identified is the lack of space and crowdedness.

As for the San Pedro de la Costa Stage 1 neighborhood, corresponding to 66 cases in the sample, 58% of households have between 3 or 4 family members. In contrast, households with five or more represent 24% of the households. Regarding the perception of cold thermal sensation in their homes, 34% of the people surveyed indicated that it is the most important problem during the winter, followed by the lack of space (26%). The 46% of those surveyed associate problems with interior conditions derived from spending more time inside their home during the winter in the middle of the pandemic due to enforced quarantines by the government.

Multiple forensic pathologies were identified, in Table 2, classified into three categories: Dwelling construction materiality, self-construction solutions and irregular house extensions, and material & usage weathering**.**

Table 3:
Forensic pathologies identified in building envelope & usage weathering.

	Image	Diagnostic
Dwelling construction materiality		Lack of wall insulation causes cold interior surfaces in winter, condensation, mold & humidity
		Thermal bridges with discontinuous insulating material are evident, which provides energy losses to the outside
Self-construction solutions & irregular extensions	 	House extensions take up most of the site's footprint, leaving little patio and access to daylight. Extensions are made with low-quality construction materials, with poor finishes favor air and water infiltration and leakage from the outside, letting the interior air escape.
Material & usage weathering		High concentration of clutter indoor and outdoor in homes. High concentration of dust in rooms utilize as storage.

Note: Categories of multiple forensic pathologies identified through an observational diagnostic of existing housing conditions of building envelope materials

4. CONCLUSION

Constructive solutions of social housing are poor and imply additional severe health and well-being problems due to deficient indoor environmental quality such as thermal comfort, which are not solved by only modifying heating systems or energy sources. The state needs to address the problem from its origin, which is to improve housing envelopes and indoor conditions systematically.

The challenge is not only for future social housing to be built with higher construction quality standards and indoor habitability but also a considerable effort should be paid to repair deficiencies through retrofit techniques of existing housing construction towards a more sustainable approach. It is urgent to increase the responsibility, relevance, and comprehensiveness of current policies and incentives of the state, which truncate the possibilities of the well-being of the communities and threaten the sustainability of the cities.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the research support provided by CEDEUS, ANID FONDAP 15110020 and ANID PAI 77180057.

REFERENCES

1. Espinosa Cancino, Constanza Francisca, & Cortés Fuentes, Alejandra. (2015). Confort higro-térmico en vivienda social y la percepción del habitante. *Revista INVI*, *30*(85), 227-242. https://dx.doi.org/10.4067/S0718-83582015000300008

2. Jirón Martínez, P., Toro Blanco, A., Caquimbo Salazar, S., Goldsack Jarpa, L., & Martínez Muñiz, L. (2004). *Bienestar habitacional: guía de diseño para un hábitat residencial sustentable*. Instituto de la Vivienda FAU Universidad de Chile. Disponible en https://doi.org/10.34720/s0k1-2823

3. Wegertseder, P., & Trebilcock, M. (2015). Integración de criterios de desempeños en el mejoramiento energético-ambiental de viviendas sociales existentes en Chile. Ambiente Construído, Porto Alegre, v. 15, n. 2, p. 47-63, abr./jun. 2015. ISSN 1678-8621 Associação Nacional de Tecnologia do Ambiente Construído. http://dx.doi.org/10.1590/s1678-86212015000200013

4. Pávez, J., Barraza, C., Durán, C., Rivera, M.I., de la Barrera, F. (2020, November 12). *Frío, contaminación y hacinamiento: un millón de viviendas sociales con fallas que facilitan la expansión del Covid-19*. CIPER. https://www.ciperchile.cl/2020/11/12/frio-contaminacion-y-hacinamiento-un-millon-de-viviendas-sociales-con-fallas-que-facilitan-la-expansion-del-covid-19/

5. Instituto Nacional de Estadísticas INE (2018). Anuario de Estadísticas Vitales, 2018.

6. Instituto Nacional de Estadísticas INE (2017). Anuario de Estadísticas Vitales, 2017.

7. Aguirre C. D'Alençon R., Justiniano C. & Faverio F. (2006). Lineamientos generales para la terminación de las viviendas dinámicas sin deuda. Resumen investigación y propuesta. http://www.subdere.gov.cl/sites/default/files/documentos/articles-69777_recurso_1.pdf

8. Sarricolea, P., Aliste, E., Castro, P., & Escobedo, C. (2008). Análisis de la máxima intensidad de la isla de calor urbana nocturna de la ciudad de Rancagua (Chile) y sus factores explicativos. Re*vista de Climatología,* 8(2008), 71-84.

9. Pérez, J., y De la Barrera, F. (2021). Rol de la vegetación en el control del microclima urbano y en la adaptación a los efectos del cambio climático en un barrio de San Pedro de la Paz, Chile. URBE. Arquitectura, Ciudad y Territorio, (13), 36-53. http://dx.doi.org/10.29393/UR13-3RVJP20003

10. Park, J., Kim, Jun-Hyun., Kun Lee, D., Yeon, C., y Gyu Jeong, S. (2016). The influence of small green space type and structure at the Street level on urban heat island mitigation. Urban Forestry & Urban Greening 21. Pp. 203-2012. 10.1016 / j.ufug.2016.12.005

PLEA SANTIAGO 2022
Will Cities Survive?

I Lived in a Passive House Building: Here's What I Learned

A post-occupancy evaluation comparing indoor environmental quality and performance between one residential unit built to passive house standards and another residential unit built to conventional standards

SIGAL SHEMESH[1]

[1]LEED AP BD+C, WELL AP, LFA

ABSTRACT: Passive House buildings are considered to be the epitome of high-performance design. Industry experts understand that Passive House design implies airtightness and ultra-low energy consumption. High-performance design is also associated with superior air quality and thermal comfort, but how do these variables actually perform in a real-world design? This paper unravels the benefits and drawbacks of an anectodal experience living in a Passive House-designed multifamily residential building in Manhattan, New York. Three variables, which include indoor air quality, thermal comfort, and energy consumption have been studied to compare a Passive House building to a conventional building of similar size in the same neighborhood in Manhattan, New York. In this work, the author concluded that the Passive House unit differed in air quality with an 894% increase in average TVOCs, a 155% increase in average CO_2, and a 2% reduction in average $PM_{2.5}$ as compared to a conventional unit. The author additionally concluded that the Passive House unit had thermal comfort improvements resulting from a 13-degree F reduction in temperature differential, a 24% improvement in average humidity, and a 14% annual reduction in energy consumption from electricity end uses as compared to a conventional unit.

1. INTRODUCTION

The experiment was conducted over a one-year period and measured the performance of three variables: air quality, thermal comfort, and energy consumption. First, the experiment involved measurements taken in one unit in a conventional building constructed in 1921 in the Hamilton Heights neighborhood of Manhattan, New York. Second, the experiment involved measurements taken in one unit in a Passive House building constructed in 2017 in the same neighborhood. Both measurements were taken on separate dates as the author did not occupy the units for the same timeframe.

1.1 Indoor Air Quality Background

Humans spend approximately 90% of their time indoors (EPA). It's estimated that the indoor concentration of pollutants is 2-5 times the outdoor concentration of pollutants. (Fisk, 2017, p.909-920; Parsons Healthy Materials Lab; EPA). This suggests that creating an indoor environment with good air quality is essential to human health and wellbeing. Several variables contribute to environmental quality. Poor air and environmental quality are prime contributors to sick building syndrome (SBS) among other factors (Joshi, 2008, p.61-64). The environmental performance variables discussed in this report are detailed in the following section.

1.1.1 Total Volatile Organic Compounds (TVOCs)

Airborne chemicals come from a variety of indoor sources. Furniture, wet-applied products such as paints and glues, cleaning products, products with synthetic fragrances, such as candles, and secondhand smoke are significant sources of TVOCs indoors (Joshi, 2008, p.61-64). While TVOCs can go unnoticed by occupants, high concentrations can cause significant health issues. Exposure to formaldehyde and benzene is associated with eye, nose, and throat irritation, but more importantly, exposure to formaldehyde is linked to nasopharyngeal cancer and leukemia (International Agency for Research on Cancer, 2018). Acute exposure to high levels of toluene can cause central nervous system dysfunction and narcosis in addition to dizziness and loss of coordination (National Research Council, 2009; EPA,2017).

An acceptable TVOC range is between 0 and 333 parts per billion (ppb) as illustrated by the air quality sensor application developed by Awair and shown in Figure 1 in green. Yellow, orange, and red are in the ranges that could cause adverse health impacts for building occupants.

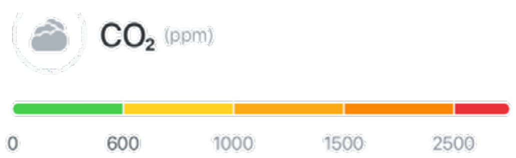
Figure 1:
TVOC Concentration Range

1.1.2 Carbon Dioxide (CO_2)

A high concentration of CO_2 is a prime contributor to reductions in cognitive ability, associated with headaches, drowsiness, and a proxy for adequate or inadequate ventilation (Fisk & Mirer, 2009, p.159-165). The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) requires a minimum of 5 cubic feet per minute (CFM) of outdoor air per person for a bedroom or living room (ASHRAE 62.1, 2016, p.14). Improving ventilation to approximately 20-50 cfm/person can have a 29% decrease in the prevalence of SBS symptoms (Fisk & Mirer, 2009, p.159-165). CO_2 levels at even 1000 ppm can have negative health impacts on humans and have been measured in poorly ventilated spaces (Jacobson, et al, 2019, p.691-701).

While there is not yet agreement on optimal CO_2 levels, an acceptable CO_2 range is between 400 and 600 parts per million (ppm) as illustrated by Awair and shown in Figure 2 in green. Note that atmospheric CO_2 is at 400 ppm and readings below 400 ppm are unrealistic. Yellow, orange, and red are in the ranges that could cause adverse health impacts for building occupants.

Figure 2:
CO_2 Concentration Range



1.1.3 Particulate Matter ($PM_{2.5}$)

Particles that have a diameter of less than 2.5 microns (µm) are known as $PM_{2.5}$ and are considered fine particles. They can penetrate deep into the lungs and are linked to greater health risks compared to larger particles, such as PM_{10} (Xing, et al., 2016, p.E69-E74). Inhaling elevated levels above 10 micrograms per meter cubed (µg/m^3) of particulate matter has been linked to adverse health effects, such as cardiopulmonary issues and lung cancer (Rückerl, et al, 2011, p.555-592; WHO, 2010).

An acceptable $PM_{2.5}$ range is between 0 and 15 µg/m^3 as illustrated by Awair and shown in Figure 3 in green. Yellow, orange, and red are in the ranges that could cause adverse health impacts for building occupants.

Figure 3:
PM2.5 Range

Unlike TVOCs and CO_2, $PM_{2.5}$ does not require additional ventilation to reduce concentrations. A filter, such as one with a Minimum Efficiency Reporting Value (MERV) higher than 13 is enough to capture $PM_{2.5}$ and recirculate clean air. TVOCs, however, require carbon filtration to adsorb chemicals from the air or the introduction of outdoor air. CO_2 requires the introduction of outdoor air to replace CO_2 saturated air. While the introduction of outdoor air is essential for good air quality, it is associated with higher energy consumption, especially to temper outdoor air supplied in cold climates. Additional outdoor air in areas with poor outdoor air quality requires filtration media to reduce particulate matter from entering the indoor environment.

Temperature and humidity can equally impact air quality and occupant health and wellbeing and are considerable variables to incorporate when discussing thermal comfort. The impacts of these variables are detailed below.

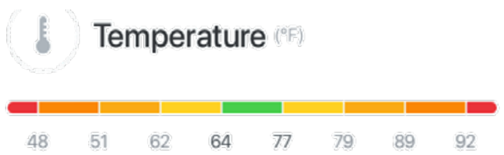
1.2 Thermal Comfort Background

1.2.1 Temperature

Thermal dissatisfaction is associated with too hot or too cold conditions that can contribute to health impacts, such as dry throat, coughing, itchy skin, and fatigue (Mendell & Mirer, 2009, p.291-302; Joshi, 2008, p.61-64). Too low indoor temperatures can increase blood pressure, asthma symptoms, and are associated with poor mental health while too high indoor temperatures are associated with emergency hospitalizations, cardiovascular and all-cause mortality. Temperatures outside of the acceptable range can lead to poor employee performance in an office environment and increased absenteeism.

An acceptable air temperature range is between 64 and 77 degrees F as illustrated by Awair and shown in Figure 4 in green. Yellow, orange, and red are in the ranges that could be thermally uncomfortable for building occupants.

Figure 4:
Temperature Range

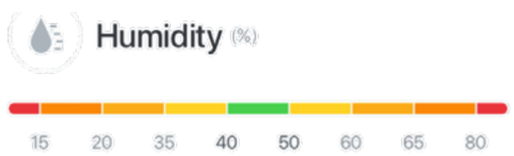


1.2.2 Humidity

Exposure to high or low humidity over the long term can lead to the potential accumulation of dust mites and mold, which can negatively impact occupant respiratory health (Arundal, et al., 1986, p.351-361; EPA, 2016). High indoor humidity is associated with discomforts such as stuffiness or staleness while low indoor humidity is associated with favorable transmission of certain viruses, such as influenza, increase in respiratory issues, as well as eye irritation, and dryness of the nose and throat.

An acceptable humidity range is between 40% (the lowest is 30% as described in a Mayo Clinic study published in 2015) and 50% as illustrated by Awair and shown in Figure 5 in green. Yellow, orange, and red are in the ranges that could cause discomfort for building occupants.

Figure 5:
Humidity Range



1.3 Energy Consumption Background

Passive House Institutes in the US and internationally emphasize a passive approach to energy reduction by improving façade design. Passive House buildings aim to reduce heating and cooling loads compared to conventional buildings, particularly in cold climates, as they are well insulated, tightly sealed, and lack thermal bridging (Passive House Institute US (PHIUS)).

2. METHODOLOGY

The methodology involved an assessment of indoor environmental quality (IEQ) characteristics in one apartment unit of roughly 800 square feet in a conventional building and one apartment unit of similar size in a Passive House building. Quantitative measurements utilized data collected by an Awair air quality sensor. Both units had the same type and number of appliances. Both units and their respective buildings were of roughly similar size and within a half-mile radius from each other in Manhattan, New York. Only one occupant of the apartment unit was present during the time period of the datasets shown in this paper. An important consideration is the location of the occupant in each apartment unit. In the case of the conventional unit, the occupant lived in a separate room from where the experiment had taken place. In the Passive House unit, the author occupied the same room as the experiment. Both units were occupied during different timeframes and the location of the monitor in each unit may contribute to variations seen in the data. A summary comparison of each unit is shown in Table 1.

Table 1:
Unit Comparison

	Conventional Unit	Passive House Unit
Location	Manhattan, NY, USA	Manhattan, NY, USA
Climate Zone	4A	4A
Size of Unit	~ 800 SF / 3 bedroom	~ 800 SF / 2 bedroom
Size of Building	5 Stories / 20 units	7 Stories / 34 units
Floor Level	2	5
Glazing Orientation	235 Degrees SW	235 Degrees SW
Window to Wall Ratio (WWR)	~ 10-20%	~ 40-50%
Envelope Performance	Unknown	Unknown
Equipment Power Density	Unknown	Unknown
Lighting Power Density	Unknown	Unknown
Heating	Central Steam Boiler	ERV
Cooling	Window AC	ERV
Ventilation	None	ERV
Gas/Electric Cooking	Gas	Electric
Awair Sensor Location	Bedroom	Bedroom

3. EXPERIMENT

The data analyzed in this paper were collected using an Awair air quality sensor with a collection frequency of 5-minute intervals at a height of two feet above the floor and at a location away from the window. The air quality data collected in the conventional unit (CU) were collected for the month of November 2020, while the data collected for the Passive House unit (PHU) were collected from the time period of December 2020 through December 2021. For the purposes of this paper, shorter periods of data are highlighted to show certain trends and links to the variables. The results discussed in detail are based on the following data sets pertaining to each variable. The decision to solely include air quality and thermal comfort during the winter was made because natural ventilation was consistently used during the shoulder seasons and summer months and therefore does not show the impact of a sealed indoor environment. While windows were opened for certain time periods during the study period, this is noted in the discussion section.

Indoor Air Quality and Thermal Comfort:

CU – November 18, 2020 – November 28, 2020

PHU – December 22, 2021 – January 2, 2022

Energy Consumption:

CU – November 2019 – October 2020

PHU – November 2020 – December 2021

Indoor air quality, energy consumption, and thermal comfort were quantitatively measured, however, there is a certain level of qualitative analysis associated with thermal comfort as this is a subjective variable. Limitations to data collection are due to the variables available for measure using the Awair Element sensor and the available information from ConEdison utility bills for both residential units.

4. RESULTS AND DISCUSSION

The results discussed below are correlated to graphs shown in a separate appendix not included within this paper due to page number limitations.

4.1 Indoor Air Quality

Between the two units, indoor air quality differs depending on the variable studied.

4.1.1 Total Volatile Organic Compounds (TVOCs)

The concentration of chemicals in the air was significantly higher than acceptable concentrations for a majority of the time period in the PHU while remaining at acceptable concentrations in the CU. Periods of lower concentrations in the PHU can be linked with windows being opened to provide additional ventilation. While the dataset shows periods of acceptable TVOC concentrations, the TVOC concentration was never reduced below 333 parts per billion (ppb) when windows were not open. The maximum concentration of TVOCs recorded during the study period was 21,250 ppb. This is well above the threshold of 8,332 ppb, which is considered hazardous according to Awair.

4.1.2 Carbon Dioxide (CO_2)

The concentration of CO_2 in the PHU was consistently elevated when there was an occupant in the same room as the Awair sensor. During the study period, the author was primarily in a separate room during the day and in the same room as the Awair sensor at night. Even while the author occupied a separate room, the CO_2 concentration remained at an elevated position between 600 and 1000 parts per million (ppm). Periods of CO_2 concentrations below 600 ppm are predominantly a result of increasing ventilation by opening a window.

The CU CO_2 concentration remained around 400 ppm, though the occupant in the CU was primarily in a different room. A key data point is when the CO_2 concentration jumps to 1650 ppm while there is an occupant in the same room. There is a noticeable and rapid decline back to 400 ppm once the occupant leaves the room. In the PHU, even when there are no occupants in the unit, the CO_2 concentration remained between 600 and 800 ppm (not shown in the datasets in this paper).

An additional dataset for a one-day period resulted in a maximum CO_2 concentration of 1983 ppm with the windows closed during this timeframe.

4.1.3 Particulate Matter ($PM_{2.5}$)

The concentration of particulate matter of 2.5 microns or less in diameter was similar in both the CU and PHU. While infiltration in the CU is a contributor to particulate matter, dust and indoor activities such as cooking primarily impacted particulate matter concentrations in the PHU. PM2.5 trends at acceptable levels other than an elevated period due to cooking activities and the lack of a range hood exhausting air to the outside.

4.2 Thermal Comfort

Following closely the impact of envelope performance on energy consumption is the impact on thermal comfort. Thermal comfort is influenced by six factors, which include air temperature, mean radiant temperature (MRT), humidity, air velocity, clothing insulation, and metabolic rate (Fanger, 1973, p.313-324). The concept of comfort is subjective and depends highly on an individual's psychological, physiological, and behavioral factors (Frontczak, Wargocki, 2011, p.922-937). Due to the limitations of this experiment, only air temperature and humidity data have been collected.

4.2.1 Temperature

Air temperature differed significantly between units. The CU had more frequent temperature swings due to inconsistent heating and a poor-performing envelope, which included high infiltration rates and thermal bridging at the IGUs. The data shows that while the temperature was predominantly in the comfort range between 64 and 77 degrees F, the lowest temperature in the space was 59 degrees F. Windows were not opened during this study period.

The PHU on the other hand had a consistent trend of stable temperatures that were subjectively comfortable throughout the study period even when windows in other rooms had been opened for certain periods of time. The PHU has a low infiltration rate and mitigated thermal bridging.

4.2.2 Humidity

Similarly, humidity differed significantly between the units. The lack of humidity control in the CU meant that the humidity tracked outdoor humidity levels closely and was predominantly outside of the acceptable humidity range (40-50%). The PHU had a higher level of humidity control. When windows are not open, the humidity in the space was consistently in the acceptable range.

4.3 Energy Consumption

Between the two units, energy consumption is similar for electricity end uses that are not heating or cooling. Detailed analysis was not performed to understand the intricacies of the end uses and exact performance criteria such as envelope values, lighting power densities, equipment power densities, and HVAC efficiencies are not known, nor were the various end uses submetered. In addition, heating energy use in the CU was not accessible by the author as it is typical for the building management company to cover this cost for tenants. Therefore, electricity rather than total energy consumption data for each unit can only be compared at a conceptual level.

5. CONCLUSION

In this work, the author summarized the post-occupancy performance of an apartment unit in a Passive House building compared to a similar apartment unit in a conventional building.

5.1 Indoor Air Quality

5.1.1 Total Volatile Organic Compounds (TVOCs)

TVOCs in the PHU were 2279 ppb on average compared to 229 ppb on average in the CU. This is an 894% increase in average TVOC concentration. While the source of the TVOCs is still unknown, the likely conclusion is second-hand smoke from cigarette smokers and scented candle use by neighbors on the same floor. The entrance to the PHU is not well sealed and the recirculation intake is located at the entrance of the PHU. Possible other spikes in TVOC concentration can be related to cooking with aromatic foods and cleaning activities during which TVOCs were mitigated by increasing ventilation by opening the window within the PHU. Since the unit had not been recently painted or new furniture introduced prior to the study period, off-gassing was an insignificant concern. Lastly, the PHU had its own ERV with supply air intake and exhaust only catering to the PHU and therefore contaminants were not exchanged between other units through ducts.

5.1.2 Carbon Dioxide (CO_2)

CO_2 was 1329 ppm on average in the PHU compared to 470 ppm on average in the CU. This is a 155% increase in average CO_2 concentration. The source of CO_2 is known and serves as a proxy to determine whether the space was receiving adequate ventilation. The likely conclusion is that the space did not receive adequate ventilation to reduce the high presence of contaminants such as CO_2 and TVOCs. While the thermostat and ventilation control were confirmed early in the experiment with the building's superintendent and design engineer, further steps to investigate the issue should be considered.

5.1.3 Particulate Matter ($PM_{2.5}$)

$PM_{2.5}$ was 2.81 µg/m³ on average in the PHU compared to 2.88 µg/m³ on average in the CU. This is a 2% reduction in particulate matter, however, both levels are acceptable for what is considered to be good indoor air quality and were not of concern.

Based on these findings, particulate matter is less associated with the type of building and more with the use of air filtration devices whether freestanding or within the HVAC system. Cleaning filters frequently is important to avoid particulate matter build-up that can impact airflow and filtration efficacy.

5.2 Thermal Comfort

5.2.1 Temperature

While both the PHU and CU maintained a similar average temperature, the PHU had a 6-degree F temperature differential between 70 and 76 degrees F while the CU had a 19-degree F temperature differential between 59 degrees F and 78 degrees F. This is due primarily to poor envelope performance and inconsistencies in heating supplied via steam radiator in the CU.

While setpoints were not applicable to the CU since heating and cooling are provided by uncontrollable steam radiators and window air conditioners, the PHU setpoints were set to 75 degrees F during the summer (cooling season) and between 67 and 70 degrees F during the winter (heating season). It should be noted that due to the envelope performance of the PHU, and with the addition of internal gains such as heat from people, lights, cooking, clothes dryer, computer equipment, as well as beneficial external solar gain, the space maintains an average temperature of 72 degrees F, which is higher than the minimum heating setpoint.

5.2.2 Humidity

Humidity was 40% on average in the PHU compared to 32% on average in the CU. This is a 24% improvement in humidity in the PHU and falls within a comfortable range. This is primarily due to active conditioning provided by the ERV in the PHU as compared to no active conditioning in the CU.

5.3 Energy Consumption

The annual reduction in electricity consumption in the PHU was 14%. These results require additional analysis to understand overall energy consumption by incorporating heating energy from the steam boiler in the CU. Due to limitations in accessing this data, only electricity consumption has been compared.

5.4 Overall Conclusions

The results suggest that Passive House units may require a higher rate of ventilation to reduce detrimental health impacts of high concentrations of indoor pollutants such as TVOCs and CO_2. More specifically, occupants are not always aware of the air quality within their units and therefore occupant engagement, such as opening a window or using air filtration devices, are not options when air quality is poor. Similarly, occupants generally do not know when to alert the building engineer or superintendent to inspect equipment.

A key finding is that a well-sealed building such as the case for the Passive House building needs additional design thought to ensure occupant health and wellbeing are prioritized. Based on the experiment's findings, there are key considerations that should influence how designers and engineers design high-performing buildings. These key considerations include to:

1. Implement HVAC and envelope commissioning to ensure ventilation is adequate and perform a blower door test to ensure infiltration of air and water is significantly reduced.
2. Ensure proper sealing around doors and windows to mitigate infiltration.
3. Implement natural ventilation to reduce energy consumption and improve air quality.
4. Implement healthier materials to reduce occupant exposure to TVOCs.
5. Implement triple-pane glazing to improve thermal comfort and reduce indoor air temperature swings.
6. Perform post-occupancy evaluation of indoor air quality.
7. Consider and account for potential user or occupant errors such as leaving windows and doors open that can reduce energy performance.

ACKNOWLEDGEMENTS

I wish to show my appreciation and extend thanks to the team at Awair for providing the data and my colleagues for reviewing this paper and providing valuable and constructive feedback.

REFERENCES

1. American Society of Heating Refrigerating and Air-Conditioning Engineers, (2016). ANSI/ASHRAE Standard 62.1-2016 -- Ventilation for acceptable indoor air quality. American Society of Heating Refrigerating and Air-Conditioning Engineers, p.14.
2. Arundel AV., Sterling EM., Biggin JH, Sterling TD., (1986). Indirect health effects of relative humidity in indoor environments. Environ Health Perspect, 65: p. 351-361.
3. Awair Air Quality Monitor. 2021.
4. Fanger PO., (1973). Assessment of man's thermal comfort in practice. Br J Ind Med, 30(4): p. 313-324.
5. Fisk WJ., Chan WR., (2017). Effectiveness and cost of reducing particle-related mortality with particle filtration. Indoor Air, 27(5): p. 909-920.
6. Fisk WJ., Mirer AG., Mendell MJ., (2009). Quantitative relationship of sick building syndrome symptoms with ventilation rates. Indoor Air, 19(2): p. 159-165.
7. Frontczak M., Wargocki P., (2011). Literature survey on how different factors influence human comfort in indoor environments. Building and Environment. 46(4): p. 922-937.
8. International Agency for Research on Cancer. Formaldehyde [Monograph 88-6A], (2018). International Agency for Research on Cancer.
9. Jacobson TA., Kler JS., Hernke MT., Braun RK., Meyer KC., Funk WE., (2019). Direct human health risks of increased atmospheric carbon dioxide. Nature Sustainability, 2(8): p. 691-701.
10. Joshi SM., (2008). The sick building syndrome. Indian J Occup Environ Med. 12(2): p. 61-64.
11. Mayo Clinic. Humidifiers: Air moisture eases skin, breathing symptoms, (2015) https://www.mayoclinic.org/diseasesconditions/common-cold/in-depth/humidifiers/art-20048021. Accessed January 9, 2022.
12. Mendell MJ., Mirer AG., (2009). Indoor thermal factors and symptoms in office workers: findings from the US EPA BASE study. Indoor Air, 19(4): p. 291-302.
13. National Research Council (US) Committee on Contaminated Drinking Water at Camp Lejeune. 3. Systemic exposures to volatile organic compounds and factors influencing susceptibility to their effects. In: Contaminated water supplies at Camp Lejeune: assessing potential health effects. Washington, DC: National Academies Press; 2009.
14. Parsons Healthy Materials Lab. https://healthymaterialslab.org/. Accessed January 10, 2022.
15. Passive House Institute United States. Passive house principles. https://www.phius.org/what-is-passive-building/passive-house-principles. Accessed January 9, 2022.
16. Rückerl R., Schneider A., Breitner S., Cyrys J., Peters A., (2011). Health effects of particulate air pollution: A review of epidemiological evidence. Inhal Toxicol, 23(10): p. 555-592.
17. United States Environmental Protection Agency. Care for your air: A guide to indoor air quality, (2016) https://www.epa.gov/indoor-air-quality-iaq/care-your-air-guide-indoor-air-quality. Accessed January 9, 2022.
18. U.S. Environmental Protection Agency. Toluene: Hazard Summary, (2017).
19. World Health Organization. WHO guidelines for indoor air quality: selected pollutants, (2010).
20. Xing Y-F., Xu Y-H., Shi M-H., Lian Y-X., (2016). The impact of $PM_{2.5}$ on the human respiratory system. J Thorac Dis, 8(1): p. E69-E74.

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

Analysis of urban thermal behaviour in hot dry climate in relation to its vegetation before and after the COVID-19 pandemic

RUTH MARIA GRAJEDA-ROSADO[1], CLAUDIA ERÉNDIRA VÁZQUEZ-TORRES[2], CRISTINA SOTELO-SALAS[3]

[1] Facultad de Ingenieria de la Construcción y el Habitat, Universidad Veracruzana, Veracruz, Mexico
[2] Facultad de Arquitectura, Universidad de Guanajuato, Mexico
[3]Facultad de Arquitectura y Diseño, Universidad Autónoma de Baja California, Mexicali, Mexico

ABSTRACT: Spaces modified by anthropogenic activities reflect climatic and environmental alterations such as the Urban Heat Island phenomenon. A commonly used measure for thermal performance improvement in urban spaces is the incorporation or increase of vegetation, particularly endemic vegetation, due to its low maintenance requirements. The rapid expansion of the COVID-19 pandemic has drastically modified the activities, occupation, influence, and perception of users in urban spaces. In this study, a comparative thermal and vegetative analysis was carried out within an urbanized area with a hot dry climate, taking UHI variables such as Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI), during the period of lockdown due to the contingency and normalized typical periods. The objective was to know the weighting of anthropogenic activities in the thermal and vegetative profiles of a city with hot dry climate (Mexicali, Mexico). Temperature patterns in the winter season showed a constant surface temperature in 2019 and 2020, however, in 2021 the homogeneous distribution of temperature is noteworthy. In summer, the studied period of 2019 presented an oscillation of 6°C, while in 2020 temperature oscillation diminished, as the temperatures in some areas dropped by 2°C.
KEYWORDS: Land Surface Temperature, NDVI, Tele-detection, Urban Heat Island, Covid-19

1. INTRODUCTION

Spaces modified by anthropogenic activities reflect climatic and environmental alterations from micro, medium and macro scales such as the Urban Heat Island (UHI). UHI is often the result of drastic changes in land use, observed in urbanized areas, usually to accommodate the relentless increase in urban population (Ngarambe et al., 2020). Urban sprawl and industrialization immersed in these areas, will only be exacerbated in the short term, as the UN indicates, by the year 2030, 60% of the world's population will live in urban areas (ONU, 2014), this has forced researchers, urban planners and builders within the private, public and academic sectors to seek sustainability and urban health measures to mitigate these adverse effects.

To determine urban thermal patterns, Land Surface Temperature (LST) has become and affordable methodology for measuring and monitoring UHIs (Zhou & Chen, 2018), information that allows us to analyze the isotherms corresponding to the temperatures recorded on built surfaces. In the work of Wang & Murayama (2020) the study of LST while monitoring land use distribution and land cover, not only revealed its efficiency in reducing the UHI, but also the green areas and bodies of water demonstrated their effectiveness in cooling the city, as is the case of Sapporo, Japan, within this research. In addition to cool materials and urban land use policies; a commonly used measure to improve thermal performance in urban spaces is the incorporation or increase of vegetation, particularly endemic vegetation, due to its low maintenance requirements. Earlier studies have shown that there is a relationship between vegetation and thermal performance both at the building scale and in a group of buildings at the urban level. Meili et al. (2021) demonstrated that increasing urban vegetation cover can reduce 3°C using the Universal Thermal Index in the tropical city of Singapore. Increased vegetation in urban areas is used to mitigate the heat island. However, there are other less explored benefits such as the possibility of increased rainwater retention, carbon storage, biodiversity enhancement, aesthetic benefits, and user health (Meili et al., 2020).

With the arrival of the COVID-19 pandemic, its rapid expansion worldwide, drastically modified the activities, perceptions, occupation, and influence of urban spaces on users. Several investigations took place during this event such as the study by Kwok et al. (2021) which showed that the transmission of COVID-19 increased in urban areas affected by building geometry and green area distribution (Sabrin et al., 2021), (Perera et al., 2021), additionally, a recent study found that, during periods of lockdown, the levels of pollutants in the United Arab Emirates, decreased for the same pollutants during 2019 (Alqasemi et al., 2021).

Furthermore, the research by Firozjaei et al. (2021) showed that the ecological status of the urban surface improved due to the reduction of anthropogenic activities in the urban environment, determined with its methodological proposal: comprehensive ecological evaluation index and the ecological status of the surfaces, concluding that the impact is noticeable especially in the green spaces of the cities of Milan and Wuhan.

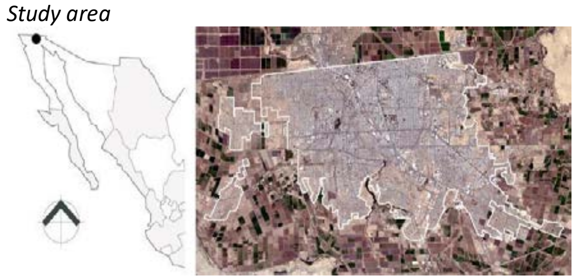
Therefore, in this study, a comparative thermal and vegetative analysis was carried out within an urbanized area with a hot dry climate, taking UHI variables such as Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI), during the period of lockdown due to the contingency and normalized typical periods. The objective was to know the weighting of anthropogenic activities in the thermal and vegetative profiles of a city with hot arid climate (Mexicali, Mexico). To answer the question: How did anthropogenic behaviour, during COVID-19 lockdown, impact the thermal and vegetative patterns of the city?

2. METHODS

2.1 Study area

Mexicali (Figure 1) is located in Baja California, Mexico; between latitudes 32˚ 38' North and 115˚ 20' West, within a border region contiguous with the State of California in the United States, with a population of approximately 1.033 million, an urbanized area of 113.7 km2 and elevation above sea level of 8.23 m. The entire region belongs to the physiographic province of the Delta of the Colorado River in the Sonoran Desert. As a result, the region has a very arid climate, only 75 mm of annual precipitation, and extreme temperature conditions: maximum temperatures exceed 50˚ C in summer and minimum temperatures below 0˚ C in winter (Villanueva-Solis, 2017).

Figure 1:
Study area



According to recent data, Mexicali requires the increase of green spaces because the inhabitant-green area ratio is 2.43 m^2, well below the 9 m^2 suggested by the UN, the same study states that 60% of green areas do not significantly affect the UHI, providing a thermal comfort effect per inhabitant of 1.27 m^2 (Saiz-Rodriguez et al., 2021). Its distribution of land use is 56% residential, 7% industrial, 6% commerce and services, and 8% urban infrastructure, additionally, urban expansion has caused the inclusion of eleven industrial Parks with 1,164 manufacturing companies (825 hectares), which contribute to the increase in temperature and pollution emissions. According to government data, Mexicali's emissions of carbon monoxide rank as the third highest in Mexico, these emissions are generated by its mobile sources, reaching 350,000 tons per inhabitant (SEMARNAT, 2015).

2.2 Data analysis

To obtain the UHI thermal and vegetative maps, ArcGIS software was used, data obtained from the images (route 39 and row 37) of the Landsat 8 satellite downloaded from the U.S. Geological Survey website, were used as input. The selected dates correspond to representative days of the winter and summer periods. To obtain the UHI data, the raster calculator tool of ArcGIS was used, which allows the creation and execution of an algebraic expression of maps on the metadata and generating a raster as output. The bands used in the processing were:

- Fourth band (red, µm= 0.64–0.67, resolution 30m)
- Fifth band (near infrared NIR, µm= 0.85–0.88, resolution 30m)
- Tenth band (thermal infrared sensor TIR 1, µm= 10.60–11.19, resolution 100m)
- Eleventh band (thermal infrared sensor TIR 2, µm= 11.50–12.51, resolution 100m)

The methodology required data such as radiance, brightness temperature, and emissivity of the different land cover. These data were obtained from the equations used in the Land Surface Temperature (1) and vegetation proportion (2), processing, as shown below (Rahaman et al., 2020) (Rosado et al., 2020).

$$LST = BT/1 + w * (BT/p) * \ln(e) \qquad (1)$$

where *LST* - Land Surface Temperature (◦C);
BT - satellite brightness temperature (°C);
w - wavelength of emitted radiance (11.5µm);
p - 1.438x10^{-2} (mK);
e - emissivity (m^2K^4).

The NDVI is used to correlate the land cover with the LST variable, determined with band 4 and 5 in equation (2) (Kaplan, Avdan, & Avdan, 2018).

$$NDVI = NIR - Red / NIR + Red \qquad (2)$$

where *NDVI* - Normalized difference vegetation index (values from 1 to -1);

NIR - Near-infrared band 5 (digital number);

Red – Red bands´s digital number value.

Values close to 1 represent leafy vegetation, crops, shrubs, pastures, forests, and extensive green areas, while values close to -1 are bodies of water, desert surfaces, sandy or concrete surfaces (Jones & Vaughan, 2010).

3. RESULTS

Of the selected dates (Table 1), four days of the year 2019 are examined, classified as "typical" urban activity, and five days between 2020 and 2021, which due to the COVID-19 quarantine presented unusual anthropogenic behavior.

Table 1:
Air temperature (Celsius) and relative humidity (%) data

Date	Air Temperature Max - Min	Relative humidity Max - Min
January 08, 2019	17 - 2	64.4 - 13.2
January 24, 2019	18 - 4	69.8 - 12.6
July 01, 2019	43 - 26	12.8 - 3.9
July 17, 2019	41 - 25	62.5 - 9.6
January 11, 2020	19 - 4	80.8 - 20.7
January 27, 2020	24 - 10	71 - 16.4
July 3, 2020	40 - 24	69.2 - 13.2
July 19, 2020	45 - 24	36.5 - 4.1
January 13, 2021	22 - 3	51.8 - 10

Figure 2a and 2b show the maps obtained by ArcGIS of the thermal behavior of the study area and the NDVI on January 11, 2020, and figure 3a and 3b on July 3, 2020. From the eight proposed dates and their maps, the metadata, and the frequency in which they are repeated in the study area describes the behavior of both variables (Figures 4 - 7).

Figure 2a:
Thermal map of the study area on January 11th, 2020.

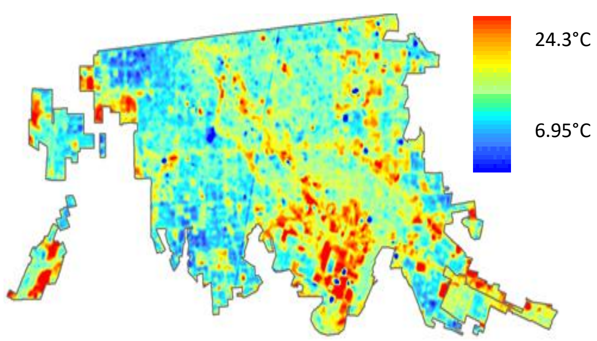


Figure 2a:
Thermal map of the study area on January 11th, 2020.

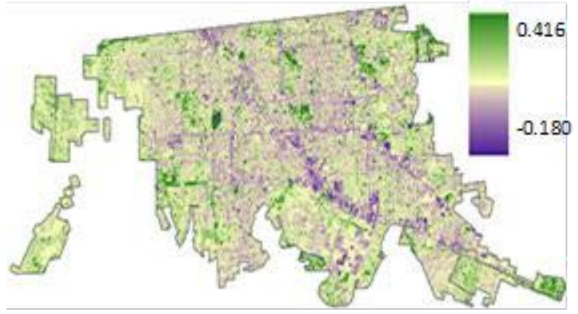


Figure 3a:
Thermal map of the study area on July 3rd, 2020.

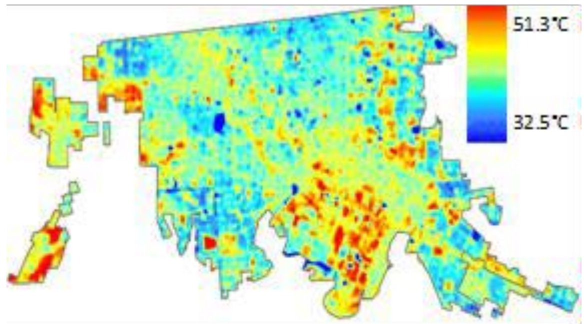


Figure 3a:
NDVI map of the study area on July 3rd, 2020.

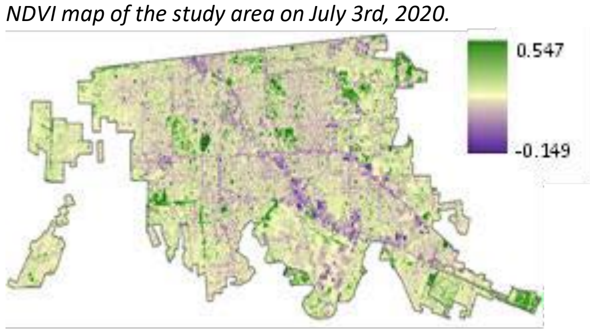


Figure 4 presents the surface temperature values and the percentage covered by each thermal value in relation to the study area, in the five days of the winter period analyzed from 2019 to 2021. Figure 5 represents the same variables explained for Figure 4 corresponding to the summer period.

Figure 4:
Thermal behavior in the winter period.

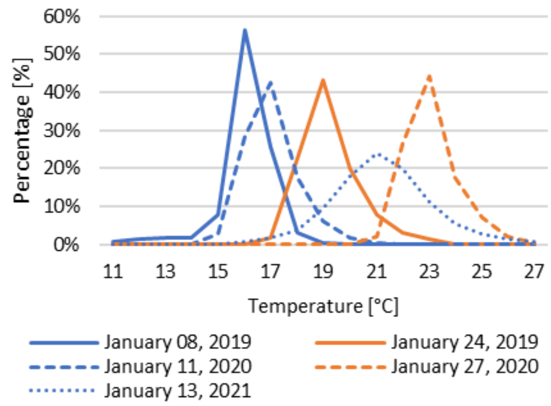


Figure 5:
Thermal behavior in the summer period.

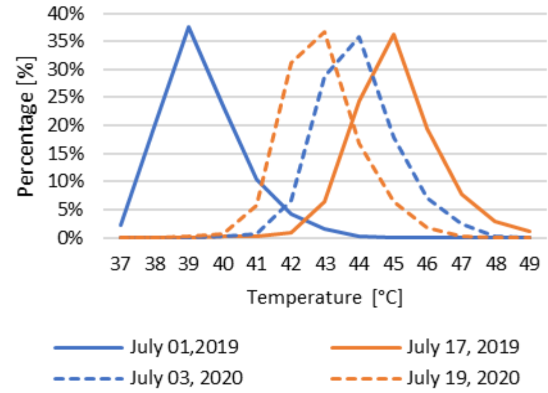


Figure 6 shows the NDVI values and the land cover percentage, in the five days of the Winter period analyzed from 2019 to 2021. Figure 7 examines the same variables, within the four selected days of the summer period. From the thermal maps (figures 2a and 3a) obtained it was observed that the position of the highest isotherms, both in winter and in summer, are in the same position, as well as the lowest points of NDVI (figures 2b and 3b), therefore, the most affected areas are still the industrial sector, large parking spaces and arid zones within the urban zone.

Figure 6:
NDVI behavior in the Winter period

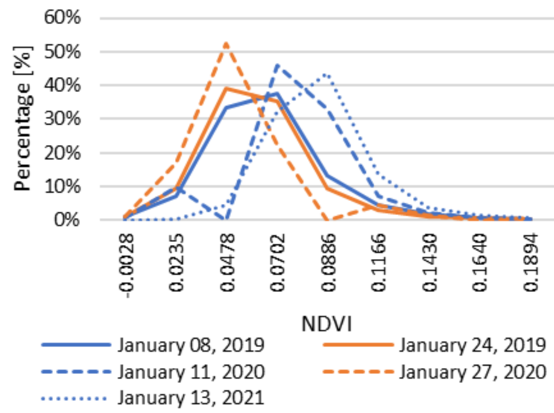
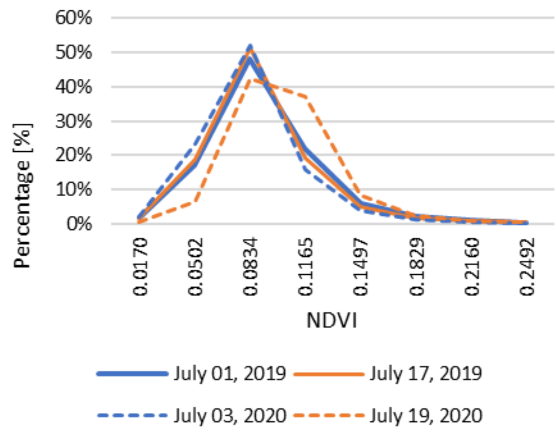


Figure 7:
NDVI behavior in the summer period.



In relation to the global temperatures shown, the following reflections were made:

- In the winter season, the increase in surface temperature is constant in 2019 and 2020, however, in 2021 the homogeneous distribution of temperature shown in the curve is noteworthy.
- In summer, the two days of 2019 presented an oscillation between their temperatures of 6°C, however, for the year 2020 the temperatures presented an increasingly similar behavior, which led to a decrease in oscillation.

The NDVI graphs show:

- In the winter season, an improvement of one hundredth from the year 2019 to 2020 was perceived, and an increase of 2.5 hundredths for the year 2021, observing an improvement in the NDVI curve pattern.
- In summer, only July 19th, showed an increase of five hundredths in the NDVI value.

4. DISCUSSION

In this study, variables of the surface energy balance equation (Li & Zhou, 2019) were analyzed from the perspective of environmental monitoring with approximate values before and after the recent COVID-19 pandemic in a border city with a hot arid climate. The events that generate change in urban behavior drive research to determine the weighting of human activities or anthropogenic heat (QF) in the energy balance. Collective research in this field, further corroborates the effect of the COVID 19 pandemic on urban climatology, as commented below.

A study in the city of Osaka, Japan, which used a climate and energy model, estimated that during the temporary closure of the G20 event, there was a reduction in traffic of 33%, which generated a decrease in QF=15.6 Wm-2 and 0.05 °C ambient temperature, and estimated a decrease of QF=76.3 Wm-2 and 0.13 °C in urban areas during the COVID-19 lockdown (Nakajima et al., 2021) (El-Kenawy, et al., 2021). In the works of Firozjaei et al. (2021), applied to the cities of Milan and Wuhan before and after the lockdown, the LST and NDVI figures indicate a decrease for the minimum Surface temperature of 7.5° and 2.9°C respectively, and an increase of 0.015 in the NDVI. Some authors (El-Kenawy et al., 2021) (Alqasemi et al., 2021) when carrying out comparative studies during the periods of lockdown or confinement, especially dated April and May 2020 compared to the same period in 2019, it was found that in addition to the decrease in pollutants such as NO2, possible causes of the event, there was a significant decrease in the surface heat island (SUHI) during the day and at night, as was the case of the United Arab Emirates, registering a decrease of the nocturnal SUHI of 19.20% in its mean values. However, as in our work, these decreases are not spatially uniform, as in the case of Tehran (Roshan, Sarli, & Grab, 2021) due to the complexity of land uses, between residential, commercial, and industrial. In addition, in the work of Ali et al. (2021) it is stated that the drop in SUHI temperatures and the pollutants detected in the cities of Pakistan is a result of severe transport restrictions.

In comparison to the three previous studies, and despite differences in climate, area, population and density, our research can also observe the modified pattern due to the changes in anthropogenic behaviour, where the LST always decreases and the NDVI increases, our results indicate that the increase in NDVI in both periods homogenized and reduced the temperatures of the city of Mexicali in ranges of 0.5 to 2°C in some areas, especially in the case of January 13th, 2021, when the quarantine substantially reduced the anthropogenic activities for more than six months, particularly urban mobility, showing a shift in the thermal curve of 3°C.

5. CONCLUSIONS

This study analysed the configuration of UHI and NDVI in an arid city from the information and images of the LandSat8 satellite and its processing with ArcGIS software, comparing Temperature and NDVI values based on different anthropogenic behaviours, according to the analysed period (2019, 2020 and 2021). The results showed that bare soils, industrial areas, and parking areas require the implementation of mitigation techniques, since they are the surfaces with higher isotherms, compared to urbanized areas.

Returning to the question: how did the anthropogenic behaviour, influenced by COVID-19 during the lockdown, modify the thermal and vegetative values of the city? we can confirm its importance because, consistently with previous investigations, LST values in this study have decreased in a range between 0.05 to 7.5°C.

For the mitigation of the UHI, the implementation of cooling materials, an increase in green areas and bodies of water in the urban environment have been recommended, however, the water resource in this area is limited. Therefore, initiatives focused on the use of high-reflective materials in building envelopes, especially on roofs, and the implementation of facade design policies that increase shading and convection to move airflows of heat are suggested in urbanized areas. The results give urban planners and authorities the opportunity to consider the impact of human activities on the urban climate and generate possible changes and recommendations in mobility logistics and land use in favor of user comfort and the environment.

ACKNOWLEDGEMENTS

The authors are grateful for the support of the Facultad de la Construcción y el Hábitat of the Universidad Veracruzana, the Facultad de Arquitectura of the Universidad de Guanajuato, and Facultad de Arquitectura y Diseño of the Universidad Autónoma de Baja California.

REFERENCES

1. Ali, G. A., Qamer, F., Wong, M., Rasul, G., Irteza, S., & Shahzad, N. (2021). Environmental impacts of shifts in energy, emissions, and urban heat island during the COVID-19 lockdown across Pakistan. Journal of Cleaner Production, 291: p. 125806. doi:10.1016/j.jclepro.2021.125806.
2. Alqasemi, A., Hereher, M., Kaplan, G., Al-Quraishi, A., & Saibi, H. (2021). Impact of COVID-19 lockdown upon the air quality and surface urban heat island intensity over the United Arab Emirates. Science of The Total Environment, 767: p. 144330. doi:10.1016/j.scitotenv.2020.144330.
4. El-Kenawy, A., Lopez-Moreno, J., McCabe, M., Dominguez-Castro, F., Peña-Angulo, D., Gaber, I., . . . Vicente-Serrano, S. (2021). The impact of COVID-19 lockdowns on surface urban heat island changes and air-quality imporvements across 21 major cities in the Middle Eeast. Environmental Pollution, 288: p. 117802. doi:10.1016/j.envpol.2021.117802
5. Firozjaei, M. K., Kiavarz, M., Arsanjani, J., Homaee, M., & Alavipanah, S. (2021). Modeling the impact of the COVID-19 lockdowns on urban surface ecological status: A case study of Milan and Wuhan cities. Journal of environmental management, 286: p. 112236. doi:10.1016/j.jenvman.2021.112236.
6. Jones, H., & Vaughan, R. (2010). Remote sensing of vegetation: principles, techniques, and applications. Oxford university press, 22(6): p. 1151-1153. doi:10.1111/j.1654-1103.2011.01319.x.
7. Kaplan, G., Avdan, U., & Avdan, Z. (2018). Urban heat island analysis using the landsat 8 satellite data: A case study in Skopje, Macedonia. In Multidisciplinary Digital Publishing Institute Proceedings, 2(7): p. 358. doi:10.3390/ecrs-2-05171.
9. Kwok, C., Wong, M., Chan, K., Kwan, M., Nichol, J., Liu, C., . . . Kan, Z. (2021). Spatial analysis of the impact of urban geometry and socio-demographic characteristics on COVID-19, a study in Hong Kong. Science of the Total Environment, 764, 144455. doi:10.1016/j.scitotenv.2020.144455
10. Li, X., & Zhou, W. (2019). Spatial patterns and driving factors of surface urban heat island intensity: A comparative study for two agriculture-dominated regions in China and the USA. Sustainable Cities and Society, 48: p. 101518. doi:10.1016/j.scs.2019.101518.
11. Meili, N., Acero, J., Peleg, N., Manoli, G., P., B., & F. S. (2021). Vegetation cover and plant-trait effects on outdoor thermal comfort in a tropical city. Building and Environment, 195: p. 107733. doi:10.1016/j.buildenv.2021.107733.
12. Meili, N., Manoli, G. B., Bou-Zeid, E., Chow, W., Coutts, A., & Fatichi, S. (2020). An urban ecohydrological model to quantify the effect of vegetation on urban climate and hydrology (UT&C v1.0). Geoscientific Model Development, 13(1): p. 335-362. doi:10.5194/gmd-13-335-2020.
13. Nakajima, K., Takane, Y., Kikegawa, Y., Furuta, Y., & Takamatsu, H. (2021). Human behaviour change and its impact on urban climate: Restrictions with the G20 Osaka Summit and COVID-19 outbreak. Urban Climate, 35: p. 100728. doi:10.1016/j.uclim.2020.100728.
14. Ngarambe, J., Nganyiyimana, J., Kim, I., Santamouris, M., & Yun, G. (2020). Synergies between urban heat island and heat waves in Seoul: The role of wind speed and land use characteristics. PLoS One, 15(12): p. e0243571. doi:10.1371/journal.pone.0243571.
15. ONU. (2014). Sustantibles Development Goals. Retrieved from Goal 11: Make cities inclusive, safe, resilient and sustainable. [Online], Available: https: //www.un.org /sustainabledevelopment/cities/
16. Perera, T., Jayasinghe, G., Halwatura, R., & Rupasinghe, H. (2021). Modelling of vertical greenery system with selected tropical plants in urban context to appraise plant thermal performance. Ecological Indicators, 128: p. 107816. doi:10.1016/j.ecolind.2021.107816.
17. Rahaman, S., Kumar, P., Chen, R., Meadows, M., & S. R. (2020). Remote sensing assessment of the impact of land use and land cover change on the environment of Barddhaman district, West Bengal, India. Frontiers in Environmental Science, 8(127): p. 127. doi:10.3389/fenvs.2020.00127
18. Rosado, R., Guzmán, E., Lopez, C., M. W., García, H., & Yedra, E. (2020). Mapping the LST (Land Surface Temperature) with Satellite Information and Software ArcGis. IOP Conference Series: Materials Science and Engineering, 811(1): p. 012045. doi:10.1088/1757-899X/811/1/012045.
19. Roshan, G., Sarli, R., & Grab, S. (2021). The case of Tehran's urban heat island, Iran: Impacts of urban 'lockdown'associated with the COVID-19 pandemic. Sustainable Cities and Society, 75: p. 103263. doi:10.1016/j.scs.2021.103263.
20. Sabrin, S., Karimi, M., Nazari, R., P. J., & Bryk, J. (2021). Effects of different urban-vegetation morphology on the canopy-level thermal comfort and the cooling benefits of shade trees: Case-study in Philadelphia. Sustainable Cities and Society, 66: p. 102684. doi:10.1016/j.scs.2020.102684.
21. Saiz-Rodríguez, J., Salazar-Briones, C., Ruiz-Gibert, J., Moctezuma, A., & Lomeli-Banda, M. (2021). Analysis of urban heat island and flood-prone areas for green space planning. Proceedings of the Institution of Civil Engineers-Urban Design and Planning, 174(2): p. 47-62. doi:10.1680/jurdp.21.00006.
22. SEMARNAT, Secretaria del Medio Ambiente y Reursos Naturales. (2015). Informe de la Situación del Medio Ambiente en Mexico. Compendio de Estadisticas Ambientales, Indicadores de Desempeño Ambiental y de Crecimiento Verde. [Online], Available: https://apps1.semarnat.gob.mx:8443/ dgeia/informe15/tema/cap5.html.
23. Villanueva-Solis, J. (2017). Urban heat Island mitigation and urban planning: the case of the Mexicali, BC Mexico. American Journal of Climate Change, 6(01): p. 22. doi:10.4236/ajcc.2017.61002.
24. Wang, R., & Murayama, Y. (2020). Geo-simulation of land use/cover scenarios and impacts on land surface temperature in Sapporo, Japan. Sustainable Cities and Society, 63: p. 102432. doi:10.1016/j.scs.2020.102432.
25. Zhou, X., & Chen, H. (2018). Impact of urbanization-related land use land cover changes and urban morphology changes on the urban heat island phenomenon. Science of the Total Environment, 635: p. 1467-1476. doi:10.1016/j.scitotenv.2018.04.091.

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

Neurourbanism
Analysis of public space of a small town Peruíbe -SP

HALANA DUART DE OLIVEIRA[1] DENISE DAMAS DE OLIVEIRA MORELLI [1]

[1] Adventist University Centre of São Paulo Campus Engenheiro Coelho

ABSTRACT: More than half of the world's population lives in urban centres and with each passing year this number increases. The indexes of psychological diseases are higher in cities than in rural areas. Thus, neururbanism seeks to understand, from the concepts of neuroscience, which are the brain processes and reactions of the nervous system that occur in the experience of a big city. The object of study is the city of Peruíbe, Brazil. The aim is to analyse how a small city impacts the quality of life of its inhabitants. The method is a case study that carried out field research through interviews with inhabitants and tourists to find out how they feel in relation to the city. The result was that the indexes of employment, health and public transportation are the same requirements that generate stress in the population of a big city. It is concluded that for a city to be healthy, it needs to provide quality of life, so the study of neuro-urbanism is essential for urban planning.
KEY WORDS: Neurourbanism, Urban Health, Small Towns, Peruíbe

1. INTRODUCTION

The number of people living in large cities increases every year. Currently about 55% of the world population resides in urban centres. It is estimated that by 2050 this percentage will reach 70% [4]. However, living conditions in cities can generate problems in the physical and especially mental health of its residents.

Many people move to the cities in search of better working conditions, education, culture, development of spirit and creativity, but they become victims of the ills of this environment. Precisely because of their attractiveness and dominance, urban centres have created unhealthy circumstances for human life. Among these circumstances we can cite the high population density causing a housing deficit, which generates tenements, slums and street dwellers; violence, people who had no opportunity to study, have no qualification for the labour market resulting in socioeconomic exclusion, unemployment or informal work of low quality; urban pollution is concentrated in the air that leads to the formation of acid rain, greenhouse effect, thermal inversion, heat island, noise and visual pollution. Traffic pollution due to traffic congestion, predominance of private cars, accumulation of rubbish and lack of recycling, contamination of water due to lack of sewage and treatment of collected sewage and lack of green areas such as squares, woods, and parks. All this scenario in urban centres generates stress, nervousness, irritability, and intolerance in man, because he spends more energy to deal with the adversities that are happening around him.

Recent research affirms that in cities the levels of stress are higher. There are two types of stress: acute, a physiological system essential for survival; and chronic, which happens when the individual is exposed to small doses of stress over a prolonged period. Different from acute stress, chronic stress is harmful to health. Therefore, inhabitants of big urban centres are more vulnerable to develop psychological diseases such as anxiety, depression, panic syndrome, etc. In view of this, identifying mistakes in urban planning and avoiding them becomes a key issue. Understanding the impact of spaces on the human mind helps in the development of projects that improve people's performance and provide quality of life.

There are several reasons why cities have high levels of stress, including the feeling of not identifying with the city. This factor is responsible for making cities unfamiliar and threatening environments for their inhabitants, as it keeps people away from public spaces and turns them into mere transitional spaces. The absence of connecting spaces in cities leads to a feeling of loneliness even in crowded places. To solve the problem, it is first necessary to understand how city morphology contributes to the increase of stress levels, to inform about the health risks of large urban centres and to redesign urban environments to create more humanized spaces [5].

To discover how physical spaces, affect the human brain, researchers have begun to apply neuroscience knowledge to architecture and urban planning. Neuroscience can be very useful in the development of architectural projects, as it is through neuroscience that one can evaluate human sensations, emotions, and behaviours in built environments by collecting physiological data. The aspect related to the spatial behaviour of man to the urban environment, one should consider as personal space, territoriality, areas of overcrowding and the issue of privacy of the individual, are important issues to be analysed in neuroscience applied to urbanism [6]. The integration of psychology, neuroscience and architecture originates a new field of study called Neuroarchitecture, which investigates the emotional and cognitive repercussions of visual forms associated with architecture.

It is necessary to assess the impacts that are caused by different living conditions in urban centres. Urban managers and architects can acquire several benefits from neuroscience. Neurourbanism consists of the interaction between urban planners, architects, neuroscientists, psychiatrists, and social scientists that aims to investigate the psychological and neurobiological consequences of different ways of living in cities [8].

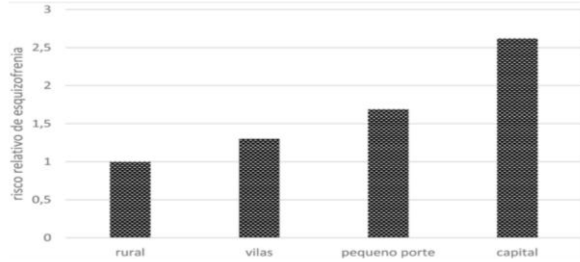
The few research on the subject seek to understand how the urban morphology in large cities relates to people's health and well-being. It is known that large metropolises have become environments conducive to the development of physical diseases and psychological illnesses such as anxiety, depression, and schizophrenia; in addition to facilitating the manifestation of violence, pollution, and thermal discomfort. However, it remains to be identified how the urbanization process affects the quality of life of residents of medium and small cities and how the urban spaces of these cities relate to their users. The investigation about the psychological and hygienic impacts of urban morphologies is an extremely important public health issue for the planning of big and small cities. Thus, the work proposes to study the concepts of urban planning and to analyse its aspects in a small city. The results of the research will be of great value for urban architects and urban managers engaged in designing healthier and more pleasant cities. Since there are few studies on the subject, such results will collaborate in the advancement of research on urban planning and will help in new urban planning projects.

2. THEORETICAL REFERENCE

2.1 Stress in cities

Cities have numerous advantages, such as access to education, culture, and possibilities for individual development. However, human brains are not well programmed to live in the world's overcrowded metropolises. Urban living is related to increased levels of stress and psychiatric illnesses: the risk of developing schizophrenia is twice as high in cities than in rural areas (fig. 1); the same happens with depression, with 40% more chances of developing it; and anxiety, with 20% [8]. These trends are influenced by the amount of time a person has lived in a big city, i.e., individuals who have grown up in an urban environment have less emotional control. However, this does not mean that cities cause psychological illnesses, but it does express that the way in which cities interact with people's minds leads to a greater propensity for these disorders [8].

Figure 1:
Relative risk of developing schizophrenia as a function of size and complexity in Danish cities.



Note: Translation from left to right: relative risk of schizophrenia; rural; villages; small size; capital.

Paulo Saldiva, professor at the Medical School of USP, explains that the tendency to develop mental disorders is modulated by the early stages of human development and has a genetic basis. Factors such as the quality of the family environment and the amount of time spent with parents during early childhood can reduce or increase the risk of mental disorders in later stages of life. However, it is noticeable that mental disorders are more frequent in the urban environment and that cities have characteristics that favour their emergence [7]. Social and environmental aspects can hinder or facilitate the emergence of mental disorders. The human mind is protected when, in urban regions, it becomes possible the formation of a network of affection, solidarity and support [7]. On the contrary, social isolation, common in cities, becomes a factor that contributes to mental suffering and the increased risk of developing anxiety and depression [7].

Another factor that interferes with the possibility of developing psychological disorders is the quantity and quality of sleep. Hormones, such as melatonin, are produced during sleep and protect our cognitive and behavioural functions [7]. Cities have some characteristics which are harmful to sleep, for example: overwork and inefficient urban mobility which reduce sleep time, urban noise, and the luminosity of the environments. The excess of light in the urban environment deregulates the human biological clock and thus affects mental health [7].

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

The conditions of urban life led to the development of chronic stress and the changes in brain neurochemistry caused by it are risk factors for the development of mental disorders [7]. Urbanization is correlated with individual stress through the fusion between urban density and social isolation, a mixture that generates social stress. This stress is responsible for causing behavioural changes, irritability, mental illness, and higher mortality in several species [7].

Many people feel lonely in cities due to the feeling of not belonging to the group or place they are in. In the human brain, when an individual is in an environment with people they can identify with, oxytocin levels increase and generate a sense of belonging. In an opposite way, the urban distress generated by the feeling of not belonging to public spaces and by the impression of being in a crowd of strangers is related to the low activity of the limbic system and the low production of oxytocin [9].

Urban loneliness results from the repetition of four components: human crowding, low social interaction, isolation, and stress. It is possible to use a very important concept from neuroscience called brain plasticity to understand the impacts of urban loneliness. Brain plasticity is the ability of the brain to change physically every time a recurring process occurs, such as learning something. Therefore, recurrent urban loneliness and social stress cause significant effects on the human brain [9].

2.2 Object of study

As object of analysis, the city of Peruíbe was chosen, with approximately 69 thousand inhabitants, located in the metropolitan region of Santos, coast of São Paulo/Brazil. The city was chosen due to its size, touristic importance, existence of environmental heritage and historical relevance. Another important point for choosing this city was the opportunity to study the same urban environment with the behavioural perception of two distinct groups of individuals: residents and tourists.

The work seeks to investigate the profile of the city according to the principles of neururbanism and to understand how the morphology of a small town affects the perception of well-being of its residents and visitors. Therefore, field research was necessary to find out how the inhabitants and tourists of Peruíbe behave in relation to the city.

3. METHODOLOGY

A case study was carried out with the purpose of analysing the psychological and behavioural effects caused by the urban environment of a small city, based on the parameters of neuroscience and the conceptions of the main researchers in the area. The intention is to study the neuro-urbanistic aspects of a city to improve the quality of life of its inhabitants.

The research approach used is qualitative, with quantitative data collection techniques. To this end, the research is based on studies of authors such as Andrea Paiva, Madza Adly, Paulo Saldiva among other researchers who prepare relevant papers on the subject. In addition to the analysis of graphs and tables.

Then, a questionnaire was applied with residents and tourists in which the result was based on 12 multiple choice questions with the purpose of analysing the satisfaction of residents with certain sectors of the city. The sectors were chosen considering the factors related to the increase or reduction of stress in the city: violence, lighting, lack of contact with nature, absence of connection spaces and urban mobility. The questions are related to the culture of living of free spaces in Brazilian cities, according to the population's needs and concerns (Table 1).

Table 1:
Questions in the questionnaire.

What grade would you give to the sectors below in the municipality of Peruíbe considering that 1 is not at all satisfactory and 5 is totally satisfactory?	
Question A	Afforestation
Question B	Pavements
Question C	Street lighting
Question D	Public transport
Question E	Cycle paths
Question F	Urban cleaning
Question G	Leisure activities
Question H	Quality of public spaces
Question I	Public health
Question J	Public safety
Question K	Urban mobility
Question L	Job opportunities

Note: The question in the first row was used to assess each area of interest identified in questions A to L. Table prepared by the author.

The number of responses was defined using the sample calculation formula. Through 5% of the margin of error and 90% confidence of the total of 332 responses. The application of the research took place through the online research tool google forms, to reach the largest number of respondents in a short period. The questionnaire was answered by residents and tourists of Peruíbe present in virtual groups of the municipality. The online survey remained available until it reached the expected number of responses. With the data collection carried out through google form, the data analysis was done through the Microsoft Office Excel Software Version 2206. The evaluation of data resulting from the research is made by means of the Likert scale, which has a range of 1 to 5 (Table 2). The Likert scale was used to measure the intensity of satisfaction that corresponds to the behaviour of respondents in relation to a particular sentence.

Table 2:
Likert Scale.

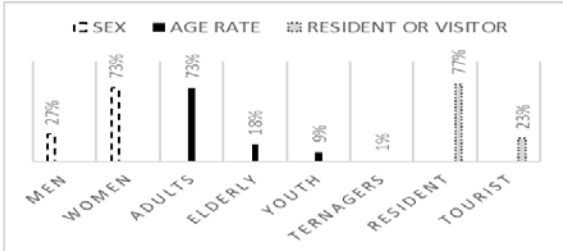
Very Poor	Poor	Reasonable	Good	Excellent
1	2	3	4	5

Note: Table prepared by the author.

4. RESULTS

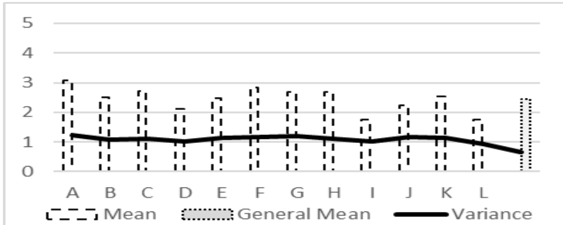
The case study was conducted through the application of 332 evaluative questionnaires about the city of Peruíbe, Brazil. From these results, it is possible to ponder on the quality of certain sectors of the municipality (Sectors A to L of Table 1), through the identification of the main problems from the perception of the community. The characterization of the interviewees (figure 2) is composed of 73% women and 27% men of various ages, 77% residents and 23% tourists. It is observed that the adult women who live in the city were the most concerned in answering the questionnaire.

Figure 2:
Characterisation of the interviewees.



Note: Graph prepared by the author herself.

Figure 3:
Overall result.



Note: In the general result, the final average was below the averages of the questions evaluated from A to L. Graph prepared by the author herself.

With the application of the survey, the general average and the average per domain were obtained. The questions that had the highest averages were about afforestation (A), 3.09; urban cleaning (F), 2.82; and street lighting (C), 2.72. The behaviour of tranquillity and relaxation of residents and tourists can be attributed to the contact with nature that the city provides through the wooded places, since nature reduces stress levels and provides protection against sun exposure. Already the urban cleaning when well executed produces positive sensations such as calm, happiness and well-being to experience the environment, as well as generates the behaviour of care and belonging. In contrast, the lack of urban cleaning is linked to the behaviour of repulsion to the place where it is, consequently the place is empty. Moreover, at night-time, the behaviour of safety or insecurity is related to the quality of public lighting. Although these topics had the highest scores and represented the most positive perceptions of the respondents regarding the city, none of them achieved a good score (4 or 5 according to the Likert scale). The behaviour of man in the built environment is related to feelings of satisfaction or dissatisfaction, so we have a result for the areas studied, which indicates the need for improvements to meet the maximum users of these places.

The lowest averages were about job opportunities (L), 1.74; public health (I), 1.75; and public transportation (D), 2.12 (fig. 3). Unemployment in the city is responsible for an increase in crime rates; an increase in poverty and, mainly, the development of psychological illnesses, related to the individual's behaviour of frustration and sadness due to the lack of an occupation or income. Furthermore, the precarious service provided by the city's public health system contributes to the behaviour of insecurity and indignation that motivates the feeling of not belonging. Not only that, but the inefficient public transportation causes the disappointment of not being able to access the city's spaces easily. All these problems are harmful to the city because they cause an exodus of people who move in search of opportunities and better living conditions, as well as preventing the city from developing its tourism potential.

To reaffirm this user's behaviour, the Likert scale was used to corroborate the behaviour of the residents and tourists in these places surveyed. Considering the Likert scale (variation from 1 to 5), the overall average reached was 2.45, which indicates the dissatisfaction of respondents in relation to the urban environment in which they live.

The highest variations of answers are related to afforestation (A), leisure activities (G) and urban cleaning (F), 1.23, 1.20 and 1.18 respectively. The questions that had the least variations were about employment opportunities (L), public health (I) and public transport (D), 0.94, 1.01 and 1.01 respectively (fig. 3).

5. DISCUSSION

Violence is a factor that alters urban life and causes disorders in the health of the population, this can be considered one of the reasons for chronic stress in the city of Peruíbe, which occurs mainly in downtown and peripheral areas with low employment opportunities. As previously mentioned, chronic stress is harmful to health, since it aggravates, besides psychological diseases, physiological diseases such as diabetes and blood pressure. The low-income population of the municipality, have difficulty in accessing public health care for the treatment of psychological illnesses [7]. In Peruíbe, the average score for public safety was 2.24, a bad score. Since, according to the Likert scale, 5 would be a very good index and 3 a reasonable index. While public lighting, an essential point in the feeling of safety, reached the average of 2.72, this confirms the feeling of fear and insecurity that promotes violence.

Another stressor is inefficient mobility. Depending on the degree of its inefficiency, urban mobility may drastically impair the inhabitants' standard of living because: it wastes time and contributes to the growth of obesity [7]. In small/medium size cities, despite the rare occurrence of major traffic jams, there may be other problems in urban mobility such as: lack of infrastructure for non-motorized displacement, difficulty in finding parking spaces, inadequate public transportation, lack of accessibility, etc. Four questions in the case study were devoted to this subject: questions B, D, E, K. Sidewalks (question B) reached an average of 2.51, i.e., considered inadequate for pedestrians (Fig. 4).

Figure 4:
Inadequate pavements on Avenida Padre Leonardo Nunes, Peruíbe.

Note: Photo taken from Google Street View.

The question on public transportation obtained an average of 2.12 due to quality, low frequency in the outskirts and insufficient quantity to meet the population's needs. The bicycle paths (question E), with an average of 2.48, are existing but fragmented and without connection between them. On the topic of urban mobility (question K), average 2.53, it is important to consider the relationship between residents and tourists. For the resident the meaning of place is the São João Batista Church Square and for the tourist it is the Ambrósio Baldim Square. In the high summer season, the resident has mobility difficulties due to the high concentration of tourists who fill the square Ambrósio Baldim, the square of St. John the Baptist Church and the shopping centre, which hinders the flow of daily life. The absence of traffic lights, elevated zebra crossing, pedestrian zebra crossing, and accessibility areas contributes to the unsatisfactory outcome for the population and tourists.

Contact with nature is very important for human health. The natural environment provides food, water, energy, environmental comfort, and psychological well-being. Recent research has recorded the relevance of nature in human mental functioning, the results show a decrease in stress and an increase in good mood after a prolonged experience with nature [1]. In contrast, urbanization can overload the neurons responsible for dealing with stress. However, in comparison to previous generations, lately, people experience less and less daily contact with nature [1]. An example of this is the São João Batista Church square that after renovations, lost part of its vegetation (fig. 5). In Peruíbe, the question that acquired the highest average was about urban forestation: 3.09, reasonable, according to the Likert scale. This result reveals that most interviewees consider the amount of vegetation in the city acceptable but feel the need for more natural elements in the construction of the urban landscape. This concern with the city landscape is reinforced by the average obtained in the question about urban cleaning: 2.82, deemed unsatisfactory despite being the second highest average in the questionnaire.

Figure 5:
São João Batista Church Square before and after the reform.

Note: Photo on the left taken by a resident and the one on the right taken from the town's newspaper: Bemtevi.

The existence of spaces for action is crucial to mitigate stress, reduce social isolation and generate a sense of belonging. In Peruíbe, given that the topics about the quality of public spaces and leisure activities reached an average of 2.69 and 2.70 respectively, one notices a lack of identification of the population with the city's spaces. Furthermore, essential points such as public health and employment opportunities had the lowest averages: 1.74 and 1.75 respectively, considered very bad according to the Likert scale. The feeling of insecurity generated by the absence of means of support and the vulnerability of health institutions cause stress to the inhabitants.

To solve these problems, we suggest implementing some methods, such as:

1. Afforestation: increase the presence of natural elements in public environments. Recover and preserve the city's natural resources.
2. Urban mobility: Requalification of pavements to promote accessibility. Connecting the cities' bicycle paths. Qualification of the infrastructure for bus transport.
3. Public lighting: to have more lighting points, especially in the streets near the centre which are used as car parks.
4. Urban cleaning: selective rubbish collection, informing and educating the population on the correct disposal of waste.
5. Leisure activities: valorisation of local culture and history. Implementation of cultural events. Invest in tourist attractions not related to the beach and that can be carried out in all seasons of the year.
6. Quality of public spaces: revitalize or build humanized and appropriate spaces for social contact and thereby reduce vulnerability to stress [5; 7 - 9].
7. Public health: Inform the population on how to maintain good physical and mental health [7 -8]. Completion of the work of the city hospital started in 2017 and stopped since 2018. Improve the infrastructure of the health units. Minimize social isolation, especially for people at risk [8].
8. Employment opportunities: strengthening the local economy.

All indications are possible to be implemented in a small city like Peruíbe, however, it is necessary to study together with the public power to develop guidelines, instruments that provide small, medium- and long-term actions, to organize and implement projects that benefit the vulnerable population.

6. CONCLUSION

For a city to be healthy, it needs to provide quality of life. The discussion on how and why cities make their inhabitants ill is an essential agenda [7]. The well-being of the population needs to be the fundamental principle of urban planning, to prevent that only influential citizens or companies make the important decisions and to ensure the equal distribution of urban benefits [7].

The way cities interact with the human brain today is alarming, as they induce physical and psychological diseases. Thus, interaction between urban planners, architects, neuroscientists, psychiatrists, and social scientists is necessary to discuss the best forms of urban planning. The application of neuroscience concepts in public spaces becomes a primary tool. Consequently, the study of neurourbanism becomes invaluable.

ACKNOWLEDGEMENTS

To Professor Denise Damas, for having guided me in the performance of this work with dedication and friendship. To my parents for all the support and help. And to all who participated, directly or indirectly in the development of this research work, enriching my learning process.

REFERENCES

1. Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. Annals of the New York Academy of Sciences, 1249(1), 118–136.
2. Duarte, F., & Sánchez, K. (2008). Introdução à mobilidade urbana (1st ed., p. 107). Juruá.
3. MascaróL. R., & MascaróJ. L. (2010). Vegetação urbana (3rd ed., p. 212). Masquatro.
4. ONU prevê que cidades abriguem 70% da população mundial até 2050. (2019, February 19). ONU News. Retrieved May 5, 2021, from https://news.un.org/pt/story/2019/02/1660701
5. Paiva, A. (2019, August 2). O Que O NeuroUrbanismo Nos Ensina Sobre Nossas Cidades. NeuroAU. Retrieved March 23, 2021, from https://www.neuroau.com/post/o-que-o-neurourbanismo-nos-ensina-sobre-nossas-cidades
6. Rodrigues, E. (2020, May 20). NEUROARQUITETURA - Utilizando o EEG para criar ambientes mais alegres e produtivos. Brain Support. Retrieved April 15, 2021, from https://www.brainlatam.com/blog/neuroarquitetura-utilizando-o-eeg-para-criar-ambientes-mais-alegres-e-produtivos-1592
7. Saldiva, P. (2018). Vida urbana e saúde: os desafios dos habitantes das metrópoles (p. 130). Editora Contexto. https://middleware-bv.am4.com.br/SSO/unasp/9788552000389
8. TEDx Talks. (2013). Stress in the city: Mazda Adli at TEDxBerlin [online]. In YouTube. https://www.youtube.com/watch?v=chmRjQP8-e0
9. TEDx Talks. (2019). Neurourbanismo contra a epidemia de solidão | Robson Gonçalves | TEDxMauá [online]. In YouTube. https://www.youtube.com/watch?v=6ekPfTvU7v0

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

Co-producing healthy communities

A methodological approach to prevent arbovirus epidemics in a Brazilian social housing neighbourhood

GARREFA, FERNANDO[1]; VILLA, SIMONE BARBOSA[1]; BORTOLI, KAREN CARRER RUMAN DE[1]; STEVENSON, FIONN[2]; VASCONCELLOS, PAULA BARCELOS[1]; CARVALHO, NATHALIA LYA DE MELO[1]

[1] Federal University of Uberlândia
[2] The University of Sheffield

ABSTRACT: Dengue, Zyka and Chikungunya are dangerous arboviruses transmitted by the Aedes aegypti mosquito. In 2019, 1.4 million people were infected, causing 414 deaths. Studies show that the proliferation of the mosquito is correlated to the accumulation of waste and other water-retaining elements in private backyards. Most cases occur in social housing developments, especially in the 'Minha Casa Minha Vida' Programme (PMCMV) for 4.4. Million homes. In Uberlândia, these cases represent 78% of the 38,000 people infected in 2019. The MORA group, from the Federal University of Uberlândia and the group People, environments and performance, from the University of Sheffield faced this situation with the project, affectionately nicknamed as "My House Without Dengue Fever", financed by the Global Challenges Research Fund between 2020 and 2021. Given the UN Sustainable Development Goals 3, 11 and 15, this project has developed an effective approach to co-produce strategies to eliminate the dengue mosquito from communities in a lasting way. This work discusses the importance of community engagement in containing the contamination by the dengue virus, describing the methodological toolkit developed to understand risk situations and behaviours. Are also described the artifacts developed in order to guide the resilient community fight against the disease – namely, a web app and a digital guidebook.

KEYWORDS: Coproduction, Social housing, Post occupancy evaluation, resilience, Arbovirus epidemics.

1. INTRODUCTION

The repetition of poor planning and construction models in the national 'Minha Casa Minha Vida' Programme (PMCMV) for 4.4 million homes – Brazilian Social Housing Federal Programme - continues to have a negative impact [1, 2]. Developing resilient housing communities that can respond to climate change requires a rapid action to address increasing short-term environmental and health shocks and long-term environmental change in such housing. This article investigates the resilience of the PMCMV housing model in reality through a case study of a typical PMCMV social housing neighbourhood in the city of Uberlândia, Brazil, in this significant national housing programme.

Previous Post-occupancy evaluation (POE) studies of PMCMV in the area encompassing 4,000 semi-detached houses identified three significant issues impacting residents' health and well-being: (i) poor acoustics; (ii) poor thermal comfort and (iii) backyard breeding grounds for Dengue, Zika and Chikungunya diseases significantly affecting social housing communities. In 2019, the disease affected 1.4 million people in Brazil and killed 419 [3]. Considering that the intensity of the disease symptoms debilitates the patient for up to 7 days, an estimated total of 9.8 million work days were lost in 2016 [4, 5]. In the city of Uberlândia mapping of Dengue shows that viruses mainly affect the social housing communities which are located in peripheral areas [5].

Despite local authority efforts to control the spread of the epidemic, solutions remain challenging because: the vaccine isn't safe and efficient enough to be used; the Aedes Aegypit mosquito proliferates in urban areas; accumulated waste and sealed soil areas are the favourite places for mosquitoes to lay eggs; private backyards with these conditions are difficult to access by the health agents; the major of mosquito breeding grounds are in the backyards; and low-income people are less aware of the measures needed to keep houses free of mosquitoes. Previous research in social housing communities [6,7,20] indicated that some practices could contribute to the establishment of grounding breeds in the houses. This paper considers the following research questions arising from the consideration of housing resilience to these key diseases and their sources: Are there shared practices in terms of how PMCMV backyards are used? What practices can reduce mosquito breeding grounds? Are residents able to positively change their practices?

To answer these questions, this study aims to assess the Shopping Park Neighbourhood, a typical PMCMV enterprise and to develop a retrofit toolkit to help to reduce arboviruses infections. POE and co-production methods and techniques are used, aiming to involve the community and develop a long-lasting toolkit, which can engage the entire neighbourhood through promotion by the residents themselves.

Based on this single case study, the findings of this study show that the developed retrofit toolkit is successful in reducing the number of possible breeding grounds, changing residents 'practices, being long-lasting and engaging the community in the face of mosquitoes.

2. DENGUE IN SOCIAL HOUSING: ENVIRONMENTAL CONDITIONS AND VULNERABILITY

Dengue Fever is currently the most important among the arboviruses that affect man and is a serious public health problem in the world. Its proliferation is related to the presence of objects that accumulate water in backyards long enough to attract the female Aedes aegypti mosquito [8, 9].

According to the rapid survey of infestation by Aedes aegypti carried out in the city of Uberlândia in 2019, 84% of positive breeding sites for Aedes aegypti are inside homes, with 17% inside homes and 83% in backyards [10, 20]. Private backyards with these conditions are difficult to access by the health agents.

Dengue needs to be combated by stopping the mosquito life cycle, preventing it from being born in the vicinity and inside homes. For this, the good management of backyards must be constant. This research assumes that lasting solutions demand continuous intervention, especially with most vulnerable audiences, as those living in SH [8, 9].

3. CO-PRODUCING RESILIENCE: METHODOLOGICAL APPROACH TO CHANGING PRACTISES

People naturally reproduce practises that directly affect the organization and characteristics of the environment in which they live most of their lives (indoors). These practises may often lead to environmental conditions potentially favourable to dengue proliferation.

To help eliminate dengue-favourable environments, a solid methodology is developed as a solution space capable of helping the community to avoid the dissemination of dengue.

This consists of a 3 stages´ toolkit that enable the understanding of the socioeconomic and environmental context, the recognition of home management practices, residents´ profiles, in addition to providing opportunities for reflection and intervention on the built environment.

The work stages are outlined seeking to: raise evidence on the relationship between mosquito proliferation and socioeconomic, environmental, behavioural and morphological conditions of the set, and engage residents in the co-production of strategies.

The methodology comprises 3 main stages as follows:

1) Pre-study assessment

These studies seek to understand a) Residents' demographic profile; b) Mapping of the conditions of the built environment favourable to the proliferation of the Aedes Aegypit mosquito; c) Occurrence of dengue in the neighbourhood; d) amount of mosquito eggs present in houses; e) Number of possible mosquito breeding sites in backyards; f) Identification of practices favourable to the proliferation of mosquitoes. The objective of this pre-study phase is to establish a general understanding of the factors that leads to the proliferation of dengue in the neighbourhood; to know the practices and profiles of the residents to better select the methods for the elaboration of the toolkit; in addition to establishing an initial framework for comparison after studies and actions. This stage combines post-occupancy assessment methods (walkthrough and questionnaires), spatial mapping (drone flight and morphological mapping), and monitoring of the presence of mosquitoes (installation of eggtraps). For this phase, based on the morphological mapping that identifies areas most conducive to the proliferation of mosquitoes, it is decided to sample 32 questionnaires evenly distributed throughout the neighbourhood, of which 11 residents are selected for further studies with walkthrough and installation of eggtraps[1] that are monitored for 6 weeks each time.

2) Toolkit development

This stage involves working with the community to develop a toolkit, capable of helping residents to identify and eliminate possible mosquito outbreaks from their homes. To this end, 7 residences are selected among the 11 participants of the previous study from the identification of their greater

[1] An Eggtrap is a very simple device consisting of a small plastic vase and a wooden strip. The vase is filled with water to 3/4 and the wooden strip is inserted into the vase leaving 1/4 of its length out of the water. The device is then placed in a quiet place in the house. Mosquitoes will lay their eggs on the dry part of the strip expecting them to fall into the water after a week. Before that, however, the researchers collect the wooden strip and with the aid of a microscope they count the number of eggs deposited. This is a very efficient method to check for mosquito infestation in certain places.

engagement. Starting from the pre-study results, co-production workshop sessions are held (4 face to face and 2 online, across 5 months) [11, 12]. A toolkit is developed to help the community recognize and remove breeding grounds, as the most effective way to stop the Dengue disease spreading. These activities are based on the Practice Theory methodology [13] covering the socioeconomic and environmental context, home management practices and residents´ practises [13, 14, 15]. They contained different co-production exercises to address the following objectives: a) Knowing and understanding the relationship between practices and the occurrence of dengue; b) deepening knowledge and ways to avoid it; c) Change in practices and automation of the response to the problem; d) engagement and assimilation of the toolkit in the community. The assimilation indicators are measured at the last workshop, when participants are asked to find potential mosquito breeding grounds in neighbours' houses, that is, in uncharted territory.

3) Post-study assessment

This stage comprised the assessment of project impacts in terms of the effectiveness of changes in practices and persistence over time of these changes. Thus, 6 months after the last workshop, eggtraps were installed to measure the presence of mosquitoes in 11 houses, of which 7 participated in the two previous stages and another 4 that participated only in the first stage. Through a walkthrough, the possible breeding grounds of mosquitoes in the backyards were quantified. This evaluation allowed us to compare results before and after the toolkit, as well as between participants and non-participants, enabling us to obtain performance indicators.

Table 1:
Stages, methods and actions.

Stage	Methods	Actions
Pre-study assessment	Post-Ocupancy Evaluation Georeference. Mosquito infestation test	Questionnaire. Walkthrough. Spatialization from drone images using diverse softwares. Eggtraps monitoring.
Toolkit development	Theory of Change. Practise theory. Co-production exercises	Workshop 1 - Assessing previous knowledge of residents regarding dengue fever. Workshop 2 - Raising awareness about the mosquito, how it is behaving and the risks it offers. Workshop 3 - Identifying the critical points of the backyard. Workshop 4 - Empowering resident-yard relationship. Impact questionnaire.
Post-study assessment	Mosquito infestation test Post-Occupancy Evaluation	Eggtraps monitoring Walkthrough – number of breeding grounds

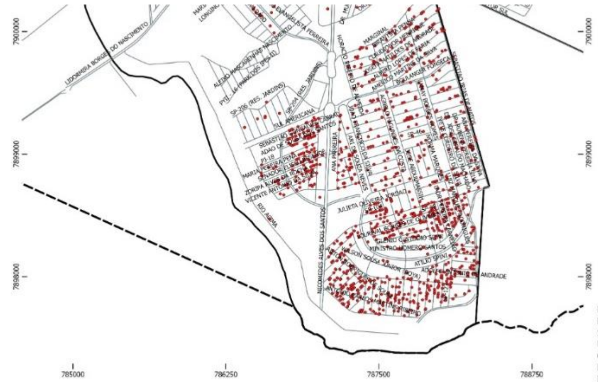
Note: (2020), Authors

4. RESULTS AND DISCUSSION

4.1 Pre-study stage

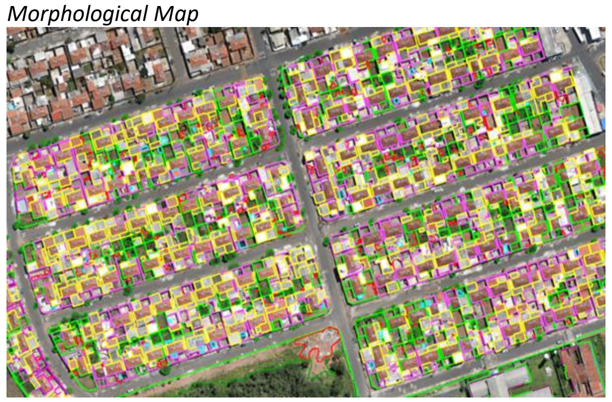
The pre-study stage indicated a high incidence of dengue in the neighbourhood in 2019. Shopping Park recorded 1225 cases of dengue, approximately one case every 3 homes (Fig. 1) [3]. Geographical distribution of cases was homogeneous, indicating that the presence of mosquitoes was not prevalent in a specific location. The morphological mapping (Fig. 1) showed a high incidence of paved areas and soil waterproofing interventions (91%), which favour the accumulation of water and possible breeding sites (Fig.2). The accumulation of material for recycling or future use by residents in the backyards in all 10 sampled houses was also recorded through the walkthrough. These materials become possible mosquito breeding grounds. The questionnaire results showed that the residents did not see materials as garbage, but as resources. Although they had no intention or planning for the use of certain materials, they stored them for some possible use in an indefinite period. Residents also showed reasonable awareness of dengue prevention measures (60% knew how Dengue was transmitted). However, about 80% said they did not take any action, a fact also observed by the researchers during the walkthroughs. The installation of eggtraps indicated that there were eggs in all participating houses, with small variations between them (27 eggs in average). The scenario, therefore, was largely favourable to an uncontrolled proliferation of mosquitoes and an increase in the incidence of the disease.

Figure 1:
Dengue fever incidence in the Shopping Park Neighbourhood



Note: Uberlandia's Zoonosis Control Centre (2019) – Adapted by the authors.

Figure 2:
Morphological Map



Note: Google Earth Pro (2020), Maxar Technologies (2020), Authors.

Figure 3:
Typical backyards – All sort of material stored

Note: (2020), Authors

4.2 Toolkit development

The workshops developed interest and engagement by residents. The degree of knowledge about dengue increased considerably and there were indications of its persistence over time, as demonstrated in impact questionnaires applied in each workshop. There were expected variations depending on the higher or lower level of schooling of each family. An average accuracy level of 80% was observed in the questions related to dengue applied to residents in the first two workshops. Among participants there was already some prior knowledge from previous government campaigns, but in all cases positive change in practices were observed, which were verified in the post-study stage. The following questions were progressively addressed in 4 workshops as follows: a) what do you have in your backyard? b) What would you like to have in your backyard? c) Where is the mosquito in your backyard? d) On-site backyard inventory; e) Mosquito hunt in participants and neighbour's hoses. The assimilation indicators were measured at the last workshop, when participants were asked to find potential mosquito breeding grounds in neighbours' houses, thus, in uncharted territory. In this dynamic, everyone got a 100% hit level. In the qualitative analysis the researchers noticed the increase of interest and absorption of information along the workshops. All these positive results are strong indicators that the toolkit is effective in promoting persistent practices change.

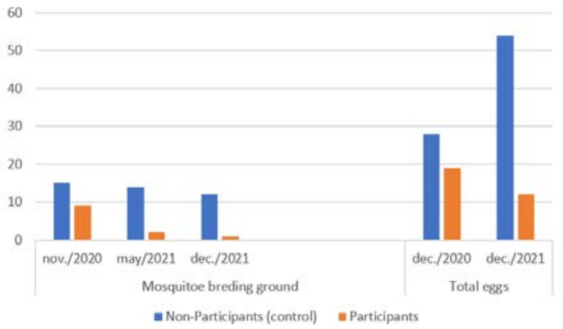
Figure 4:
Interacting with the residents

Note: (2020), Authors

4.3 Post-Study assessment

The post-study assessment was carried out 1 year after the conclusion of the workshops, during which time the residents had no contact with the researchers. After this time lapse, it was possible to assess the effectiveness of the toolkit on a daily basis and the level of assimilation of the residents. The results of this stage demonstrated the success of the methodology used. The comparisons made it possible to doubly monitor the situation in the participating houses in relation to the pre-study indicators, as well as in relation to their neighbours who had not completed stage 2. The results were encouraging and show that among the participants there was a significant 90% reduction in possible mosquitoes breeding grounds in backyards while the egg number reduced by 38%. In relation to those who participated only in the first stage (Pre-study stage) the number eggs grew by 112% while the breeding grounds decreased in 10%, however remaining in a higher level (11 in average) when compared to the participants` (1 in average) (Chart 1). The samples were taken at the same time of the year corresponding to the wet season, which is the peak of the mosquitoes' proliferation.

Chart 1:
Eggs and breeding grounds



Note: (2022) authors

As an outcome from the development and successful performance of the study, two main digital tools were designed: 1. Guidebook; and 2. Web App [11, 12, 16, 17, 18, 19]. Their main purpose is to influence the broader context, replicating the experience of the workshops, expanding knowledge/action on fighting dengue in social housing neighbourhoods

5. CONCLUSION

The findings of this study show that the toolkit and methodology developed provides a successful solution space capable of helping the community to avoid the dissemination of arboviruses. The results also indicate that all participants changed their practises to avoid mosquitoes proliferating, and the results, as seen 1 year after the end of the workshops, shows that they had changed their practises effectively. Despite performing the activities directly with only 7 families, hundreds of people in the community were informed of the methods including: 325 students from the Shopping Park Secondary School, 168 families from the NGO Estação Vida and 23 neighbours of the 11 sampled families.

The methodology as developed also proved to be quite resilient to COVID-19 challenges. Due to the pandemic contingencies, the team turned the methods into digital ones, developing tools that will be a legacy for future projects.

The project provided intense training for students at different levels from undergraduate to doctorate. All 11 students participated and actively contribute to their studies. This methodology was put into practice at the Research Group MORA and is an example of vertical integration between different levels of skills.

ACKNOWLEDGEMENTS

The authors would like to thank the following institutions for supporting and funding this research: Federal University of Uberlândia; University of Sheffield; National Council for Scientific and Technological Development (CNPq); Research Support Foundation of the State of Minas Gerais (FAPEMIG) and; Global Challenges Research Fund (GCRF).

REFERENCES

1. Amore, C. S.; Shimbo, L. Z.; Rufino, M. B. C. (org.), (2015). Minha Casa… e a Cidade? Rio de Janeiro: Letra Capital.
2. Angélil, M., and R. Hehl, (2014). Minha Casa-Nossa Cidade: Innovating Mass Housing In: Brazil. ETH Zurich, MAS Urban Design, Ruby Press: Berlin.
3. Ministério Da Saúde, (2019). Boletim Edpidemiológico n. 22. Monitoramento dos casos de arboviroses urbanas transmitidas pelo Aedes (dengue, chikungunya e Zika), Semanas Epidemiológicas 1 a 34. [Online], Available: https://portalarquivos2.saude.gov.br/images/pdf/2019/setembro/11/BE-arbovirose-22.pdf [20 October 2019].
4. Hasan, S., Jamdar, S. F., Alalowi, M., & Al Ageel Al Beaiji, S. M., (2016). Dengue virus: A global human threat: Review of literature. Journal of International Society of Preventive & Community Dentistry, 6(1), 1–6. https://doi.org/10.4103/2231-0762.175416
5. Schaefer TJ, Panda PK, Wolford RW. Dengue Fever. 2021 Nov 18. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 jan. PMID: 28613483.
6. Portal G1 (2016). Cerca de 80% dos focos do mosquito da dengue continuam sendo encontrados dentro das casas. https://g1.globo.com/to/tocantins/noticia/2019/02/26/cerca-de-80-dos-focos-do-mosquito-estao-dentro-das-casas-aponta-levantamento.ghtml
7. Garrefa, F.; Villa, S. B.; Bortoli, K. C. R; Stevenson, F.; Vasconcellos, P. B. (2021). Resilience in social housing developments through post-occupancy evaluation and co-production. AMBIENTE CONSTRUÍDO ONLINE), v. 21, p. 151-175.
8. Oliveira, J. C. (2012). Mobilização comunitária como estratégia da promoção da saúde no controle dos Aedes (aegypti e albopictus) e prevenção do dengue no Distrito de Martinésia. Tese (doutorado) – Universidade Federal de Uberlândia, Programa de Pós-Graduação em Geografia.
9. Silva, A. F. (2018) Vulnerabilidade social e contexto de vida. Observação social sistemática para avaliação do risco de transmissão da dengue em Uberlândia – MG. Dissertação (Mestrado em Saúde Ambiental e Saúde do Trabalhador) Universidade Federal de Uberlândia.
10. Prefeitura Municipal De Uberlândia (2019). Prefeitura finaliza pesquisa de outubro do índice de infestação do Aedes. Available at: https://www.uberlandia.mg.gov.br/2019/10/28/prefeitura-finaliza-quarta-pesquisa-de-indice-de-infestacao-do-aedes/
11. Silva, A. F. (2018) Vulnerabilidade social e contexto de vida. Observação social sistemática para avaliação do risco de transmissão da dengue em Uberlândia – MG. Dissertação (Mestrado em Saúde Ambiental e Saúde do Trabalhador) Universidade Federal de Uberlândia
12. Garrefa, F.; Villa, s. B.; Stevenson, F.; Bortoli, k. C. R.; Vasconcellos, P. B.; Mendes, P. C.; lima; S. C.; Barbosa, G.; Borges, l.; Carvalho, N. L.; Miranda; N. L.; Miranda, R. Final Report – CO-PRODUCING HEALTHY COMMUNITIES: Backyard retrofit to prevent arboviruses epidemics in Brazilian social housing developments. 2021. Uberlândia: UFU/PPGAU/FAUED, TUoS/SSoA. Global Challenges Research Fund (Research Report).
13. Gram-Hanssen, K. (2009). Standby consumption in households analyzed with a practice theory approach, research and analysis. Volume 14, number 1.
14. Frances, Z.; Stevenson, F. 2019. A relational approach to understanding inhabitants' engagement with photovoltaic (pv) technology in homes, architectural science review, doi: 10.1080/00038628.2019.1682962.
15. Stevenson, F.; Rijal, H. B. (2010): developing occupancy feedback from a prototype to improve housing production, building research & information (2010) 38(5), 550–564.
16 VILLA, S. B. et al. (2022). Lack of adaptability in Brazilian social housing: impacts on residents. Buildings and Cities, v. 3, n. 1, doi http://doi.org/10.5334/bc.180
17. Kowaltowski, D. C. C. K.; Muianga, E. A. D.; Granja, A. D.; Moreira D. C.; Bernardini, S. P.; Castro, M. R. (2018) A critical analysis of research of a mass-housing programme. Building Research & Information, v.47, n.6, p.716-733. https://doi.org/10.1080/09613218.2018.1458551
18. Chandler, C.; Unger, R. (2009) O Guia para Projetar UX: a experiência do usuário (UX) para projetistas de conteúdo digital, aplicações e web sites. Rio de Janeiro: Alta Books.
19. Cole, R. (2005) Building environmental assessment methods: redefining intentions and roles. Building Research & Information, 33(5), pp.455-467.
20. Web Arapicara. Prefeitura Municipal De Arapicara (2019). Cerca de 85% das larvas do mosquito da dengue estão dentro de casa.

PLEA STGO 2022

November 22 - 25, 2022

ANALYSIS AND METHODS

DAY 01
14:15 — 15:45

CHAIR
VINCENT BUHAGIAR

PAPERS
1172 / 1585 / 1199 / 1468 / 1213

10TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Urban vulnerability assessment and urban planning management to urban heat islands in France

A multicriteria analysis

MAGALIE TECHER[1], HASSAN AIT HADDOU[1], RAHIM AGUEJDAD[2,3]

[1] Laboratoire LIFAM, Ecole Nationale Supérieure d'Architecture de Montpellier, France
[2] USR 3330, UMIFRE 21, CNRS-MAE, PF, India
[3] UMR TETIS, Maison de la télédétection, CNRS, France

ABSTRACT: This paper presents a methodology to assess Urban Heat Island (UHI) vulnerability, of Montpellier Metropolitan area, in France. The aim of this work is to assess the vulnerability, through the prism of urban planning policies as an innovative adaptation capacity of assessment. The main objective is to provide advice to urban decision makers on how to adapt and mitigate this risk. A multi-criteria analysis is used to evaluate UHI vulnerability. We propose an analysis with two components: urban planning challenges and urban overheating exposure. Maps are generated for each component and aggregated to generate vulnerability map. Results shows that most exposed areas are located in urban centers, with the most challenges, while the analysis of planning characteristics reveal behaviors similar to those found in scientific literature. The results are relevant for French urban planners. Map produced is a support for urban planning, by targeting the most vulnerable areas in order to define priorities of interventions. Therefore, this method and its results could be reproduced in other French territories in research on urban vulnerability to Urban Heat Islands.
KEYWORDS: Urban vulnerability, Urban Heat Island, Urban Planning Policies, Exposure, Multicriteria Analysis

1. INTRODUCTION

Cities, due to the modification of their urban environment and human presence, are facing Urban Heat Island (UHI) phenomenon [1]. Exacerbated by global warming effects, this phenomenon is intensifying and exposing populations and urban areas to thermal stress, which leads to health, comfort and energy overconsumption issues during the summer in particular [2].

To meet this challenge, in recent years, many studies have been developed, on the one hand, around the proposal of solutions to mitigate Urban Heat Island [2,3] and on the other hand, to identify areas prone to overheating [4]. Vulnerability assessments and maps are one of the methodologies proposed in the field of the mitigation and adaptation to Urban Heat Islands and have been used internationally [5] and in France [6]. Vulnerability is defined as the fragility and action capacity of an area or a population following its exposure to a risk, a stress or a disturbance [5].

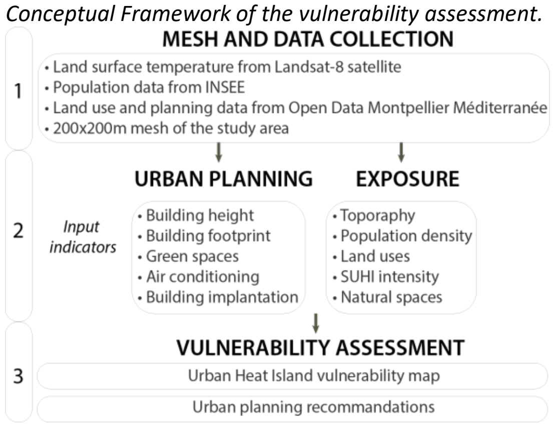
In parallel, with the developments of these studies which demonstrate a direct relationship between planning, morphology and Urban Heat Island [7], urban decision-makers try to seize this question. However, results interpretation and realization of this type of study remain a challenge due to a lack of tools, skills and a language related to the field of urban climatology far from their practice of regulatory urban planning [8]. Studies to identify areas vulnerable to the Urban Heat Island effects and their consideration within urban planning must therefore be considered as a major asset and perspective for responding to the development challenges of urban territories and mitigation of urban overheating [8].

This research proposes a methodology to integrate and take into account the challenges of urban planning as adaptation capacity following the exposure of the territory to the risk represented by urban overheating. By carrying out a vulnerability map summarizing the relationships between urban planning challenges and exposure to climate hazards, an identification of the zones characteristics is carried out. This analysis enables to highlight mitigation and adaptation solutions adapted to the language of urban planning and which can be integrated into urban planning documents. Finally, this work aims to support urban decision makers in the search for solutions to fight and intervene against the intensification of urban heat islands.

2. METHODOLOGY

This research involves three stages (fig.1). The first consists of generating multi-criteria database of urban planning challenges and exposure to Urban Heat Island effects. The second consists of generating the vulnerability map and the last step concerns the analysis of the distribution and areas characteristics and the proposal of mitigation and adaptation solutions adapted to urban planning.

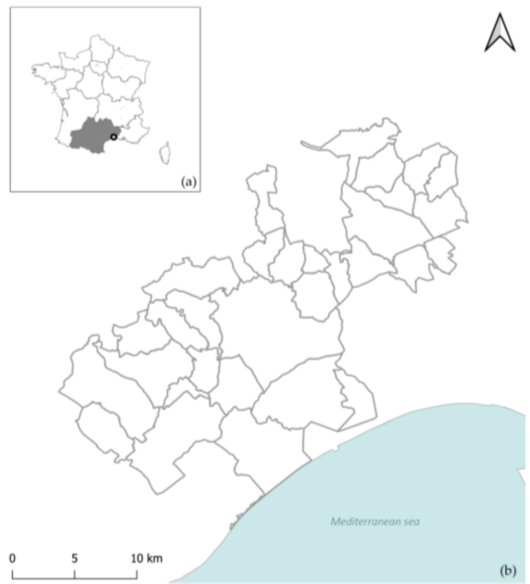
Figure 1:
Conceptual Framework of the vulnerability assessment.



2.1 The study area

Montpellier Méditerranée is a metropolitan area located in Occitanie region, in the south-east of France (fig.2). With a surface area of approximately 49 000hA, it hosts 481 276 inhabitants distributed in 31 municipalities in 2018 [9].

Figure 2:
(a) Location of Montpellier Méditerranée metropolitan area in France ; (b) 31 municipalities of Montpellier Méditerranée metropolitan area.



Bordered by the Mediterranean Sea, the climate is a typical Mediterranean climate according to Koppen-Geiger classification. In recent years, it has experienced an increase of populations which leads to significant urban sprawl, densification which exacerbated Urban Heat Island phenomenon [10]. For this study, the entire surface of the territory is investigated, however, the resolution and precision of the data used is a set of cells of 200 x 200m which form the study mesh of approximately 11500 cells.

2.2 Data acquisition

To produce a map of areas subject to Urban Heat Island effects representing the metropolitan area of Montpellier Méditerranée, data is acquired from satellite observations, demographic data and regulation from urban planning.

Climatic data (Land Surface Temperature) is obtained from the processing of images from LANDSAT-8 satellites [11]. The characterization of urban planning comes from the integration of Local Urban Plans in force in the study area. The demographic data are taken from the population census carried out by the French National Statistics and Economics Studies Institute in 2018 [9]. Finally, the data relating to the characteristics of the territory (use, topography, proximity) are acquired from the open data of the metropolis of Montpellier Méditerranée. Through the scientific literature, results have made it possible to better understand the impacts of urban parameters integrated into the study on Urban Heat Island phenomenon. A brief summary is provided to explain the classification of each indicator.

The data processing was carried out within a geographic information system (GIS), a tool used in the practice of urban planners and urban decision makers [12]. QGIS software was used, version 3.22, to generate the vulnerability study and indicators database presented in this study.

2.3 Urban planning challenges

Local Urban Plans, at municipal or inter-municipal level, govern the territory development project and have an impact on the urban morphology and the appearance of the urban environment [13]. The indicators used in the formation of the urban planning challenges layer come from the spatial translation of sections from the regulation of Local Urban Plans.

This regulation is one of the documents that make up the Local Urban Plans [14]. It enables to regulate, thanks to 16 sections, all construction projects on the territory by defining the urban, architectural and landscape characteristics within each plot [14]. For this study, 5 sections - indicators (tab.1) are integrated, namely the building footprint coefficient (section 9), the proportion of planted spaces (section 13), the air conditioning system implantation (section 11), the building's maximum height (section 10) and the building's location in relation to plot boundaries (sections 6 and 7).

Table 1:
Urban planning challenges indicators and layers.

Indicators	Class	Definition
Building footprint (section 9)	1	5-35%
	2	35-65%
	3	65-100%
Green areas (Section 13)	1	65-100%
	2	35-65%
	3	4-35%
Building height (Section 10)	1	2-5m
	2	5-10m
	3	10-30m
	4	30-50m
	5	50-70m
Air-conditioning (Section 11)	1	Prohibited
	2	Authorized
Building's location (Sections 6 and 7)	1	Withdrawal on all
	2	1 withdrawal min.
	3	1 alignment min.
	4	Alignment on all

The building footprint coefficient indicators and the proportion of planted spaces are negatively correlated, the increase of the first exacerbates urban overheating [15] while the increase of the second constitutes one of the most cited solutions to fight against Urban Heat Island within the scientific literature [3]. The air conditioning system implantation is one of the intensification causes of Urban Heat Island phenomenon, due to the anthropogenic heat generation toward the outside environment and surrounding unequipped buildings [16]. The construction's height is linked to the street's prospect, which has an impact on radiative exchanges contributing to the modification of urban materials temperatures [17]. Finally, building's location on plots has an impact on urban porosity and roughness, which disrupts air circulation and therefore the trapping of urban overheating [18].

2.4 Urban overheating exposure

The exposure of the territory and the populations to urban overheating characterizes the extent of Urban Heat Island effects and the possible local aggravation degree of the phenomenon according to geographical and demographic characteristics. In this work, 6 indicators (tab.2) are taken into account. This involves taking into account: topography, population density, land uses, daytime Surface Urban Heat Island intensity and proximity to green and water spaces. Increase in altitude has a positive attitude on temperatures, the higher it is, the more the temperature decreases with an order of 0.6°C decrease for every additional 100m [19].

Population density has a negative impact on urban overheating, in fact, density is an indicator of the concentration of populations within the same place, and this is directly linked to the increase in urban temperatures due to anthropogenic heat generation. Land uses influence Urban Heat Islands effects, because urban areas see their environment modified compared to the rural environment (modification of urban materials, air circulation and loss of vegetation cover) [1,2,3].

Table 2:
Urban overheating exposure indicators.

Indicators	Class	Definition
Topography	1	> 300 m
	2	150-300m
	3	< 150m
Population density	1	0-48
	2	48-126
	3	126-231
	4	231-384
	5	384-627
	6	627-1231
	7	1231-2439
Land uses	1	Unbuilt areas
	2	Housing
	3	Business, industrial, education, historic center, public
Surface Urban Heat Island intensity	1	< 0°C
	2	0-1°C
	3	1-2°C
	4	2-5°C
	5	5-10°C
	6	> 10°C
Proximity to green and water areas	1	Near green spaces
	2	Away from green spaces

The Surface Urban Heat Island intensity is an indicator of urban overheating, since it represents the thermal gradient, characterized by the difference in mean surface temperature between natural areas and urban areas. Finally, the proximity to green and aquatic spaces is beneficial in reducing Urban Heat Island effects because the presence of plants and water allows the nearby urban air to be refreshed by evaporation [3].

2.5 Global vulnerability map production

From 11 indicators, layers summarizing the urban planning challenges and the exposure of the territory and the population to the risk of urban overheating are generated using an explicit weighting method with equal weights [5]. A classification is made for each indicator, according to its behaviour on the intensification of urban heat islands. The lowest degrees of challenges and exposure are assigned a low value while the highest degree is assigned a high value. The global map is then generated from challenges and exposure layers. The synthetic map includes 9 different classes (tab.3) which represents the relationship between urban planning challenges and exposure to urban heat island effects.

Table 3:
Urban vulnerability classification.

Class	Nomenclature	Urban planning challenges	Exposure to urban overheating
1	A1P1	Low	Low
2	A1P2	Medium	Low
3	A1P3	High	Low
4	A2P1	Low	Medium
5	A2P2	Medium	Medium
6	A2P3	High	Medium
7	A3P1	Low	High
8	A3P2	Medium	High
9	A3P3	High	High

3. RESULTS AND DISCUSSION

3.1 Urban overheating vulnerability assessment

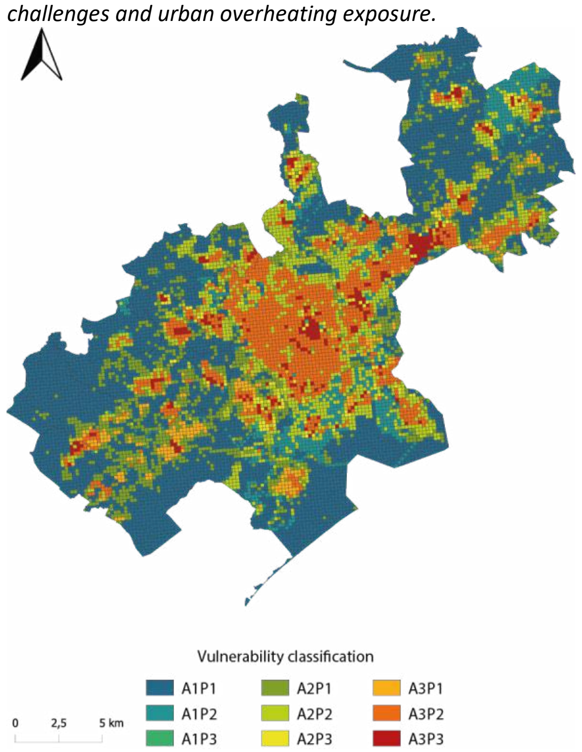
The most vulnerable areas, because they present highest planning challenges and strongest exposure to urban overheating, are concentrated within the territory's urban centers (fig.3), where proximity to green and water spaces are rarer as well as the built and demographic density is higher. Data show that areas with more vegetation both on the plot with more planted spaces and less built spaces as well as proximity to green spaces, are less prone to urban overheating. Indeed, these areas show an average surface temperature gain of up to 3.55°C compared to the most exposed areas (tab.4). The most exposed areas represent 25.79% of the surface of the territory while the least vulnerable areas represent 56.14% of this surface, i.e., more than half of the overall surface of the territory. It also appears that on average, the most exposed areas are 2.42°C warmer than the less exposed areas.

Table 4:
Percentage of total surface area and land surface temperatures of vulnerability classes (A1P1 to A3P3).

Nomenclature	% of total surface area	LST°C min	LST°C mean	LST°C max
A1P1	47.35	24	32.67	41
A1P2	8.72	24	33.55	42
A1P3	0.07	31	33.73	36
A2P1	15.32	25	34.75	60
A2P2	12.20	26	34.10	41
A2P3	1.40	30	34.81	42
A3P1	2.74	29	36.22	60
A3P2	9.67	30	34.98	42
A3P3	2.52	30	35.99	45
N areas	44.30	24	30.94	42

Note: N areas: natural N areas included in urban zoning of Local Urban Plans.

Figure 3:
Vulnerability map: relationship between urban planning challenges and urban overheating exposure.



The most exposed areas (A3P3, A3P2, A3P1 and A2P3), are mainly made up of mixed areas with dominant habitats and activities, located in urban centers, which present strong challenges due to the high concentration of populations and activities generating anthropogenic heat, a high density (tab.5) which reduces their air circulation potential and their proportion of green cover.

Table 5:
Mean urban planning challenges classes for each vulnerability classes.

Nomenclature	S_9	S_{13}	S_{10}	S_{11}	$S_{6/7}$
A1P1	1	1	2	1	2
A1P2	1	3	2	1	3
A1P3	3	3	3	1	3
A2P1	1	1	2	1	2
A2P2	2	3	2	1	2
A2P3	2	3	3	2	3
A3P1	1	1	2	1	2
A3P2	2	3	2	1	2
A3P3	3	3	3	1	3
Total area	2	2	2	2	2

Note: S_9: Building footprint coefficient (section 9); S_{13}: Proportion of green areas (section 13); S_{10}: Building height (section 10); S_{11}: Air-conditioning systems (section 11) and $S_{6/7}$: Building's location in relation to parcel boundaries (sections 6 and 7).

The less exposed areas (A1P2 and A1P1) are mostly made up of mixed areas, predominantly agricultural and natural areas, where challenges seem lower, due to a lower concentration of population and activities, a lower density and greater vegetation cover. Finally, the intermediate level areas (A2P2, A2P1 and A1P3) are made up of mixed zones which present less serious challenges due to a lower concentration of population and activities characterized by the suburban areas, with average built and vegetation coverage and better ventilation potential.

In the table 6 (tab.6) are presented the minimum, average and maximum temperatures for each class of indicators of urban planning challenges for the entire territory. It appears that the areas allowing a higher building footprint coefficient are warmer by 2.41°C on average than the less built-up areas. Similarly, more heavily planted areas are cooler by an average of 1.37°C than lightly green areas. Areas allowing implantation of air conditioning are warmer by 1.2°C on average than the areas which prohibit it. The analysis of the construction maximal height indicates that the highest temperatures are found in areas where the height is between 10-30m while this area covers only 13.5% of the territory. This result can be explained by the fact that this height corresponds to an average height that does not allow sufficient shade to be generated and that these constructions are located in areas where air circulation is not optimal. Finally, the location of construction least impacted by urban overheating is defined as imposing a minimum alignment with an average cooler temperature of almost 2°C compared to the other configurations.

Table 6:
Land surface temperatures of urban planning challenges indicators 's classes.

Indicators	Class	LST °C min	LST °C mean	LST °C max
Building footprint S_9	1	24	33.17	42
	2	30	34.907	42
	3	27	35.58	45
Green areas S_{13}	1	26	33.38	41
	2	30	34.46	42
	3	27	34.75	45
Building height S_{10}	1	29	33.85	39
	2	24	33.96	60
	3	30	35.26	45
	4	30	34.81	38
	5	32	34.77	38
Air-conditio. S_{11}	1	24	33.02	45
	2	28	34.22	43
Building's location $S_{6/7}$	1	29	34.32	42
	2	24	34.17	60
	3	24	32.62	44
	4	30	34.23	39

3.2 Mitigation and adaptation measures

The vulnerability map enables to identify areas most prone to Urban Heat Island effects and the analysis of planning challenges makes it possible to visualize the planning characteristics of these areas. Mitigation and adaptation solutions can thus be defined (tab. 7) and orientations considered during the development of new urban planning regulations to fight against Urban Heat Island phenomenon.

Table 7:
Adaptation and mitigation measures from urban regulations of Local Urban Plans.

Nomenclature	S_9	S_{13}	S_{10}	S_{11}	$S_{6/7}$
A1P1	▼	▲	▼	▼	▼
A1P2	▼	▲▲	▼	▼	▼
A1P3	▼▼▼	▲▲▲▲	▼▼	▼	▼
A2P1	▼	▲	▲	▼	▼
A2P2	▼▼	▲▲▲▲	▲▲	▼	▼
A2P3	▼▼▼	▲▲▲▲	▼▼	▼▼	▼
A3P1	▼	▲	▲	▼	▼
A3P2	▼▼▼	▲▲▲▲	▲	▼	▼
A3P3	▼▼▼▼	▲▲▲▲	De	▼	▼
Total area	▼▼	▲▲	▼	▼▼	▼

Note: ▲ recommend increasing indicator impact on UHI; ▼ recommend decreasing indicator impact on UHI.

Thus among the 5 indicators - sections taken into account in the study, recommendations are defined to improve their behaviour on Urban Heat Islands intensification: improve the proportion of permeable spaces and green spaces by reducing building footprint coefficient and the percentage of planted areas; improve urban ventilation and heat exchange by optimizing the height and location of buildings on the plot and finally, reduce the anthropogenic heat generation by controlling and limiting the installation of air conditioners on these plots.

3.3 Application and impacts

This work consisted in developing a methodology which enables to link the climatology sciences to the operational practices of urban decision makers and urban planners. This methodology provides results allowing these stakeholders to grasp this issue while providing them with levers of action that they had at their disposal within urban planning documents. Carried out in a French context, this work is applicable to all French territories with a regulation of Local Urban Plan, i.e., 65% of the territory in 2022 [20]. It allows these stakeholders to carry out a vulnerability diagnosis of their territory to a fine mesh close to the block and using data and tools (GIS) from their daily practices.

4. CONCLUSION

This research brings two perspectives for urban planning. The first is that vulnerability map enables to spatially visualize and identify the different degrees of Urban Heat Island vulnerability [5-6,21]. Indeed, it appears that the percentage of the most vulnerable areas with a medium to high hazard level and a medium to high urban planning challenge represents ¼ of the total area of the metropolis with an average surface temperature 4.79°C warmer than N natural areas.

The second is that this research including urban planning characteristics presents results similar to studies of the impact of urban form on Urban Heat Island [2-3,16-19] while employing a language understandable to urban planners [7,21]. This method enables to anticipate and plan mitigation strategies among the solutions most cited in the scientific literature and translated for urban decision makers.

This research involved a limited number of vulnerability indicators and do not allow to assess it entirely. Further development could involve the integration of more socio-economics and climatic indicators, such as wind and air temperature, in order to obtain a more global view of the risk posed by Urban Heat Islands. Despite these limitations, thanks to the integration of urban planning indicators as an adaptation capacity to urban overheating, it is possible, on the one hand, to understand the effects of planning on the amplification of Urban Heat Island phenomenon.

Thus, controlling built areas density, green areas and anthropogenic heat generation would allow an improvement in urban temperatures and a reduction in thermal stress suffered by urban populations. On the other hand, mitigation and adaptation strategies that can be integrated into urban planning documents enable to adapt, justify and optimize interventions or projects to implement solutions.

ACKNOWLEDGEMENTS

Authors are grateful to the French Ministry of Culture and the French Environment and Energy Management Agency (ADEME) for the financing of this work.

REFERENCES

1. Arnfield, A.J. (2003). Two decades of urban climate research: A review of turbulence, exchanges of energy and water and the urban heat island. *International Journal of Climatology*, *23*, 1-26.
2. Tsoka, S., Tsikaloudaki, K., Theodosiou, T., and Bikas, D. (2020). Urban warming and cities' microclimates: Investigation methods and mitigation strategies—A review. *Energies*, *13*(1414), 25.
3. Bernard, J., Musy, M., & Marie, H. (2020). Rafraîchissement des villes : Solutions existantes et pistes de recherche. In *O*, Éditions Paranthèses, ADEME, pp. 16.
4. Gonzalez-Trevizo, M.E., Martinez-Torres, K.E., Armendariz-Lopez, J.F., Santamouris, M., Bojorquez-Morales, G., & Luna-Leon, A. (2021). Research trends on environmental, energy and vulnerability impacts of Urban Heat Islands: An overview. *Energy and Buildings*, *246*, 111051.
5. Cheng, W., Li, D., Liu, Z., & Brown, R.D. (2021). Approaches for identifying heat-vulnerable populations and locations: A systematic review. *Science of The Total Environment*, *799*, 149417.
6. IAU Ile-de-France. (2017). *Adapter l'Ile de France à la chaleur urbaine : Identifier les zones à effet d'îlot de chaleur urbain (ICU) et établir leur degré de vulnérabilité afin de mieux anticiper*, IAU Ile-De -France, p. 155.
7. Lin, P., Siu Yu Lau, S., Qin, H., & Gou, Z. (2017). Effects of urban planning indicators on urban heat island: A case study of pocket parks in high-rise high-density environment. *Landscape and urban planning*, *168*, 48-60.
8. Mills, G. (2006). Progress toward sustainable settlements: A role for urban climatology. *Theoretical and Applied Climatology*, *84*, 69-76.
9. INSEE. (2018). *Populations légales 2018 – Recensement de la population – regions, départements, arrondissements, cantons et communes*, INSEE, available online.
10. Audric, S., Canonero, B., & Tasqué, O. (2018). *Montpellier Méditerranée Métropole : Diagnostic de territoire*, INSEE, available online.
11. Avdan, U., & Jovanovska, G. (2016). Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. *J. Sensors*, *2016*, 1480307:1-1480307:8.
12. Mineau, D. (2003). L'apport des SIG en urbanisme (The contribution of GIS to town planning). *Bulletin de l'Association de géographes français*, *2003*, 443-453.
13. Ministère de la cohésion des territoires. (2017). *PLUI-Un outil pour l'avenir des territoires*, Ministère de la cohésion des territoires, p. 4.
14. GRIDAUH. (2018). *Ecriture du PLU, Le règlement, Caractéristiques urbaine, architecturale, environnementale paysagère—Fiche 2.1.3.2.,* GRIDAUH, available online.
15. Li, Y., Schubert, S., Kropp, J. P., & Rybski, D. (2020). On the influence of density and morphology on the Urban Heat Island intensity. *Nature Communications*, *11*(1), 2647.
16. Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., & Wang, M. (2014). Anthropogenic heating of the urban environment due to air conditioning. *Journal of Geophysical Research: Atmospheres*, *119*(10), 5949-5965.
17. Escourrou, G. (1991). *Le Climat et la Ville*, Nathan.
18. Athamena, K., Musy, M., & JULIEN, B. (2009). *Proposal of Indicators Dedicated to the Analysis of Contribution of Urban Projects to Urban Heat Island*. 6.
19. Ren, C. (2015). Urban climatic map studies in Taiwan: Kaohsiung. In *The urban Climatic Map: A Methodology for sustainable urban planning* (Routledge, p. 185-208). Taylor & Francis Group.
20. Géoportail de l'Urbanisme (2022, August, 1) *Statistiques, France entière.* https://www.geoportail-urbanisme.gouv.fr/statistics/france/
21. Weber, S., Sadoff, N., Zell, E., & de Sherbinin, A. (2015). Policy-relevant indicators for mapping the vulnerability of urban populations to extreme heat events: A case study of Philadelphia. *Applied Geography*, *63*, 231-243.

PLEA SANTIAGO 2022
Will Cities Survive?

The microclimate effects of urban green infrastructure under RCP 8.5 projection and plant vitality

Will plants be enough?

DANIEL F. O. YOSHIDA[1] PAULA SHINZATO[1] DENISE HELENA SILVA DUARTE[1]

[1]Faculty of Architecture and Urbanism - University of São Paulo

ABSTRACT: The rise of mean temperature and urban heat island threatens the health of people and can raise the energy consumption of cities. Vegetation can be an important strategy to mitigate and adapt cities to the impacts of climate change Therefore, this research aims to analyze and quantify the effects and vitality of vegetation on the urban microclimate under RCP 8.5 IPCC scenario within the São Paulo city. ENVI-met model and climate data from PROJETA/INPE and IAG/USP Meteorological Station were utilized for modeling parametric models representing the three most common Local Climate Zones (LCZ) found in São Paulo city: LCZ 3, LCZ 6 and LCZ 8 under RCP 8.5 IPCC conditions. To analyze how vegetation can impact urban microclimate, trees were implemented along each LCZ studied and new simulations on ENVI-met for each condition were carried out. The results of this research shows that vegetation in extreme heat conditions barely can change air temperature but reduces significantly mean radiant temperature, surface temperature and PET (Physiological Equivalent Temperature. But the results also show that vegetation may not be enough and may suffer from heat stress as the Leaf Temperature results show temperatures near to 50ºC which can be dangerous to your vitality.

1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change IPCC (2021), human settlements will be affected by more frequent extreme climate events, such as heatwaves, with more hot days and warm nights. It also indicated rising sea levels, more tropical cyclone storms and a higher intensity of rainfall, that will increase the probability of coastal city flooding.

Vegetation can improve the urban microclimates and contribute to the mitigation of the warming effects in cities. The cooling effect by vegetation is achieved through evapotranspiration process in combination with shading, which can increase specific humidity and reduce surface temperatures. In parallel, trees and other green components filter the air, mask noise in cities, and prevent soil erosion while contributing to the mental balance of city dwellers (8).

Therefore, green urban infrastructure has been promoted as promising for reducing the adverse effects of climate change in urban areas, for example, by balancing water flows to alleviate flooding, providing thermal comfort by shading vegetation, and supporting coping capacities by providing people with opportunities to grow food for themselves (6).

[1] Institute of Astronomy, Geophysics and Atmospheric Sciences - University of São Paulo.

The Representative Concentration Pathways (RCPs) were presented on IPCC Fifth Assessment Report (AR5), which adopt different greenhouse concentrations and are used for climate modeling to generate future projections. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5) (IPCC, 2014). The RCP8.5 is the high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250) (8).

This present research aims to quantify and analyze the effects of vegetation on microclimates, considering RCP 8.5 IPCC scenario in the city of São Paulo.

The ENVI-met model was used to build the parametric models that represent the most common LCZs in São Paulo For RCP 8.5 IPCC conditions, simulations considered climate data from the National Institute for Space Research - INPE/PROJETA[1] platform and IAG USP[2] Meteorological Station.

ENVI-MET is a three-dimensional, high-resolution prognostic microclimate model (1). One of the main advances in the ENVI-met model is the detailed modeling of vegetation. With the development of the plant-as-object model, plants are no longer treated as loose grid cells of leaf area density (LAD) but rather considered as aggregate, dynamic objects that react immediately with environmental conditions (15). Through a high-resolution modeling area, ENVI-met is able to calculate carbon dioxide (CO_2) and water vapor exchange at the leaf scale using an adaptation of Jacobs (1994) studies for stomata behavior (2).

[2] PROJECTIONS OF CLIMATE CHANGE FOR SOUTH AMERICA REGIONALIZED BY THE ETA MODEL -

The urban morphology of the parametric scenarios considered the Local Climate Zones from the studies of Steward and Oke (2012), which are uniform regions of surface cover, structure, material, and human activities that extend hundreds of meters to several kilometers within the horizontal scale. LCZs are classified into 17 classes, 10 of which can be classified as urban; thus, it is a system originally designed to promote better understanding for urban heat island studies by allowing standardization of urban temperature observation (17).

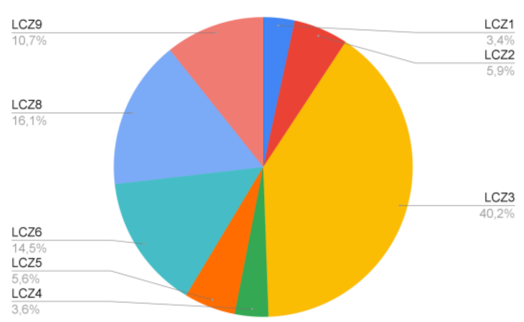
To analyze the effect of vegetation, simulations were run with and without plants. The simulation results were compared and indicated how vegetation influenced the surroundings, for different LCZs and considering RCP 8.5 projection.

2. METHODS

2.1 LCZs in the city of São Paulo

The LCZ data in the city of São Paulo were generated by Ferreira (2019) following the WUDAPT methodology to classify the LCZs in the city of São Paulo, for 2017.

Figure 1: Percentage of each LCZ in São Paulo, according to Ferreira (2019).



These LCZs data were processed through the QGIS geoprocessing model, raising the percentage for each LCZ typology existing in the city (Fig. 1). In this way, the three most representative LCZs are: LCZ 3 (40.2%), LCZ 6 (14.5%) and LCZ 8 (16.1%) and these urban typologies were considered in this research.

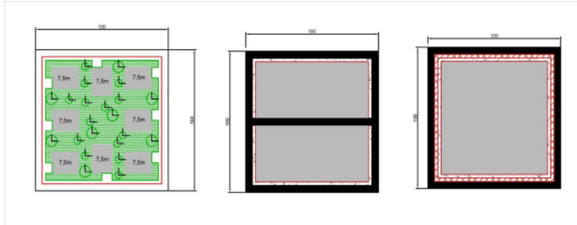
[3] Kropp, Tim et al. 2018. "Enhancement of the WuDapT Portal Tool WUDAPT2Envi-MET: Introducing Site-Specific Local Climate Zones to WUDAPt2Envi-MET." *PLEA 2018 - Smart and Healthy within the Two-Degree Limit: Proceedings of the 34th International Conference on Passive and Low Energy Architecture* 1(December): 256–61.

2.2 Modeling the case studies

The tile LCZs used in this research were adapted to the context of the city of São Paulo following parameters from previous research [3]within the Laboratory of Energy Efficiency and Environmental Comfort of the School of Architecture and Urbanism of the University of São Paulo. Thus, the typologies LCZ 3, LCZ 6 and LCZ 8 were modeled (Fig 2).

Each LCZ was digitized, having a total size of 100m x 100m and the surface properties according to each LCZ typology (type of concrete, asphalt and building materials).

Figure 2: *LCZ 3, LCZ 6 and LCZ 8 (100x100m)*



For each scenario, an area with 9 blocks was modeled in a 3m x 3m grid cell resolution (Fig. 3), with a total area size of 300m x 300m. This simulation format was chosen because it can show better results, mainly in the central block, as the edges of the scenarios are more unstable regions and largely influenced by wind flow.

Figure 3: *LCZ 3, LCZ 6 and LCZ 8 with 9 blocks.*

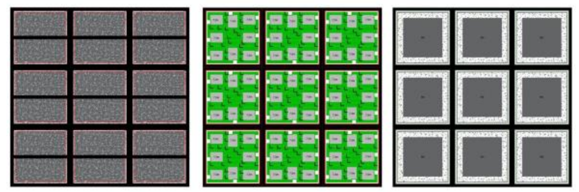
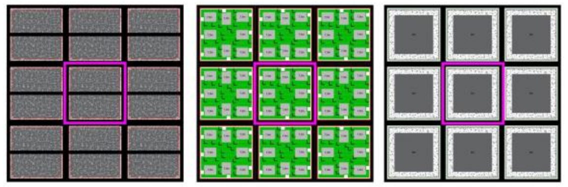


Figure 4 indicates the central block considered for the analysis of the simulation results.

Figure 4: *Central block in models LCZ 3, LCZ 6 and LCZ8*

Ferreira, Luciana Schwandner. 2019. "E Morfologia Urbana Temperatura De Superfície E Morfologia Urbana."



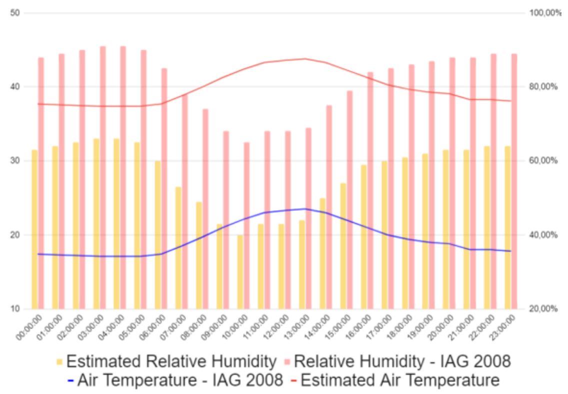
2.3 Assembling meteorological data from climate projections RCP 8.5

As mentioned previously, the future climate projection data were obtained from the INPE/PROJETA[4] platform for air temperature at 2m and relative humidity for the period from January 1st 2006 to January 31, 2099. The climate data taken from INPE/PROJETA are data corresponding to the climate scenario with 5km resolution, RCP 8.5 of the HADGEM2-ES model for the municipality of São Paulo.

In this time frame, the simulations started at 0 a.m. on 11.23.2099, which was chosen as it presents the highest average air temperature: 39.9ºC, about 12 degrees Celsius above the current average.

Each simulation ran during 24 hours and, in the ENVI-met settings, climatic conditions used simple forcing configuration, requiring hourly data for air temperature and relative humidity. However, INPE/PROJETA data for air temperature has only hourly values with time intervals for every 3 hours; the relative humidity data are organized in daily average values for each corresponding day. For this reason, adjustments[5] were necessary in order to use the forcing tools of ENVI-met,

Figure 5: Simple forcing data for air temperature and relative humidity, considering INPE/PROJETA RCP 8.5, on 11.23.2099.



To estimate the hourly values of air temperature and relative humidity, a simple estimation was made utilizing the average value of of air temperature (39,9ºC) and relative humidity (63%) for 11.23.2099 and the the hourly curve of air temperature and relative humidity from IAG 2008 Weather Report. The estimated values for air temperature and relative humidity follows the same hourly curve proportion of the IAG Weather Report but corresponds to the average values of air temperature and relative humidity of the day 11.23.2099.

Figure 5 illustrates the results of air temperature and humidity estimations and illustrates its simplicity.

2.4 General Simulation properties

For all simulations the same meteorological conditions were submitted, according to table 1. The simulation covers a 24-hour period for November 11, 2099, the projection date with the highest temperature averages. The wind speed for 2m height was set as 1 m/s. The initial soil humidity and soil temperature for the simulations was set 65% and 20°C, respectively.

Table 1: *ENVI-met input data*[6]

Start Simulation at day	11.23.2099
Wind Speed in 10m ab. Groud (m/s)	1m/s
Wind Direction (0N/90E/180S/270W	135
Specific Humidity in 2500m (g Water/ kg air)	8
Simulation Duration	24hrs
Simulation Start Hour:	00:00
Simulation Ending Hour	23:59
Nesting Grids	4
Simulation Resolution	3m
Simulation Type	simple forcing

2.5 Vegetation data

ENVI-met has an extensive editable vegetation database in Albero. Within this database, a new tree type was created based on information by the Municipal Environmental Agency (SVMA), which has published a Technical Manual of Urban Arborization, indicating the main tree species existing in the city of São Paulo.

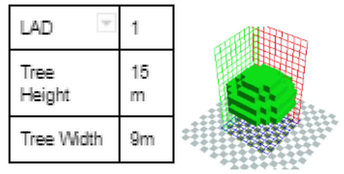
Based on this document, a new tree type was created in the ENVI-met model: a15 m high tree, with a crown width of 9 m and a LAD value of 1 m^2/m^3. The size, width and LAD of this tree corresponds to the values of the large adult tree, categorized by the Urban Tree Planting Technical Manual.

[4] More information in https://projeta.cptec.inpe.br/#/dashboard.

[5] These adjustments were suggested by Professor Dr. Humberto Ribeiro da Rocha from IAG/USP (Institute of Astronomy, Geophysics and Atmospheric Sciences).

[6] Data based on previous research from Shinzato (2019): Paula et al. 2019 Calibration process and parametrization of tropical plants using ENVI-met V4 – Sao Paulocase study, Architectural Science Review, 62:2, 112-125, DOI: 10.1080/00038628.2018.1563522

Figure 6: *New tree type created in Albero.*



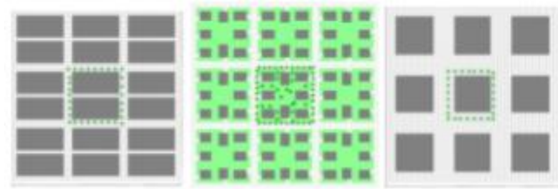
2.6 Building and surface data

The surface properties for concrete and asphalt were defined based on Gusson (5) (2020) research that created specific urban materials for São Paulo and also defined the constructive profile for façades and roofs of the existing buildings in the city. The soil profile was based on Shinzato (2014), which considered a sandy clay loam soil.

2.7 Scenarios with vegetation

For the vegetation scenarios, street trees were placed in all scenarios. Only in the LCZ 6 that it also considered trees within the block. Thus, trees were located along the perimeter of the central block of each LCZ scenario, with a 6m to 9m spacing between trees (Fig. 7).

Figure 7: *Scenarios with vegetation for LCZ3, LCZ6 and LCZ8*



2.8 Thermal Comfort Index: PET (Physiological Equivalent Temperature)

ENVI-met can calculate thermal comfort indexes for the whole modeling area, using BIO-met. In this research, PET was configured as the following table:

Table 2: *BIO-met PET configuration*

Age of person	35
Weight	70kg
Height	170cm
Gender	Male
Static Clothing Insulation	0.5[7]
Sum working Metabolism	130 W[8]

3. RESULTS

Figure 8, Figure 9 and Figure 10 demonstrate the differences in air temperature, mean radiant temperature - MRT, surface temperature, comparing scenarios without and with vegetation for each LCZ.

Regarding the air temperature, and focusing in the central block, it could be seen that small temperature reductions occur during the afternoon, with the maximum reduction up to -0.19ºC in the hottest period for the LCZ 3 case; -0.18ºC for the LCZ 6 case; -0.19ºC for LCZ 8.

When analyzing the simulations and observing the results from the scenario with vegetation and without it, it is possible to see that vegetation is capable of reducing air temperature. But in this situation of high air temperatures, the difference between the vegetated scenarios and non-vegetated ones are little and near to nothing.

Figure 8: *Potential air temperature differences between vegetated scenarios and non-vegetated ones.*

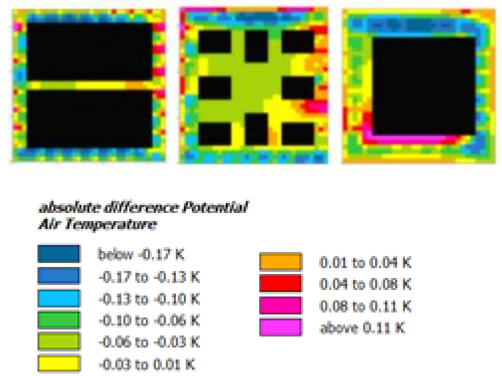
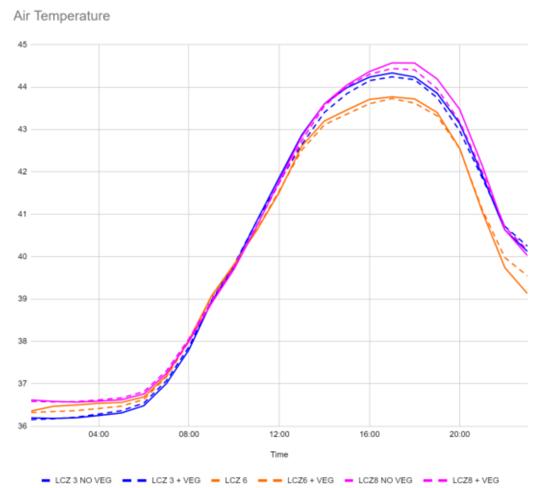


Figure 9: *Average air temperatures for LCZ 3, LCZ 3 vegetated, LCZ 6, LCZ 6 vegetated, LCZ 8 and LCZ 8 vegetated.*



By analyzing the data from the simulations of the central block in all cases, it can be seen that vegetation showed significant impacts, mainly with the reduction of Mean Radiant Temperature (MRT) values, surface temperature and Physiological Equivalent Temperature (PET). These differences are especially due to the effect of tree shading, reducing

[7] Light clothing for clo value.

[8] Mean working metabolism for light walking.

the incident solar radiation on surfaces such as asphalt and concrete.

Figure 10: *Average mean radiant temperatures for LCZ 3, LCZ 3 vegetated, LCZ 6, LCZ 6, LCZ 8 and LCZ 8 vegetated (°C).*

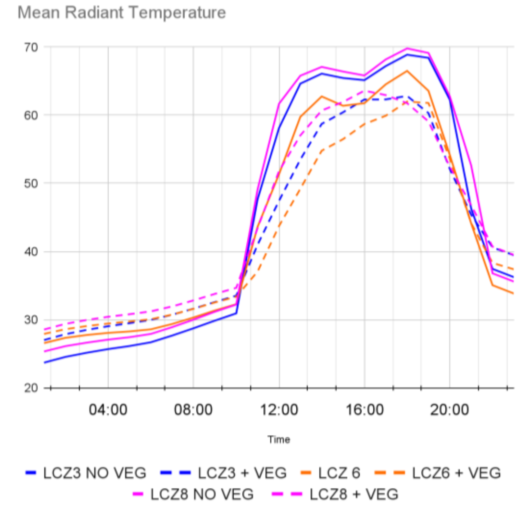
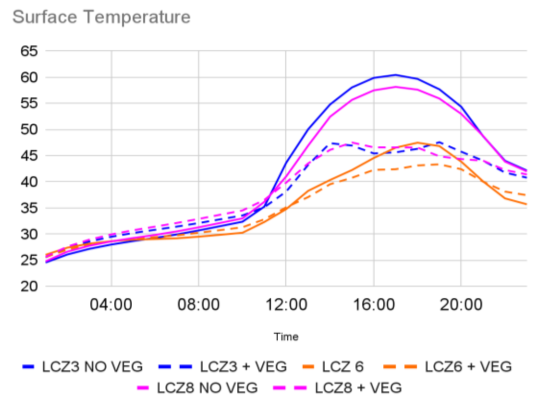


Figure 11: *Surface Temperatures for LCZ 3, LCZ 3 vegetated, LCZ 6, LCZ 6, LCZ 8 and LCZ 8 vegetated (°C).*



Also, all simulation results showed high PET values in all situations. With the presence of vegetation, it is possible to observe a significant reduction in PET values, especially for LCZ 3 and LCZ 8, and not enough to provide better thermal sensation. Although the reduction, the vegetation in these simulations were not enough to provide better thermal sensation.

Figure 12: *The comfort/sensation scale of the physiological equivalent temperature (PET)*

PET/°C	Thermal perception	Grade of physiological stress
≤4.0	Very cold	Extreme cold stress
4.1–8.0	Cold	Strong cold stress
8.1–13.0	Cool	Moderate cold stress
13.1–18.0	Slightly cool	Slight cold stress
18.1–23.0	Comfortable/Neutral	No thermal stress
23.1–29.0	Slightly warm	Slight heat stress
29.1–35.0	Warm	Moderate heat stress
35.1–41.0	Hot	Strong heat stress
41.1≤	Very hot	Extreme heat stress

Figure 13: *PET for LCZ 3, LCZ 3 vegetated, LCZ 6, LCZ 8 and LCZ 8 vegetated(°C).*

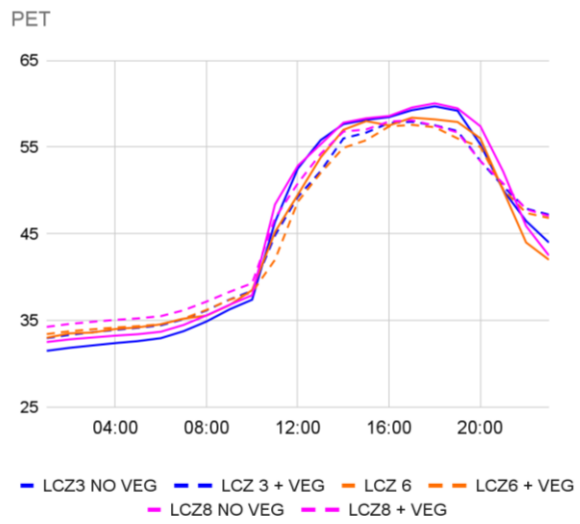
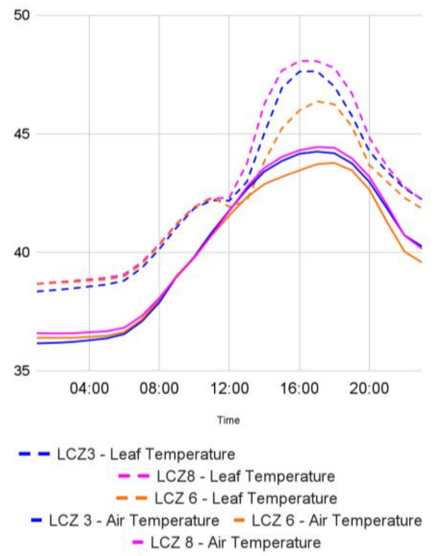


Figure 14: *Air temperature and leaf temperature for LCZ 3, LCZ 3 vegetated, LCZ 6, LCZ 8 and LCZ 8 vegetated (°C).*



The leaf temperature is a parameter that shows how the ambient affects its vegetation. All simulations with vegetation present high values for leaf temperature near to 50°C at the peak air temperature and it is even higher than air temperature. It is also possible to observe that leaf temperatures are higher than air temperature in all simulations. This shows that vegetation may be under heat stress and evapotranspiration has ceased. According to Slot et al. (2019) the critical and heat tolerance values of leaf temperature are between 46°C to 51°C. This indicates that urban vegetation may struggle to survive and may lose its vitality in RCP 8.5 conditions.

4. CONCLUSIONS

This ongoing study demonstrates that vegetation has a significant impact on the urban microclimate, reducing air, surface and mean radiant temperatures, as well as PET. Although vegetation in the simulations struggles to reduce air temperature, still, can reduce important values such as mean radiant temperature, surface temperature and PET; vegetation alone is not sufficient to ensure adequate conditions for people's thermal comfort, under extreme air temperatures.

The simulations on ENVI-met results also showed that vegetation may suffer from thermal stress during these periods of extreme heat and its vitality may be threatened, especially knowing the increased frequency of extreme heat days.

The expansion of urban greening is indeed a path to reduce urban impacts such as excessive heat and many municipalities are adopting this strategy, but this research demonstrates that urban greening must follow good planning and take into account the health and well management of trees before its implementation.

ACKNOWLEDGEMENTS

Grants from São Paulo Research Foundation (FAPESP) #2020/01610-0, National Council for Scientific and Technological Development (CNPq) #312592/2021-3

and #409774/2018-9. Thanks to Prof. Humberto Ribeiro da Rocha (IAG/USP) and the PhD Candidate Fernanda Diniz (IAG/USP) for their support in this research.

5. REFERENCES

1. Bruse, Michael. 2004. "ENVI-Met 3.0: Updated Model Overview." (March): 1–12.
2. Bruse, Michael, and Heribert Fleer. 1998. "Simulating Surface-Plant-Air Interactions inside Urban Environments with a Three Dimensional Numerical Model." *Environmental Modelling and Software* 13(3–4): 373–84.
3. Brune, Miriam. 2016. "Urban Trees under Climate Change." *Climate Service Center Germany*: 123.
4. Ferreira, Luciana Schwandner. 2019. "E Morfologia Urbana Temperatura de Superfície e Morfologia Urbana."
5. Gusson, C. S., & Simon, H. (2020). Impact of Built Density and Surface Materials on Urban Microclimate for Sao Paulo, Brazil: Simulation of Different Scenarios Using ENVI-met Full Forcing Tool. Planning Post Carbon Cities: 35th PLEA Conference on Passive and Low Energy Architecture, A Coruña, 1st-3rd September 2020: Proceedings, Vol. 1, 2020 (Technical Articles), ISBN 978-84-9749-794-7, Págs. 818-823, 818.
6. IAG-USP. 2008. "BOLETIM CLIMATOLÓGICO ANUAL DA ESTAÇÃO METEOROLÓGICA DO IAG-USP." 12: 59.
7. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.
8. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press
9. Kropp, Tim et al. 2018. "Enhancement of the WuDapT Portal Tool WUDAPT2Envi-MET: Introducing Site-Specific Local Climate Zones to WUDAPt2Envi-MET." *PLEA 2018 - Smart and Healthy within the Two-Degree Limit: Proceedings of the 34th International Conference on Passive and Low Energy Architecture* 1(December): 256–61.
10. Oke, Timothy, Gerald Mills, Christen A., and James Voogt. 2017. *Urban Climates*. New York: Cambridge University Press.
11. Santamouris, M. et al. 2001. "On the Impact of Urban Climate on the Energy Consumption of Building." *Solar Energy* 70(3): 201–16.
12. ———. 2017. "Passive and Active Cooling for the Outdoor Built Environment – Analysis and Assessment of the Cooling Potential of Mitigation Technologies Using Performance Data from 220 Large Scale Projects." *Solar Energy* 154: 14–33. http://dx.doi.org/10.1016/j.solener.2016.12.006.
13. Shinzato, Paula et al. 2019 Calibration process and parametrization of tropical plants using ENVI-met V4 – Sao Paulo case study, Architectural Science Review, 62:2, 112-125, DOI: 10.1080/00038628.2018.1563522
14. Simon, Helge. 2016. "Modeling Urban Microclimate. Johannes Gutenberg Universität Mainz.
15. Slot M, Krause GH, Krause B, Hernández GG, Winter K. Photosynthetic heat tolerance of shade and sun leaves of three tropical tree species. Photosynth Res. 2019 Jul;141(1):119-130. doi: 10.1007/s11120-018-0563-3. Epub 2018 Jul 27. PMID: 30054784.Stewart, I.D. & Oke, T.. (2012). Local Climate Zones for Urban Temperature Studies. Bulletin of the American Meteorological Society. 93. 1879-1900. 10.1175/BAMS-D-11-00019.1. tosynthesis Research, 141, 119-130.

PLEA SANTIAGO 2022
Will Cities Survive?

Analysing the effect of cool and green roof design scenarios on building energy loads and air temperature at pedestrian level in a hot arid climate

MOHAMED H. ElNABAWI[1], NEVEEN HAMZA[2], ALI SEDKI[3]

[1] Architectural Engineering Department, College of Engineering, United Arab Emirates University, Al Ain P.O. Box 13393, United Arab Emirates; mohamedmahgoub@uaeu.ac.ae
[2] School of Architecture, Planning and Landscape, Newcastle University, Newcastle upon Tyne, UK
[3] College of Engineering, Applied Science University, 601 Sitra, Bahrain,

ABSTRACT: This study compared the effect of roof retrofit technologies, green roofs and a high albedo coated 'cool roof' to a typical concrete roof in order to mitigate the urban heat island effect and building cooling energy demand in an extreme hot arid climate. Dynamic energy simulations predicted a 9.2% and 7.5% reduction on the cooling load for the cool and green roofs, respectively, compared to the conventional. In the urban microclimate simulations, the air temperature difference at pedestrian level for the modelled cool and green roofs was -0.8ºC and -0.6ºC compared to the conventional, and the average surface temperature for the roofs' external layer was 31.5ºC (cool) and 31.3ºC (green) compared to 40.2ºC (conventional).
KEYWORDS: Air temperature, cool roof, ENVI-met, microclimate, urban heat island

1. INTRODUCTION

Accelerated economic growth has combined with urban spread and a dearth of land resources to create extremely dense clusters of buildings in urban centres. This urbanization and densification have degraded the urban microclimate and caused an increase in ambient urban air temperatures, leading to urban heat islands (UHI) [1–3]. UHIs are caused by an increase in the temperature in a built-up urban area compared to the adjacent countryside. They are mainly created by the comparatively larger amount of incident solar energy absorbed by manmade materials and held within them. UHIs can impact day and night-time temperatures alike, and in turn negatively affect air conditioning loads and exacerbate heat waves. The latter are classed among the greatest global dangers likely to happen in the forthcoming decade [4]. Focused on hot and arid climates, a few studies have considered active approaches, such as ponds, green roofs, and high albedo reflective materials, but these are less common than other climatic typologies [5–9]. Such research has shown that expanding the amount of green space and increasing the use of higher albedo materials within urban areas can mitigate UHI effects. By lowering sensible heat flux, green spaces transform solar radiation into latent heat, and higher albedo materials reflect around 90% of solar radiation back to the sky [10]. The application of reflective coats/paints is easier than other passive approaches [11]. Such coats are widely used on building roofs to create 'cool roofs', due to the longer sun exposure of a roof versus other building envelope components [12]. At peak times, the temperature of conventional roofing materials can reach 88ºC, whereas cool roofs may peak at 49ºC [13]. A 15% energy reduction can be achieved with a cool roof in a hot climate, alongside an average roof surface temperature decrease of 1.4–4.7˚C [14]. The thermal properties of this new material are extremely promising for heat mitigation infrastructure as surfaces remain cooler than the ambient air when there is high solar insolation [15].

The literature has also prioritized the impact of cool materials on building cooling demand [16–17] or decreasing roof surface temperature [18]; however, less is known about how a decrease in indoor cooling demand could reduce UHIs in a hot arid climate. For a typical residential house in such a climate (Bahrain), this study investigates how green and cool roofs, compared with a conventional roof, might decrease ambient air temperature at the micro-urban scale. The study also evaluates potential building energy reductions. The findings should guide green and cool roof approaches and assist strategy decisions on building envelope retrofitting.

2. METHODOLOGY

Building performance simulation tests single variable changes in the construction layers of a calibrated base case model, to examine the effect of applying different roofing scenarios on building energy saving loads. An urban performance simulation model is then used to test the impact of surface temperatures on outdoor air temperature at the pedestrian level. The aims were to:

1) Identify a typical residential building typology and characteristics from construction drawings;
2) Create a calibrated base case based on actual energy consumption data and occupancy profiles;
3) Develop a parametric energy analysis for different roof scenarios, based on the annual cooling load energy savings;
4) Analyze and compare the respective effects of cool, green, and conventional roofs on pedestrian-level air and roof surface temperatures using ENVI-met microclimate modelling.

2.1 Dynamic energy modelling and software selection

DesignBuilder has been validated in studies with similar aims to the current study [19–21]. As per the DesignBuilder manual, all the required data were identified, including the location, weather file, building geometry, construction materials, HVAC system, operational schedule, and internal load.

2.2 Building model and climate—the base model

Residential buildings consume more than 48% of the electricity used in Bahrain [22–23], and so the selected case study was a typical semi-detached two-storey residence developed by the Ministry of the Housing as an affordable public housing unit, known as T3M (Figures 1–2). The unit is in Hamad, a city in northern Bahrain (26.07ºN, 50.30ºE) categorized as BWh in the Köppen-Geiger climate classification [24]. This means extreme hot summers from May to October and mild winters from November to April.

Figure 1: *T3M residential unit as a reference case study residential unit [25]*

2.3 The base model setups

This four-bedroom house has a total floor area of 210m^2 and window to wall ratio of 15%. The construction layers and their relevant specifications are listed in Table 1. A lighting density of 5 W/m^2 was set for the building during operational hours, assuming that on weekdays from 9am–4pm family members are at work or school and only the housemaid is home. The occupancy load at these times is only 20%, rising to 100% when all the family is home, such as at the weekend. Occupancy density was assumed to be six occupants.

Figure 2: *DesignBuilder model of the T3M residential unit*

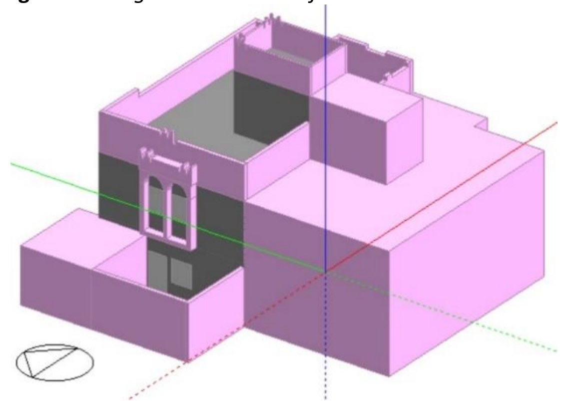


Table 1: *Construction layers and their relevant specifications for the base case design*

Building Properties		Unit
No. of floors	2	
Total area	209	m^2
Floor height	3.17	m
Ground level	0.45	m
External wall area	421.6	m^2
External opening area	104.03	m^2
External wall insulation	U-value: 2.746	W/m^2-K
Roof insulation	U-value: 0.53	W/m^2-K
Glazing	Double coated 6/8/6 (SHGC 0.31) 3.26 W/m^{2}K	W/m^2-K
Window-to-wall ratio	24.6	%
Shading	Blinds (inside) with high-reflectivity slats	
Occupancy density	6 occupants	
System type	Split air-conditioning units	
Thermostat setting	24°C for cooling (no heating)	
Cooling system seasonal CoP	2.5	

2.4 ENVI-met micro-urban modelling setups

The micro-urban simulations were conducted with the three-dimensional non-hydrostatic climate model ENVI-met version 5 [26,27]. This simulates three-dimensional wind fields, turbulence, air temperature, humidity, radiative fluxes and vegetation- and building-atmosphere interactions, based on the fundamental laws of thermodynamics and fluid dynamics [28,29]. The simulated area was transformed into an ENVI-met model grid of 50 x 50 x 40 with a resolution of 4m x 4m x 4m, as X, Y and Z, respectively (Figure 3). Note that the model area was rotated eastwards 320º out of grid north. The simulated building properties were adapted for the different roof types, and all other building parameters, such as construction layers and their relevant specifications, were adjusted as in Table 1. Vertical grid generation was equidistant, meaning that all dz are equal except the lowest grid box. Table 2 presents the simulation parameters and boundary conditions. All simulations were dated 30 June and 1 July as a typical summer day, starting at 5am. However, only the outcomes of second day were considered for further analysis while the first day acted as a spin-up period.

Figure 3: *The ENVI-met 3D model of the ASU campus*

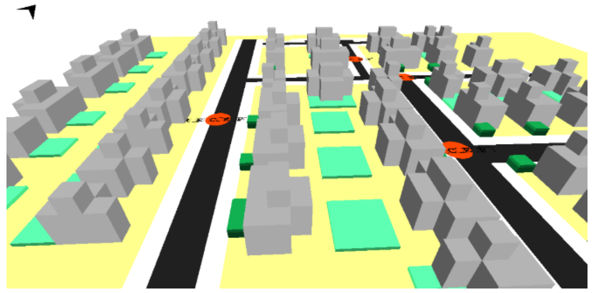


Table 2: *ENVI-met main parameters used for all tested scenarios*

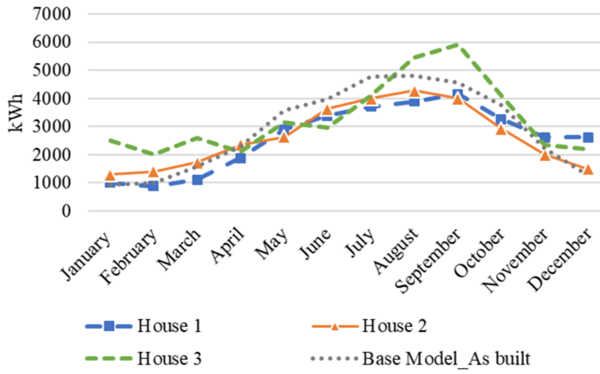
Start date (local)	01.07.2020 at 5am
Duration	48 h
Wind speed	4 m/s
Wind direction	315º
Dimension	50 X 50 X 40
Resolution (X, Y, Z)	4 m x 4 m x 4 m
Meteorological boundary conditions	Full forcing

3. RESULTS AND DISCUSSIONS

3.1 Base model energy validation and performance

The building model was simplified and the inside spaces and zones identified and labelled; all other required data for the model were identified and used to create a dynamic energy simulation model for the base case for validation purposes before testing the various building roofs' technologies, and because energy consumption can vary according to users' behaviour and lifestyle and the number of occupants using the house unit. Therefore, official monthly electricity bills for three typical T3M houses were gathered and benchmarked with the DesignBuilder and the simulated outcomes were plotted against the three houses' actual electricity consumption (Figure 4). All shared the same consumption trends, with substantial escalation in the summer season from May to October; this consumption trend is very common due to the heavy dependency on mechanical cooling, which accounts for 60–65% of electricity usage in buildings [30]. In terms of root mean square error (RMSE), which is a good measure of how accurately the model predicts the response. The RMSE was 6.80%, 5.23%, and 8.89% for houses 1–3, respectively, falling within ASHRAE 14 tolerance criteria for RMSE of ± 20% [31,32]. This shows that the developed DesignBuilder base model captured the main aspects of the building's physics. The annual consumption value of the three houses ranged between 31,403–39,420 kWh, with an average of 34,194.33 kWh. Although DesignBuilder predicted an electrical consumption of 34,720.19 kWh/year, this still falls within the acceptable average range of < 10–20% [33], as it recorded variations of 10.5%, 9.3% and 11.9% for houses 1–3, respectively.

Figure 4: *Actual monthly electricity usage v. DesignBuilder*



3.2 Comparative analysis of the experimental roof performance

Cool and green roofs

Cool roof materials have higher reflectivity and lower absorptance compared to conventional ones. The specifications of the chosen cool roof product are listed in Table 3. Bitumen with a synthetic rubber modification and added styrene-butadiene-styrene (SBS) has higher flexibility and can withstand greater wind stress and temperature fluctuations [34].

Table 3: *The selected cool roof specifications*

Material types	SBS with polyester reinforcement
Thickness	4 mm
Reflectance	0.83
Emissivity	0.91

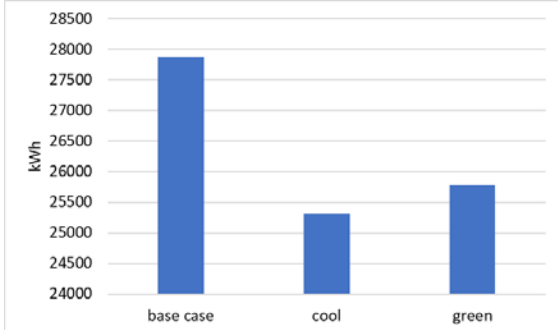
A green roof is another design option which could be considered for this two-storey residential building. The model tested an extensive roof, as a structurally lighter substrate suitable for retrofitting existing roofs with little or no additional structural support; the intensive type is more suited to new constructions. The extensive green roof model parameters are presented in Table 4.

Table 4: *Extensive green roof model parameters*

Properties	Value
Thermal conductivity (W/(m_K))	0.3
Height of plants (m)	0.3
Leaf area index (LAI)	5
Leaf reflectivity	0.4
Leaf emissivity	0.95
Minimum stomata resistance (s/m)	50.0
Maximum volumetric moisture Content at saturation	0.50
Minimum residual volumetric moisture content	0.20

In order to examine the impact of the scenarios on the cooling loads, as the greatest factor in energy consumption used to improve indoor thermal conditions. Figure 5 presents the cooling loads for each case compared to the base. The base had an annual cooling load of 27,878 kWh, while the cool and green roofs had 25,312 kWh and 25,785 kWh, respectively. This is a 9.2% reduction for the cool and 7.5% for the green roof compared to a conventional concrete roof.

Figure 5: *Annual energy consumption for space cooling for the tested roofing scenarios*



3.3 ENVI-met micro-urban modelling

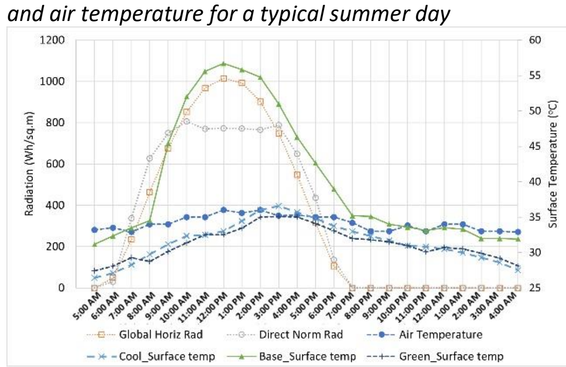
Micro-urban modelling using ENVI-Met examined roof surface temperature and its cooling impact on pedestrian level air temperature over the diurnal cycle of a typical summer day. All simulations used the same wall material properties (Table 1).

3.3.1 Analysis of the modelled roof surface temperatures over the diurnal cycle

Figure 6 presents the simulated surface temperatures (ST) for the base case, cool, and green roofs, and direct solar radiation and ambient air temperature on a typical summer day. All roof STs followed the direct solar radiation pattern with a delay. The cool and green roof findings were almost identical. During the day, the concrete roof ST was close to ambient air temperature, but the green roof ST remained below the average ambient air temperature throughout; the cool roof ST exceeded the ambient air temperature by 1.4ºC at noon. The base case had a higher ST during the day, when solar irradiation is more intense. At night, all STs dropped significantly due to the lack of solar irradiation and the sky vault radiative exchange cooling effect. However, the base case took longer to cool and had almost the same ambient temperature, while the cool roof ST was lower than the green.

In conclusion, the cool and green roofs performed similarly, with small daily fluctuations in the STs compared to the base conventional roof. The smaller variations in STs against ambient temperatures as compared to previously reported variations of 8–10ºC against ambient were in the hot climate of Riyadh, Saudi Arabia [18]; this variation is due to the concrete slab's thermal mass being insulated from the ambient environment, which reduces cooling demand, and the cool and green roofs acting as thermal retrofit options.

Figure 6. *Comparison of STs: base, cool and green roofs and air temperature for a typical summer day*



3.3.2 The roof scenarios cooling effect on air temperature at pedestrian level

To compare the air temperature cooling impact of the different roof scenarios at pedestrian level, air temperature was recorded by receptor 2, located in the centre of the model 1.2 m above the ground. Temperatures were averaged and plotted for the whole diurnal cycle (Figure 7). The cooling effects of the cool and green roofs were always less compared to the base case roof. The maximum reduction in air temperature was -0.95ºC for the cool roof at 12pm against -0.72ºC for the green roof versus the conventional. From 8am to 3pm, the average reduction in air temperature was -0.8ºC for the cool and -0.6ºC for the green. After 3pm, the cooling effect of the green roof averaged -0.6ºC compared to -0.4ºC for the cool (Figure 8). This may be due to the properties of the roofs, since high albedo reduces stored energy but the concrete roof absorbs more daytime heat and releases it at night. The green roof is a radiant flux absorber aided by daytime evapotranspiration; post-sunset, the lack of photosynthesis means evaporation only occurs in the substrate layer [35].

Figure 7. *Simulated air temperature difference of cool and green roofs v. base at 1.2 m above ground level*

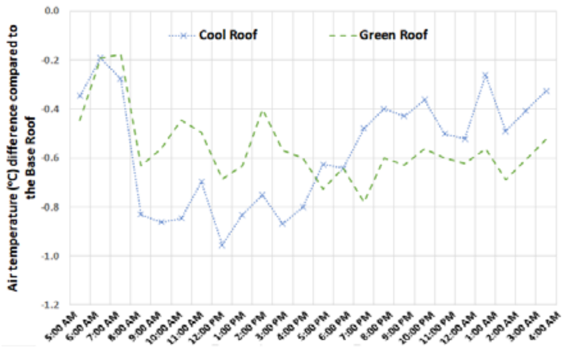
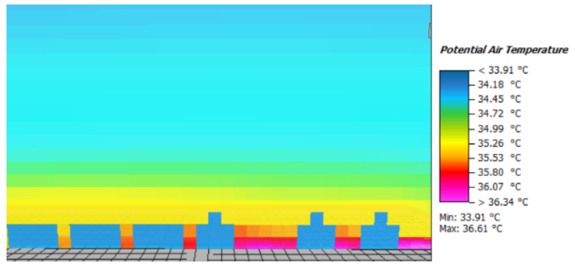


Figure 8. *Simulated air temperature for the cool roof scenario 3pm local time*



4. CONCLUSION

This study sought to improve the energy efficiency of a two-storey prototypical house in the extreme hot arid climate of Bahrain. A building model was developed to assess the impact of cool, green, and conventional concrete roof characteristics on both energy demands for cooling and any subsequent positive impact on outdoor air temperature at street level. The key findings of the building energy and micro-urban simulations are:

- Building performance simulation predicted a 9.1% reduction in the cooling load for the cool roof compared to 7.5% for the green roof against the conventional insulated concrete roof. This concurs with [36] in that the fewer radiative flux absorptive layers the roof has, the lower the cooling load and potentially higher the heating load;
- The surface temperature of the cool and green roofs closely followed ambient air temperature. The green roof surface temperature remained below the average ambient air temperature throughout, while the cool roof exceeded the ambient air temperature by 1.4ºC at noon;
- The average surface temperature was 31.5ºC for the cool roof and 31.3ºC for the green roof compared to 40.2ºC for the conventional roof;
- For the micro-urban environment at pedestrian level around buildings using cool or green roofs, ambient air temperature slightly decreased by an average of 0.8ºC and 0.6ºC, respectively, compared to the conventional roof during peak solar radiation. Although the cool roof was better at reducing pedestrian level air temperatures by only 0.8ºC, further studies using 'super cool' materials with higher albedo and emissivity (both above 0.95) may lead to further reductions in ambient urban outdoor temperatures. Moreover, reduced maintenance costs and irrigation demands in a desert climate are required to maintain the green roof.

REFERENCES

1. Oke TR. (1982) The energetic basis of the urban heat island. Q J R Meteorol Soc 1982;108(455):1e24.
2. Zhou W, Wang J, Cadenasso ML. (2017) Effects of the spatial configuration of trees on urban heat mitigation: a comparative study. Remote Sens Environ 2017;195:1e12.
3. Li H, et al. (2018) A new method to quantify surface urban heat island intensity. Sci Total Environ 2018;624:262e72.
4. The Global Risks Report 2020, available online (https://www.weforum.org/reports/the-global-risks-report-2020) accessed on 10 February 2022)
5. Morini E, Touchaei A G, Rossi F, Cotana F and Akbari H (2017) Evaluation of albedo enhancement to mitigate impacts of urban heat island in Rome (Italy) using WRF meteorological model Urban Climate
6. Touchaei A G, Akbari H and Tessum C W (2016) Effect of increasing urban albedo on meteorology and air quality of Montreal (Canada) - Episodic simulation of heat wave in 2005 Atmospheric Environment. 132 188-206
7. Razzaghmanesha M, Beechama S and Salemi T (2016) The role of green roofs in mitigating Urban Heat Island effects in themetropolitan area of Adelaide, South Australia Urban Forestry & Urban Greening 15 89–102
8. Razzaghmanesha M and Razzaghmanesha M (2017) Thermal performance investigation of a living wall in a dry climate of Australia Building and Environment 112 45-62
9. Sharma A, Conry P, Fernando H J S, Alan F H, Hellmann J J and Chen F (2016) Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: evaluation with a regional climate model Environmental Research Letters. 11 6 064004
10. Akbari H. (2003) Measured energy savings from the application of reflective roofs in 2 small non-residential buildings. Energy 2003;28:953–67. DOI: 10.1016/S0360-5442(03)00032-X
11. Hernández-Pérez, I.; Álvarez, G.; Xamán, J.; Zavala-Guillén, I.; Arce, J.; Simá, E. (2014) Thermal performance of reflective materials applied to exterior building components. Energy Build. 2014, 80, 81–105.
12. Todeschi, V.; Mutani, G.; Baima, L.; Nigra, M.; Robiglio, M. Smart solutions for sustainable cities—The re-coding experience for harnessing the potential of urban rooftops. Appl. Sci. 2020, 10, 7112.
13. Hernández-Pérez, Iván. 2021. "Influence of Traditional and Solar Reflective Coatings on the Heat Transfer of Building Roofs in Mexico" Applied Sciences 11, no. 7: 3263. https://doi.org/10.3390/app11073263
14. M. Rawat, R. N. Singh, (2021) ''A study on the comparative review of cool roof thermal performance in various regions,'' Energy Built Environ., no. March, 2021, 10.1016/j.enbenv.2021.03.001.
15. Mandal, J., Fu, Y., Overvig, A.C., Jia, M., Sun, K., Shi, N.N., Zhou, H., Xiao, X., Yu, N., Yang, Y., 2018. Hierarchically porous polymer coatings for highly efficient passive daytime radiative cooling. Science 362, 315–319. https://doi.org/10.1126/science.aat9513.
16. Baniassadi, A., Sailor, D.J., Crank, P.J., Ban-Weiss, G.A., 2018. Direct and indirect effects of high-albedo roofs on energy consumption and thermal comfort of residential buildings. Energy Build. 178, 71–83. https://doi.org/10.1016/j.enbuild.2018.08.048.
17. Tim Sinsel, Helge Simon, Ashley M. Broadbent, Michael Bruse, Jannik Heusinger, (2012) Modeling the outdoor cooling impact of highly radiative "super cool" materials applied on roofs, Urban Climate, Volume 38, 2021, 100898, ISSN 2212-0955, https://doi.org/10.1016/j.uclim.2021.100898.
18. Alexi E. and Jones P. (2006) Ponds, green roofs, Pergolas and High Albedo Materials; which cooling technique for urban spaces, PLEA 2006, the 23rd conference of Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 Sept.2006
19. Pollock, M., Roderick, Y., McEwan, D., & Wheatley, C. (2009). Building simulation as an assisting tool in designing an energy efficient building: a case study. Proceedings of the Eleventh International IBPSA Conference, Glasgow, Scotland, July 27–30, 2009.
20. Annan, G., Ghaddar, N., & Ghali, K. (2014). ''Natural ventilation in Beirut residential buildings for extended comfort hours.'' International Journal of Sustainable Energy (2014) 35(10):1-18 Follow journal DOI: 10.1080/14786451.2014.972403
21. Elnabawi MH (2020) Building Information Modeling-Based Building Energy Modeling: Investigation of Interoperability and Simulation Results. Front. Built Environ. 6:573971. doi: 10.3389/fbuil.2020.573971
22. Dubey, K., & Krarti, M. (2017). An Evaluation of High Energy Performance Residential Buildings in Bahrain. Riyadh, Saudi Arabia : King Abdullah Petroleum Studies and Research Centre.
23. Krarti, M.; Dubey, K. Benefits of energy efficiency programs for residential buildings in Bahrain. J. Build. Eng. 2018, 18, 40–50
24. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. 2007, 11, 1633–1644.
25. Elnabawi, Mohamed H. 2021. "Evaluating the Impact of Energy Efficiency Building Codes for Residential Buildings in the GCC" Energies 14, no. 23: 8088. https://doi.org/10.3390/en14238088
26. Bruse, M., Fleer, H., 1998. Simulating surface plant air interactions inside urban environments with a three-dimensional numerical model. Environ. Model. Softw. 13, 373–384. https://doi.org/10.1016/S1364-8152(98)00042-5.
27. Simon, H., 2016. Modeling Urban Microclimate: Development, Implementation and Evaluation of New and Improved Calculation Methods for the Urban Microclimate Model ENVI-Met (PhD Thesis). Universit¨atsbibliothek Mainz, Mainz [Online], Available:https://www.ipcc.ch/site/assets/uploads/sites/2/201F9/06/SR15_Summary_Volume_Low_Res.pdf [17 October 2019].
28. Forouzandeh, A., 2021. Prediction of surface temperature of building surrounding envelopes using holistic microclimate ENVI-met model. Sustain. Cities Soc. 70, 102878. https://doi.org/10.1016/j.scs.2021.102878.
29. Elnabawi, M.H., N. Hamza, and S. Dudek (2013). Use and evaluation of the ENVI-met model for two different urban forms in Cairo, Egypt: measurements and model simulations. in 13th Conference of International Building Performance Simulation Association, Chambéry, France. 2013.
30. The Kingdom of Bahrain National Energy Efficiency Action Plan (NEEAP), 2017, Sustainable Energy Unit (SEU) accessed online on the 11th of June 2021 http://www.sea.gov.bh/wp-content/uploads/2018/04/02_NEEAP_full-report.pdf
31. Hong, T.; Kim, J.; Jeong, J.; Lee, M.; Ji, C. (2017) Automatic calibration model of a building energy simulation using optimization algorithm. Energy Procedia 2017, 105, 3698–3704.
32. Cipriano J, Mor G, Chemisana D, Pérez D, Gamboa G, Cipriano X. (2015) Evaluation of a multi-stage guided search approach for the calibration of building energy simulation models. Energ Buildings 2015; 87: 370-385.
33. Oleiwi, M. Q., Mohamed, M. F., Sulaiman, M. K. A. M., Che-Ani, A. I., and Raman, S. N. (2019). Thermal environment accuracy investigation of integrated environmental solutions-virtual environment (IES-VE) software for double-story house simulation in malaysia. J. Eng. Appl. Sci. 14, 3659–3665. doi: 10.36478/jeasci.2019.3659.3665
34. SOPREMA. (2021). TYPES OF BITUMEN: SBS VS APP. Retrieved from soperma.co.uk: https://www.soprema.co.uk/en/article/sopravoice/types-of-bitumen-sbs-vs-app
35. Tim Sinsel, Helge Simon, Ashley M. Broadbent, Michael Bruse, Jannik Heusinger, (2021) Modeling the outdoor cooling impact of highly radiative "super cool" materials applied on roofs, Urban Climate, Volume 38, 2021, 100898, ISSN 2212-0955, https://doi.org/10.1016/j.uclim.2021.100898.
36. Dominguez-Delgado, Antonio, Helena Domínguez-Torres, and Carlos-Antonio Domínguez-Torres. 2020. "Energy and Economic Life Cycle Assessment of Cool Roofs Applied to the Refurbishment of Social Housing in Southern Spain" Sustainability 12, no. 14: 5602. https://doi.org/10.3390/su12145602

PLEA SANTIAGO 2022
Will Cities Survive?

FOS GIS to support regenerative design processes in urban areas

MATTEO CLEMENTI [1] ALESSANDRO ROGORA[1] MANUELA ROMANO[1]

[1] Department of Architecture and Urban Studies, Politecnico di Milano

ABSTRACT: The paper presents a method and connected tools useful to support regenerative design activities in an urban area. In particular, the insights presented in this paper are part of a research funded by the Department of Architecture and Urban Studies of Politecnico di Milano, aimed at developing a game that can be used by students and local public administrations (Rogora, 2020). The aim of the game is to develop improvement scenarios oriented towards local self-sustainability and functioning regeneration of local natural ecosystems. The proposed method is divided into the following steps: (1) Recognition of free data that can be processed through GIS and referred to the local urban context. (2) Mapping of energy, carbon and water flows, in particular: imported energy and material flows, energy and material flows available locally, energy and material flows exported from the local reference context. (3) Mapping of specific indicators able to support strategies consistent with the main goal functions of a natural ecosystem. This paper focuses on the potential use of Free and Open Source (FOS) GIS and open data in order to develop support maps for regenerative design processes.

KEYWORDS: regenerative design, FOS GIS, solar mapping, carbon balance, water balance.

1. NOTES ON REGENERATIVE DESIGN

With Regenerative Design (RD) (Pedersen Zari, 2018) we refer to a type of design oriented towards energy and material sustainability, characterized by an improvement approach on the functioning of natural ecosystems that interact with the territorial metabolism associated with the project. A regenerative design approach involves knowledge of:

- The general features of the ecosystem in which the territorial metabolism activated by the project is located
- The main players in the system.
- Consequently the flows of energy and matter exchanged between them.

RD, starting from the awareness of the strategies normally used by a natural ecosystem in evolutionary process (goal functions) (Fath et al., 2001), is mainly oriented towards the integrated design management of the main dynamics that characterize the territorial area of reference with the twofold objective:

- Maximize the amount of local solar energy useful for carrying out work (Odum, 2006), in the specific case of the anthropized environment, useful for carrying out the main activities that characterize the local territorial metabolism, reside and work, nourish and clean, transport and communicate (Baccini, Brunner, 2012).
- Ensure an maximize matter circularity. In fact, the inclusion of anthropogenic dynamics in natural dynamics implies the maintenance of the balance between the flows and stocks of production and consumption. In particular, the actual development phase of the game is aimed at providing useful information to transfer such strategies to regenerative design initiatives in existing neighbourhoods. This paper focuses on the potential use of Free and Open Source (FOS) Geographic Information Systems (GIS) and open data in order to develop support maps for regenerative design processes, laying the foundations for a Design Oriented Georeferenced Database (DOGD).

2. METHOD

The proposed method is divided into the following steps:

- Recognition of free data that can be processed through GIS and referred to the local urban context.
- Mapping of:
  - imported energy and material flows,
  - energy and material flows available locally
  - energy and material flows exported from the local reference context.

Attention is paid to the main dynamics exchanged between the nodes of the local urban system (energy flows, carbon flows and water flows) (Chrisoulakis, 2015).

- Mapping of specific indicators able to support strategies consistent with the main goal functions of a natural ecosystem.

The paper summarizes some of the results of applying the method to a portion of the urban fabric of the Corvetto district in the southern part of Milan.

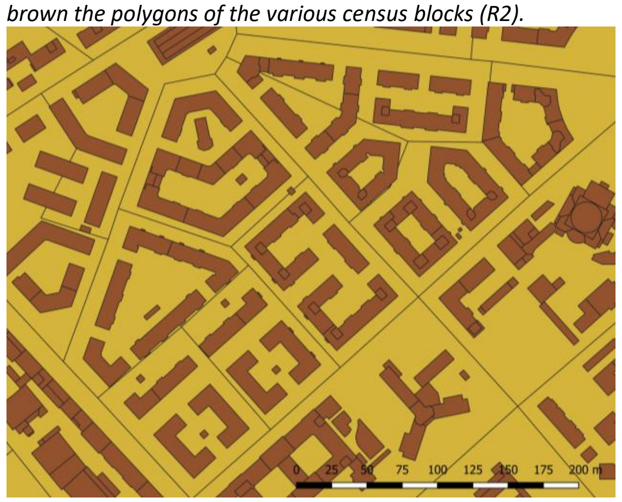
2.1 Free Open Source FOS GIS

The current development of the open source software allows to carry out operations of equal complexity compared to the proprietary sw and at the same time gives the possibility of using complex data even to actors who cannot purchase a proprietary sw such as local administrations, especially minor ones, and designers who are not directly involved in urban planning. These tools represent an important opportunity to process and communicate information to support decisions aimed at both planners and local administrations. The open source feature of these tools allowed the creation of specific institutions and related websites that report news relating to the current level of development of such tools, such as the Open Geospatial Foundation (https://www.osgeo.org/). Among the open source GIS tools made available, the elaborations of this work used Quantum GIS (https://www.qgis.org) and GRASS-GIS (https://grass.osgeo.org).

2.2. Available Open Data

The elaborations presented in this work were carried out on a portion of the urban fabric of Milan, in particular in the Corvetto district in the southern outskirts of the city.

Figure 1:
Portion of the area considered in this work, in brown the different volumetric units of the buildings (R1), in light brown the polygons of the various census blocks (R2).



The main georeferenced data available identify three main types of cartographic documentation:

R1 - vector maps elaborated from aero-photogrammetric surveys, which show the geometry of the buildings, the relative heights of the eaves and the different land uses (Figure1).

R2 - vector maps of census blocks that store data relating to the resident population and the present work activities (Figure 1).

R3 - Lidar surveys at a resolution of 1 meter per pixel that add additional information to the geometry of existing buildings and greenery, in particular trees and roof geometries (Figure 2).

Figure 2:
Lidar model of the same area, resolution of 1 pixel/m^2.

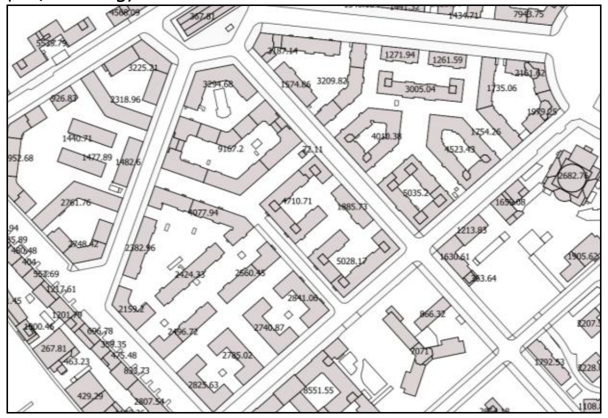
2.3. Mapping Energy Flows

Imported energy flows

As regards the imported energy flows, the available georeferenced data allow to map specific shape indicators that can be associated with each single building or a portion of the urban fabric identified by a census block, mapping useful information in order to assess the energy consumption of existing buildings. Starting from what can be read and processed through FOS GIS, it is possible to create specific thematic maps (TM) that publish significant data on the shape of buildings and the relationships between them and outdoor areas (Morganti et al. 2022) :

- TM1 - the amount of vertical surfaces exposed to the outside (Figure 3)
- TM2 - the combination of TM1 with data relating to the number of inhabitants associated with each census blocks, makes it possible to map the availability of different amount of building surfaces per person in order to assess the per capita weight of building efficiency measures (Table 1).
- TM3 - building shape indicators such as the Exposed Surface to Volume ratio ES/V.}

Figure 3:
Amount of building vertical surfaces exposed (m²/building).



Locally available energy

The availability of information relating to the height of buildings volumetric units together with the data relating to the local orography allow to use FOS GIS to create a high-resolution Digital Elevation Model (Figure 4). These are raster maps in which a pixel corresponds to a square surface of 0.5 m side which represents as gray tones the different heights of the buildings present in the analysed urban area. Starting from this model it is possible to represent particular urban form indicators as the Sky View Factor (Figure 5) and then proceed with the mapping of the incident solar radiation (Hofierka, Suri, 2002) (Figure 6, 7, 8).

Figure 4:
Digital Elevation Model of the area, 1pixel side equal to 0,5m.

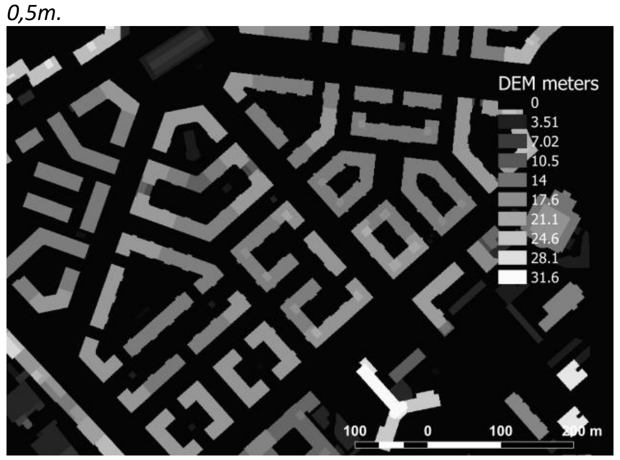
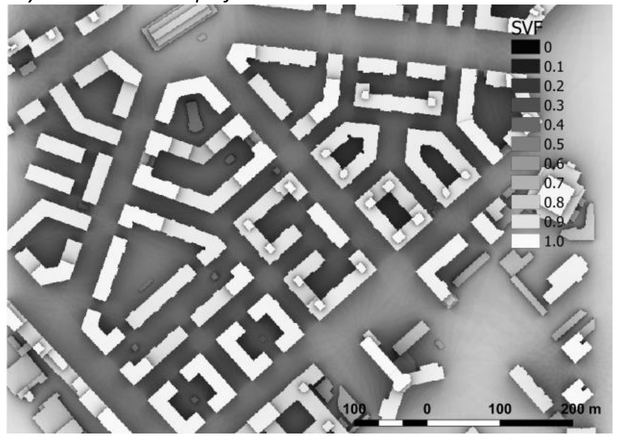


Figure 5:
Sky View Factor map of the chosen area.



This processing allows to create various types of thematic maps, for instance:

- TM4/5 – Direct solar radiation mapping on the horizontal plane to associate production capacities with the building's rooftop and outdoor areas (Figure 6, 7) (all the maps refer to the average daily monthly irradiation).
- TM6/7/8/9 – Direct Solar radiation available per person on rooftop and outdoor areas for each census block.

Figure 6:
*Direct solar irradiation representative of an average day in December (Wh/m²*day).*

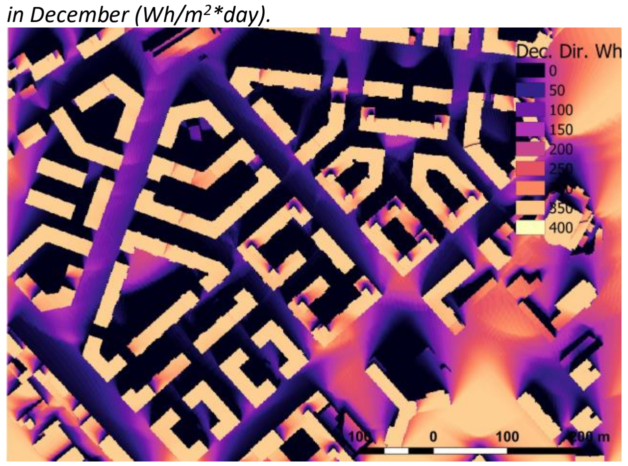


Figure 7:
*Direct solar irradiation representative of an average day in June (Wh/m²*day).*

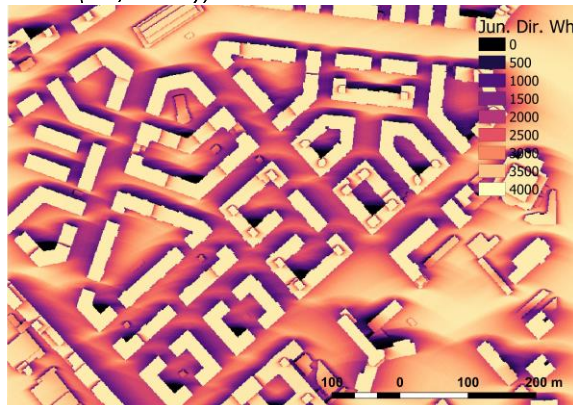
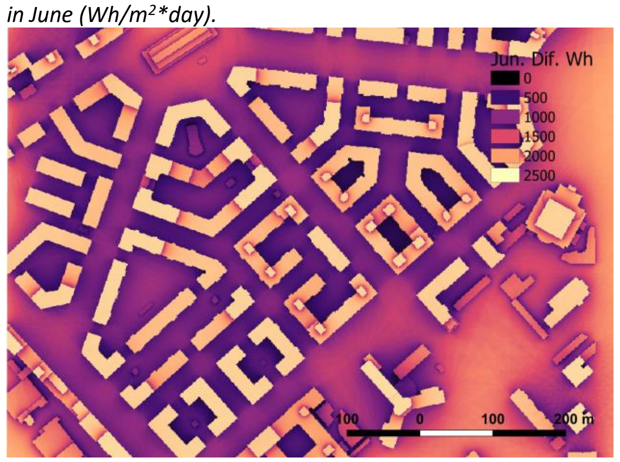


Figure 8:
*Diffuse solar irradiation representative of an average day in June (Wh/m²*day).*



Furthermore, by using lidar surveys, the georeferenced database (DOGD) is enriched with important new information such as the geometric configuration of the existing roofs and trees. This data are of fundamental importance to develop maps of the local renewable potential from solar energy. At the current state of the study, the elaborations carried out on the lidar model have proved to be very effective in detecting the geometric consistency of the trees. As for those conducted on the roof coverings, they were found to be unusable due to the low resolution of the maps, 1pixel/m², they require future further elaborations (Figure 9).

Exported Energy

In this case, the flows of urban waste exported from paper, the flows of organic and metabolic waste (potentially useful for the production of biogas), the biomass produced by the maintenance activities of the parks (tree pruning, for example), have to be taken into consideration.

2.4 Mapping Carbon Flows

Imported carbon flows

A local carbon balance needs to complement information on carbon emissions with data on carbon storage and sequestration. In the first case, R1 can provide information relating to the extension of the green areas detected, this information can be enriched by integrating the Lidar data (R4) into the GIS by carrying out specific processing to calculate the volume of trees (Figure 10). The mapping of solar radiation on the ground and on the roofs can supports the choice of herbaceous or tree species to be cultivated and the effective possibility of absorbing CO_2 based on the available energy. Indeed, this capacity depends on the availability of solar energy as well as on the availability of water and nutrients.
The numerical values currently adopted in the calculation methods proposed in the regulations of the Milan municipality, and used for the calculation of the CO_2 emission, are equal to 6 kg of CO_2/year per square meter of green vegetated surface, and to 50kg of CO_2/year for each tree (Comune di Milano, 2020).

Locally available carbon

This indicator refers to the quantity of woody biomass present.

- TM10 - Volume of trees present in each census block (m^3).
- TM11 - Volume / person of trees present in the census block (m^3/person).

Figure 9:
Direct solar irradiation during the 21st of June on lidar model (1pixel/m²).

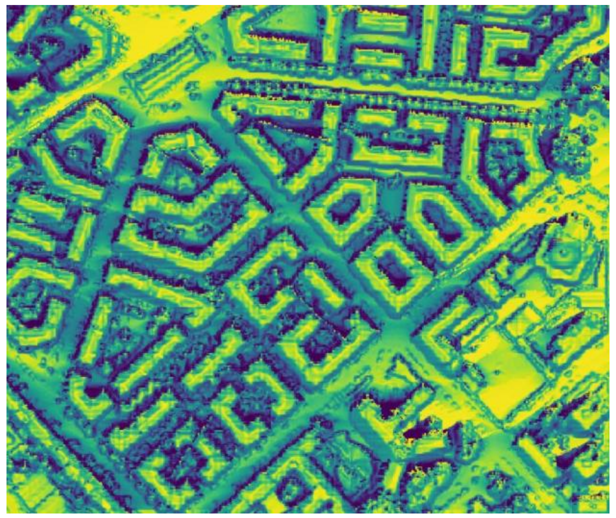


Figure 10:
Lidar map relating to tree volumes. In order to reduce the inaccuracies due to the low resolution, buildings have been eliminated from the map by using a mask increased by a buffer zone of 3 meters. To reduce some defects detected at higher altitudes, interval from 1 to 20 m from the ground has been considered (the white parts of the trees refer to volumes above 20 m).

Exported carbon flows

The mapping of the energy consumption of buildings, if combined with information relating to the type of energy sources, can be used to assess the CO_2 emissions into air associated with building energy consumption. The same census data can be used to map the amount of carbon exported as municipal solid waste (from organic waste to paper). Another aspect in which the regenerative systemic design favours the implementation of carbon neutral strategies is related to the possibility of locally producing nutrients. Buildings regularly export nutrients in the form of metabolic waste and organic waste. In the second case, the local treatment of organic waste would provide a contribution to the ability of local ecosystems to absorb CO_2 both in the soil and in the metabolic activity of plants (Chrisoulakis, 2015).

- TM12 - maps of carbon flows emitted into the air in the form of carbon dioxide.
- TM13 - maps on the amount of carbon and nitrogen emitted through organic waste.

2.5 Mapping Water Flows

Imported water flows

The number of inhabitants and the number of employees associated with a production activity present in the census block can be used to map the flows of imported water

TM14 - incoming water flows used in local residential and work activities.

Locally available water

Making this information available requires associating information relating to the quantity of rain incident monthly and annually on the roofs to the geometric data provided in the aerial photogrammetric survey relating to buildings and open spaces (R1). This information refers to data representative of the annual average and data relating to extreme events not representative of the average but representative of the possibility that an extreme event occurs in a multi-year interval of time usually 20, 50 or 100 years. In the case of the data referring to the monthly average, the open data website of the municipality of Milan reports the monthly average of the atmospheric precipitation values (Comune di Milano, 2022). Rainfall was measured in the urban area in Milan between 2008 and 2014, values ranging from January 2008 to December 2014. Data show an average annual quantity equal to 1006 mm, with monthly average values that fluctuate depending on the month from 50 in August to 100mm in April, with the exception of November where values around 170 mm are recorded.

The mapping of rainwater availability makes it possible to use rainwater not only for irrigation but also to reduce the water consumption from the aqueduct. To understand the precise effectiveness of this solution it is important to compare the capture capacities of roofs and waterproof open spaces with the mapping of water consumption per building. As in the case of solar energy mapping, starting from data concerning the climatic variables (in this case the pluviometry in the different months of the year), it is possible to enrich the database (DOGD) with information to support the design process.

- TM15/16 - the amount of rainwater incident monthly on roofs and open spaces
- TM17/18 - the amount of rainwater incident annually on roofs and open spaces

Exported water

This category includes the flows of water introduced into the sewer by weather events and by local residential and production activities.

- Tm19 - Waste water in the sewer from residential activities

3. RESULTS AND CONCLUSIONS

3.1 Results and indicators

The results illustrate how the integration on the same geo-database of data relating to energy, carbon and water flows allow the mapping of effective indicators, able to verify the transferability of good regenerative design practices, consistent with the main ecological goal functions. In particular, the indicators refer to:

The amount of available solar radiation used to perform work and specifically to meet the needs related to housing, mobility and food.

Closing the cycles on a local scale, reducing the quantity of exported flows and increasing the flows that close in the census block or in the area share by several blocks.

Figure 11:

Map of the census block associated with the table 1.

The quantities reported in the various thematic maps constitute useful information to verify the transferability of good practices through specific indicators, for example:

- Average monthly solar irradiance incident on the roofs of buildings and outdoor spaces used by the local community for housing, mobility or food production (data can be quantified per square meter of census block or per inhabitant)
- The ratio between the quantity of carbon stored and the emitted amount per inhabitant in each census block.
- Local water balance by census blocks: Ratio between water used in buildings and the one collected from their roofs and outdoor space in different months of the year.

Table 1:
Some numerical values relating to the thematic maps described in the text and referring to three census blocks of the area under study (Figure 11)

Thematic maps	Census blocks	2574	2579	2580
TM1	m^2	11695	12535	11044
TM2	m^2/person	32,13	38,69	50,20
TM3	ES/V	0,2761	0,2571	0,2840
TM6	Wh/p*d June rooftops	31416	41165	48870
TM7	Wh/per*d June outdoor	29664	40369	60774
TM8	Wh/per*d Decemb. rooftops	2644	3745	4538
TM9	Wh/per*d Decemb. outdoor	711	419	1126
TM10	m^3	25557	22203	19809
TM11	m^3/person	70,21	68,52	90,04
TM17	liters/per*year rooftops	8590	11258	12910
TM18	liters/per*year outdoors	14914	19193	27008

The association with the census block of quantitative data relating to energy inputs and outputs, CO_2 emissions and water within the same territorial information system allows the development of profitable strategies to interlace the dynamics activated by the various ecosystem actors, including human activities. The possibility of operating in this tran-scalar environment allows:

- on the one hand to identify strategies that take advantage of the different metabolic features of the census blocks by identifying possible complementarities and therefore synergies;
- on the other hand to verify the transferability of scale sensitive strategies. Associating data to census blocks allows to use GIS to aggregate values and therefore to verify the actual transferability depending on the extent of the territorial area of reference..

REFERENCES

1. Baccini, P. and Brunner, P.H. (2012). Metabolism of the anthroposphere: analysis, evaluation, design. Second edition, MIT Press, Cambridge, US.
2. Chrisoulakis N., (2015). Understanding Urban Metabolism, Earthscan.
3. Comune di Milano (2020), Piano di Governo del Territorio. Piano delle regole.
3. Comune di Milano (2022), [Online], Available: https://dati.comune.milano.it/dataset/ds306-ambientemeteo-precipitazioni-mese-2008-2014 [15 December 2021].
4. Fath, B.D, Patten, B.C. and Choi, J.S. (2001). "Complementarity of ecological goal functions", Journal of theoretical biology, Vol. 208 (4), pp. 493-506.
5. Hofierka, J., Suri, M.: The solar radiation model for open-source GIS: implementation and applications. In: Ciolli, M., Zatelli, P. (eds.) Proceedings of the Open-source GIS-GRASS Users Conference. University of Trento, Trento, Italy (2002)
6. Morganti, M., Clementi, M., Rogora, A., (2021), Open-Source Integrated Mapping of Urban Form and Solar Radiation for Environmental Design, in Sustainability in Energy and Buildings 2021 Littlewood J. et al Editors, Springer Nature, Singapore.
7. Odum, H. T., 1996: Environmental Accounting, Emergy and Environmental Decision Making, John Wiley & Sons
Pedersen Zari M. (2018). Regenerative Urban Design and Ecosystem Biomimicry, Routledge, Oxon 2018
8. Rogora, A. (2020), New Proposals for Sustainable Design: The Imitation Game as an Experience of Shared Co-design, in Sustainability in Energy and Buildings 2020, Littlewood J. et al Editors, Springer Nature, Singapore.

PLEA SANTIAGO 2022
Will Cities Survive?

Aerodynamic analysis of urban blocks

Case study in open, row and vertical blocks

CAROLINA GIROTTI[1] SAMUEL BERTRAND MELO NAZARETH[1] ALESSANDRA RODRIGUES PRATA SHIMOMURA[1]

[1] University of São Paulo, Faculty of Architecture and Urbanism, Laboratory of Environmental Comfort and Energy Efficiency (LABAUT)

ABSTRACT: In the urban environment, the urban form has direct interference in the behavior of natural ventilation, mainly due to the roughness and porosity of the urban fabric. The urban form and its interference in the behavior of natural ventilation is explored in this article through three types of urban block: open block, laminar block and vertical block. Thus, the objective of this work is to evaluate how the block typology influences the behavior of natural ventilation, using as a study the climatic data of the city of São Paulo/ Brazil. The evaluation was performed using the Computational Fluid Dynamics simulation software: OpenFOAM®. The results indicate that the block typology that has the lowest aerodynamic impact, when using weather patterns in the city of São Paulo - Brazil, is the open court typology.

KEYWORDS: Urban Morphology, Urban block, Computational Fluid Dynamics, Natural Ventilation

1. INTRODUCTION

In an urban environment, the roughness and porosity of the urban fabric interfere with the behavior of natural ventilation. In this way, when a solid obstacle is inserted, such as a building, natural ventilation undergoes changes (Adolphe, 2001; Gan & Chen, 2016; Oke, 2006; Ratti et al., 2006).

Roughness is understood as the "roughness" of the urban environment and Romero (2000) reveals that the variation in the heights of the built-up masses in the city are fundamental for understanding the displacement of air masses in the intra-urban layers.

Oliveira (1993) conceptualizes porosity in the urban fabric as the permeability of the urban fabric to the penetration of winds. In other words, the flow within the city, which can be different due to the direction of the wind flow.

Changes in flows caused by buildings occur mainly with the presence of recirculation zones behind tall buildings, which are called wake effect, which affect not only the building, but also affect the health and air quality of the neighborhood. of the Building (Oke, 2006; Ratti et al., 2006).

Several factors of urban morphology modify the flow zones in an urban area. For Azizi and Javanmardib (2017) and Guo et. al. (2017), the main factors are the height of buildings and the width of adjacent roads. According to the authors, strategies such as the use of natural ventilation channels and the variation in the height of buildings can improve the performance of urban ventilation.

In this article the studies considered the aerodynamic analysis in the Urban Canopy Layer (UCL). In this case, the buildings positioned close to each other shape the airflow in the urban Roughness Sublayer (RSL) and, particularly, in the UCL layer. Such aerodynamic conditions strongly affect the wind (Merlier et al., 2018).

The analysis of aerodynamics in conjunction with the analysis of urban morphology in the UCL layer is important; because urban morphology mainly refers to the smallest scales of urban spatial analysis: neighborhood, block and building, which correspond to micrometeorological scales in urban physics. In addition, when compared to neutral atmosphere, the air change rate per hour and air quality in the UCL decreases by half in the inversion condition (Jing et al., 2021; Merlier et al., 2018).

Thus, for this article, the aerodynamic analysis in the UCL layer was considered, using three urban block typologies: open, blades and horizontal. The objective is to evaluate how urban morphology influences natural ventilation in urban centers.

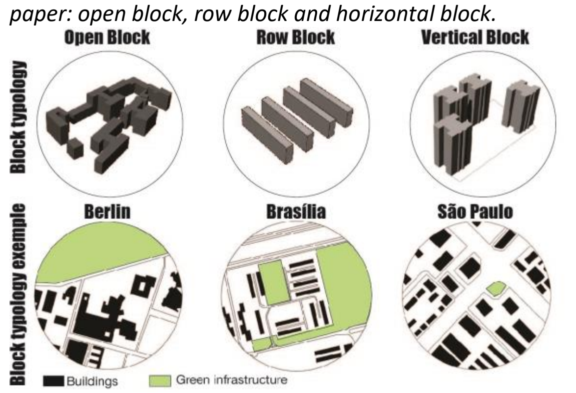
2. METHODOLOGY

The present article is proposed from an exploratory approach, with the aid of satellite images, CAD - Computer-Aided Design modelers and CFD - Computational Fluid Dynamic simulators. The approach is divided into seven steps: 1. Data collection, 2. 3D modeling, 3. Mesh production, 4. Definition of boundary conditions, 5. Numerical calculation of the simulation, 6. Validation of the simulation and 7. Data analysis.

2.2 Case study: Open block, row block and vertical block

For the case study, three scenarios were selected with different block typologies: 1. open block typology with morphological data from Berlin, Germany; 2. row block typology, with morphological data from Brasília/Brazil; and 3. horizontal block typology with morphological data from São Paulo/Brazil, as shown in Figure 1.

Figure 1: *Top view of the different scenarios applied in the paper: open block, row block and horizontal block.*



The open block typology was conceived by Christian de Portzamparc and is an example of application in Berlin, used since the 20th century with the objective of densifying the block, without losing access to natural light and green infrastructure (Sonne, 2009).

The row block typology was conceived in the modern period, where a clear division of activities was created in urban planning. In addition, the buildings were spread out in the form of columns in the open space, this typology being characterized by high density in height (Oikonomou, 2014).

The vertical typology is the result of the block divided into several lots. It is a typology present in most large Brazilian cities, including the city of São Paulo, and the buildings have a high density of height.

The models developed, based on the three analysis scenarios, were based on real urban areas. However, the climatic particularity of each site was not considered, but rather the climate data of the municipality of São Paulo (23.55 S, 46.63 W), with the objective of exploring new types of urban morphology for the urban fabric of São Paulo.

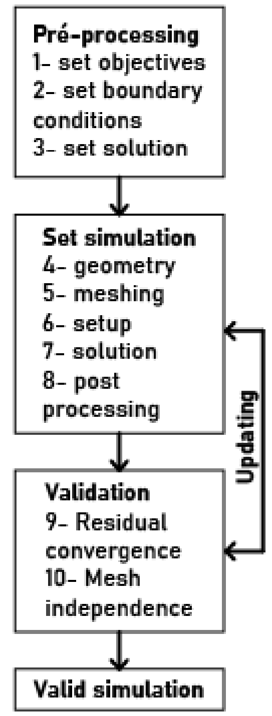
2.2 Method: Computational Fluid Dynamics (CFD) Simulation

The fluid dynamics simulation was performed with the aid of an open software, OpenFOAM (ESI Group, 2020). What makes it different from other software on the market is its collaborative and free nature. Therefore, it is a platform which any user can use and collaborate with the system. However, all its methods and calculations are validated and used in different academic spheres, from mechanical engineering to chemistry and civil construction.

In this article, the simpleFOAM calculation method was performed, considering, therefore, the turbulent air flow. As a form of boundary condition, the equation proposed by Hargreaves and Wright was used to produce an Atmospheric Boundary Layer (ABL) that best mimics the characterization of natural ventilation in an urban environment, thus producing an urban gradient from roughness values, porosity and turbulence (Hargreaves & Wright, 2007).

The methodology of fluid dynamics simulation was divided into four stages: 1. Pre-processing; 2. Setting boundary initial values; 3. Solving equations; and 4. Post-processing, as shown in Figure 2.

Figure 2: Methodological process.

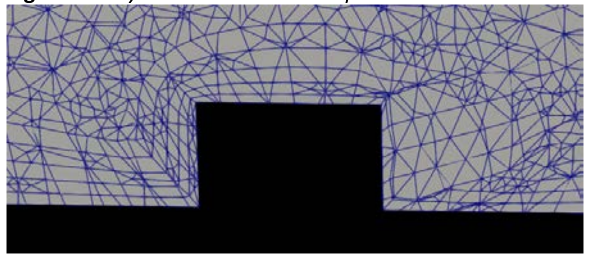


In the Pre-processing stage, the geometry survey was carried out from Google Earth satellite images and the planning of the model analysis points. As boudary conditions: air velocity input data, 10 m/s was considered, in the characteristic SE direction, for the city of São Paulo/Brazil. The simulation was performed with the SimpleFoam calculation method in a stationary, adiabatic, incompressible and turbulent regime, using air as an ideal gas at 25°C.

The following steps were developed setting simulation: solid geometry, modeled in CAD software, simplifying the geometry proposed for the primary volumes; mesh production, the division of the solid into smaller parts; the setup, where the variables that describe the initial system to be analyzed are inserted, considering the ABL mentioned above and, finally, the solution of the equations from the input data for later post production and data analysis.

Meshing is an important step of any CFD simulation. Mesh production is the procedure that breaks the analyzed geometry into smaller parts for analysis. The mesh was made in an unstructured way, seeking the production of prisms close to the ground and buildings to better measure the detachment of the boundary layer, in addition, tetrahedral elements were produced conforming a non-linear polymesh, as illustrated in Figure 3 (Brandão & Alucci, 2010; PRATA et al., 2019).

Figure 3: *PolyMesh - Tetraédrica e prismática*



Finally, the solution was carried out with the calculation tool, solving the equations in a repetitive way, seeking at each interaction to reduce the number of residues. This repetition occurs due to the differential nature of the Navier Stokes equation, thus seeking values that tend to 0.

In addition to the residuals, a physical stability of the analyzed variables is required. As a comparative parameter, the air velocity was indicated at a central point of the models where the pressure incident on the windward face of the buildings was analyzed.

For the analysis and validation of the simulation results, only simulations with residuals smaller than 10e-4 and with a physical stability of less than 5% between simulations were considered (NASA, 2021).

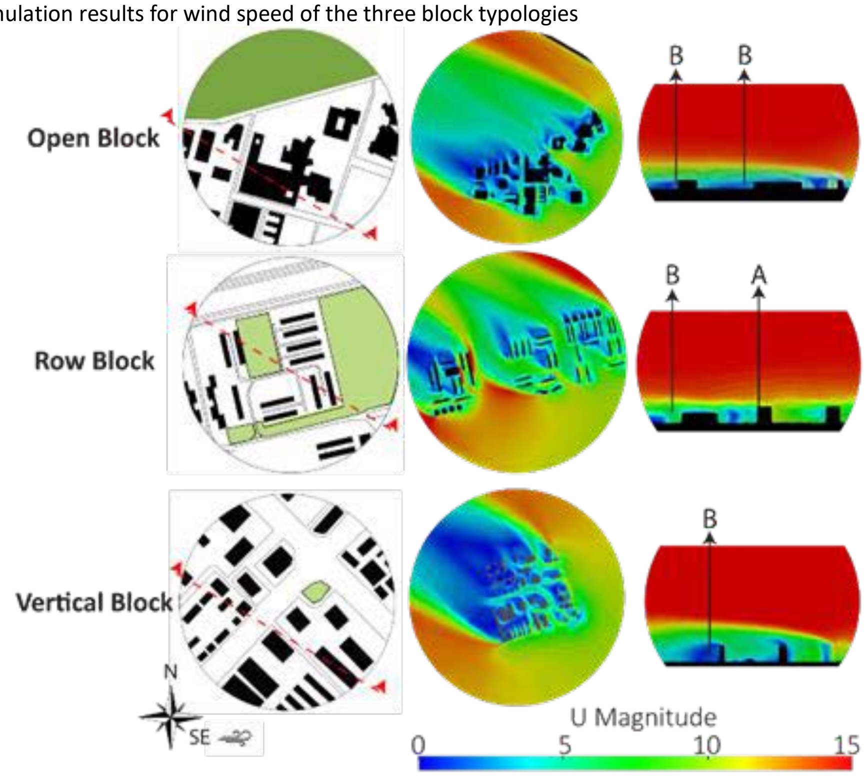
In addition, in a qualitative way, the aerodynamic effects provided by the analyzed geometries were observed. Buildings with less impact on the natural path of the winds and that collaborate with the non-stagnation or recirculation of urban ventilation were sought. In this way, it is expected to provide greater salubrity in areas outside the buildings.

3. RESULTS

The value used for the morphological comparison of the blocks was the H/W, which is calculated by the width and height, with the width referring to the street and sidewalks and height to the building template. The H/W value in the canyon calculated from the open block is 0.48; of the row block typology is 1.09; and the vertical block typology is 0.80.

Results of wind speed (m/s) at different levels in the urban fabric and pressure (Pascal) incident on vertical obstacles of each typology were analyzed. Figure 4 shows the air velocity results obtained in the three types of analysis.

Figure 4: CFD simulation results for wind speed of the three block typologies



Regarding the wind speed, the urban canyons illustrated by Figure 4 present turbulence variations found in the simulations, where: A - represents air recirculation zone; and B - represents wake region. The cut where they are represented represents the critical points of each scenario, therefore considering the worst possible situation.

Table 1 presents air velocity data at three heights in the urban canyon: at pedestrian level (h = 1.50 m), at the center of the canyon and at the top of the canyon (top of buildings). This division is based on the need to analyze in three dimensions the aerodynamic effects of the proposed scenarios. Thus, it is possible to determine the impact at the pedestrian level, in the middle of the buildings, or at the building level and at the top of the buildings, representing the city impact.

Table 1: Wind speed (m/s) values

	Wind Speed (m/s)		
	pedestrian level (1,50 m)	center of canopy	top of canopy
Open block	1.53	0.53	4.48
Row block	5.72	7.50	8.66
Vertical block	2.00	5.24	5.98

Figure 4 and Table 1 show that the open block typology has good ventilation capacity at pedestrian level (1.53 m/s), which according to LDDC Lawson criteria represents the “Pedestrian sitting” range of pedestrian ventilation comfort (Murphy et al., 2016). In addition, this typology presents little wake region in the leeward.

The row block typology in this flow direction does not present extensive wake regions, and the air is channeled between the buildings with little or no disturbance. As expected from the simulated orientation, the highest H/W of this typology presented higher speed at the three heights analyzed, with a speed of 5.72 m/s at the pedestrian height, which means moderate wind speed according to the LDDC Lawson criteria, this speed already influences pedestrian comfort and dust movement (Murphy et al., 2016).

The vertical typology has the greatest aerodynamic impact on the urban canopy, on the other hand, due to the high roughness that has good natural ventilation capacity at the pedestrian level. However, this typology does not have a pre-established pattern at the block level, as the morphology is developed through lots, which have different sizes, which directly affects the porosity of the urban fabric. Regarding comfort at the pedestrian level, the vertical typology presents good natural ventilation capacity at the pedestrian level (2.00 m/s), which according to the LDDC Lawson criteria represents the “Pedestrian sitting” range (Murphy et al., 2016).

Figure 5 shows the pressure results obtained in the three types of analysis.

Figure 5: CFD simulation results for the pressure of the three court typologies

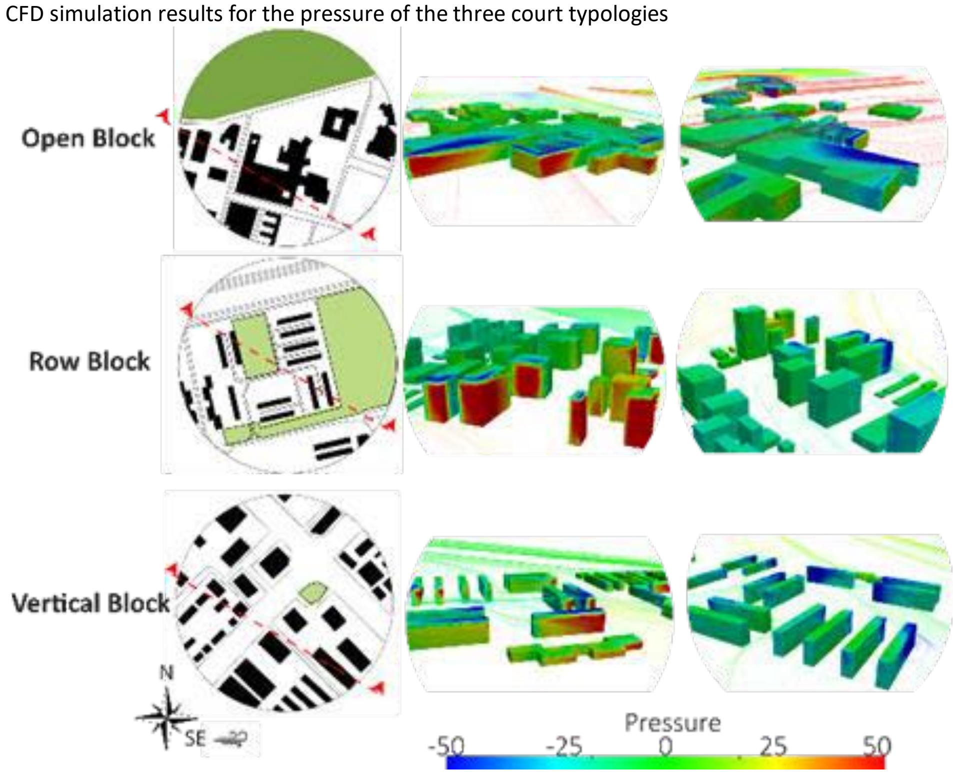


Figure 5 shows how the pressures that affect the façade of buildings. In the open block typology, due to the low porosity, higher pressures are seen on the windward side. As expected, the first buildings act as screens, reducing the wind inertia in relation to the inner pressures of the presented urban fabric. Inferring, therefore, that the large dimensions of the buildings, together with their low height, do not promote a great variation in the pressure gradient of the buildings, thus reducing the possible capacity of natural ventilation of these constructions.

In the row block typology, due to the low porosity, higher pressures are seen on the windward side. With an urban fabric in which the buildings have a very similar height pattern, the first buildings act as screens, reducing the inertia of the wind in relation to the more internal pressures of the presented urban fabric. In relation to the pedestrian level, a channeling is promoted through urban canyons perpendicular to the direction of the wind, on the other hand, in perpendicular canyons, low air speed is observed.

Finally, in the vertical block typology, due to the high porosity, lower pressure values are seen on the windward side. In the sense of simulated air, the aerodynamic effect of the simulated buildings does not suggest a great obstacle, therefore, presenting higher speeds in the three levels placed in this work.

4. CONCLUSION

The results indicate that in the SE orientation, the urban typology that has the lowest aerodynamic impact in the leeward is the open block typology, since it has a lower height of the buildings, H/W ratio (0.48) with greater distance between the buildings.

The vertical block typology, despite presenting values within the comfort level for activities of low metabolic activity, has a greater impact on the urban fabric due to the high patterns characteristic of this typology.

On the other hand, the open block, with lower speeds inside the urban fabric, does not have an extensive impact due to the low size of the buildings. In addition, the morphology of this block allows for a possible natural ventilation capacity greater than the others analyzed in this article.

Finally, this analysis infers that the row block is potentially harmful to pedestrians due to its possible aerodynamic effects. Due to the air speed inferred by the simulations in pedestrian level: Open block 1.53 m/s, Row block 5.72 m/s and Vertical block 2.00m/s and considering possible gusts of wind, the morphological characteristics promote discomfort at the pedestrian level. The proximity of buildings promotes a channeling of the wind flow, as well a threefold increase in wind speed, possibly being harmful to pedestrians.

For future work, it is proposed that the blocks be analyzed in different orientations to verify their leeward impacts, verifying the impacts of these orientations on the pedestrian level and on the pressure coefficient of the proposed buildings. In this way, it would be possible to build an assertive analysis in terms of the natural internal ventilation capacity in each typology.

ACKNOWLEDGEMENTS

Grant #2021/14533-7, São Paulo Research Foundation (FAPESP).

REFERENCES

1. Adolphe, L. (2001). A Simplified Model of Urban Morphology: Application to an Analysis of the Environmental Performance of Cities. *Environment and Planning B: Planning and Design*, *28*(2), 183–200. https://doi.org/10.1068/b2631
2. Azizi, M. M. & Javanmardi, K. (2017). The Effects of Urban Block Forms on the Patterns of Wind and Natural Ventilation. *Procedia Engineering*, *180*, 541–549. https://doi.org/10.1016/J.PROENG.2017.04.213
3. Brandão, R. S. & Alucci, M. P. (2010). Thermal Behavior of Urban Canyons Using Numerical Modeling, Cfd Simulation and Gis Mapping. *SimBuild 2010*, 244–251.
4. ESI Group. (2020). *OpenFOAM® v2012* (No. v2012). https://www.openfoam.com/news/main-news/openfoam-v20-12
5. Gan, Y. & Chen, H. (2016). Discussion on the Applicability of Urban Morphology Index System for Block Natural Ventilation Research. *Procedia Engineering*, *169*, 240–247. https://doi.org/10.1016/J.PROENG.2016.10.029
6. Guo, F., Zhu, P., Wang, S., Duan, D. & Jin, Y. (2017). Improving Natural Ventilation Performance in a High-Density Urban District: A Building Morphology Method. *Procedia Engineering*, *205*, 952–958. https://doi.org/10.1016/J.PROENG.2017.10.149
7. Hargreaves, D. M. & Wright, N. G. (2007). On the use of the k– model in commercial CFD software to model the neutral atmospheric boundary layer. *Journal of Wind Engineering and Industrial Aerodynamics*, *95*(5), 355–369. https://doi.org/10.1016/j.jweia.2006.08.002
8. Jing, Y., Zhong, H. Y., Wang, W. W., He, Y., Zhao, F. Y. & Li, Y. (2021). Quantitative city ventilation evaluation for urban canopy under heat island circulation without geostrophic winds: Multi-scale CFD model and parametric investigations. *Building and Environment*, *196*. https://doi.org/10.1016/j.buildenv.2021.107793
9. Merlier, L., Kuznik, F., Rusaouën, G. & Salat, S. (2018). Derivation of generic typologies for microscale urban airflow studies. *Sustainable Cities and Society*, *36*, 71–80. https://doi.org/10.1016/J.SCS.2017.09.017
10. Murphy, R. W., Senior, J. W. & Modeller, C. (2016). *Pedestrian Wind Comfort Analysis Report*.
11. NASA. (2021). *Tutorial on CFD Verification and Validation*. https://www.grc.nasa.gov/www/wind/valid/tutorial/iterconv.html
12. Oikonomou, M. (2014). The transformation of the urban block in the European City. *ISUF, Our Common Future in Urban Morphology*, *July 2014*, 484–497.
13. Oke, T. R. (2006). INITIAL GUIDANCE TO OBTAIN REPRESENTATIVE METEOROLOGICAL OBSERVATIONS AT URBAN SITES. *WORLD METEOROLOGICAL ORGANIZATION*, 51.
14. PRATA, L., LINS, S. C. R., CARVALHO, T., LEITE, R. C. v. & NAZARETH, S. B. M. (2019). A INFLUÊNCIA DA MUDANÇA EM PADRÕES DE OCUPAÇÃO DO SOLO SOBRE AS CONDIÇÕES AMBIENTAIS URBANAS: O CASO DO POÇO DA DRAGA, EM FORTALEZA-CE. *XV Encontro Nacional Do Ambiente Construído, 2019. XV ENCAC*, 399–408.
15. Ratti, C., di Sabatino, S. & Britter, R. (2006). Urban texture analysis with image processing techniques: Winds and dispersion. *Theoretical and Applied Climatology*, *84*(1–3), 77–90. https://doi.org/10.1007/s00704-005-0146-z
16. Sonne, W. (2009). Dwelling in the metropolis: Reformed urban blocks 1890–1940 as a model for the sustainable compact city. *Progress in Planning*, *72*(2), 53–149. https://doi.org/10.1016/j.progress.2009.06.001

PLEA STGO 2022
WILL CITIES SURVIVE? ANALYSIS AND METHODS

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE URBAN DEVELOPMENT

DAY 01
16:00 — 17:30

CHAIR
MAGDALENA VICUÑA

PAPERS
1673 / 1434 / 1300 / 1305 / 1309

11TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Mind the Gap

Bridging the void between energy policy as business and social policy as equality

MARTIN MURRAY[1], SHANE COLCLOUGH[1], PHILIP GRIFFITHS[1]

[1] Department of Computing, Engineering, and the Built Environment, Ulster University, Shore Road, Jordanstown, Belfast, Co Antrim, BT37 0QB
Corresponding author: Murray-M46@ulster.ac.uk

ABSTRACT: There is a gap between Energy Policy and Social Policy and the question asked by this paper is whether such a gap is inevitable, or might be avoidable, were energy policy to be calibrated to reflect social policy. Post-Covid the EU has experienced an extraordinary increase in energy cost inflation, with associated energy security severely eroded. The value of the case study project and research lies in the belief that with an increased communization of local energy sources, we can support local microgrids, balance out discrepancies in energy performance within architectural conservation areas and promote in society, a culture of understanding of energy use and disuse, attuned to the resource limits within which we need to operate. Fuel Poverty is not a predetermined destiny, if we regard energy reduction as a community endeavour, greater than the instigation of many individual heat pumps. Collective effort is always a greater resource than individual performance.
KEYWORDS: Energy Policy, nZEB, Fabric First, Social Policy, Community Energy

1. INTRODUCTION

All Member States (MS) of the European Union (EU) have been mandated to achieve the status of carbon emissions neutrality by 2050. The three main areas of reduction for Ireland to establish such a nett zero carbon emissions economy, concern Agriculture, Transport and Energy, [1]. This paper is concerned primarily with operational energy in buildings, the regulatory control of which dates back as far as 1997, with the most recent iteration, reflected in the nearly Zero Energy Buildings Standard (nZEB) which was introduced for all buildings as and from January 1st, 2021. However, the race is now on within the EU toward 2030 and 2050 emission reduction targets. There is an undoubtable urgency due largely to years of climate denial, and a lethargy of response, which one suspects, is due in no small part to legislators not having the appetite to upset either the established 'status quo' framework of energy supply or for that matter energy demand norms [2].

Undoubtably traditional energy supply has been a win-win situation both for energy companies and legislators. The supply of fossil fuels has allowed economies to prosper, tax bases to broaden and lifestyles to emerge, which would have been unimaginable to our ancestors. However there has also been the darker side of energy production including worldwide degradation of nature, social inequalities expressed through abuse of indigenous peoples and fake climate denials. Transition periods allow a readjustment of the scales of life, and so as we progress now in striving toward 2050, the business of energy and the equality of social policy must align. This will not happen, other than through a specific and deliberate intention. The purpose of this paper therefore is to explore how such a deliberate intent might be framed in the context of how we design buildings and plan our towns and villages. We are on the cusp of significant change internationally and unless that change is framed and managed in unequivocally clear terms, chaos will follow.

2. COMMUNITY ENERGY.

A hint as to how such chaos might evolve is reflected in the fact that although a gradual improvement in energy saving and carbon emission reductions has been achieved in recent years, it has been paralleled by an equally gradual increase in energy use and associated costs for both electricity and gas. It is well observed how the 'rebound effect' and 'comfort taking' can significantly affect the carbon emissions of properties post renovation.

Research indicates that poor instruction regarding optimal use of controls, reflects one shortfall, however the presentation of the problem as one requiring individual response loses the sense of community endeavour which would really galvanise energy savings. Alex Laskey in a TED talk from 2013, shows how a quirk of human behaviour can make us all better, wiser energy users, with lower bills to prove it [3]. Using behavioural science and working with utility companies across the USA, he designs utility bills to outline to energy users how they rank with their neighbours and within their community. The experience is that this has the capacity to profoundly alter people's behaviour.

By way of contrast in Ireland we have individualised the problem. We encourage people to turn to heat pumps and electric cars, with the subliminal suggestion that all can be as it was, if we electrify everything. We fail to highlight that our behaviour also must change, from the way that we live, to for some, where we live. The case study project is an endeavour to progress this message and create a community project with built-in energy equity and resilience. We need this now more than ever, given the precarious sources of our fossil fuels. Post-Covid the EU had already experienced an extraordinary increase in energy cost inflation, with associated energy security severely eroded. Russia's invasion of Ukraine has ensured that energy inflation will be a key economic determinant for a significant period across our energy transition. What are the implications of this?

2.1 Private or public?

In recent years Ireland has initiated a series of citizen assemblies to address issues of social concern. The assembly meetings of Sept/Oct/Nov 2017 dealing with Climate Change addressed thirteen questions and supported thirteen resolutions. It is notable that only two resolutions gained 100% support of the members, (others varied from 80% to 99% support). These particular resolutions unequivocally recommended that sustainable energy initiatives be promoted as community endeavours.

The resolution recommended that the State take a leadership role in addressing climate change through mitigation measures, including, for example, retrofitting public buildings, having low carbon public vehicles, renewable generation on public buildings and through adaptation of measures, such as increasing the resilience of public land and infrastructure. 100% of the Members recommended also that the State should act to ensure the greatest possible levels of community ownership in all future renewable energy projects by encouraging communities to develop their own projects and by requiring that developer-led projects make share offers to communities obligatory, so to encourage greater local involvement and ownership

Such citizenry deliberations are hugely important in identifying the real concerns which exist about placing control of energy into private equity control, whose sole focus is, (almost by legal necessity), one of providing profit for investors, an obligation which may at times be contrary to the needs of the communities they serve. Already in the UK various green energy companies have had to cease business due to ill-considered financial forecasting, while in Texas during an unusual climate event in February 2021 the grid ceased to function as a result of under-investment by the operator, in preparing for extreme winters. The deregulation of the American electricity market in the 1990s had resulted in extreme competition in wholesale electricity prices, and associated cost cutting, which resulted in poor contingency preparation throughout the industry. More than 4.5 million homes and businesses were left without power in the Texas, blackout, and at least 246 people were killed directly or indirectly. What is perhaps of even greater concern regarding resilience of energy supply, is that during the Texas disaster, some energy companies made billions in profits, while others went bankrupt [4].

In Ireland where the percentage of the population over 60 is expected to double from 16% to 32% between 2011 to 2050, and where fuel poverty is one of the highest in Europe, all citizens need to be assured that access to energy is possible at a reasonable cost. However, it is difficult to conceive of a community energy resilience being readily achievable if we fail to structure our energy policy to parallel social policy. Energy policy as business and social policy as equality are on divergent pathways and the social equality gaps identified by Piketty, Klein, Christophers et al. [5] have exposed the harsh reality that the future control of energy will reflect itself also in the future control of wealth and influence, unless we take specific actions against that reality arising and bridge that void.

The void to be bridged is really one of a philosophical outlook, one which reflects on the one hand, an neo-liberal viewpoint that determines energy as an asset to be exploited for maximum profit, or on the other hand, a socially centred viewpoint which would view energy to be like water or food or shelter, a basic human right. For a neoliberal mind-set this is perhaps nothing less than a profound philosophical change of outlook.

2.2 Another industrial revolution

At the launch of the UK's press release detailing their path to net zero emissions by 2050, (19th October 2021), both the Prime Minister, Boris Johnston and Kwasi Kwarteng, the Business and Energy Secretary, referred to the great *'green industrial revolution'*. Mr Kwarteng went on to say that *'today's plan will not only unlock billions of pounds of investment to boost the UK's competitive* *advantage in green technologies, but will create thousands of jobs in new, future-proof industries – clearly demonstrating that going green and economic growth go hand in hand'* Clearly this is energy policy as business first and central. Equally it would seem to display a rather benign concern as to the whole concept of 'Industrial Revolution', with no hint of irony as to the reality of where the last industrial revolution got us.

The concept of green growth is highly problematic, and many literatures argue that it is a fundamental contradiction in terms [6]. To understand if going green and economic growth can go hand in hand, the EU has instigated a taxonomy for sustainable activities which will help to create a commonality of sustainable definitions. Perhaps the most notable aspect of the taxonomy is the intention to set the performance level of buildings 10% above the current nZEB standard.

All literatures reflecting post occupancy evaluations concur that in Northern European countries, where moderate heat is required, the better the fabric standard the closer the final energy use reflects predictive use. This is important for overall planning and would therefore suggest that the green revolution required is one of renovation skill sets, and an energy approach which is passive in lieu of active, [7] where fabric first becomes the first fuel source in line with the EU "energy efficiency first principle".

3.0 COMMUNITY ENERGY.

This paper derives from research related to a mixed-use, low-rise construction project located within the backhands of a mid-sized town in Ireland. The project design is premised on creating an energy-plus development and to investigate how optimal energy performance can be utilised to support the concept of community energy, energy generated on the consumer side of the meter for use by the consumer in as efficient a way as possible.

This is an energy system that is (i) bottom up and community driven, is (ii) regenerative and therefore resilient. Finally, it is also (iii) interdependent with the grid, both supporting it, and in turn be supported by it. In such a way the traditional consumer becomes served by a smart metering infrastructure which if the 'policy-will' is in place, will support a community of 'empowered prosumers', as opposed to 'beleaguered consumers'.

3.1 Follow the money

Energy policy at present does not support community endeavour and certainly not empowered prosumers. Part of the problem which is now upon us is the very limited timescale within which we must decarbonise energy. For a Northern European climate all the literatures tell us that where energy prices and interest rates were (historically) low and stable, then cost optimality solutions to creating low energy buildings, favour more active solutions to reducing energy. We therefore have an 'active' legislative policy which promotes a plentiful of heat pumps and PV installations without real concern for fabric. In renovation this is hugely problematic as poor fabric and airtightness will lead to sub optimal use of heat pumps and therefore excessive energy bills.

Fabric aside, governments across Europe see the low carbon electrical grid as the optimal solution. This may relate to a belief that by moving everyone currently purchasing fossil fuels, onto the national power grid, they can also transfer all of the hidden fossil fuel taxation onto the electricity system. They can then subsidise significant industrial scale wind and solar installations to green the grid to 100% renewable energy, and consumers will still purchase their energy as usual. These are lost opportunities.

Hone Revolutionary Energy make this point clear across their webpage. Their calculations point again to the fundamental weaknesses of poorly performing buildings relying on heat pumps to meet their energy needs. If such heat pumps operate inefficiently then their electrical loads increase and comfort taking creates significant costs for the electrical consumer [8].

A Central Statistics Office (CSO) report from August 2019 revealed that Ireland's overall carbon emissions equated to 13.3 tonnes of CO_2 per capita, making Ireland the third-highest carbon emissions producer in the EU, after Latvia and Estonia. Social change therefore will not just be confined to reducing home energy use but rather is a challenge to our entire lifestyle which is carbon intensive. If we are to follow the money, then it is obvious that altering such a carbon intensive lifestyle will therefore need to create profound change, not least being in the way governments collect and redistribute monies through taxation.

3.2 Altered patterns of taxation.

It is inevitable that energy transformation will also give rise to a tax transformation. As fossil fuel supported energy produces significant amounts of tax revenue every year, this revenue will need to transfer over the course of the energy transition to alternative forms of energy production, albeit nuclear or renewables. The volume of commerce involved, indicates the 'gravy-pot' which the electrical grid will become. In 2019, the UK exchequer took in £27.57 Billion on petrol and diesel fuel duty alone, with another £12.84 Billion on VAT related to petrol & diesel sales, all together totalling £40.41 Billion or c. €46.87 Billion.

In Ireland the Irish Exchequer receives circa €5 billion annually in tax receipts from motor, fuel, and carbon taxes (prior to the pandemic). Full 'electrification' of the national fleet of vehicles will put a signification proportion of these revenue streams at risk unless there are changes to the structures of these taxes. Separately motor taxation raises almost €1 billion for the Irish State annually. If you now add other recurrent taxes related to the national gas grid, power generation, industrial use and current residential use, (i.e. all the other fossil fuel consumption that they collect taxation on), one can quickly see how important tax-wise it will be to create a 'controlled', market for domestic heat pumps and electric vehicles (EV) as fast as possible.

The problem however for domestic consumers is that the highest value use of a kW will determine the benchmark value for overall electricity use. Currently kW use within electric cars sets this highest value. The replacement value of a kWh of electricity used within an EV in lieu of a diesel car running at 50 miles to gallon, is close to 55 cents, substantially more than the default value of 15 cents being touted as the buyback value to the grid and twice the value of electricity as sold currently via the network. In these circumstances it seems inevitable that electricity costs will increase enormously in the next few years.

4.0 INTERGENERATIONAL OBLIGATIONS.

Perhaps the best known and used definition of sustainability had been that emanating from the UN sponsored Brundtland Commission (1987), which stated it as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."* In the intervening 35 years many of the parameters which might have framed that definition have changed. Our present needs have if anything, become inflated, while the needs of our future generations have been actively deflated by the wonderful economic tool of 'discounting'. However, it is beyond dispute (as the definition above claims), that real equitable and sustainable social policy across the entire energy transition period, must take consideration of future generations.

In his seminal book, *The Good Ancestor,* Roman Krznaric [9] considers how intergeneration justice might be supported by reviewing our understanding of 'financial discounting'. Through discounting, we value resources today greater than those located at some future time, and this valuation is reflected in the discount rate. In such a way discounting acts as a form of colonialisation, not of countries, but of the future. While economic discounting is used widely in economic calculations such as cost optimality, (as if it were bounded by science), it is in fact according to the Nobel prize-winning economist Amartya Sen deeply driven by value judgement, and this should be a matter for public deliberation. If we are on the cusp of an energy transformation, then our obligations to the future generations might well be guided and tempered by reference to the scale of those unborn generations.

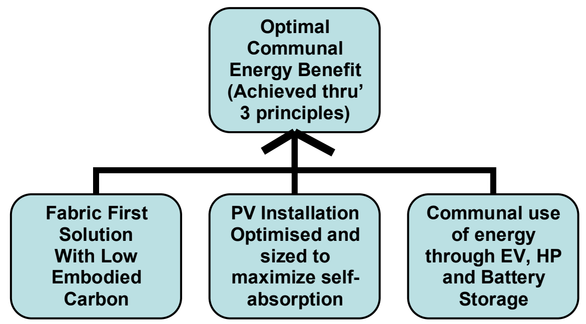
Looking 50,000 years back and forward and assuming current birth-rates remain constant, then the dead represent 100 billion, the living represent 7.7 billion and the generations to come, reliant on our strategic decisions today and the wisdom underlying them, represent 6.75 trillion [9].

5. AN ENERGY TRANSITION PROJECT

In this light, the value of transition projects will undoubtably lie in their ability to support local microgrids and the communization of local energy sources. The development case study consists of a mixed-use, low-rise development of three campus-style buildings (492m^2) located on a 600m^2 back-lands urban site, located within an Irish country town. The research highlights the importance of such sites in the revitalisation of our towns and villages and as operational fulcrums around which the patterns of a low carbon lifestyle will mature.

Because the project is intended to be 'energy-plus' it is also an investigation of the interface which almost by default has evolved between our large energy suppliers on the one side, and the end user/prosumer on the other. The fossil fuel generation of electricity is a system unchanged for over 100 years, the consumer relationship and the financial profile of distribution costs are well established. Transitioning will change this. Fossil fuel generation stations will function at reduced capacities and (in)efficiencies, consumers will need smart metering to control their energy costs and allow for energy management on the smart supply side of the meter. The design principles of the case study site are encapsulated in the Figure 1 below:

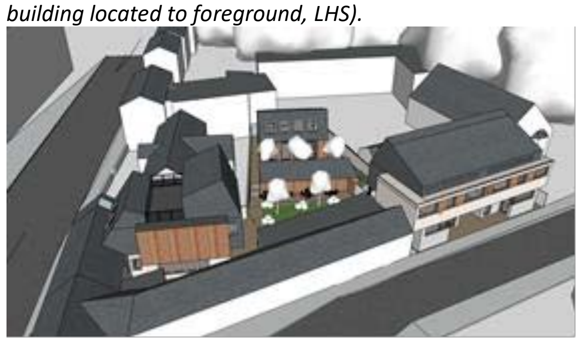
Figure 1: *Formatting optimal low-energy building(s) to support the realisation of communal energy.*



5.1 The case study

The case study site is set within an architectural conservation area with adjoining buildings carrying high architectural and social heritage value. As an energy plus development it can contribute to the balancing out of discrepancies in energy performance across such a diverse collection of architecturally protected structures. By location within a town setting, it can also promote in society at large, a culture of understanding of energy use and disuse, attuned to the resource limits within which we need to operate.

Figure 2: *Overview of case study site. (Three storey building located to foreground, LHS).*



5.2 Energy systems

Energy use is defined by systems. The purpose of the case study is to expand our concept of such systems. The closed system underlying the historic fossil fuel generation of energy is now defunct and the model we need now is one of communal energy, distributed through smart metering and system sizing to ensure maximum self-absorption of renewable energy (RES) generated on site. The buildings themselves have been designed to the Passive House Plus standard which creates surplus energy to be disposed on site, via EV charging, battery storage and communal heat pump operation which allows heat also to be shared across boundaries.

Optimal resource allocation would suggest that any such new buildings must be capable of long-life use, requiring loose-fit design, using low-embodied carbon materials and capable of future reuse, flexibility, and resource circularity. To facilitate this scenario, the buildings are designed in section, and plan to be capable of a variety of uses from residential, to office to commercial use, (Fig. 3).

Figure 3: *Three storey building reflecting the potential for a variety of uses across the three levels.*

The Roadmap for the Global Energy Sector, (2021) by the International Energy Agency (IEA), sets a clear pathway for achieving a warming limit of 1.5ºC. It categorises the necessity for buildings to be brought forward into a condition of 'zero-carbon-ready'. It defines this term as a building which is 'highly energy efficient' and which either uses renewable energy directly or utilises an energy supply that can be fully decarbonised, such as electricity or district heat. This elusive metric, by which a building is deemed 'highly energy efficient' is at the core of this research and case study, as by its very definition, we may economically favour either (i) the modus operandi of the energy supplier, or alternatively (ii) the energy conservation of the energy consumer. This decision is now ours.

5.3 Energy substitution

Today the emphasis on reducing operational energy only, has evolved into an expanded awareness of embodied carbon and the recalibration of the distinct advantages of renovating buildings, over their removal. Equally a well performing fabric, either new or refurbished, buffers against significant variations in temperature, allowing an improved capacity for energy storage potential, particularly if combined with PV installations, such as those exemplified by PH 'Plus' and PH 'Premium' models of operation. Such an approach favours the energy consumer.

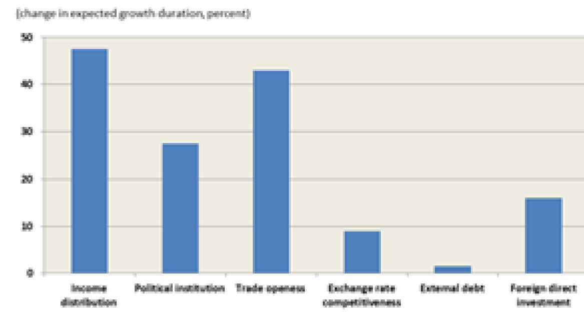
The literatures related to the potential of PV installations combined with battery arrays and EV's have also shown how the relationship of the nZEB building, to both its physical and energy context, has transformed from one defined by primary energy demand, to one which must now negotiate both the timing of demand, and the timing of supply of energy to the power grid. This in turn has raised the potential for greater building autonomy when significant storage potential is introduced within the energy boundary. It is this latter issue that brings us to the tipping point, or the leverage point, as defined by Diederen (2010), whereby our energy response must now be governed by resource allocation considerations primarily, [10].

6. THE BEGINNING OF A CONCLUSION

The case study is set within a professed ideological outlook, which would hold that energy is a social good, from which we must always look to protect the surplus value. The interface of energy use and energy conservation, as defined by the Irish nZEB standard has failed to bring this value forward because being defined by market values it is also defined by market solutions which are predominantly technological based. (The case study itself is detailed within another PLEA paper, which is part of the conference submission).

Morozov (2014), uses the expression 'technological solutionism' to address this modern phenomenon which he views critically as an endemic ideology that looks at complex social phenomena like politics or public health as *'neatly defined problems with definite, computable solutions or as transparent and self-evident processes that can be easily optimized—if only the right algorithms are in place!'* [11]. Technological solutions can also tend to favour the providers of those solutions. By way of contrast fabric first either for renovation or new build requires human labour, the present-day cost of which usually fails to meet cost optimality criteria. Human labour, being that most renewable of energies, is ignored in many of the literatures reviewed, but it is undoubtably an energy input capable of bridging the gap between technological solutions and socially favourable ones. It also favours a greater distribution of income across projects and society and so in accordance with Figure 4 below contributes also to a sustainable level of economic growth, [12].

Figure 4: *When it comes to assessing the potential of economies to sustain economic growth 'income distribution' (LHS) is the dominant influencer next to trade openness (3rd from left),* [12].



The current market appears skewed toward facilitating high value technological solutions at the power grid level, to service buildings regardless of their individual performance profile. The fundamental error appears to lie in a blind belief in this low carbon efficacy, created by supporting the supply end of the power grid and leaving the demand side deeply underfunded and lacking demand end solutions. This lack of a subsidiarity principle works against the possibility of the individual energy user becoming a prosumer, capable of producing power in support of the grid's resilience and consuming to a level which is financially sustainable for individuals and communities at large. One EU research initiative, 'Enefirst', has tried to understand the circumstances within which efficiency improvements might be shown to be most cost-effective or valuable, and has argued that if so, they should be prioritised over any investment in new power generation, grids or pipelines, and fuel supplies, [13]. In line with this initiative the case study research is also an endeavour to step outside this closed circle of standards and beliefs which have evolved to serve the marketplace and investigate the real metrics necessary for the evolution of an energy standard that serves both energy and social policy. Even with rapid deployment of renewable energy and efficiencies, between now and 2050, negative climatic consequences are virtually unavoidable. However, when it comes to energy we need to understand, the concept of value and how economic value is created in society, [14]. The Irish nZEB policy strategy postulates that cost determines the ultimate value of the solution. However, to follow Mazzucato (2018) we must allow value to determine the price, and we cannot do this unless we begin the task of pricing the real environmental cost of carbon, community, and human labour.

ACKNOWLEDGEMENTS

This paper is supportive of ongoing Ph D research at Ulster University. I am grateful to the University for their academic sponsorship and to my supervisors, Dr. Shane Colclough, and Prof. Philip Griffiths, for their ongoing advice and support.

REFERENCES

1. Sustainable Energy Authority of Ireland. (2020) Energy-related CO_2 emissions in Ireland 2005 – 2018, *SEAI Renewable Energy Information Office*, (2020).
2. Klein, N., (2014), This Changes Everything: Capitalism vs the Climate, *Simon & Schuster, New York.*
3. Alex Laskey, A. 'A quirk of human behaviour' TED 2013
4. Rio, G., McDonnell N del, Fausset, R, Diaz, J. (Feb. 19th, 2021). "Extreme Cold Killed Texans in Their Bedrooms, Vehicles and Backyards". *The NYT. ISSN 0362-4331.*
5. Christophers, B., (2020), Rentier Capitalism. Who owns the economy and who pays for it? *Verso.*
6. Hickel J., Kallis G, (2020) Is Green Growth Possible? *New Political Economy, 25:4, 469-486, DOI: 10.1080/13563467.2019.1598964.*
7. International Passive House Association. https://passivehouse international.org./
8. Hone Revolutionary Energy, (webpage accessed, 2022)
9. Kr Krznaric, R., (2020), The Good Ancestor: A radical prescription for long term thinking. *Ebury Publishing.*
10 Diederen, A., (2010) Global Resource Depletion. *Eburon, Delft.*
11 Morozov, E., (2014). To Save Everything, Click Here: The Folly of Technological Solutionism. *Journal of Information Policy, 2014, Vol. 4 (2014), pp. 173-175*
12. Andrew G. Berg, A.G. and Ostry J.O., International Monetary Fund - "Equality and Efficiency" *Finance and Development, September 2011, Vol. 48, No. 3.*
13. Enefirst: *EU Horizon 2020, (n°839509) toward achieving 'Efficiency first principle operational in the EU'.*
14. Mazzucato, M (2018). *The Value of Everything.* Allen Lane, 2018.

PLEA SANTIAGO 2022
Will Cities Survive?

Hygrothermal characterization of water-absorbing granules

A preliminary experimental study for the development of an evaporative cooling façade module

FABIAN GÖRGEN[1,2] MONICA ROSSI-SCHWARZENBECK[1]

[1] Leipzig University of Applied Sciences (HTWK), Leipzig, Germany
[2] Brandenburg University of Technology, Cottbus, Germany

ABSTRACT: This research investigates the potential of moist porous granules as a sustainable lightweight water-absorbing material to be used in an evaporative cooling façade module to improve outdoor thermal comfort. The experiments were conducted under laboratory conditions and focused on determining material properties, drying rates and cooling efficiency. Compared to bricks, the granules showed a weight reduction of up to 95% in the dry state and 83% when fully saturated with water. The amount of stored water increased by up to 123%. A high water suction capacity and hygroscopic characteristics proved the granules' potential to gather and store water from either rain water or humid air as an alternative to active irrigation. The granules showed increased evaporation rates, resulting in a decrease of surface temperatures by up to 4.66 K on average compared to the ambient air. An alternative construction demonstrated an approach that controls the drying process naturally while increasing cooling efficiency.

KEYWORDS: Evaporative Cooling, Porous Materials, Hygrothermal Characterization, Outdoor Comfort, ECFM

1. INTRODUCTION

Anthropogenic climate change results in a steady increase of hot days, tropical nights and heavy rainfall (Fallmann et al., 2017), affecting the quality of human comfort. Apart from the increase in temperature, the urban heat island effect exacerbates the situation in urban areas, as heat stored in buildings, anthropogenic heat and a lack of vegetation contribute to overheating (Yamamoto, 2006). In order to mitigate heat stress, evaporative cooling is one well-tried strategy (Watt, 1986).

Studies focusing on evaporative cooling in outdoor spaces have proven this approach's high potential for mitigating urban heat islands. Broadbent et al. (2017) proved that the increase in humidity still improved outdoor human thermal comfort during heatwave conditions. While Ulpiani (2019) investigated the influence of mist cooling on the urban environment, further research focused on evaporation from wet porous media, including permeable pavements (Han et al., 2017) and a water-retaining roof (Wang et al., 2018). He and Hoyano (2009, 2010) developed a passive evaporative cooling wall (PECW) made of moist bricks while Chen et al. (2015) used ceramic pipes as a medium for an evaporative cooling wall. Zhang et al. (2016) developed a porous face brick wall and exposed it to outdoor conditions to investigate the influence of moisture content on the cooling performance of moist bricks. A wider range of materials, including vegetable fibers (Jain & Hindoliya, 2013), plastic and cellulose (Franco-Salas et al., 2014) and ceramics (Abdullah et al., 2019), have been investigated in connection with evaporative cooling pads. A general distinction is made between rigid media pads, fiber pads and fill pads (Tejero-González & Franco-Salas, 2021). Previous studies provide many useful methods and data to evaluate the perfomance of various evaporative cooling devices and materials.

This research is part of a project that aims to develop a lightweight evaporative cooling façade module (ECFM). As water often is a scarce resource in hot arid regions, this approach investigates lightweight water-absorbing materials to gather and store water in addition to active irrigation. Following the example of living walls, the weight limit lies at 50-75 kg/m², as heavier materials like bricks complicate practical implementation in urban areas. As a lightweight, water-absorbing material of natural origin, porous granules have potential to match these requirements. The goal of this research is to investigate the selected granules regarding their material properties and evaporative cooling perfomance. First, the material properties, including density, water storage capacity, water absorption and hygroscopicity, were determined. To evaluate the cooling performance, two drying experiments were conducted under laboratory condtions. Experiment I compared the selected materials, evaluating the evaporation rates and the resulting surface temperatures of the specimens. Experiment II included a different set-up, using an alternative construction to optimize the process of evaporative cooling.

2. EXPERIMENTAL SET-UP

The experiments were carried out under laboratory conditions at the Leipzig University of Applied Sciences in Leipzig, Germany, and included three different types of granules (Fig. 1) and one type of red bricks as a reference. The selection criteria for the granules were low weight and high porosity. The following materials were investigated:

- 4-8 mm broken expanded clay (EC)
- 2-6 mm perlite (PE)
- 5-8 mm pumice (PU)
- Red brick (BR)

Figure 1: *Specimens (perlite, expanded clay and pumice)*

2.1 Material properties

The material properties were determined according to the respective International Organization for Standardization (ISO) standards. The following values were determined:

- Moisture content (mass by mass u, mass by volume v, volume by volume ψ) according to ISO (2000)
- Water absorption coefficient A_w according to ISO (2002)
- Equilibrium moisture content at RH=80 w_{80} according to ISO (2021)
- Bulk density ρ_{bulk} according to ISO (1981)

It should be noted that values may vary due to the random and unique structure of every filling, which will contain different particles of varying grain size and shape.

2.2 Drying experiments

The drying experiments (convective drying) were conducted under laboratory conditions using a climatic chamber (Feutron KPK 200, Type 3423/17). To gather the required data, a scale and combined temperature and relative humidity sensors (Almemo FH A646-R) were installed. The boundary conditions inside the climatic chamber were set to 30°C and 30% RH to simulate a realistic summer day in a temperate climate. The data, including weight, temperature and relative humidity, were recorded in time intervals of 5 minutes over a total period of 48 hours.

2.2.1 Experiment I

The first experiment focused on the one-dimensional drying of the selected materials, pointing out differences regarding drying behaviour and surface temperature. Prior to the experiment, the specimens were placed in a water bath until fully saturated (m_{sat}). Then, the specimens were placed in a box (230 x 240 x 70 mm), open on one side, to guarantee one-dimensional moisture transport. The box was placed onto a scale in the centre of the climatic chamber, with the open side facing upwards (Fig. 2). A combined temperature and relative humidity sensor was placed in the centre of the specimen's surface to record the surface temperature over the defined period of 48 hours.

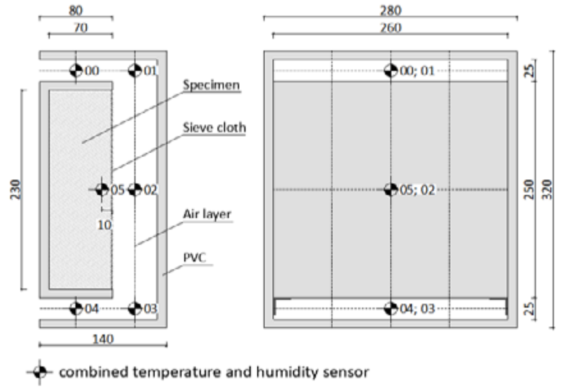
2.2.2 Experiment II

For the second experiment, the same specimens were investigated over the same period of time, but the wet surface was not exposed to the environment directly. The goal was to find out if the drying rates could be held constant to control evaporation naturally using an alternative construction. For the experiment, a small-scale prototype of the ECFM was used (Fig. 2).

Figure 2: *Experimental set-up (I and II)*

The ECFM consists of two parts: a smaller box (230 x 240 x 70 mm) open on one side and a larger box (300 x 260 x 130 mm). The fully saturated specimens (m_{sat}) were first placed in the smaller box. The open side was supported with a sieve cloth to prevent the granules from falling out. The smaller box was plugged into the larger box, with the open side facing inside the construction. To measure temperature and relative humidity, the ECFM was outfitted with six combined temperature and relative humidity sensors. Figure 3 shows the set-up and the sensor distribution. The ECFM was placed onto a scale in the centre of the climatic chamber. To minimise heat loss through conduction, the ECFM was additionally coated with a 100 mm layer of polystyrene.

Figure 3: *Dimensions (mm) and sensor* distribution



3. RESULTS

3.1 Material properties

Table 1 shows the material properties of the specimens. The results represent the average value of five samples per material.

Table 1: *Material properties of the specimens*

	u (-)	w (kg/m³)	A_w (kg/m²*h$^{0.5}$)	w_{80} (kg/m³)	ρ_{bulk} (kg/m³)
EC	0.50	152.77	0.81	0.43	305.49
PE	2.77	250.40	5.49	2.90	90.56
PU	0.78	274.21	2.06	5.48	351.55
BR	0.06	122.67	5.62	0.79	1899.5

Regarding the moisture content, the perlite granules showed the largest water storage capacity by mass, storing approximately four times its own weight. The maximum moisture content of the bricks was determined to be 6.46%. The pumice granules showed the greatest total amount of water per unit, storing 274.21 kg/m³. The results proved the bricks to be the heaviest and least efficient water-storing option. A decrease in total weight of up to 95.23% (-1808.94 kg/m³) in the dry state and 83.14% (-1681.25 kg/m³) when fully saturated with water could be achieved when using porous granules. The total amount of stored water could be increased by up to 123.53% (+151.54 l/m³). The bricks and the perlite provided the highest absorption coefficient, absorbing water more quickly, as in, for instance a heavy rainfall event. The pumice granules showed a high w_{80}-value, gathering the most water from the surrounding humid air. Especially at night, with higher relative humidity values, this could help collect water without active irrigation.

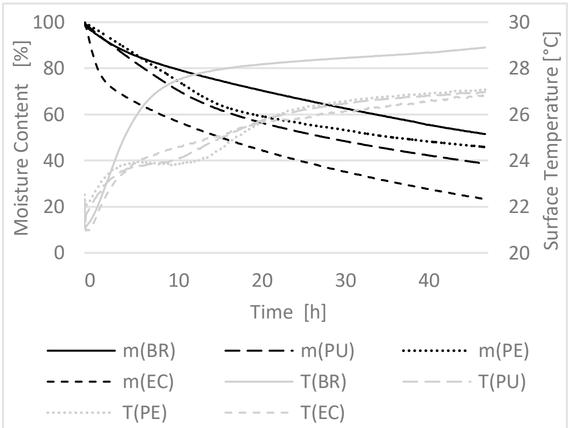
3.2 Drying experiments

According to Krischer and Kast (2014), under constant conditions the drying process for capillary porous materials can be divided into three stages. In the first stage (Constant Rate Period = CRP), water evaporates from the material's wet surface. The drying rates are constant and controlled by external influences. The second stage (Falling Rate Period = FRP) starts once the surface is dry and the plane of evaporation moves into the material. The turning point between the first two stages is called the critical moisture content (w_{crit}). In this stage, the drying rates decrease rapidly. The FRP is controlled by heat and mass transfer and therefore depends on the material properties. Hygroscopic materials show a third drying stage, reaching an equilibrium mass moisture content according to the boundary conditions.

3.2.1 Experiment I

Figure 4 shows the mass moisture content and the surface temperature of the specimens over 48 hours. The drying stages according to Krischer and Kast (2014) are easily recognizable. After an initial rapid moisture loss, the curves of all specimens flattened. Referring to Table 1, the granules were able to store higher amounts of water compared to the bricks, with 123.53% (PU), 104.12% (PE) and 24.54% (EC). During the 48-hour period, a total loss of water of 253.2 g (BR), 574.2 g (PU), 618.1 g (PE) and 507.6 g (EC) was measured. Compared to the bricks, evaporation rates increased by 126.78% (PU), 144.11% (PE) and 100.47% (EC). Comparing the increased amount of moisture to the increased evaporation rates, the granules showed an overall better drying behaviour emphasized by the individual moisture contents of 51.51% (BR), 38.62% (PU), 45.80% (PE) and 23.23% (EC) (see Fig. 4). Also, the data showed an elongated CRP and therefore a time lag of the w_{crit} due to the higher amount of water stored.

Figure 4: *Moisture content and surface temperature (I)*



However, to evaluate the cooling performance, the measured surface temperatures must be considered. After reaching their low, the surface temperatures of all specimens increased rapidly. The curves of all granules, however, stabilized earlier, entering a constant period at lower temperatures. This was mainly due to the higher evaporation rates that all granules provided at the beginning of the experiment, decelerating any further increase. The subsequent movement showed further differences between the specimens. While the bricks merged into a constant period after reaching w_{crit}, the granules' surface temperatures experienced a second increase after the first constant period. The second increase was then followed by a second constant period that approached the respective end temperatures. Over a defined period of 48 hours, the measured results showed significantly lower surface temperatures for the granules. The average surface temperatures were calculated to be 27.57°C (BR), 25.47°C (PU), 25.48°C (PE) and 25.34°C (EC). Surprisingly, the average values for all granules were very close. On average, the surface temperatures showed a maximum temperature drop of 2.23 K and 4.66 K compared to the bricks and the ambient air, respectively.

To evaluate the cooling performance, an approach commonly used to assess the efficiency of, e.g., cooling pads was applied. The saturation efficiency η is a ratio to set the actual temperature drop in relation to the wet bulb depression. In this case, the actual temperature drop refers to the difference between ambient temperature in the climatic chamber and surface temperature of the specimens (see equation (1)):

$$\eta = (T_a - T_i) / (T_a - T_{WB}) \qquad (1)$$

where η - saturation efficiency (-);
T_i - surface temperature at time i (°C);
T_{WB} - wet-bulb temperature (°C);
T_a - ambient temperature (°C).

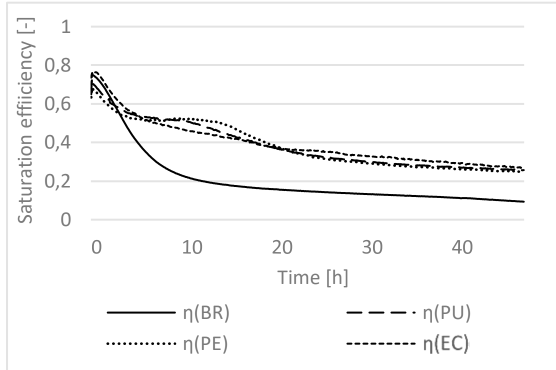
The wet-bulb temperature (T_{WB}) for the ambient climate conditions was calculated using equation (2), developed by Stull (2011):

$$T_{WB} = T * \text{atan}(0.151977\,(RH + 8.313659)^{0.5}) + \text{atan}(T + RH) - \text{atan}(RH - 1.676331) + 0.00391838\,(RH)^{1.5} * \text{atan}(0.023101 * RH) - 4.686035 \qquad (2)$$

where T_{WB} - wet-bulb temperature (°C);
T - temperature (°C);
RH - relative humidity (%).

Figure 5 shows the saturation efficiencies of the specimens over the defined period of 48 hours. The granules' η-values at the end of the experiment were close, reaching 0.257 (PU), 0.248 (PE), and 0.269 (EC). The bricks' saturation efficiency was calculated to be 0.093 after 48 hours. Despite storing the third largest amount of water among the specimens, the expanded clay was most efficient, reaching the highest saturation efficiency after 48 hours and the highest average η-value (0.39) over the defined time period. The high water release of the material provided made the expanded clay the best choice for this set-up in terms of efficiency, as 66.77% of the stored water could be used for cooling purposes.

Figure 5: *Saturation efficiency (I)*

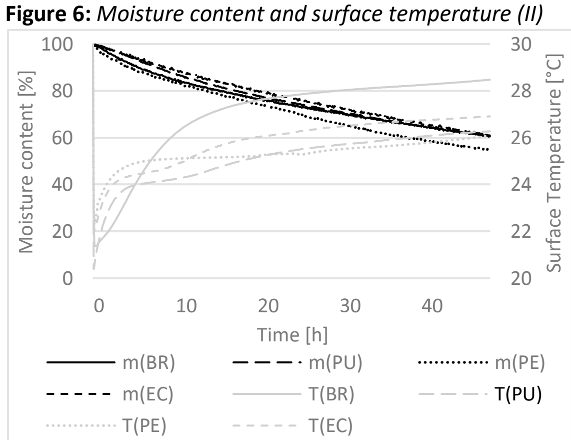


However, an elongated investigation period might lead to the total desiccation of the expanded clay and change the average values for saturation efficiency in favour of pumice or perlite, which held larger amounts of water at the end of the experiment. Overall, the approach illustrated a significant difference when comparing any type of granules to bricks, due to their high water storage and release.

3.2.2 Experiment II

Figure 6 shows the mass moisture content and surface temperature of the specimens.

Figure 6: *Moisture content and surface temperature (II)*



In comparison to experiment I, the moisture loss in experiment II is more linear and Krischer and Kast's (2014) drying stages are not as easy to determine. The total loss of water was measured to be 210.4 g (BR), 365.5 g (PU), 387.5 g (PE) and 273.6 g (EC). In comparison to experiment I, evaporation was reduced by 16.90% (BR), 36.35% (PU), 30.00% (PE) and 46.10% (EC). All specimens evaporated a significantly lower amount of water, resulting in a higher individual moisture content at the end of the experiment, with 60.52% (BR), 60.91% (PU), 54.65% (PE) and 60.60% (EC).

Regarding surface temperature, the results showed only slight differences on average compared to experiment I. The average surface temperatures over 48 hours were 26.98°C (BR, -0.59 K), 25.10°C (PU, -0.37 K), 25.30°C (PE, -0.18 K) and 25.84°C (EC, +0.50 K). Again, the bricks' temperature curve was different from the s-shaped curves of the granules, which showed two increasing periods and two constant periods.

To make a comparative evaluation of the two experiments, it was important to define the major experimental differences that may have influenced the drying behaviour of the specimens. First, the sieve cloth attached to the open side of the box added extra water vapour diffusion resistance, limiting mass transfer. Second, ventilation in front of the wet surface was reduced in experiment II. In experiment I, the wet surface was exposed to ventilation, which the climatic chamber used to keep temperature and relative humidity levels constant. The third factor was the changing climate conditions in front of the wet surface. While the climate conditions in experiment I were held constant to 30°C and 30% RH, the temperature and relative humidity in experiment II varied. Evaluating the climate conditions at measuring point 02, the data showed that the relative humidity within the first 24 hours was 21.83% higher compared to experiment I. The temperature during the same time was 4.53% lower. This also had an impact on the drying rates. In the first ten hours, the drying rates in experiment I were at around 20-25 g/h whereas in experiment II the drying rates were at about 10 g/h, thus preventing the initial rapid drying of the surface and great moisture loss. In the second half of the experiments, the rates were more similar, at around 5 g/h.

The maximum humidity level inside the air gap was 50.80%, meaning the wet-bulb temperature could not be reached. This was mainly due to the small size of the prototype. The evaporation rates were too low to saturate the air in the proportionately large air gap while the air was constantly exchanged. The exchange of air through natural convection is illustrated by the values in Table 2. The data revealed differences in air temperatures on the inlet (00) and outlet (04) of the ECFM. The cool and humid air was led towards the bottom outlet due to pressure difference. The results clearly showed buoyancy-driven convection. The total drops in temperature seem low, as the maximum decrease compared to the ambient air temperature is 2.94 K. However, given the fact that the wet surface had a total area of only 0.055 m², evaporating around 5-15 g/h, the results are remarkable.

Table 2: *Inlet (00) and outlet (04) temperatures [°C] (II)*

t	PU	PE	EC	BR
1	29.5/27.3	29.6/27.2	29.8/27.6	29.8/27.1
2	29.9/27.8	29.7/27.6	29.9/27.9	29.8/27.3
5	29.9/27.9	29.9/28.0	29.9/28.2	29.9/27.9
10	29.9/28.1	29.9/28.2	29.9/28.4	29.9/28.7
12	29.9/28.2	29.9/28.2	29.9/28.5	29.9/28.8
24	29.9/28.8	29.9/28.4	29.9/28.9	29.9/29.2
48	29.9/29.2	29.9/29.1	29.9/29.1	29.9/29.4

Therefore, it can be concluded that the construction worked but needs modifications to the size of the wet layer and the dimensions of the air gap. However, the idea of controlled evaporation was nonetheless demonstrated: the climate was changed due to evaporation by influencing the drying process and making it controllable.

4. CONCLUSION

All investigated granules showed a significantly higher moisture content compared to bricks, saving up to of 95% of the weight in the dry state and 83% when fully saturated. This resulted in a total increase of water storage of 151.54 l/m³. Increased hygroscopicity might also make a useful contribution, as gathering water from humid air can be an alternative to active irrigation. The investigated features prove all granules under study to be a useful alternative to wet bricks, especially if the water supply is limited. Their light weight facilitates practical implementation. The drying experiments demonstrated differences between materials and set-ups regarding cooling performance. Experiment I showed that the granules evaporated more than twice as much water as the bricks, resulting in lower surface temperatures of up to 3.23 K on average over the defined period. The longer-lasting saturation efficiency was a result of the increased amount of stored water and the quicker drying process. The ECFM used in experiment II provided a base for a controlled evaporation process. Through changing internal climate conditions, the evaporation rates were held constant while providing low temperatures on the specimens' surfaces. The bundled cool air showed differences of up to 2.94 K compared to the ambient air temperature.

To develop a functioning ECFM, further research needs to be conducted. In-situ measurements on a large-scale prototype of the ECFM, including solar radiation and wind velocity, would provide more detailed information about the heat and mass transfer within the construction. Such results would also help to calibrate and validate a hygrothermal simulation model to predict heat and mass transfer site independently under varying climate conditions. This might help in adjusting the dimensions of the module and in developing a smart irrigation system to achieve the best cooling efficiency for the respective location and orientation. The goal is to reflect radiation, increase thermal mass, decrease surface temperatures and decrease air temperatures in front of the ECFM through the cool air provided through evaporation. In a next step, a validated CFD-simulation study will visualize these effects on the outdoor environment, thus predicting thermal comfort indices in front of the ECFM.

Nevertheless, the results of this study legitimize porous granules as a lightweight, highly water-absorbing material to provide high-efficiency cooling. This provides a basis for the development of an affordable, cooling façade module for large-surface application. The goal of the project is to reach wide sections of the population in order to make a significant difference in improving the urban microclimate.

ACKNOWLEDGEMENTS

This research was co-funded by tax funds according to the budget approved by the Saxon State Parliament.

REFERENCES

1. Fallmann, N., Wagner, S., & Emeis, S. (2017). High resolution climate projections to assess the future vulnerability of European urban areas to climatological extreme events. *Theoretical and Applied Climatology*, *127*(3-4), 667-683. https://doi.org/10.1007/s00704-015-1658-9
2. Yamamoto, Y. (2006). Measures to Mitigate Urban Heat Islands. *Quarterly Review,* 18(1), 65-83.
3. Watt. J.R. (1986). History of Evaporative Cooling. In *Evaporative Air Conditioning Handbook* (1st ed., pp. 5-11*).* Springer. https://doi.org/10.1007/978-1-4613-2259-7
4. Broadbent, A. M., Coutss, A. M., Tapper, N. J., & Demuzere, M. (2017). The cooling effect of irrigation on urban microclimate during heatwave conditions. *Urban Climate*, *23*, 309-329. https://doi.org/10.1016/j.uclim.2017.05.002
5. Ulpiani, G. (2019). Water mist spray for outdoor cooling: A systematic review of technologies, methods and impacts. *Applied Energy, 254*, 113647. https://doi.org/10.1016/j.apenergy.2019.113647
6. Han, R., Xu, Z., & Qing, Y. (2017). Study of Passive Evaporative Cooling Technique on Water-retaining Roof Brick. *Procedia Engineering*, *180,* 986-992. https://doi.org/10.1016/j.proeng.2017.04.258
7. Wang, J., Meng, Q., Tan, K., Zhang, L., & Zhang, Y. (2018). Experimental investigation on the influence of evaporative cooling of permeable pavements on outdoor thermal environment. *Building and Environment*, *140*, 184-193. https://doi.org/10.1016/j.buildenv.2018.05.033
8. He, J., & Hoyano, A. (2009). A 3D CAD-based simulation tool for prediction and evaluation of the thermal improvement effect of passive cooling walls in the developed urban locations. *Solar Energy*, *83*(7), 1064-1075. https://doi.org/10.1016/j.solener.2009.01.006
9. He, J., & Hoyano, A. (2010). Experimental study of cooling effects of a passive evaporative cooling wall constructed of porous ceramics with high water soaking-up ability. *Building and Environment*, *45*(2): 461-472. https://doi.org/10.1016/j.buildenv.2009.07.002
10. Chen, W., Liu, S., & Lin, J. (2015). Analysis on the passive evaporative cooling wall constructed of porous ceramic pipes with water sucking ability. *Energy and Buildings*, *86*, 541-549. https://doi.org/10.1016/j.enbuild.2014.10.055
11. Zhang, L., Liu, X., Meng, Q., & Zhang, Y. (2016). Experimental study on the impact of mass moisture content on the evaporative cooling effect of porous face brick. Energy Efficiency, *9*(2), 511-523. https://doi.org/10.1007/s12053-015-9377-8
12. Jain, J. K., & Hindoliya, D. A. (2013). Correlations for Saturation Efficiency of Evaporative Cooling Pads. *Journal of The Institution of Engineers (India): Series C, 95*(1), 5-10. https://doi.org/10.1007/s40032-014-0098-0
13. Franco-Salas, A., Valera, D., & Peña, A. (2014). Energy Efficiency in Greenhouse Evaporative Cooling Techniques: Cooling Boxes versus Cellulose Pads. *Energies, 7*(3), 1427-1447. https://doi.org/10.3390/en7031427
14. Abdullah, A., Said, I. B., & Ossen, D.R. (2019). A sustainable bio-inspired cooling unit for hot arid regions: Integrated evaporative cooling system in wind tower. *Applied Thermal Engineering*, *161*, 114201. https://doi.org/10.1016/j.applthermaleng.2019.114201
15. Tejero-González, A., & Franco-Salas, A. (2021). Optimal operation of evaporative cooling pads: A review. *Renewable and Sustainable Energy Reviews, 151*, 111632. https://doi.org/10.1016/j.rser.2021.111632
16. International Organization for Standardization. (2000). *Hygrothermal performance of building materials and products — Determination of moisture content by drying at elevated temperature* (ISO Standard No. 12570:2000). https://www.iso.org/standard/2444.html
17. International Organization for Standardization. (2002). *Hygrothermal performance of building materials and products — Determination of water absorption coefficient by partial immersion* (ISO Standard No. 15148:2002). https://www.iso.org/standard/26500.html
18. International Organization for Standardization. (2021). *Hygrothermal performance of building materials and products — Determination of hygroscopic sorption properties* (ISO Standard No. 12571:2021). https://www.iso.org/standard/79595.html
19. International Organization for Standardization. (1981). *Surface active agents – Washing powders – Determination of apparent density – Method by measuring the mass of a given volume* (ISO Standard No. 697:1981). https://www.iso.org/standard/4897.html
20. Krischer, O., & Kast, W. (2014). *Die wissenschaftlichen Grundlagen der Trocknungstechnik (German Edition*) (3. Aufl. 1978 ed.). Springer. https://doi.org/10.1007/978-3-642-61879-6
21. Stull, R. (2011). Wet-Bulb Temperature from Relative Humidity and Air Temperature. *Journal of Applied Meteorology and Climatology*, *50*(11), 2267-2269. https://doi.org/10.1175/jamc-d-11-0143.1

Impact-based project ideas for sustainable cities

The case of digital planning tools in Piura, Peru

TRINIDAD FERNANDEZ[1] STELLA SCHROEDER[2]

[1] Fraunhofer Institute for Industrial Engineering IAO, Stuttgart, Germany
[2] University of Piura, Piura, Peru

ABSTRACT: Climate change combined with increasing urbanisation has made cities undergo significant transformations, becoming the main actors in mitigating their effects. Evidence-based methodologies, smart and sustainable urban development planning strategies, and potential for developing synergies are recognised as key aspects to tackling these challenges. The Morgenstadt Global Initiative (MGI) targets accelerating urban transformation through conducting City Labs in model cities in India, Peru, and Mexico. Based on an extended urban analysis, a sustainability profile and a strategic roadmap with innovative measures and project ideas are developed for each city, prioritising and implementing one within the MGI framework. This research analyses the design process of a digital planning tool as a pilot project in Piura, Peru which involves a methodology based on potential outcomes, impacts and benefits contributing to the values defined in the city's vision. Furthermore, the relevance of performance indicators and monitoring plans ensuring urban transformation on a large scale is analysed and discussed.
KEYWORDS: smart cities, evidence-based planning, impact-based design, urban strategies

1. INTRODUCTION

Cities are undergoing significant transformations and face substantial challenges due to climate change and constantly growing urbanisation. The concept of smart and carbon-neutral cities has emerged as a strategy focused on solutions for sustainable development, local adaptation, and the efficient use of resources.

In 2015, the United Nations (UN) adopted the Agenda for Sustainable Development, known as Agenda 2030. This strategy includes developing programmes until 2030 and establishes the 17 Sustainable Development Goals (SDGs) that will guide the sustainable development of the 193 member states that have committed to its implementation (UN, 2015). The SDGs are defined with the aim of eradicating poverty, promoting prosperity and well-being for people, protecting the environment, and tackling climate change, among others, to ensure peace and prosperity on the planet. One important aspect of this agenda is that the global goals show relevance at all governmental levels, international, national, regional and local.

Cities play a fundamental role in the definition and capacity to meet these goals, as they are one of the primary sources of greenhouse gases (GHG) emissions and, therefore, represent an excellent opportunity for climate change mitigation (Cities Alliances, 2015). Accordingly, the use of reliable methodologies as well as new planning strategies around smart and sustainable urban development and the potential of developing synergies are key to tackling some of the most pressing challenges, such as climate change mitigation and adaptation and improving resource efficiency (Gregorio et al., 2016). In this vein, the concept of "smart sustainable cities" has been recently proposed as a combination of urban sustainability and smartness, emphasising that both aspects should be considered simultaneously (Ahvenniemi et al., 2017).

Morgenstadt Global Smart Cities Initiative (MGI) is a project strengthening the development and implementation of sustainable transformation processes in model cities in India, Mexico and Peru. The primary objective is to mitigate the consequences of climate change in the pilot cities, increase their resilience to climate risks, and preserve their natural resources.

In the last 70 years, Peru has been transformed into an urban society. The urban growth was driven by the need for housing and urban land occupation (Matos Mar, 1990). According to a study by the Inter-American Development Bank (IADB), Peru has the third largest housing deficit in Latin America and the Caribbean and squatting continues to be used by low-income families as a suboptimal housing solution (Bouillon, 2012). It produced unplanned horizontal growth, and large and intermediate cities are struggling due to the pulsing demand for urban development management instruments. At the local level, governments have limited financial resources to achieve their development goals. More than 1800 regulations governing property rights duplicate functions and are not enforced due to the lack of technical and financial resources (Banco Mundial, 2016). Yet, in 2019 only 15% of cities have elaborated and approved the Urban Development Plan (INEI, 2019).

As part of the MGI project, a city sustainability profile(Fernández et al., 2021) based on a multi-sectoral and evidence-based approach analyses the performance and resilience of Piura, a city highly vulnerable to climate change and meteorological events of the El Niño-Southern Oscillation (FEN), causing both, floods and droughts in the city. In its last FEN event in 2017 more than 10,000 families were documented living in areas exposed to floods and extreme rains, representing a vulnerable sector of the population with limited resources. Piura is the fifth most populated city with around 480,000 inhabitants (INEI, 2017) and the eighth with the highest urban growth in Peru, with a growth rate of 2.3% (Zucchetti & Freundt, 2018). Urban poverty in the city of Piura has followed a trajectory almost parallel with the region, higher than the national average with 24.2% and 20.2% in 2019, respectively (IPE, 2020). Over one-third of the population has at least one unmet basic need, such as access to housing and sanitation, among others (MPP, 2015).

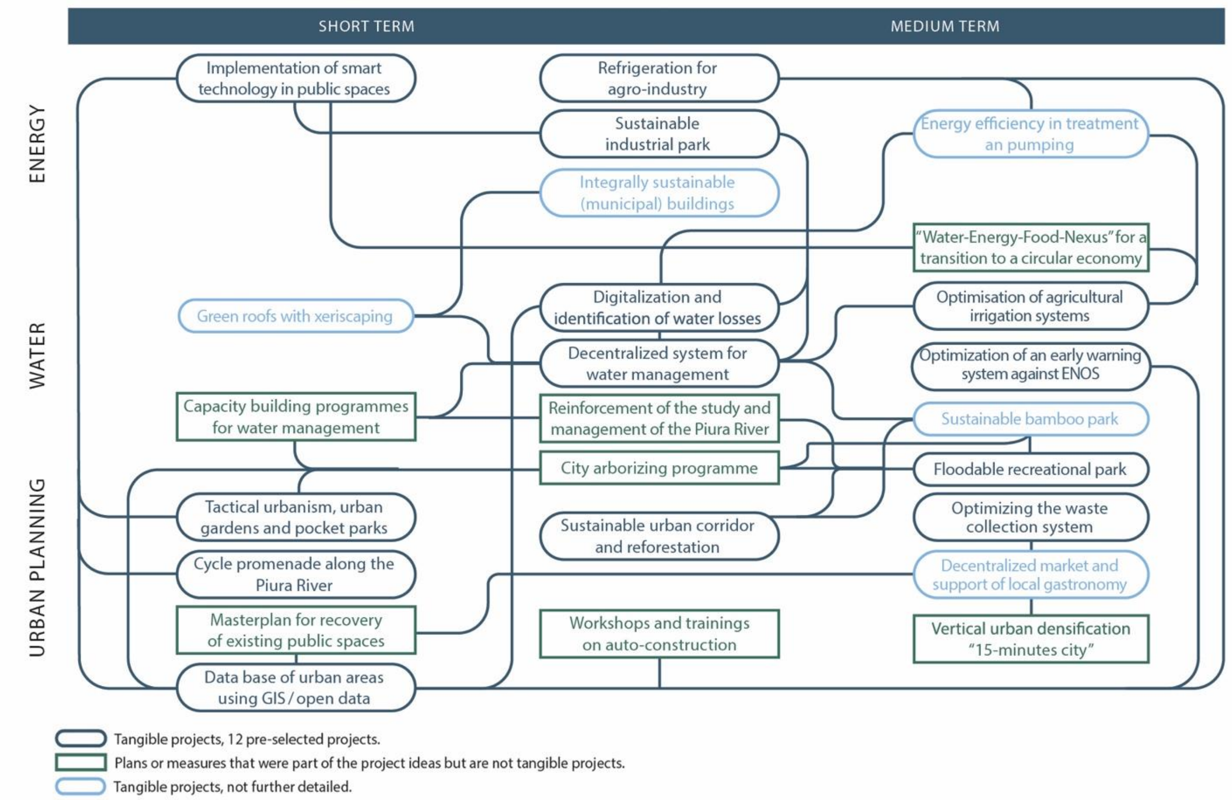
The City Lab assessment focused on three main infrastructure sectors: urban planning, energy, and water, identified as those with the most significant potential for climate change adaptation in Piura. The work included the review of policies, studies, planning documents and city initiatives, as well as interviews and workshops with key local stakeholders and a collaboration developed by members of the project team.

An important approach for supporting urban planning and implementation strategies is using roadmaps as a means to understand and build these complex processes. Roadmaps provide useful indications on how to formulate strategies, set priorities and goals, and translating plans into concrete action (Pereira & De Azambuja, 2022). In this context, to facilitate sustainable development in Piura, combining projects with a similar context and developing a long-term vision would benefit the city in achieving its sustainability goals.

Figure 1 shows the 25 proposed measures and ideas and their relationship with each other in an integrated system roadmap aiming to address the identified challenges featuring concrete, innovative and scalable plans and projects to drive sustainable development in Piura. These projects have been designed co-creatively, considering the feedback and opinions received during different workshops with stakeholders from the public, private and academic sectors, as well as internal sessions with local project partners. To detail and refine the project ideas, a methodology based on the potential outcomes, impacts and co-benefits that each project could contribute to the strategic and sustainable urban planning Piura was employed.

In the beginning, 35 project ideas were drafted.

Figure 1: *Simplified Roadmap City Profile Piura 2021. Source: Own elaboration.*



However, some have been combined into a single project proposal, as they addressed similar issues. While most of these projects focus on specific challenges of the identified priority sectors, the projects also have great potential to help improve climate resilience.

Among many other aspects related to sustainable urban development, the SDGs present the concept of data-driven governance and highlight the challenge to “significantly increase the availability of high-quality, timely, reliable and disaggregated data by 2030”. In agreement with ElMassah & Mohieldin (2020) major databases are recently becoming even more important. In this sense, countries, regions and cities should invest in acquiring different methods for data gathering. The advent of the Geographic Information System (GIS) has a long tradition in urban planning and created a field of opportunity for the development of new approaches to spatially referenced data, which add a new dimension to the management, analysis and presentation of information required in process related to decision making (Healey, 1988). Adequate data are necessary to identify and follow up with decision makers. It requires a review of institutional competence in dealing with information and data and digital transformation usage (ElMassah & Mohieldin, 2020).

One of the pilot projects defined in the roadmap involves developing a database through a GIS platform to collect information and update existing data about the city and thus more efficiently manage and register cadastral mapping of urban areas. In this way, a digitalised and georeferenced map can become an instrument for improving urban planning according to public services, urban expansion and reducing the informal occupation of land located in vulnerable and high-risk areas. Furthermore, a GIS allows municipal authorities to improve decisions about projects based on reliable data. As an additional benefit, this project aims to ensure the transparency and efficiency of public processes concerning land management and provide reliable information on which the population can draw in the future.

In this context, this research paper explores the definition of appropriate indicators for impact-based project design. The objective is to explain the design process based on the evaluation of expected outcomes, quantified impacts and co-benefits of the pilot project in Piura. Planning the impact measurement of projects in advance is an increasingly important subject on the government’s agendas. In this vein, demonstrating estimated results in specific areas of a project opens doors to resources, which can be achieved through various investment strategies (Fedorciow, 2012). It also enhances the improvement potential for urban social and ecological conditions for its residents. Anchoring impact across the city's narrative, including monitoring and evaluation ensures demonstrators to excel and accelerate urban transformation and future urban deployments (Elelman & Feldman, 2018).

The pilot project in Piura achieves several outcomes with a direct impact, resulting from the actions to be carried out within MGI, and indirect impacts related to the long-term goals also considering replication of the activities on a larger scale. In this context, the project monitoring seeks not only to use outcomes measuring the efficiency of the implementation but also the impact that contributes towards the ultimate goals such as environmental, economic, or social sustainability.

2. IDENTIFY MEASUREMENT: IMPACT ANALYSIS, CONTRIBUTION OF THE PROJECT

The broader MGI methodology consists of an in-depth urban analysis based on indicators assessing the quantifiable sustainability performance, key action fields essential for sustainable development and the impact factors affecting each city. The roadmap illustrates the cross-cutting and integrated implementation of the project ideas and shows the complexity of the relationships between them.

For the project implementation, outputs and outcomes are defined beforehand to guide the design process and to achieve the desired impacts and co-benefits. Outputs refer to the overall project objective, are mainly quantifiable, relate to the result of an activity and are a prerequisite for achieving the outcomes. Outcomes describe a target group level change enabled by the project, which can be verifiably attributed to it. Finally, the impact is the long-term objective of the project, referring to a change in the situation in the future when the specific goals have been achieved, also understood as a long-term ambition.

For the definition of the long-term project objectives, the potential contributions are identified based on an impact monitoring concept (IMC) developed within MGI (Diaz et al., 2022). This approach builds on the International Climate Initiative (IKI) objectives (IKI, 2022) together with the European framework CITYkeys (Bosch et al., 2017), framing outcomes and outputs within a holistic structure for smart and sustainable city solutions. The possible outcomes of each project are measured under five impact categories, each having two to eight outcome indicators. The indicators are defined either through existing indicators (e.g. ISO 37122:2019 on sustainable cities and communities) or by creating new ones considering the SMART criteria of the IKI (specific, measurable, assignable, realistic and time-related) (IKI, 2022). Each project idea was analysed and detailed according to possible impacts or co-benefits and outcome indicators, shaping them according to their possible contribution.

A list of all outcome indicators related to the five impact categories is demonstrated in Figure 2; as part of the results, the figure displays the impact fulfilled by the pilot project. The representation frames the idea that each category is equally important and must interact with each other to provide sustainable integrated solutions. Furthermore, it aims to present the project impacts clearly and precisely, facilitating the comparison and understanding of the potential contribution of each one of the pilot projects.

3. RESULTS

All project ideas seek to become agents of urban transformation and sustainable integration, supporting social inclusion in vulnerable areas in the city. With data-based information, decision-makers can improve development and evaluation strategies to mitigate or avoid anticipated impacts. In Piura, different measures relate to GIS-based components, highlighting the importance of its implementation. Project-defined indicators, baseline values, and possible data collection sources were suggested to understand the outcomes and impacts of such a project in the city.

Figure 2: *Impacts categories and outcome indicators achieved by the pilot project. Source: Own elaboration.*

The pilot project in Piura will have a variety of outcomes with a direct impact, resulting from the actions to be carried out within the MGI framework, and indirect impacts, which are related to the long-term goals also considering the replication of the activities on a larger scale. Both direct and indirect impacts bring with them several benefits, detailed in the following subchapters and highlighted in Figure 2.

3.1 Contribution to the planet: climate resilience and ecosystems

Around the planet category; the project strongly impacts the city's climate resilience by improving urban territorial planning and applying concepts of sustainability, resilience, and adaptation to climate change.

By working on urban analysis with digital tools, it will minimise on a long-term the impact of natural catastrophes such as FEN and climate change, applying mitigation and adaptation measures to minimise their impacts. Components to identify elements such as the lack of green areas that cause alterations in the microclimate and contribute to the generation of urban heat islands are considered, so that related data can be gathered to understand and plan the urban ecosystems strategically.

3.2 Contribution to people: access

The rapid and disorderly urban growth of Piura has created numerous challenges. The project solidifies the municipality's capacity to solve the city's problems using a GIS tool that improves urban data, and information efficiency and management. The project contributes indirectly towards improving other relevant aspects for people, such as health, education and reduction of vulnerability in the long term through strategic urban planning. Such contributions are detailed in the co-benefits subchapter as they are not considered as direct impacts.

3.3 Contribution to governance: organisation, multi-level of governance and community involvement

Until 2022, each municipal department in Piura works independently, causing duplication of records, outdated and dispersion of information, parallel efforts, incompatibility of formats and difficulty accessing data. The project generates a cartographic base in a centralised municipal digital GIS data system, increasing efficiency and enabling work and data transfer between different departments. Georeferencing of all urban projects in the execution process helps city organisation, provides a systematic order and avoids overlapping of civil works of any kind. The main project components aim to support decision-making based on up-to-date systematised information and correlations between different areas, supporting the impact on multi-level governance. The intervention allows also working in a cross-cutting manner between disciplines, thus systematising and efficiently managing information, facilitating the creation of a flexible management system with the capacity to integrate different information sources and with regular updates.

In this vein, the project supports the efforts of the national government to foster GIS-based datasets and platforms development. Furthermore, it supports the idea of the city presented within its Metropolitan Development Plan to create an urban observatory for Piura.

The generated maps are available to the public and citizens to involve the community, empower and raise citizens' interest around actual and new plans and projects in the city. Having the maps online means to have an online information repository ensuring transparency in public space decisions and building trust on the long-term within the community. GIS tools allow citizens to access information about the city's plans and processes, increasing transparency on municipal activities towards the community.

3.4 Contribution to prosperity: economic performance and innovation

By avoiding duplication of efforts, the project has a cost-effective impact by saving time, money, and personnel assets in obtaining data for the creation of projects. This saving improves the management of municipal economic resources and performance.

The project also enhances connectivity and supports innovative and environmentally friendly initiatives. The work and publication of urban maps and data through the GIS tool are designed to foster partnerships with business and civil society to find economic and social support, respectively for the measures proposed.

3.5 Contribution to propagation: replicability and scalability

The project presents a methodology that can be replicated in other districts of the metropolitan area, the region and the country, making Piura a model for urban transformation addressing urban challenges and adaptation to climate change.

Moreover, the use of GIS tools can be scalable within the districts, e.g., including other digital platforms such as those utilised by the energy or water companies, or on the provincial level incorporating more data on neighbouring districts and extending its area of influence. For the digitalisation sector, this project paves the way for e-government in the region as it builds upon an accelerated digital transformation reinforced by the Covid-19 pandemic crisis. Therefore, the project counts with a possible expansion to other departments and areas inside the city administration and beyond.

3.6 Co-benefits

The project includes capacity-building activities to develop competencies and skills around digital and strategic urban planning, thus increasing the potential to solve problems and be prepared for the upcoming climate change challenges. In a long-term, it is expected that the use of GIS will be integrated as university or school subjects, aiming to create a spatial understanding of data-driven organisation and development information and fundamental aspects defining project design and implementation organisation models.

Furthermore, building capacities on digital tools would support planning a more equal and just city, considering the citizen's needs, ensuring that the city provides basic services, health services and education helping and reaching the most vulnerable population, and preparing them better for climate change. To support the listed outcomes, site selection, suitability land analysis, transportation, and land use modelling are included among the project actions.

4. CONCLUSION

Piura is highly vulnerable to climate change impacts; thus, there seems to be a high demand for holistic and sustainable solutions. The three analysed sectors of the project are at the heart of the contemporary urban development challenges the city is facing. Yet, these sectors hold great potential for enhancing the city's resilience to climate change, preserving the natural resources and mitigating GHG emissions.

The study contributes establishing an understanding of the local development demands, generating, and implementing strategies that initiate a positive transformation process to secure equitable, resilient, and sustainable living conditions for the people in Piura. However, city efforts should focus not only on implementing the roadmap, but institutionalising the performance measurement framework, operationalising the methodology for successful implementations and ensuring its integration with the city's climate change and sustainable urban development vision and goals.

With the pilot project example, this study demonstrates the establishment, development and design of impact-based project ideas. The definition of outcomes and impacts help understanding the real project potential, as well as secure public and private sector investment and interest. Promoting effective communication on the implementation of sustainable urban development projects promotes engagement with different city's stakeholders. Key parties, such as donors or investors, often seek a return on their investment, whereas a larger group of stakeholders are keen to understand city's progress. Once project definition based on impact has been successfully applied, each city also gains insight into performance KPIs and guidance for conducting assessments to measure the effectiveness of the implementations.

As the areas or priority of project outcome may change over the years, capturing the effective performance of pilot projects remains crucial. Performance indicators including benchmarking support the city in understanding the results and disseminating them to the public in a better way. It allows a competitive advantage over other cities without impact measurement as part of their action plan. Following project design, it is recommended to identify which projects will be implemented in the short and long term, prioritising them in terms of expected outcomes and impacts, as well as their contribution to sustainable urban development and climate adaptation and mitigation.

ACKNOWLEDGEMENTS

The project is funded by the International Climate Initiative (IKI) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

REFERENCES

1. Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., & Airaksinen, M. (2017). What are the differences between sustainable and smart cities? *Cities*, *60*, 234–245. https://doi.org/10.1016/j.cities.2016.09.009
2. Banco Mundial. (2016). *Hacia un sistema integrado de ciudades*. ISBN 13: 978-612-46748-6-0
3. Bosch, P., Jongeneel, S., Rovers, V., Neumann, H. M., Airaksinen, M., & Huovila, A. (2017). *CITYkeys Indicators for Smart City Projects and Smart Cities*. https://doi.org/10.13140/RG.2.2.17148.23686
4. Bouillon, C. P. (2012). *Un espacio para el desarrollo: Los mercados de vivienda en América Latina y el Caribe*. https://doi.org/10.2307/j.ctvc5pc23.58
5. Cities Alliances. (2015). Sustainable Development Goals and Habitat III: Opportunities for a successful New Urban Agenda. In *Cities Alliances Discussion Paper* (Issue 3). http://www.citiesalliance.org/node
6. Diaz, C., Fernández, T., & Schlecht, V. (2022). *MGI Impact Monitoring Concept (Internal project documentation)*.
7. Elelman, R., & Feldman, D. L. (2018). The future of citizen engagement in cities—The council of citizen engagement in sustainable urban strategies (ConCensus). *Futures*, *101*, 80–91. https://doi.org/10.1016/j.futures.2018.06.012
8. ElMassah, S., & Mohieldin, M. (2020). Digital transformation and localizing the Sustainable Development Goals (SDGs). *Ecological Economics*, *169*(August 2019), 106490. https://doi.org/10.1016/j.ecolecon.2019.106490
9. Fedorciow, L. (2012, November 20). *Why measuring impact is essential to any social enterprise | Guardian sustainable business | The Guardian*. https://www.theguardian.com/social-enterprise-network/2012/nov/20/measuring-impact-social-enterprise-essential
10. Fernández, T., Schroeder, S., Stöffler, S., Diego, E. L., Ordóñez, J. A., Mok, S., Atarama, E., Guillen, O., Hernández, G., Villegas, J., Garcia, J. C., Báez, M., Pudlik, M., Umana, G., Martínez, E., Rodríguez, H., Torres, R., & Zavala, D. (2021). Summary Report of the full technical City Profile Piura within the Morgenstadt Global Initiative. https://publica.fraunhofer.de/handle/publica/418573
11. Gregorio, M. Di, Ridho Nurrochmat, D., Paavola, J., Sari, M., Fatorelli, L., Pramova, E., Locatelli, B., Brockhaus, M., & Kusumadewi, S. D. (2016). *Climate policy integration in the land use sector: Mitigation, adaptation and sustainable development linkages*. https://doi.org/10.1016/j.envsci.2016.11.004
12. Healey, R. (1988). Geographic Information Systems: An overview. In R. Vaughan & R. Kirby (Eds.), *Geographical Information Systems and Remote Sensing for Local Resource Planning*. Remote Sensing Products and Publication Ltd.
13. IKI. (2022). *Guidelines on Project Planning and Monitoring in the International Climate Initiative*. https://www.international-climate-initiative.com/fileadmin/iki/Dokumente/Standardindikatoren/IKI_Guidelines_on_Project_Planning_and_Monitoring_EN_202206.pdf
14. INEI. (2019). 6. Planificación Municipal. *Indicadores de Gestión Municipal 2019*, 12.
15. IPE. (2020). *Piura: Pobreza se redujo en los últimos 5 años y fue mayor en las ciudades | IPE*. https://www.ipe.org.pe/portal/piura-pobreza-se-redujo-en-los-ultimos-5-anos-y-fue-mayor-en-las-ciudades/
16. Matos Mar, J. (1990). Las migraciones campesinas y el proceso de urbanizacion en el Peru. In *Unesco* (p. 45). UNESCO.
17. MPP. (2015). *Plan de Desarrollo Urbano de Piura, Castilla, Catacaos y el 26 de Octubre al 2032*. http://municatacaos.gob.pe/plan_desarrollo.php
18. Pereira, G. V., & De Azambuja, L. S. (2022). Smart Sustainable City Roadmap as a Tool for Addressing Sustainability Challenges and Building Governance Capacity. *Sustainability (Switzerland)*, *14*(1), 1–22. https://doi.org/10.3390/su14010239
19. UN. (2015). *The Sustainable Development Agenda - United Nations Sustainable Development*. https://www.un.org/sustainabledevelopment/development-agenda/
20. Zucchetti, A., & Freundt, D. (2018). Ciudades del Perú Ciudades del Perú. *Periferia y WWF*, 148.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

PLEA 2022 SANTIAGO
Will Cities Survive?

Where public space meets climate change

Linking urban projects with Lisbon's metropolitan adaptation plan

JOÃO RAFAEL SANTOS [1]

[1] CIAUD, Centro de Investigação em Arquitetura, Urbanismo e Design,
Faculdade de Arquitetura, Universidade de Lisboa

ABSTRACT: Using relevant cases from Lisbon Metropolitan Area (Portugal), the article offers a systematized perspective on the way how public space qualification projects developed in the past twenty years meet climate change adaptation guidelines currently used as reference, in order to identify gaps and potential for future policy and design. Using Lisbon Metropolitan Area Climate Change Adaptation Plan (PMAAC-AML, 2019) as the framework in which key territorial risks and vulnerabilities and prioritary adaptation measures are defined, the article is organised in two methodological steps: 1) a quantitative assessment of climate adaptation measures present in LMA's public space qualification projects, highlighting their distribution in type, location and preponderant measure; 2) a selective focus on seven projects in which specific measures are present, to underline their spatial integration both in local fabrics and in a wider (sub)metropolitan scale. Its contribution lies in the confrontation between public policy aims (the project's rationales and their spatial configuration) and recent adaptation guidelines (priority domains, planning guidelines, risk territories). These results can provide a basis for policy assessment and steering, particularly at the metropolitan level, in which sectoral integration and multi-level governance are intertwined.

KEYWORDS: Public Space, Climate Change, Urban Policy, Adaptation, Lisbon

1. INTRODUCTION

Using relevant cases from Lisbon Metropolitan Area (LMA), Portugal, the article offers a systematized perspective on the way how public space qualification projects developed in the past twenty years meet climate change adaptation guidelines currently used as reference, in order to identify gaps and potential for future policy and design. This assessment is developed as part of *MetroPublicNet* [1], an ongoing research project aimed at exploring the experience of public space qualification projects in LMA since 1998, with a critical insight into their rationale, aims and results, and their emergent contribution towards a future metropolitan public space network. *MetroPublicNet* gathered information on over 900 projects delivered in the past two decades, allowing for systematic a multi-entry approach to the spatial transformation triggered around recent public space interventions.

One of the areas in which urban policies have triggered significant change in LMA in the past two decades has been the upgrade of public space in its relationship with urban regeneration, promotion of sustainable mobility and environmental qualification and resilience. Considerable amounts of national and EU public funding have been assigned to develop a wide array of urban and territorial projects with direct impact in the structure, use and spatial quality of public space. Planning and funding rationales used to justify these investments have included several issues directly connected with climate change adaptation such as flood prevention and stormwater management, green space and urban vegetation development, coastal protection and dune regeneration. Mitigation has also been widely present especially in what concerns promotion of sustainable mobility and walkability.

Nevertheless, a comprehensive assessment of these investments in terms of climate change adaptation impact in the urban structure is still missing, especially at the metropolitan level. This lack of assessment is partially the result of a multiplicity of processes, actors and tools through which public space projects are conceived, funded, delivered and assessed.

As a contribution to this gap, this article provides a systematized interpretation of this two-decades long process of public space qualification in LMA, under the lens of climate change adaptation, using Lisbon Metropolitan Area Climate Change Adaptation Plan (PMAAC-AML) [2] as a conceptual framework.

PMAAC-AML was drafted by Lisbon Metropolitan Area and has been approved in 2019, identifying the key territorial risks and vulnerabilities and the priorities and recommendations for implementing adaptation measures. This plan pioneered a comprehensive and multi-actor vision for the metropolitan level, thus providing a relevant reference for discussing the results of public space interventions in what concerns climate change adaptation. PMAAC-AML identifies four priority domains for adaptation in LMA: 1) high temperatures, 2) sea level rise, 3) droughts, 4) flooding. For each domain, specific strategic objectives and adaptation actions are identified. Besides a transversal framework, the plan suggests intervention in nine sectoral agendas: Agriculture and forests, Biodiversity and landscape, Economy, Energy and energy security, Water resources, Health, People and property security, Transport and communications, Coastal areas and sea. Such holistic approach goes beyond the scope of *MetroPublicNet*'s focus on public space, defining a research boundary on one hand, and a potential field on the other: public space is just one of the many areas where climate change adaptation is necessary and relevant, with many of the guidelines falling beyond of this research scope; nevertheless, a comprehensive understanding of the adaption challenges opens news paths for public space development, entangling it with complementary fields (i.e. agriculture, coastal and wetland management, drainage infrastructure, etc.).

Additionally, one of PMAAC-AML's transversal recommendations is to establish a metropolitan network of green infrastructure and a network of green and blue corridors. This approach is fully aligned with *MetroPublicNet*'s central hypothesis and argument that metropolitan perspective on planning public space can provide better integrated, robust and cohesive responses to the challenges of environmental resilience, low-carbon mobility and territorial cohesion.

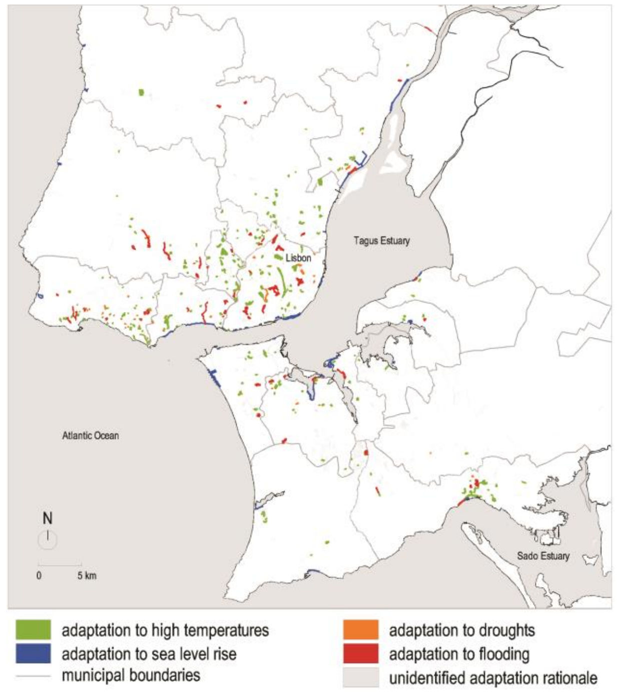
2. THE RESEARCH STRUCTURE: THREE TERRITORIALZED PERSPECTIVES ON PUBLIC SPACE AND ADAPTION ACTIONS IN LISBON METROPOLITAN AREA

The research followed six methodological steps: 1) identification, mapping and data-gathering regarding public space projects delivered in LMA, as the core of *MetroPublicNet* geo-referenced database; 2) systematization of public space intervention *types* (i.e. streets, green spaces, waterfronts); 3) cross-referencing of types and individual projects with the PMAAC-AML priority domains and adaptation actions guidelines, assigning those attributes to each project; 4) quantitative assessment and mapping of climate adaptation measures present in LMA's public space qualification projects, highlighting their distribution in type, location and preponderant measure, using GIS tools; 5) a selective focus on seven projects in which specific measures are present, to underline their spatial integration both in local fabrics and in a wider territorial scale, under the argument of a metropolitan network rationale; 6) discussion of results and conclusions.

2.1 A typological systematization of adaptation-oriented public space projects

Using *MetroPublicNet* geo-referenced database, the alignment of each project with PMAAC-AML guidelines was identified and geographically charted (Fig. 1). For each project, elements contributing to each to the PMAAC-AML's four priority domains for adaptation were highlighted, offering a cartographic representation of how different actions are distributed in the territory. By looking to the public space projects according to different types from a merely quantitative perspective, there are three types with a higher presence (Table 1): 1) streets, roads and cycle paths, 2) green spaces, and 3) coastal and river waterfronts.

Figure 1:
Public space qualification projects delivered in LMA (1998-2021) with relevant climate change adaptation rationale. Source: author, MetroPublicNet



This distribution reflects three policy options: prioritizing walkability, active modes and traffic calming in urban environment, increasing the offer of green space throughout the metropolitan urban areas and qualifying the water-land interfaces, particularly in urban contexts. Although with fewer cases, there are relevant projects delivered in the typology of stream, stormwater management and urban agriculture,

Table 1:
Analytical matrix of public space qualification projects: Types vs Adaption Actions [PMAAC-AML]. Source: author, MetroPublicNet

	Types of public space qualification (MetroPublicNet classification)						
	Streets, roads, cycle paths	Squares and plazas	Green spaces	Stream & stormwater solutions and urban agriculture	Transport hubs and dedicated lanes	Reorganization of parking	Coastal and river waterfronts
Total projects in LMA (1998-2021) a)	375	150	295	114	46	50	300
Typologies of Adaptation Action (PMAAC-AML):							
Priority climate risk 1: **Adaptation to high temperatures**							
Creation of shaded spaces in urban environment	24	22	**295**	**46**	2	2	27
Cooling operations of urban public space	b)	b)	b)	b)	b)	b)	b)
Shading/cooling of stop shelters, stations and parkings	b)	b)	b)	b)	b)	b)	b)
Shading of public transport stop shelters and cycle lanes	b)	b)	b)	b)	b)	b)	b)
Priority climate risk 2: **Adaptation to sea level rise**							
Ecological dunes restoration	2	0	1	3	0	4	6
Construction of flood walls and protective structures	3	**7**	5	2	4	4	**18**
Creation of multi-functional areas, compatible with coast, estuary	**31**	14	26	0	2	5	**77**
Ecological restoration and creation of wetland areas	0	0	**4**	2	0	0	**7**
Protection of cultural heritage exposed to estuarine risks	**6**	5	5	2	1	1	**24**
Priority climate risk 3: **Adaptation to droughts**							
Recovery and conservation of riverside vegetation	b)	b)	b)	b)	b)	b)	b)
Collective spaces of local production	0	0	0	**53**	0	0	0
Promoting water use efficiency in green spaces	b)	b)	b)	b)	b)	b)	b)
Use of undemanding indigenous vegetal species in water	b)	b)	b)	b)	b)	b)	b)
Reuse of treated rain and waste drainage water	b)	b)	b)	b)	b)	b)	b)
Use of local groundwater in municipal outdoor uses	b)	b)	b)	b)	b)	b)	b)
Priority climate risk 4: **Adaptation to flooding**							
Relocation of sensitive housing buildings and equipment	0	0	0	**3**	0	0	**5**
Roll fill dams and upstream retention basins of risk areas	0	0	**9**	**9**	0	0	0
Renaturalisation and qualification of drainage systems	4	6	7	**47**	0	0	**12**

Notes:
a) Intervention types are non-exclusionary, with some interventions included in more than one type.
b) Adaptation Actions that were not analyzed due to lack of consistent and detailed information

emphasizing an increasing sensitivity to blue and green corridor integration with social needs. Although with fewer numbers due to its high investment requirements, the typology of transport hubs and dedicated lanes played a key role in the reorganization of several urban areas, linking heavier transport development (i.e. metro and tram lines) with public space requalification. When these numbers are compared with the geographical relevance of adaptation priorities, it is possible to see that LMA's north bank, with a higher degree of urbanized areas and more irregular physiography, has a higher coverage of flood and urban heat prevention projects. LMA's south bank has a higher presence of waterfront and sea level rise adaptation projects.

2.2 Project types *vs.* adaption priorities

Table 1 offers a second level of information by cross-referencing the typological organization of public space projects with prioritary adaptation measures. Adaptation to high temperatures in urban areas is particularly addressed through the provision of shaded spaces. Not surprisingly, green space projects provide a relevant contribution, while the remaining types are very limited. A limited use of tree-coverage in most of the identified urban projects, even in urban street and square requalification, is responsible for this uneven distribution.

Regarding the adaptation to sea level rise, the most prominent typology is the creation of multi-functional areas compatible with coastal and estuarine environments, followed by cultural heritage protection. This trend reveals a clear tendency to address more artificialized urban settings, with nature-based solutions associated with wetland creation and dunes restoration having a relatively low presence. Flood walls and protective structures are not a widely used feature; when used, raising the reference ground level is the preferred option, instead of more disruptive walls. In fact, and not surprisingly, when seen from a territorialized perspective, urban waterfronts are the most common situations in which sea level adaptation measures have been implemented. LMA is shaped by many riverine settlements with high cultural value [3, 4]. This favours a more sensitive combination of multi-functional solutions instead of hard engineering interventions.

On the field of adaption to droughts, PMAAC-AML guidelines relevant for public space are mainly focused on efficient water use practices and circularity, requiring information that was not collected for *MetroPublicNet*'s research goals. Although it is not possible to offer quantitative figures on this line, empirical knowledge and general information by municipalities acknowledges this as a well-known challenge that is being addressed. Newer gardens, urban parks and other elements of vegetation tend to reduce water-demanding lawns and large grass fields, in favour of well-adapted species to water-shortage and local climatic conditions. Nevertheless, there is a guideline of interest: promotion of collective spaces of local food and agricultural production. In this case, a number of small scale and community vegetable gardens have been developed. Some municipalities are developing their green structure with a consistent use of these agricultural patches – even with vineyards – as interesting alternatives to green field parks.

The actions regarding the fourth climate change risk priority – flooding – have been mostly focused on renaturalisation and qualification of drainage systems. In terms of public space development, these actions are particularly visible in spaces associated with water lines and streams, often used as shapers of urban parks, on a first generation, and greenways, as a later trend. In both cases, flood prevention and ground permeability are intertwined, the later with the added value of a more robust and systemic response to both natural, biological and human flows. Although with more limited numbers, but expressive funding levels, there have been some interventions based on roll fill dams and upstream retention basins of risk areas, all of which enabled the creation of multi-functional urban parks, thereby bridging the gap between stormwater management and social and ecological needs. Actions in which relocation of housing and facilities were also limited, due to high costs and demanding political and social negotiations. In most cases, they were focused on critical areas with very high risks of flooding and poorly maintained buildings.

2.3. Entangling spatial integration of public space and climate change adaptation

Although ecological issues were always acknowledged as fundamental in green space development, it was a common practice in LMA's urban transformation processes to regard them as a mere compensation to building development, particularly during the fast-growth decades of 1960 through 2000. The result was often a splintered patchwork of green pockets, with limited conditions to act on a systemic level. More recent green spaces tend to be organized as structural elements of both ecological and socio-spatial regeneration. As such, they tend to introduce and combine not only the ecological layers and flows, but also the cultural dimensions that sustain them as part of the urbanized landscape [5]. The same happened in other situations, such as the waterfronts. From a first generation of piece-by-piece public space

Table 2:
Case studies: identification of adaptation actions present and territorial integration conditions. Source: author, MetroPublicNet

Project (municipality)	Identified adaption actions	Territorial integration (1. existing, 2. potential)
Ribeira das Naus riverfront requalification (Lisboa)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment Adaptation to sea level rise Construction of flood walls and protective structures Creation of multi-functional areas, compatible with coast, estuary Protection of cultural heritage exposed to estuarine risks	1. metropolitan core, high heritage value, metropolitan transport hub (river, railroad, metro, river traffic) 2. continuous riverfront system; active mobility paths
Agualva-Cacém urban & environmental regeneration (Sintra)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment Adaptation to flooding Roll fill dams and upstream retention basins of risk areas Renaturalisation and qualification of drainage systems	1. important suburban city, railroad station, city recentered around Jardas stream linear park 2. green corridor along Jardas stream
Caparica coastal protection & requalification (Almada)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment Adaptation to sea level rise Ecological dunes restoration Construction of flood walls and protective structures Creation of multi-functional areas, compatible with coast, estuary	1. coastal urban area, touristic and beach facilities, seasonal pressure, high coastal flooding risks 2. coastal, dune and ecological restoration in adjacent waterfronts; public transport & active mobility link
Lisbon 'central axis' street requalification (Lisbon)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment	1. high density mixed-use (offices, university, shopping), well-connected with public transport network 2. relevant position in urban water drainage system and green structure
Tagus riverside linear park (Vila Franca de Xira)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment Adaptation to sea level rise Ecological restoration and creation of wetland areas Creation of multi-functional areas, compatible with coast, estuary Protection of cultural heritage exposed to estuarine risks	1. semi-natural marshland with urban and industrial surroundings; highly prone to sea-level rise & salinization 2. continuous riverfront system; active mobility paths; local agriculture production potential
Livramento stream retention basin and park (Setúbal)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment Adaptation to flooding Roll fill dams and upstream retention basins of risk areas Renaturalisation and qualification of drainage systems	1. central open space in medium-sized city, where important blue, green & grey infrastructure converge 2. prominent position in public space structure with impact on residential districts and key mobility links
Várzea ecological park (Sesimbra)		
	Adaptation to high temperatures Creation of shaded spaces in urban environment Adaptation to droughts Collective spaces of local production Reuse of treated rain and waste drainage water Adaptation to flooding Renaturalisation and qualification of drainage systems	1. transition area between important suburban district, a national road and a large stream system of very high ecological value 2. green corridor connecting Tagus estuary and Arrábida Natural Park

requalification, triggered by compositional rationales and leisure-oriented uses, newer interventions are regarded as continuous lines to be incrementally assembled into wider structures [6]. This process reclaims a much more diversified catalogue of public space, including not only the more central and urbanized quaysides, monumental squares or embankment promenades, but also spaces like, wetlands, estuarine beaches, old salt marshes or coastal dune and cliff systems. Inland streams and water lines are also good examples, as they are often a key feature in the morphological organization of urban settlements. Blurred boundaries between built and open space through linear, agricultural and forestry parks or water retention and reutilization systems can be a potential feature of future adaptation strategies.

This diversification brings four potential benefits for climate change adaptation: 1) comprehensive understanding of territorial and environmental conditions, with their systemic functioning and interdependencies, 2) governance integration of spatial planning, urban planning and public space project development under a territorial design framework, 3) consistent and coherent approach to the local design strategies, 4) strengthened social awareness of metropolitan landscape and of its functioning, enabling a stronger coalition between the society and policy-making, implementation and everyday management.

As an illustrative approach to the relationship between public space integration and climate change adaptation, table 2 presents seven cases in LMA in which both dimensions are identified.

3. RESULTS AND CONTRIBUTION

The paper sheds light on the added value and limitations of recent public space qualification projects in LMA to the spatial dimension of urban and territorial adaptation to climate change. Its contribution lies in the confrontation between public policy aims (identified in the projects' rationales and their spatial configuration) and recent adaptation guidelines (priority domains, planning guidelines, risk territories). These results can provide a basis for policy assessment and steering, particularly at the metropolitan level, in which sectoral integration and multi-level governance are intertwined. The results offer both a quantitative and a more qualitative/interpretative perspective on the public space qualification process in LMA. Both approaches are seen as fundamental to cover the complex territorial interplays at stake.

Three main contributions may be highlighted as conclusions. Firstly, a considerable number of implemented projects address mitigation measures, namely those related with low-carbon emissions (i.e. promotion of public transport, traffic calming, improvement of walkability and active mobility modes in urban streets and roads), which must be taken into account as relevant and complementary to the adaption efforts. Secondly, there is clear margin for improvement in several fields, namely: a), the limited presence of requalified street and square with trees and shade and its low contribution to heat-related risks, b) the limited use of systemic and robust water management systems (drainage, infiltration, reutilization) in public space, c) the limited integration between public space development and metropolitan scale forest and agriculture projects, d) the unclear adaption strategy (retreat, protect, advance) regarding ecological sensitive areas in the estuaries. Thirdly, a more systemic and integrated approach requires a better articulation at the metropolitan level, for which a metropolitan public space network strategy could be seen as politically and technically robust tool to address sustainable urban development challenges.

ACKNOWLEDGEMENTS

This research was supported by Portuguese national funds through FCT - Fundação para a Ciência e a Tecnologia, I.P., under the Strategic Project with the references UIDB/04008/2020 and UIDP/04008/2020 and under the grant PTDC/ART-DAQ/0919/2020 (*MetroPublicNet: Building the foundations of a Metropolitan Public Space Network to support the robust, low-carbon and cohesive city: Projects, lessons and prospects in Lisbon*). [metropublicnet.fa.ulisboa.pt]

REFERENCES

1. Santos, J.R. and Matos Silva, M. (2021), Public Space as a Metropolitan Network. Making the Bridge Between Policy and Design in Lisbon Metropolis, *Proceedings of the AHFE 2021 Virtual Conference on Human Factors*, Cham: Springer Nature Switzerland AG, p. 310-317.
2. Área Metropolitana de Lisboa, 2019, *Lisbon Metropolitan Area Climate Change Adaptation Plan – Summary*, Lisboa: Área Metropolitana de Lisboa
3. Costa, J.P., Matos Silva, M., Nouri, A. (2013). Climate Change Adaptation and Urbanism: A Developing Agenda for Lisbon within the XXI Century. *Journal Urban Design International*, 19(1), p. 77-91.
4. Anastasia, C. (2019), Urban Regeneration Projects Bound to Water, along and towards the Tagus Estuary (Portugal), *Sustainability* 11(23), p. 1–25.
5. Ajuntament de Barcelona (2013), Barcelona Green Infrastructure and Biodiversity Plan 2020, Barcelona: Ajuntament de Barcelona
6. Santos, J.R. (2019), Public Space, Tourism and Mobility: Projects, Impacts and Tensions in Lisbon's Urban Regeneration Dynamics, *The Journal of Public Space*, 4(2) p.29-56.

Targeting the most energy vulnerable

Deprived neighbourhoods at risk of winter Fuel Poverty and high summer urban heat island intensity. A study case in Madrid (Spain)

FERNANDO MARTÍN-CONSUEGRA[1], MIGUEL NUÑEZ PEIRÓ[2], CARMEN ALONSO[1], CARMEN SANCHEZ-GUEVARA[2], GLORIA PÉREZ[1], BEATRIZ ARRANZ[2]

[1] Instituto de Ciencias de la Construcción Eduardo Torroja (IETCC), CSIC
[2] Universidad Politécnica de Madrid (UPM)

ABSTRACT: The work presented here consists on the development of a statistical data driven urban model used for assessing energy vulnerability at the city scale. Using spatial analysis operations and open source GIS tools, degraded areas affected by a lack of thermal comfort are identified, including winter and summer conditions assessment. This scale allows the selection of critical neighbourhoods most affected by urban deprivation, winter Fuel Poverty and overheating issues caused by a high Urban Heat Island Intensity. The proposed methodology is illustrated through the case study of the city of Madrid. The areas identified are those most in need of urban renovation, where retrofitting operations will have the greatest impact on reducing urban deprivation and improving energy efficiency and comfort. The results will be used in future research for the proposal of tailored improvement solutions specific for vulnerable areas of the cities.
KEYWORDS: Urban energy retrofit, Fuel poverty, Urban Heat Island, heating, cooling

1. INTRODUCTION

Urban areas in Europe are showing increasing signs of environmental stress. Cities absorb an increasing amount of resources and generate a growing volume of emissions and waste [1]. The building sector is one of the largest energy consumers and major source of CO_2 emissions on the continent [2]. In the coming years, the European Union intends to boost urban renovation initiatives to reduce environmental impacts. Through the European Green Deal, different initiatives have been planned to decarbonize the continent by 2050 and significant resources will be allocated for this purpose [3]. It is urgent to identify renovation priorities to achieve the greatest possible impact in the use of these resources. This involves a comprehensive analysis of the different vulnerability factors in cities, including social, environmental and economic aspects. It is necessary to cross-reference data from multiple sources in order to make evidence-based policy decisions to reduce the environmental impact and mitigate the effects of climate change in cities. This will enable the identification of neighbourhoods that are deteriorated, inefficient in the use of energy and risk to be severely affected by CC.

Poor thermal performance of dwellings is a relevant vector causing Fuel Poverty in their occupants. Inefficient buildings with high heating needs during the winter result in heavy energy costs to achieve comfort in the home, poor indoor environmental quality, and health issues [4].

The Urban Heat Island (UHI) shows the differences among temperatures in urban environments and the surrounding rural ones. Although the UHI is mostly a night-time phenomenon, urban temperatures can largely differ from each other also during the daytime. In the city of Madrid, diurnal temperatures during the summer months tend to be higher in the southern part of the city than in its surroundings, contributing to the heat exposure of its inhabitants. Moreover, Climate Change is expected to increase the frequency and duration of hot weather. In dense urban areas, these phenomena will be exacerbated by the UHI. Associated to this effect, the impact of temperature over indoor thermal comfort seems to increase cooling energy demand. Indeed, this has in recent years brought attention to its impact on vulnerable households, who may be suffering from summer Energy Poverty [5]. In Madrid, energy poor households already suffering from inadequate indoor temperatures can face important overheating problems and, as a consequence, health problems could become more frequent and stronger [6].

In former research projects, participants of this research measured and analysed the intra-urban UHI variability in the city of Madrid on an hourly basis [7]; further research has analysed the urban distribution of Fuel Poverty based on building inefficiency and risk indicators during the winter [8]. The joint application of these results allow a comprehensive analysis of the two phenomena and the interaction between them in the city of Madrid.

2. OBJECTIVES

The aim of this paper is the identification of critical areas at the city scale. These are defined as those neighbourhoods affected simultaneously by urban deprivation and lack of thermal comfort in summer and winter conditions. The analysis of these areas should be the basis for the development of effective solutions, which must be addressed under the following premises:

- Focus should target deprived neighbourhoods as priority intervention areas for urban and building renovation.
- A multidisciplinary approach is needed to provide effective solutions. The research must be conducted on urban planning, design and renovation, energy efficiency of buildings, construction materials and their environmental impact.
- The city of Madrid will be considered for the experimental studies, although the methodology is designed to be extended to other cities with similar climatic conditions.

Thermal comfort analysis covers both the outdoor public space and the indoor environments of residential buildings. The target is to identify areas of the city that are particularly overheated in summer, which also contain dwellings that struggle to maintain an adequate level of comfort during the winter.

3. METHODOLOGY

A procedure is developed for the location of the residential neighbourhoods in need of renovation, where a greater impact is expected from the application of energy retrofitting. The work presented here identifies, among the existing deprived neighbourhoods of Madrid, those that are vulnerable from the energy point of view, taking into account:

- a high risk of Fuel Poverty (FP) during the winter
- an elevated concentration of Cooling Degree Hours (CDH) during the summer

For this purpose, spatial data from three different existing research studies are cross-referenced for the identification of critical areas. The process of identifying areas of interest is based on the development of a statistical data-driven georeferenced model of the city using open source spatial analysis operations and GIS mapping tools. The proposed model allows for the inclusion of other data sources that can complete the information with determining socioeconomic aspects such as gender perspective, type of household, urban morphology, etc…

3.1. Deprived neighbourhoods

An existing study called “Catalogue of Vulnerable Neighbourhoods” locates and analyses urban deprivation at the most populated Spanish cities [9].

Figure 1: Deprived neighbourhoods in Madrid by severity of deprivation, using 2011 census [9]

This study identifies Deprived Neighbourhoods (DN) from a multifactorial perspective using Basic Indicators of Deprivation:

- Percentage of population without education
- Percentage of unemployed population
- Percentage of dwellings in buildings in a dilapidated, poor or deficient state

The indicators are developed using statistical information from the Spanish National Population and Housing Censuses (1991, 2001 and 2011). The methodology classifies the different neighbourhoods according to the causes and the severity of deprivation (from low, medium, severe to critical). This classification is represented in Figure 1 using darker colours for more severe cases.

The study concludes that in the case of Madrid 91 neighbourhoods are classified as deprived. These areas are identified as priorities for urban renovation.

3.2. Winter Fuel Poverty risk

A recent study developed a multidimensional index that includes different issues related to the causes and consequences of Fuel Poverty to detect the areas with a higher risk [8]. The indicators used to detect these sectors were as follows:

- Deprived neighbourhoods
- with inefficient buildings (lacking thermal insulation),
- with excessive values in any of the following indicators:
  - High energy bills
  - No adequate heating facilities

- Low income population
- Concentration of elderly population

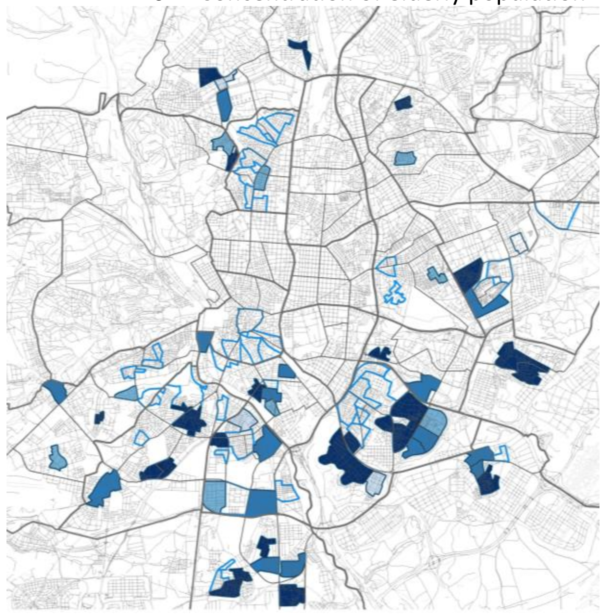


Figure 2: Deprived Neighbourhoods containing inefficient buildings, by severity of winter Fuel Poverty risk [8]

The method was applied to Madrid resulting in the identification of 53 DNs where urban deprivation overlap with building energy inefficiency. These are urban areas containing pockets of buildings with the worst heating energy rating. These neighbourhoods are classified according to the risk of FP using the above indicators. Winter FP risk spatial distribution is shown at Fig. 2 using darker colours for more severe cases. Although the study is focused on winter, the lack of thermal insulation also contributes to indoors overheating during the summer.

3.3. Cooling Degree Hours during the summer

The severity of the heat island in Madrid has been quantified in a previous study [10]. Cooling Degree Hours (CDH) were measured in 2017 for the different areas of the city, for both day and night (Fig. 3). The indicators used to detect sectors most affected by overheating were as follows:

- Sum of day and night CDH in summer
- Deprived neighbourhoods exceeding the cut-off value

The cut-off value considered as critical is set at 50% of the standard deviation in Madrid: 3311 CDH. The selection of vulnerable areas exceeding the cut-off value results in 41 sensitive cases (in red in Fig. 4).

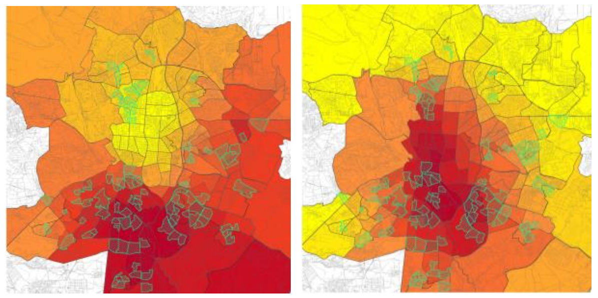


Figure 3: CDH during the day (left) and night-time in Madrid

Figure 4: CDH within deprived neighbourhoods

4. RESULTS

The results obtained from the superimposition of the data from the studies presented here are shown in Table 1 and Fig. 5.

Table 1. Results for the selected neighbourhoods

DIST	NAME	POP.	DWL	DPV	FP	CDH
02	Chopera	9085	4205	VL	VC	3369
02	Legazpi	12445	5135	VS	VM	3457
02	Delicias	13770	6575	VL	VS	3457
11	T.G-P. Bend.	10420	3825	VC	VC	3374
11	Abrantes S.	3710	1490	VM	VC	3374
11	Opañel	14160	5985	VS	VC	3407
12	Orcasitas O.	11950	4835	VL	VM	3437
12	Pl. Eliptica	4280	1785	VM	VC	3473
12	Moscardo	5600	2320	VS	VL	3473
12	Almendrales	7470	3105	VC	VS	3494
12	Orcasur	6515	2295	VM	VS	3494
13	Portazgo	10105	4165	VM	VC	3327
13	A. del Arenal	5515	2235	VM	VC	3327
13	Pal.-Villalobos	12245	4655	VS	VS	3331
13	Pal.-Buñuel	12035	4710	VM	VS	3331
13	P. Azorin	6820	2885	VS	VC	3420
13	Entrevias **E.**	7875	3100	VM	VC	3457
13	Entrevias O.	16270	6730	VM	VC	3457
13	PT Raimundo	4065	1475	VM	VL	3457
13	Picazo	9585	4005	VC	VC	3469
17	Villaverde A. S	12535	5140	VC	VC	3325
17	Villaverde A. E	5815	2225	VC	VC	3325
17	San Cristobal	14785	5100	VC	VC	3367
17	Villaverde B.	11840	4655	VC	VS	3464
17	C de los Ángeles	5555	2470	VM	VC	3469
17	El Cruce	6130	2410	VM	VS	3469
18	Congosto	10410	4140	VM	VC	3349
	TOTAL MADRID	250990	101655			

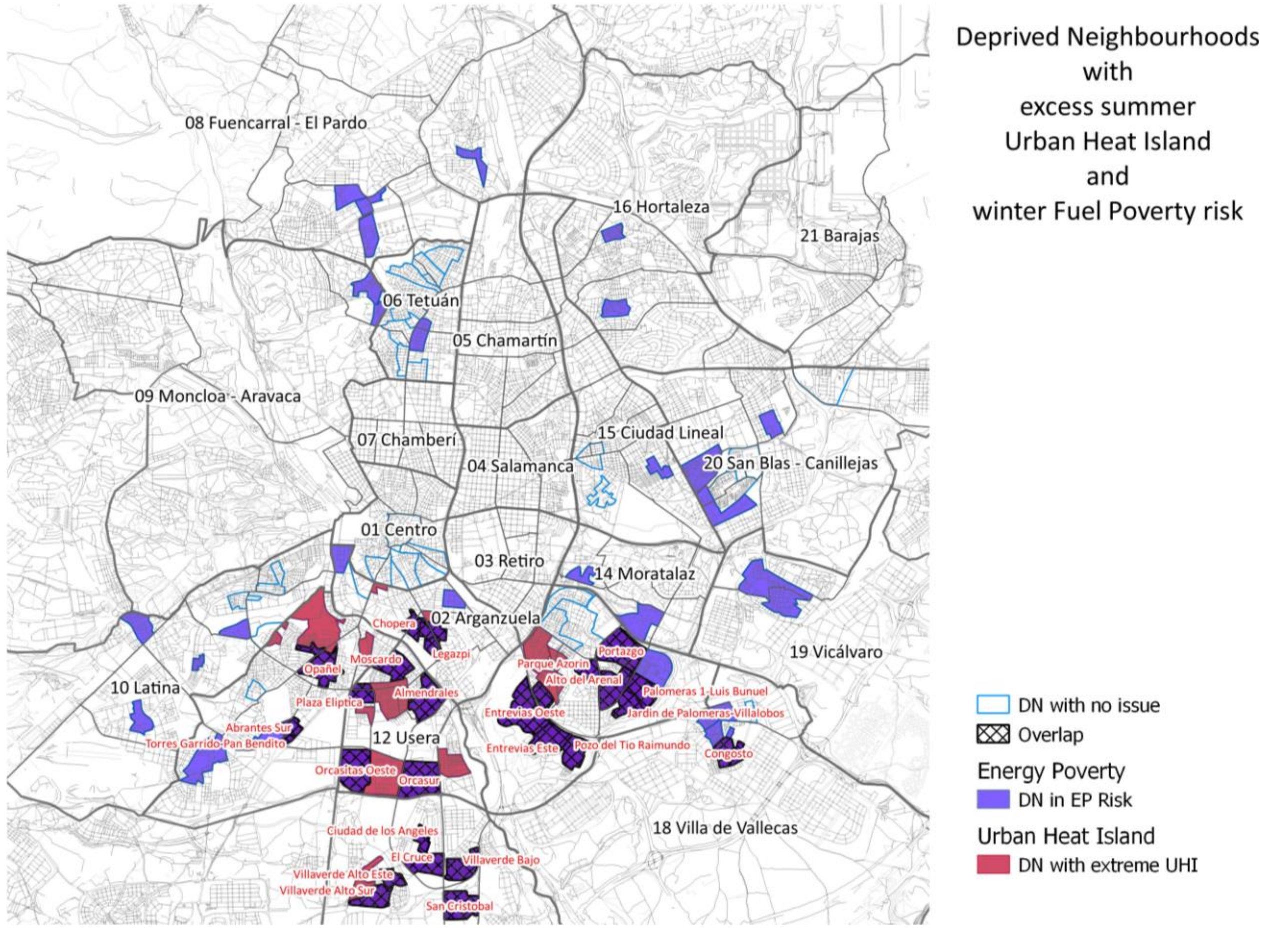


Figure 5: Identification of deprived neighbourhoods affected by Fuel Poverty risk and extreme values of UHI in Madrid

The map in Fig. 5 shows the spatial distribution of the different phenomena and the overlap of issues. Table 1 allows to quantify the population (POP) and the number of dwellings (DWL) affected, classified by district (DIST). It also includes the values of the most important parameters of each of the studies included: the degree of deprivation (DPV) and the risk of Fuel Poverty (FP) classified by degree of severity from the lightest (VL), moderate (VM), severe (VS) and critical (VC). The intensity of the UHI is evaluated on the basis of the number of summer CDH in each neighbourhood. Indicators exceeding critical values are marked in red in Table 1.

In the city of Madrid, the areas most vulnerable to overheating during the summer, combined with the risk of suffering winter FP occurs in 27 of the 96 deprived neighbourhoods in need of urgent renovation. The overlap of FP risk and overheating problems affects a total of 101,655 homes located in degraded environments. This amount represents 7.7% of the total 1,320,530 principal dwellings registered in the city. In total, this overlap of issues affects a population of approximately 250,990 people: 7.8% of the census population in 2011, set in 3,198,645 people (Table 1).

In terms of spatial distribution, these areas are concentrated in the southern periphery of the city (Fig.5). The districts most affected are District 13 "Puente de Vallecas" with 9 neighbourhoods, 84,515 inhabitants and 33,960 homes affected; District 17 "Villaverde" with 6 neighbourhoods, 56,660 inhabitants and 22,000 homes; and District 12 "Usera" with 5 neighborhoods, 35,815 inhabitants and 14,340 homes affected.

The results allow the analysis of each quarter according to the severity of the different problematics that affect it.

5. ANALYSIS OF RESULTS

The 27 selected neighbourhoods are considered as a priority for retrofitting, but there are different situations among them. For example, those with more than one parameter in red are the most critical.

The cases in which cold and heat parameters are combined will be more complicated to address.

The problem of FP in winter has its greatest impact in the areas of the first periphery with a higher incidence in areas in the south and east of the city. On the other hand, overheating issues are mainly concentrated in the south of the city.

The analysis of FP does not result in any neighbourhood contained in the central core of Madrid. This does not mean that there are no situations of Fuel Poverty within these areas, but that the problem may affect specific cases, and will not occur in a generalized manner.

It may be striking to note that deprived neighbourhoods in the historic city centre are also not identified as the highest overheated ones, despite being located in the areas most exposed to the urban heat island. This is because the CDHs mostly concentrate during the day, while the UHI is mainly a night-time phenomenon, so it is the areas with the highest exposure to daytime urban heat which are identified as the most vulnerable. This should not lead to the assumption that deprived inner city neighbourhoods do not suffer from overheating. In fact, although they do not accumulate as much CDH as other areas, they do suffer from significant nocturnal overheating. This results, in the city of Madrid, in a greater number of tropical nights, when temperatures do not drop below 21ºC. This greatly reduces the effectiveness of passive cooling strategies, which rely primarily on night-time ventilation. These are areas where households therefore also have to cope with overheating and may require different treatment than areas that accumulate overheating during the day. This might be further investigated.

In any case, it must be taken into account that Madrid has a temperate Mediterranean climate that generates both heating and cooling energy demands. The reduction of overheating in summer must be approached carefully, so as not to significantly lower the outdoor temperature as well in winter. This could lead to an undesirable increase in the heating energy demand of buildings. Mitigating urban heat must be approached from a dual summer-winter perspective as well as taking into account specific socio-economic needs of the most energy vulnerable households.

Table 2. Socioeconomic and urban indicators collected from the studies included in this research

Dimension	Indicators
Urban Deprivation	Education level
	Unemployment rate
	Buildings in poor condition, deteriorated or dilapidated
	Urban morphology
Fuel Poverty	No insulation
	No heating facilities
	Low income
	High cost on energy bills
	Elderly population
UHI Exposure	Cooling Degree Hours
	No cooling facilities

Socio-economic issues are central when establishing renovation schemes. There are a number of indicators associated with the data used for this work that can be used to analyse potential impacts related to the energy vulnerability of the population in the different areas affected. Statistical social and economic indicators allow the development of an energy vulnerability intensity index. Table 2 provides a list of variables collected by the different studies.

Data on the incidence of Fuel Poverty from a gender perspective should also be included in further research [11]. Women are the main breadwinners in over half these households, and may either be pensioners or heads of single-parent families, highlighting the existence of gender inequalities in relation to FP. In addition, women are more sensitive to extreme temperatures, which may place them suffering FP at a greater risk

In terms of urban morphology, the Catalogue of Vulnerable Neighbourhoods provides information on the type of urban fabric that characterizes each area. This information is useful when designing solutions adapted to the particularities of each type of development. As a result of this analysis, it should be noted that 10 of the 27 neighbourhoods identified correspond to areas of public housing developments built between the 1940s and 1960s. To establish recommendations for public policies for the city' s renovation, it will be interesting to relate this information to the municipal urban planning standards that are established through zonal areas with similar urban characteristics [12]. This would enable the application of appropriate regulations to incorporate specific solutions for the improvement of each neighbourhood. The morphology analysis could also be complemented with urban climate classification schemes, such as the Local Climate Zone (LCZ) classification scheme developed by Stewart and Oke [13].

6. CONCLUSIONS

Among the degraded urban areas in need of refurbishment of the city of Madrid, those with the highest intensity of Urban Heat Island in summer and risk of Fuel Poverty in winter have been identified. Such problems simultaneously affect 7.7% of Madrid's census population. Areas where the three problems overlap are established, and an index is generated to measure each of them, in order to be able to assess their intensity. Intelligent maps that allow the identification of critical areas are produced.

A number of socio-economic issues related to energy vulnerability are collected. This information is useful for the design of renovation schemes tailored to the characteristics of the population of each neighbourhood.

Most of the neighbourhoods identified correspond to areas of public development. Therefore, this points to the responsibility of public administrations in the search for solutions to these problems.

The neighbourhoods selected in this work will be analysed in depth in future, as case studies of the ongoing MATEMAD project: "Multidimensional characterization of urban materials: impact on outdoor environment, energy demand and citizens' well-being". MATEMAD project will approach them through the analysis of the public space. An inventory of surface finishing materials will be made to identify the most frequently used. Knowledge about thermo-optical surface characteristics will permit to make proposals about the improvement through the optimization of the optical and thermal response of urban coatings. Optimized materials for urban surfaces can provide efficient solutions towards Climate-neutral Cities with improved liveability and sustainability, reducing the energy demand of buildings and improving the well-being of citizens in public environments. The project will address these issues by focusing on urban materials and their impact on overheating problems. The aim is to reduce the urban heat mainly by mitigating the Urban Heat Island, mostly a night-time phenomenon, but also by taking into account the diurnal thermal variability within the city. The urban heat would be tackled through the resurfacing of streets and public spaces, as well as buildings roofs and facades, using appropriate materials. Solutions should not increase heating demand, nor worsen winter thermal comfort inside the buildings nor at the urban space. This assessment is required to avoid an increase of winter fuel poverty caused by thermal stress reduction measures designed for summer conditions.

ACKNOWLEDGEMENTS

This research was funded by Spanish *Agencia Estatal De Investigación* through *Programa Estatal de I+D+i Orientada a los Retos de la Sociedad.* Projects: (1) PID2020-114873RB-C31 *Caracterización de materiales urbanos: impacto sobre el ambiente exterior, la demanda energética y el bienestar de los ciudadanos* and (2) PID2020-114873RB-C32 *Monitorización del espacio público y del estímulo de los materiales en los ciudadanos*.

REFERENCES

[1] European Environment Agency, Europe's environment: An Assessment of assessments. Luxembourg: Publications Office of the European Union, 2011.

[2] European Commission, «Energy performance of buildings directive», Energy -, 16 de mayo de 2019. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en (accedido 8 de junio de 2021).

[3] European Commission, «A European Green Deal», - European Commission, 2020. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accedido 17 de julio de 2020).

[4] J. A. López-Bueno et al., «The effect of cold waves on daily mortality in districts in Madrid considering sociodemographic variables», Science of The Total Environment, vol. 749, p. 142364, dic. 2020, doi: 10.1016/j.scitotenv.2020.142364.

[5] T. Moore, I. Ridley, Y. Strengers, C. Maller, y R. Horne, «Dwelling performance and adaptive summer comfort in low-income Australian households», Building Research & Information, vol. 45, n.o 4, pp. 443-456, may 2017, doi: 10.1080/09613218.2016.1139906.

[6] J. A. López-Bueno et al., «The impact of heat waves on daily mortality in districts in Madrid: The effect of sociodemographic factors», Environmental Research, vol. 190, p. 109993, nov. 2020, doi: 10.1016/j.envres.2020.109993.

[7] M. Núñez-Peiró, C. Sánchez-Guevara Sánchez, y F. J. Neila González, «Hourly evolution of intra-urban temperature variability across the local climate zones. The case of Madrid», Urban Climate, vol. 39, p. 100921, sep. 2021, doi: 10.1016/j.uclim.2021.100921.

[8] F. Martín-Consuegra, J. M. Gómez Giménez, C. Alonso, R. Córdoba Hernández, A. Hernández Aja, y I. Oteiza, «Multidimensional index of fuel poverty in deprived neighbourhoods. Case study of Madrid», Energy and Buildings, p. 110205, jun. 2020, doi: 10.1016/j.enbuild.2020.110205.

[9] A. Hernández Aja et al., Barrios vulnerables de las grandes ciudades españolas. 1991/ 2001/ 2011. Madrid: E.T.S. Arquitectura (UPM), 2018. Accedido: 6 de noviembre de 2018. [En línea]. Disponible en: http://oa.upm.es/51015/

[10] C. Sánchez-Guevara, M. Núñez Peiró, J. Taylor, A. Mavrogianni, y J. Neila, «Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London», Energy and Buildings, vol. 190, pp. 132-143, feb. 2019, doi: 10.1016/j.enbuild.2019.02.024.

[11] C. Sánchez-Guevara Sánchez, A. Sanz Fernández, y M. Núñez Peiró, «Feminisation of energy poverty in the city of Madrid», Energy and Buildings, vol. 223, p. 110157, sep. 2020, doi: 10.1016/j.enbuild.2020.110157.

[12] Ayuntamiento de Madrid, «Plan General de Ordenación Urbana de Madrid. PGOUM 97. Plano de ordenación», 1997. https://datos.madrid.es/portal/site/egob/menuitem.c05c1f754a33a9fbe4b2e4b284f1a5a0/?vgnextoid=98fca5b5cfbac510VgnVCM2000001f4a900aRCRD&vgnextchannel=374512b9ace9f310VgnVCM100000171f5a0aRCRD&vgnextfmt=default (accedido 22 de agosto de 2018).

[13] I. D. Stewart y T. R. Oke, «Local Climate Zones for Urban Temperature Studies», Bulletin of the American Meteorological Society, vol. 93, n.o 12, pp. 1879-1900, dic. 2012, doi: 10.1175/BAMS-D-11-00019.1.

PLEA STGO 2022

November 22 - 25, 2022

CHALLENGES FOR DEVELOPING COUNTRIES

DAY 01
16:00 — 17:30

CHAIR
JOANA GONCALVES

PAPERS
1543 / 1318 / 1363 / 1149 / 1513 / 1443

12TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

Symptomatic Urbanism

Analysing the relationships between motorway traffic and health and food

EMANUELA ALVES DA ROCHA[1] PATRICIA REGINA CHAVES DRACH[2]

[1] Universidade Federal Fluminense, Rio de Janeiro, Brazil
[2] State University of Rio de Janeiro, Brazil; Federal University of Rio de Janeiro, Brazil

ABSTRACT: Urban configuration influences different ways of living in the city related to the house, job and their access routes. The urbanism could be a relevant tool to contribute to improving the quality of life. The increasing number of individual motor vehicles associated with urban sprawl contribute to the aggravation of problems in the city such as immobility, pollution, and the lack of access to the infrastructures, commercial establishments, and services, primarily on the scenery of centralization e polarization. The rise of obesity, diabetes, and hypertension cases among the population points to the city as a relevant source of encouragement to active mobility, both utilitarian and recreational. The decrease of rural areas is frequent and allows the growth of the fresh food costs because of the displacement dependence from producer to consumer. In this study, the road transport connected to health and food, also considering economic aspects of public health and nutritional food.
KEYWORDS: Urbanism, Urban mobility, Public health, Food, Fresh food

1. INTRODUCTION

The advent of motor vehicles allows the occupation of peripheral areas away from the downtowns. This process generates other implantations and land uses related to the decrease of natural and rural areas in many cases. Furthermore, the pollution from the industrial areas in urban centers contributed to the urban sprawl and the suburbs' occupation favoring assurance of population's health and quality of life [1]. The suburbs' occupation induces an intense and constant displacement towards the centers where there are the employees, commercial, and service establishments. The blend of centralization and urban sprawl evidences the increase of motor vehicles fleet and the impossibility of doing these displacements through active transports due to route distance in many cities.

The increase of time dedicated to daily displacements could compromise work performance. Besides that, this scenery may impact time to other activities such as food consumption. That reality could influence the rising of ultra-processed food, and fast foods consumption added to decrease nutritional quality with the less fresh food consumption. In 2017, 6.28% of the world population had type 2 diabetes, about 462 million people [2]. In 2016, 39% of adults more than eighteen years old were overweight, and 13% were obese [2]. About the child population, 39 million children until five years old were overweight or obese [3]. It is worth highlighting food insecurity which affects 30% of the world population [4]. In 2030, about 660 million people may be in hunger conditions - considering the COVID-19 (Sars-Cov-II) pandemic effects [4]. The eating disorders could be related to socioeconomic questions, such as access and purchasing power to fresh food, and daily factors, as the time dedicated to food consumption. In some cases, physical activities could also influence this condition. Approaching the lines: urban planning and mobility, climate and pollution, and economic aspects, this article intends to point the urgency of inserting health and food demands on urban management.

2. URBAN PLANNING AND MOBILITY

The advent of the combustion engine and motor vehicles qualify different forms of land occupation and consumption. The occupation areas far from urban centers and the product exchange allow other globalization scales and mobility of people, products, capital, etc [5]. Currently, mobility is a key in the debate about urban sprawl and compact cities. The reality of urban sprawl influences the increase of motorway traffic. The choice for transportation also is impacted by car status and the insufficiency of collective transports in many cities. On the other hand, compact cities intend to decrease the car fleet and stimulate active and collective transport. The discussion about urban morphology and planning regards historical questions which still are urban demands, such as air quality.

The industrial pollution concentration in urban centers encourages land occupation in peripheral areas of the city. The urban activities sector was an important starting point for urbanists, such as Le Corbusier. In Plan Radieuse, Corbusier advocated for large and rectilinear avenues to access central areas where each sector would be a specific use. The industrial, commercial, residential areas, and others, compose functional zones [6]. The population growth in urban areas, influenced by industrialization, also impacts redesigning the land occupation models in the cities. The garden city movement developed by Ebenezer Howard at the end of the XIX century is relevant for the scope of this research. Hall [6] explains Howard's intention to balance the urban and rural environment in his city model. Thus, Howard recognized the necessity to limit the urbanized area through green belts with agricultural functions and the population - with thirty-two thousand inhabitants.

The urban sprawl against the compact cities complements the discussion in the pandemic and post-pandemic scenery due to the urban mobility, and the land uses and occupation reality because of the continuous commuting and the urban centers. Motorway traffic impacts public spaces and the population's quality of life, primarily single-occupancy vehicles, considering the daily dynamic of urban sprawl and centralization and its demands. Table 1 exposes the demanded area (m²) of each transport mode - 1 for car, 2 for conventional bus, 3 for bicycle, and 4 for on-foot - both stopped and moving. The calculation related to the moving vehicle (m²) considers velocity in km/h (V), road width in meters (W), and three security seconds, except for on-foot mode.

Table 1:
Demanded area and capacity of each transportation.

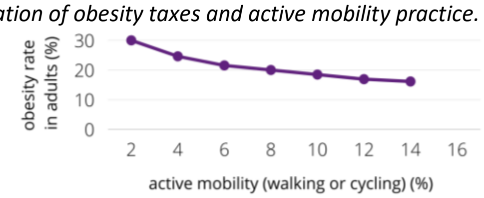
Mode	Stopped area (m²)	Moving area			Capacity
		V	W	Area	
1	9.90	50	3.0	136.32	5
2	40.50	50	3.0	164.10	85
3	0.70	16	1.5	22.55	1
4	0.80	3	1.2	0.80	1

Note: The stopped car space considers the parking space for the modal established by the Construction Code of the city of São Paulo [7]. The Urban Signalization Manual [8] was adopted for conventional bus calculation. The street width considered is three meters due to the velocity adopted. An active transportation study assisted in the pedestrian occupancy space is presented in Transporte Ativo [9] . The vehicle model Hyundai HB20 (3.94 m length) and the conventional bus Marcopolo Torino (13.20 m length) were adopted. In the pedestrian area, the three security seconds were not considered. The sidewalk width could be shared. Thus, it assumed only the space occupied by the moving body.

The focus on motorway displacement presupposes the presence of other infrastructures which impact landscape, such as parking spaces, viaducts, and tunnels. The subtraction of urban spaces due to single-occupied vehicles may reduce green areas and urban afforestation. Consequently, actions increasing motorway traffic may discourage active transport use. Contrastingly, active commuting is an ally to the population's quality of life because it is a functional or utilitarian activity. Physical activity is recommended at least thirty minutes five days a week, even in multiple smaller intervals [1]. Urban furniture, afforestation, and other measures which guarantee their safety and comfort are significant investments to assemble a healthier city.

On the urban scale, the fifteen-minute city concept invests the reduction of displacement time through urban decentralization and land-use diversity as a priority. Carlos Moreno [10], concept's author, and other urbanists [11, 12], recognize the significance of these measures to improve the quality of life in the cities. Moreno endorses employee, leisure, educational, health, and supply uses must be in a fifteen-minute access radius through active transportation. Meanwhile, it is possible to access the other areas with collective transport in thirty minutes. Saldiva [13] quotes a study which evidence physical practice growth through active transport influences on obesity condition reduction in North American and European cities (Fig. 1). Besides, decreasing time displacement allows us to reappraise daily dynamics to achieve other gains. Meal preparation and consumption time influence industrialized food intake against fresh food. The first is high in fats and sugars, such as processed or ultra-processed food [13]. Here, the time dimension joys the mobility and food consumption questions promoting healthy cities.

Figure 1:
Relation of obesity taxes and active mobility practice.



Nonetheless, time displacement could encourage measures aimed at motorway infrastructure. Motorized transport prioritization promotes actions to solve traffic problems like congestion, such as the expansion of the roads. Speck [8] characterizes that process as "induced demand"; the author explains the city encourages that transport mode and a growth car fleet consequently by creating advantages to the motor vehicles. Therefore, this increase worsens air quality because of rising CO_2 levels. Researches evidence the relation between exposure to air pollution and placental weight, autism, premature birth [13, 14]. Particles and gases compose polluted air. First is characterized as a mixture of soot, metals - including heavy - and organic compounds such as polycyclic aromatic hydrocarbons, which may promote mutations in human genetic material and cause cancer [13]. The gases, such as nitrogen (NOx), carbon (COx), and sulphur (SOx) oxides, are related to emissions from motor vehicles and fuel evaporation [13]. These elements impact the acid rain process and respiratory diseases [15].

Considering metropolitan regions and the middle-sized and small cities, the urban centers develop a dependence and influence context related to their surroundings. This reality impacts the daily displacements where the high number of single-occupied vehicles creates an immobility scenery. In the Metropolitan Region of Rio de Janeiro, 65.4% of the workers, who do not work in the city where they reside, commute to Rio de Janeiro [16]. Regarding people who do not work at home (Rio residents, 24%, and surrounding cities residents, 15%), almost half of this population, considering Rio residents or not - 44% and 46% respectively -, spend between 45 and 90 minutes on the commute from home to work [16].

In light of the significance of urban planning to the territorial connection, the compact city and the urban network on a municipal and regional scale allow the asymmetries reduction between the urban areas. In other words, encourage a relation of intracity, such as urban and rural areas, and intercity. In that way, urban mobility could benefit itself due to the capacity of regional planning, which could be effective in reducing the time displacement. Llop [17] points this articulation applied in small and middle-sized cities promotes the development of “Intermediary cities”. The author explains 70% of the population should be concentrated in a 4 km radius to encourage active displacements, such as a fifteen-minute city dynamic. The intermediary cities are based not only on demographic or territorial size, but also on their functions in mediating flows, links of rural and urban areas, and the areas of influences [17]. Regional planning could contain an economic analysis articulated urban mobility.

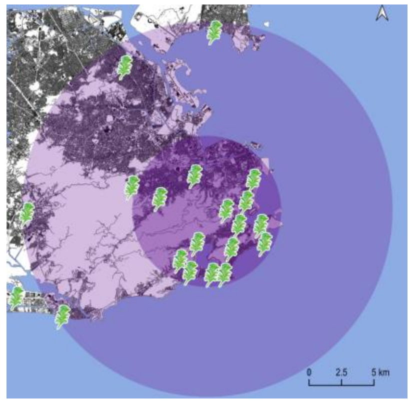
The land use and occupation facilitating compact planning with other measures could also avoid the construction in peripheral areas. In addition, housing policy is indispensable because of the inequity in many cities, guaranteeing housing supply. Informal settlement and occupation of environmental protection or risk areas impact the population’s quality of life, including health and sanitary conditions. Aiming to preserve fauna and flora and agricultural practices, the oversight and occupation control in peripheral areas and transitional zones on the border between cities are relevant measures to restrict urban growth. After that, it contributes to food production and climate.

The food displacement from the production to the consumption area impacts the increase of food waste. In Brazil, 50% of food waste - 26.3 million tons per year - occurs during the handling and transport phase [18]. The food production in the city both influences a waste reduction and could promote a decrease in the final cost. The prospecting of logistical expenses has factors related to planning and administration, characterized by the value of shipping - considering fees such as loading, unloading, insurance, and urban road tolls -, vehicle maintenance, depreciation, taxation, labor, and fuel [19]. Besides the investment in food production in peripheral areas, similar to garden cities, the city could develop spaces dedicated to urban gardens and add productive function to existing green spaces. Health and educational equipments could also contribute to that production.

The decrease in food production in the cities seems to aggravate social inequality. Usually, the urban centers concentrate more fresh food offerings compared to peripheral areas. These areas with little nutritional and quality food supply are named food deserts [20]. Although the nutritional value of fresh food, the heavy metals contamination of the air, land, water, and food is harmful to the health. A relevant source of contamination is pesticides use. Even in indirect consumption, heavy metals have high toxicity, causing damage to various body organs and carcinogenic effects [21]. Authors relate the problem of pollution to food production, which can contribute to the accumulation of one or more substances mainly in leaves, such as heavy metals [21]. Thus, the production of organic food should be encouraged in cities. Nevertheless, the decrease of motorway displacements is necessary to avoid pollution contamination. In addition, a link between food producers and consumers may potentialize access to fresh food, in other words, foods with more nutritional quality, creating a network.

In this scenery, Figure 2 [22] shows the spatial inequality of access to organic street markets in Rio de Janeiro (Brazil). The smallest circumference, where much of the street markets settle down, coincides with the downtown and south Rio de Janeiro, economically valued areas because of infrastructure presence.

Figure 2:
Organic street markets in the city of Rio de Janeiro.



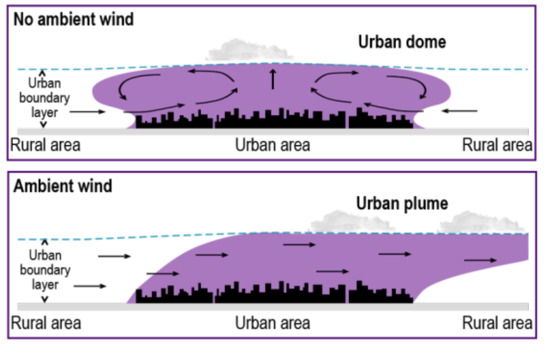
Therefore, the relationship between urbanization, health, and food should engender measures in favor of healthy cities passing through mobility, land uses and occupation, and food production. Urban gardens, decentralization, social housing programs, and the integration between urban and rural spaces are necessary to promote more quality of life. Further, they are essential to decrease social inequality. This process must regard more ecological practices: organic production, permaculture, agroforestry, sewage treatment, and active transport, for example. The actions in the city should be managed holistically to recognize problems and potentials.

3. CLIMATE AND POLLUTION

The heat sensation in urban areas is related to the constant presence of urban materials, such as concrete and asphalt, and dark surfaces in the cities [23]. The albedo is the reflecting power of a surface. That measure allows identifying the heat retention level of materials, which loses heat to the environment posteriorly. This process induces the formation of urban heat islands. The different performances about humidity, ventilation, and thermal properties between vegetation and urban materials picture the climate processes that affect life in the city. The importance of vegetation to the temperature level decrease at downtowns occurs primarily because of the evapotranspiration process. In that way, the permeability and the evapotranspiration process cause air cooling in the surroundings [23]. It is also noteworthy that the performance of this process varies according to vegetative characteristics such as size, density, etc. Besides that, the air humidity maintenance promoted by the urban trees' presence influences the decreasing of thermal amplitude compared with more dry climates [13].

The heat island is an urban microclimate characterized by heat retention compared to the surroundings and involves stagnation of winds. It could be related to urban density and materiality [23]. In a cold climate scenery, where the heat island formation may seem like a choice to promote warming, it is characteristic of this condition low air exchange, which could allow a concentration of pollutants in some city's regions. The urban dome formation [20], due to heat retention, is impacted by the wind regime. The wind action allows the air renovation through urban plume [23] (Fig. 3). Therefore, the urban densification added to the verticalization process could actuate in the wind blockage. It is a negative process since it could impact respiratory disease occurrence. The pollution originated in the urban space, derived by industrial activities and motorway traffic, affects the health and the population’s quality of life and impacts the rainfall regime [13]. Both respiratory and cardiovascular diseases and carcinogenic effects from particulate pollution are highlighted [13].

Figure 3:
The urban dome and the urban plume.



Afforestation acts as cool islands since they allow lower temperatures. The infrastructural landscape concept adds other functions to gardens, parks, and squares. A natural landscape is considered a green infrastructure. In the city, these green spaces are favorable to the urban area as in heavy rain cases as an initiative of hydraulic engineering. Nature-based Solutions (NbS) are sustainably managed actions inspired by the natural dynamic and could auxiliary on water treatment, urban drainage, and impact of droughts. Understanding the infrastructural capacity of green areas means it could be a measure to mitigate the heat sensation and the pollution, besides increasing quality of life. Furthermore, the food production possibility in urban, peri-urban, or rural areas aggregates more benefits to the community.

4. ECONOMIC ASPECTS

According to Zmitrowicz and De Angelis Neto [24], the paving and drainage systems are more expensive infrastructures in the urbanization - with participation between 55% and 60% of the total costs. Urban occupation in the city impacts what the authors characterize as the city's network infrastructure - described as a mesh of pipes, cables, or pavements distributed throughout the city. Urban layout and morphology aspects influence the efficiency of the implantation of these infrastructures and their final cost. Thus, the road system has relevant participation in the execution and performance of the sewage, water, energy, and telecommunications systems.

Comparing low and high urban density (Table 2), it is possible to note the value according to the urban network infrastructure in these different sceneries. Although the percentages relative to low and high density are close, the high density allows more people and units to enjoy urban infrastructure through a small difference in budgetary investment.

The update of these values permits the analysis of the urban density of 75 inhabitants per hectare and its 250 thousand dollars estimated cost [25]. Meanwhile, 600 inhabitants per hectare correspond to 320 thousand dollars on average. The authors evidence even though the population in the denser case equals 800% of the low density scenery inhabitants, the whole urbanisation cost of the hectare, in average, would be less than 30% higher.

Table 2:
Urban networks infrastructure and its participation value.

Network	Part of each urban networks infrastructure in the total cost (%)	
	Urban low density	Urban high density
Pavement	41.38	44.35
Drainage	14.38	15.65
Water supply	3.93	3.50
Sewage	17.10	19.73
Gas distribution	9.09	8.79
Electricity supply	13.16	6.81
Street lighting	0.96	1.17

The verticalization process could be an ally of urban densification. Nevertheless, it may worsen the quality of life in the city, due to the effects on the local microclimate, for example. The construction height, the materials, and low land permeability could influence the heat sensation and the wind regime. Another issue highlighted is the environmental comfort related to noise problems in the thirty families or more per hectare scenery [25].

The encouragement to active mobility, land-use diversity, and food production contributes to the development of healthy cities because reducing the speed, by active transport, allows slower perspectives and, thus, more attention to the surroundings. Thereby, Speck [11] describes the parking management in favor of rotativity profits the commercial establishments. Urban policy and legislation may influence car use. Shoup [26] explains a minimum number of parking spaces in buildings is usually related to land use in many cities. That measure could be according to building codes, for example. The Institute for Transportation and Development Policy [27] assesses the demand for parking spaces in Rio de Janeiro (Brazil) compared to the car number from 2005 to 2016. The study noticed the annual parking spaces growth in buildings equals 11.4% while the automobile number increased 4.1%. In the last three years of this research, 43% of parking spaces were created of the total in the ten years range [27]. On the other hand, Speck [11] mentions in the city of San Francisco (Califórnia, USA), a requirement of one parking space per unit increases 20% the habitation cost. Besides that, removing this requirement allows an increase of 24% of the number of inhabitants in the building.

Active transport demands less space compared to motorway displacement. In addition, there are multiple materials for paving which could be used without harm the dislocation and would be more efficient to the urban permeability. Therefore, these facilities aid in redesigning urban spaces even in experimental mode with low cost, but efficiency and rapidity. Tactical urbanism is an approach to promote a better appropriation and use of urban space through specific urban interventions, sometimes temporary. Besides, the constructions associated with roads and highways require a short number of human resources due to machinery presence. Indeed, buildings for collective transport along with pedestrian and bike networks engender 60% to 100% more employment [11].

The investment in a healthy city may also be profitable to the health area. Both mobility and food habits may imply a cost decrease in the health system. In the reality of Brazil, Nilson et al. [28] explain hospitalizations linked to obesity, hypertension, and type 2 diabetes in the Unified Health System (SUS) correspond to about 16% of total hospitalizations in 2018. Inpatient and outpatient care costs are, respectively, US$ 14.88 billion and US$ 643.25 million in the same year (considering the dollar exchange rate on December 31, 2018). Regarding the Brazilian Popular Pharmacy Program - a strategy to improve the access of medicines by population - the costs with obesity, hypertension, type 2 diabetes, and asthma amount to US$ 8.95 billion in 2018. Other diseases related to hypertension and diabetes, such as cardiovascular and chronic kidney, influence SUS' outlay, respectively, US$ 145.31 billion in 2015 and US$ 10.07 million.

5. CONCLUSION

The city's configuration both composes and influences population practices and habits. This study evidences the motorway traffic landscape, on the urban dimension, and its impacts on people's health and alimentation. The city could become a tool to mitigate diseases related to physical and mental health, even as food insecurity situation. Admitting the city as a diverse scene of behavior and everyday practices territory situates the mobility and alimentation in a commonplace. Nevertheless, the investment in healthy cities, including economic, which stimulate beneficial practices to the body and mind, could be a better method to increase the population's quality of life.

The car dependence reveals several impacts due to motor vehicle commuting which cities should be aware of and address them in the city management, including the land use and occupation. This scenery impacts life and health. Besides, the link between inequality, mobility, and food consumption evidences a worrying reality which connects purchasing power, housing quality, travel time, and wage. Living in peripheral areas means continuous commuting, dedicating part of the income and time to transport. Because of land speculation and precarious collective transport, the urban form impacts the population's opportunities, such as job offers, supply markets, educational and health services. Urban sprawl influences quality of life and autonomy. Investment in healthy urbanism also returns benefits to the public administration.

REFERENCES

1.Frumkin, H., Frank, L., Frank, L. D., and Jackson, R. J. (2004). *Urban sprawl and public health*. Island Press.
2. Khan, M. A. B., Hashim, M. J., King, J. K., Govender, R. D., Mustafa, H., & Al Kaabi, J. (2020). Epidemiology of type 2 diabetes–global burden of disease and forecasted trends. *Journal of epidemiology and global health*, 10(1).
3. WHO - World Health Organization (2021). Obesity and overweight [Online], Available: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight [10 February 2021].
4. FAO - Food and Agriculture Organization (2021). The State of Food Insecurity and Nutrition in the World 2021 [Online], Available: https://www.fao.org/state-of-food -security-nutrtion [10 February 2021].
5. Santos, M. (1988). Espaço e sociedade no Brasil. *Geosul*, 3(5), 85-100.
6. Hall, P. (2014). *Cities of tomorrow*. John Wiley & Sons.
7. *Decreto Lei nº 16642 of May 9th, 2017 of Prefeitura Municipal de São Paulo.* Available: https://gestao urbana.prefeitura.sp.gov.br/wpcontent/uploads/2018/04 /codigo_de_obras_ilustrado.pdf. [27 October 2021].
8. Environmental Company of State of São Paulo (n.d.). Poluentes, [Online], Availables: https://cetesb.sp.gov.br/ ar/ poluentes/ [20 July 2021].
9. Transporte Ativo (n.d.). Espaço ocupado por meio de transporte, [Online], Available: http://transporteativo.org .br/wp/2013/08/04/o-uso-do-espaco-urbano-por-veiculo/grafico/ [24 October 2021].
10. Moreno, C, (2019). The 15 minutes-city. [Online], Available: http://www.moreno-web.net/ [15 June 2021].
11. Speck, J. (2016). *Cidade caminhável*. Perspectiva.
12. Jacobs, J. (2000). *Morte e vida de grandes cidades*. Martins Fontes.
13. Saldiva, P. (2018). *Vida urbana e saúde: os desafios dos habitantes das metrópoles*. Editora Contexto.
14. Ghasemi-Tehrani, H., Fallah, S., Mozafarian, N., Miranzadeh, S., Sadeghi, S., & Azidhak, A. (2017). Effect of exposure to air pollution on placental weight in Isfahan-Iran. *Journal of Family & Reproductive Health*.
15. Carvalho, C. H. R. (2011). *Emissões relativas de poluentes do transporte motorizado de passageiros nos grandes centros urbanos brasileiros* (No. 1606).
16. Mihessen, V., Machado, D. C., & Pero, V. (2014). Mobilidade urbana e mercado de trabalho na Região Metropolitana do Rio de Janeiro. *Revista da ABET*, *14*(2).
17. Llop, J. M., Iglesias, B. M., Vargas, R., & Blanc, F. (2019). Las ciudades intermedias.
18. FAO - Food and Agriculture Organization (2017). Desperdício de alimentos. *Convenção ABRAS* [Online], Available: https://www.abras.com.br/pdf/Apresent_FAO. pdf [10 February 2021].
19. Kruger, S. D., & Diel, F. J. (2018, November). Análise da formação de custos logísticos entre rotas de transportes de uma Cooperativa do Oeste Catarinense. In *Anais do Congresso Brasileiro de Custos-ABC*.
20. IDEC - Instituto de Defesa do Consumidor. (2020). Desertos alimentares [Online], Available: https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/58842/IDL %20-%2058842.pdf [10 February 2021].
21. Pinto, R. S. B. F. F., Ribeiro, C., Simões, P. P., Gonçalves, A. B., & Ramos, R. A. (2011). Viabilidade ambiental das hortas urbanas enquanto espaços para o desenvolvimento sustentável. *Revista da Associação Portuguesa de Horticultura.*
22. IDEC - Instituto de Defesa do Consumidor (n.d.). Feiras Orgânicas [Online], Available: https://www.feirasorganicas .com.br/ [18 May 2021].
23. Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban climates*. Cambridge University Press.
24. Zmitrowicz, W., & Neto, G. D. A. (1997). Infra-estrutura urbana. *São Paulo: EPUSP*, 02-36.
25. Silva, G. J. A. D., Silva, S. E., & Nome, C. A. (2016). Densidade, dispersão e forma urbana. *Arquitextos Vitruvius*, *189*.
26. SHOUP, Donald (2017). The high cost of free parking. VOX [Online], Available: https://www.youtube.com /watch?v=Akm7ik-H_7U [01 October 2021].
27. ITDP - Institute for Transportation and Development Policy (2017). *Políticas de estacionamento em edificações na cidade do Rio de Janeiro* [Online], Available: http://itdpbrasil.org.br/wp-content/uploads/2017/07/ relatorio-politicas-de-estacionamento-itdp-julho-2017.pdf [01 October 2021].
28. Nilson, E. A. F., Andrade, R. D. C. S., Brito, D. A. D., & Oliveira, M. L. D. (2020). Custos atribuíveis a obesidade, hipertensão e diabetes no Sistema Único de Saúde, Brasil, 2018. *Revista Panamericana de Salud Pública*, *44*, e32.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

PLEA SANTIAGO 2022
Will Cities Survive?

Improving the environmental conditions of *favela* homes through a participatory process

With reference to case-studies in São Paulo and Rio de Janeiro

PATRICIA PAIXÃO [1], JOANA C. S. GONÇALVES[2], ALESSANDRA R. P. SHIMOMURA[3], EDUARDO P. PIZARRO[4], GUSTAVO O. F. CURCIO[5], GUSTAVO F. DIEGUES[6]

[1, 3, 5, 6] Faculty of Architecture and Urbanism of the University of São Paulo, Department of Technology (FAUUSP, AUT, LABAUT), São Paulo, Brazil
[2] Architectural Association School of Architecture, London; Bartlett School of Architecture – UCL, London; School of Architecture and Cities, University of Westminster, London
[4] Universidade São Judas Tadeu, Faculdade de Arquitetura e Urbanismo, São Paulo, Brazil

ABSTRACT: The living conditions of informal cities around the world are directly related to the UN 2030 Agenda. In Brazil, the most populated country in Latin America, 22.3 % of the population was estimated to be living in informality in 2015. In Sao Paulo and Rio de Janeiro, the typical compactness of the land use of its slums aggravates local microclimatic conditions. At the building scale, spatial demands lead to transformations of self-built residential buildings that overlook the need for daylight, natural ventilation and solar access. Confronting such reality, the pilot-project of technical assistance entitled Social Housing: Pictures and diagnostics in communities before and after Covid-19 addresses the gap in the knowledge of self-built practices with regards to indoor environmental quality, by means of a specialized-driven participatory process, that promotes technically informed support to residents of informal settlements in Sao Paulo and Rio de Janeiro. This pilot project demonstrates the practical efficiency of a participatory approach that addresses a socio-environmental and inclusive design agenda, at the domestic level of local self-built communities. As a final product, an on-line open-access library was made available with the outcomes of the technical critical assessment of existing situations and the associated recommendations. This pilot project was supported by the UN-Habitat programme "ONU-Circuito Urbano 2020".
KEYWORDS: Self-Built, Residential Buildings, Tropical Climate, Environmental Conditions, Design Intervention

1. INTRODUCTION

In Brazil, the most populated country in Latin America, 22.3 % of the population was estimated to be living in informality in 2015 [12]. In São Paulo, the biggest and richest of the Brazilian cities, it is estimated that between 1,16 and 2 million people live in 1.538 informal settlements, which is the equivalent of approximate 16% of the city´s population, whilst in Rio de Janeiro, it was reckoned that approximately 22% of the city's total population live in informality - one of the highest percentage of slums' population among the Brazilian cities [15].

The word slum has been commonly used to identify an agglomeration of poor quality and informal housing, often lacking proper urban infrastructure including the provision of clean water, electricity and garbage collection [13]. The living conditions of informal cities around the world are directly related to the UN 2030 Agenda [14].

In Brazil, an informal settlement is known as *favela*, named after the tree from which the wood was used to build the first informal settlements in Rio de Janeiro, in the end of the 19th century [11].

In the *favelas* found in Sao Paulo and Rio de Janeiro, the typical compactness of the land use, coupled with the lack of vegetation, impermeabilization of the urban ground and the typical materiality of the self-built environment, which is made predominantly of metallic roofs, bare brick walls and cemented or asphalt streets and pavements, end-up aggravating local microclimatic conditions of the warm and humid tropical and subtropical Brazilian cities, by accumulating and trapping the heat from impinging solar radiation [6, 3], (Fig. 1, 2). In the *favela* of *Paraisopolis* in São Paulo, the second biggest slum in the city, measurements in situ taken over a period of 6 months compared the thermal conditions in a typical dense part of the slum with urban spaces just outside its built environment and showed a wider daily temperature difference in the slum's open space, where, in the warm days, peak temperatures were up to 3°C higher than in the nearby formal urban area, whilst night-time temperatures during the cooler days were at least 1°C lower in the slum [3].

At the building scale, spatial demands lead to transformations of self-built residential buildings that overlook the need for daylight, natural ventilation (crucial for fresh-air and space cooling during the warmer periods of the year) and solar access (important in the cooler periods).

Coupled with the warmer urban conditions, the poor indoor environmental conditions of living spaces were proved to be also a consequence of the thermally inappropriate building fabric, incurring in excessive levels of solar gains [10]. A fieldwork conducted in homes in *Paraisopolis* facing the main streets, revealed air temperatures as high as 40°C in the living space at 4 pm of a weekday, when outdoor temperatures oscillated around 33°C [6]. As a common practice during warm periods, windows are kept open by the occupants during the 24 hours' daily cycle. However, given the relatively small windows deprived from external shading, and the accumulation of internal gains (as a function of internal activities and domestic appliances), the referred studies demonstrated that this measure alone is inefficient to control the rise of internal temperatures during the times of peak temperatures.

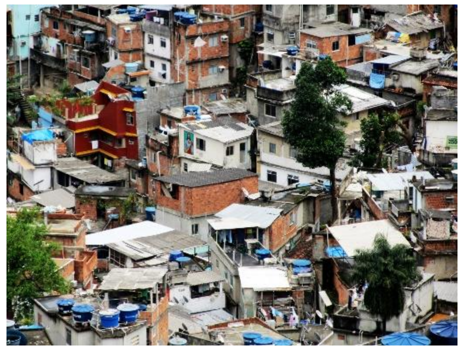


Figure 1: Overview of *Favela of Rocinha*, Rio de Janeiro, illustrating the compactness of the built form. Photo: E. Pizarro.

Figure 2: Street in *Favela of Paraisopolis*, Sao Paulo, illustrating precarious building constructions. Photo: E. Pizarro.

In Rio de Janeiro (more than in Sao Paulo), where average high summer temperatures easily reach 30ºC, it is clearly seen that the response to the intense overheating of the internal spaces has been the adoption of air-conditioning machines, often supported by an illegal use of electricity. In the context of the pandemic, that broke up in 2020 and two and a half years later is still affecting thousands of Brazilian families, the ability to properly naturally ventilate homes became a key factor for health and wellbeing, going beyond the notion of thermal comfort, particularly in the dense and poorly treated realm of the informal city.

Confronting such reality, the pilot-project of technical assistance entitled *Social Housing: Pictures and diagnostics in communities before and after Covid-19* (*Habitacao Popular: Retratos e diagnosticos nas comunidades antes e depois da Covid-19*) [2] addresses the gap in the knowledge of self-built practices with regards to indoor environmental quality, by means of a specialized-driven participatory process, that promotes technically informed support to residents of informal settlements in Sao Paulo and Rio de Janeiro, to improve their home environments. This project was realized within the context of the UN-Habitat program *Circuito Urbano 2020*, that encompassed a series of events focused on the quality of life in Portuguese speaking cities in Brazil and African countries [7].

2. METHOD: THE PARTICIPATORY PROCESS

This pilot project for environmental technical assistance to self-built homes in informal settlements took the format of an on-line workshop, in which specific advice for modifications of buildings' fabric and components – a kind of DIY (Do It Yourself) Building Design Guidelines, were elaborated and communicated with the residents during the event [2].

These guidelines were based on an environmental technical assessment made for a range of external and internal photographs provided by residents of Brazilian slums. Methodologically, the referred live on-line event was characterized by a participatory process originally formulated to this pilot project, driven by the cases presented by the residents. Although the workshop was opened for all Portuguese speaking countries in the word, the great majority of the participants were from the cities of Sao Paulo and Rio de Janeiro in Brazil (probably due to access to the online information about the event).

The guidelines encompassed a series of specific but replicable and technically simple modifications of the building fabric and components, focusing on thermal, natural ventilation and daylight conditions of the *favela* homes. In addition to the critical review of specific aspects of the buildings to be modified, existing features which were identified in the photographs and considered to be environmentally adequate were also highlighted, explained, and recommended for a wider applicability in the local context. In the assessment provided to the residents, the positive aspects were classified as *Adequate Features* – good practice that should be incentivized to be replicated, whereas the problematic ones were pointed as *In Need for Intervention*.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

In general, both the recommendations geared to modify a certain feature of the building and those related to actual existing solutions were based principles of environmental design, applicable to the local subtropical and tropical climates of Sao Paulo and Rio de Janeiro and included mainly: 1. Aspects of the materiality of the construction (meaning the insulation of the building fabric – U value), 2. General treatment of facades and roofs (color and shading), 3. Apertures for daylight and ventilation (type, size and location) and; 4. Finishing of internal floors and walls. The technical recommendations for the thermal performance of residential buildings from the Brazilian Standard (NBR15220-3) were also considered as general guidelines for this qualitative assessment [1]. As an outcome, the technical assessments of all photographs, with the associated design recommendations, were compiled and made available on a digital platform with open access, with a catalogue of design recommendations to be adopted in similar building scenarios, located in similar climatic contexts [2].

3. CLIMATIC CONTEXT

Given that the great majority of cases assessed in the workshop were from the Brazilian cities of Sao Paulo and Rio de Janeiro, the climatic conditions in these two cities is presented here. According to the Köppen Climate Classification, the city of São Paulo (latitude 23.85°S; altitude 792m) is in a region of Humid-Subtropical Climate (Cfa) and the city of Rio de Janeiro (latitude 22.91°S; at sea level) is in a region of tropical savanna climate (Aw) that closely borders a tropical monsoon climate (Am) [8]. An overview of the local climates is described below.

3.1 Sao Paulo

The average annual temperature is 19°C. January is the hottest month, with an average minimum temperature of 19°C and average maximum reaching 27°C, whilst humidity levels vary between 31% a 100%. Maximum global solar radiation on the horizontal plan in January is 1,017 W/m^2. July is the coolest, with average minimum of 17°C and average maximum 23°C, whilst relative humidity varies between 26% a 100%. The average hourly horizontal global solar irradiation in the summer is 767 W/m^2, following in the winter to 598 W/m^2.

In warm days, shading is fundamental for the thermal comfort in buildings as well as natural ventilation. In the cooler days, the use of passive solar gains and controlled (minimum) ventilation is strategic for thermal comfort. Given the significance of global solar radiation, attention should be put to the thermal resistance of the building envelope, particularly regarding the solar gains from the roof. In addition, a degree of thermal mass can assist in moderating extreme temperatures, especially when coupled with night-time ventilation in the warmer period and solar access in the cooler period.

3.2 Rio de Janeiro

In the city of Rio de Janeiro, the average annual temperature is 23.6 °C (almost 4 °C higher than in Sao Paulo). February is the hottest month in Rio de Janeiro with an average minimum temperature of 24°C and average maximum reaching 31°C, also the month with the most daily sunshine hours. This is essentially a warm and humid climate during the whole year round. The highest relative humidity levels occur in March (81.95 %) and the lowest in November (73.71 %).

The average hourly horizontal global solar irradiation in the summer is 962 W/m^2, following to 591 W/m^2, in the coolest month. Given the predominant warm and humid conditions, constant natural ventilation accompanied by shading are key building design strategies for thermal comfort in Rio de Janeiro during the whole year.

As in the case of Sao Paulo, thermal mass can assist in moderating high temperatures, especially if coupled with night-time ventilation. Because of the significance of global solar radiation, in this case too, attention should be put to the thermal resistance of the building envelope, particularly regarding the solar gains from the roof. Here, no risk of thermal discomfort because of cold conditions is identified.

4. BRAZILIAN STANDARD FOR THE THERMAL PERFORMANCE OF RESIDENTIAL BUILDINGS

The Brazilian Standard for the thermal performance of residential buildings (NBR15220-3), which has been recently revised, is geared to social housing, to guarantee minimum thermal comfort conditions for this type of residential buildings [1]. The design recommendations include size of openings, the need of shading and the specification of U Values of walls and roofs, which vary according to the specific conditions of each of the 8 preestablished climatic zones in which the country is divided. The city of Sao Paulo is in Zone 3 and Rio de Janeiro is in Zone 8.

<u>Guidelines for Zone 3:</u> External walls – Light-weight and of reflective color, U Value ≤ 3,60 W/m^2.K; Roof - Light-weight insulated and of external reflective color, U Value ≤ 2,00 W/m^2.K; Window apertures between 15 and 25% of the room floor area; Shading and cross ventilation in all rooms during the warm periods and passive solar gains for the cooler periods.

<u>Guidelines for Zone 8</u>: External walls – Light-weight and of reflective color, U Value ≤ 3,60 W/m^2.K; Roof - Light-weight and of external reflective color, U Value ≤ 2,30 W/m^2.K; Window apertures > 40% of the room floor area; Shading of all apertures and cross ventilation in all rooms for the whole year; ventilation of roof-cavity.

5. ENVIRONMENTAL TECHNICAL ASSISTANCE

In the workshop of environmental technical assistance, *Social Housing: Pictures and diagnostics* in communities before and after Covid-19 [2], – after a tutorial workshop on design principles and visual syntax for image generation –, a set of over 50 pictures including external and internal views of homes in favelas in the cities of Sao Paulo and Rio de Janeiro were sent by voluntary residents, which were examined by a group of environmental-specialist designers.

The images of the residential buildings showed a wide range of construction and design features of different environmental qualities and gathering a significant scope for practical interventions. As mentioned in the *Methodology*, the existing adequate environmental features, problems and potential solutions were systematized as *Adequate Existing Features* and *In Need of Intervention*.

A group of four referential cases were selected to exemplify the applicability of this environmental technical assistance. See figures 3 to 6. In essence, the sample depict issues associated with the roof, external walls and windows.

5.1. Referential cases

5.1.1. Case 1: Shaded Roof-Terrace, Bare External Walls & Small Window

Figure 3: Multi-story residential building cluster in the *Favela of Paraisopolis*, Sao Paulo, showing a sequency of shaded roof tops, bare brick walls and standardized aluminum windows.

<u>Adequate Existing Features:</u>

1. Roof-terrace: using top slabs as a terrace area creates opportunity for outdoor spaces, which can be more comfortably occupied in this climate when well shaded. *Lesson*: create outdoor spaces within the context of the residential building.

2. Shaded terrace: the metal roofs over the terraces reduce solar gains from the last slab due to the shading effect. *Lesson:* Shade terrace-roofs.

<u>In Need for Interventions:</u>

3. Small-size standardized aluminum windows: with only half of the window area opened for ventilation, these windows are inefficient to promote cooling ventilation to the rooms, whilst also reduce daylight access and, consequently, lead to increased use of artificial lighting during the day. *Suggestion:* Change hinges of the windows to open both panels and double the ventilation area.

4. External bare solid brick or hollow ceramic block walls: without external render, these walls facilitate heat gains mainly from impinging solar radiation (particularly intense in the North, East, West, Northeast and Northwest orientations), which can contribute to overheating in the warmer days of the year. It also facilitates heat losses during the cooler days (in the case of the Sao Paulo climate), as it means lack of insulation. *Suggestion:* rendering of external facades (of around 2,5 cm thick) and paint them with light colors.

5. Metal-roof: when left in the natural grey color of the metal sheet (α = 0.40 to 0.65), the roof will absorb and irradiate a significant number of solar gains that can compromise the thermal comfort despite the shading. Ideally, the external side of a metal roof should be painted in a light color (α = between 0.20 to 0.10).

5.1.2. Case 2: Metal-Roof, Bare External Walls & Small Window

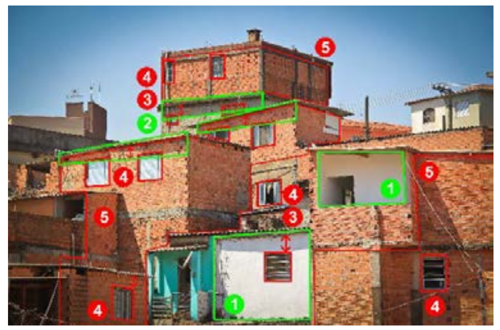


Figure 4: Multi-story residential building cluster in the *Favela of Rocinha*, Rio de Janeiro, showing a sequency of flat metal roofs, primarily bare brick walls and standardized aluminum windows.

<u>Adequate Existing Features:</u>

1. External walls rendered and painted white: help reducing solar gains through the opaque parts of the envelope as it increases reflectivity and insulation of the external walls. *Lesson*: Render and paint external walls with light colors.

2. Windows with external shading panels: provide shading during hours of impinging solar radiation in the warmer periods of the year. Usually these kinds of panels (from standardized window frames) have perforations that allow for some

number of air-changes, keeping a constant flow of ventilation. *Lesson*: have external shading in windows (ideally, in all orientations, apart from due south).

In Need for Interventions:

3. Low floor-to-ceiling heights: the proximity between the top height of the windows and the roof indicates a low floor-to-ceiling height which aggravates the compactness of internal spaces and, when coupled with the small ventilation openings, adds to overheating risks. In addition, the warmer layer of air stays close to the usable height and, therefore, to the occupants. In such spatial conditions, the likely scenario of metal roofs without internal slabs can compromise comfort and health conditions due to solar gains through the roof area alone.

4. Small-size standardized aluminum windows: as in the previous case (5.1.1.).

5. External bare solid brick or hollow ceramic block walls: as in the previous case (5.1.1.).

5.1.3. Case 3: Roof-Terrace, Permeable Facades & Louvered Window

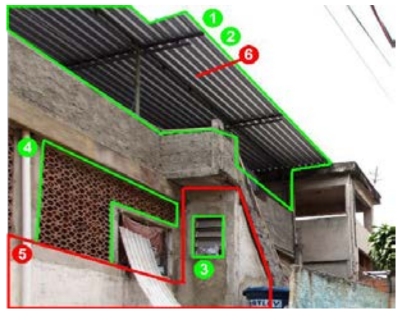


Figure 5: Residential building in the *Favela of Rocinha* - use of perforated ceramic bricks and a shaded roof top.

Adequate Existing Features:

1. Roof-terrace: as in the previous case (5.1.1.).
2. Shaded terrace: as in the previous case (5.1.1.).
3. Louvered window: allows a constant ventilation flow (that removes heat and humidity) without the need of a relatively bigger opening, being suitable for bathroom areas.
4. Perforated ceramic wall: this provides shading by filtering rather than blocking the global solar radiation, therefore, allowing daylight penetration, whilst keeping a constant rate of ventilation. The uninsulated and unglazed ceramic bricks absorb water from the rain (typical in the warmer periods of the year in Rio de Janeiro) which cool the immediate environments when reached by the sun by means of an indirect and passive evaporative phenomenon. *Lesson*: make external walls permeable to air movement, whilst blocking excessive penetration of solar radiation.

In Need for Interventions:

5. Bare cemented walls: has a similar negative effect to solar gains and heat losses as the external bare solid brick or hollow ceramic block walls, seen in the previous case (5.1.1.).

6. Metal roof: as in the previous case (5.1.1.).

5.1.4. Case 4: Occupied Roof Top

Figure 6: Roof top of a residential building in the *Favela of Paraisopolis* - permanently opened kitchen.

Adequate Existing Features:

1. Roof-terrace: as in the previous case (5.1.1.). In this case, the occupation of the terrace with a full kitchen indicates the potential of semi opened spaces for domestic functions, in this climate, if shading is provided. Coupled with the shading, permanent and significant ventilation seems to be provided by the side-openings.

2. Shaded terrace: as in the previous case (5.1.1.). In this case, without the shade provided by the metal roof, this particular use of the terrace would not have been possible.

In Need for Interventions:

3. Metal-roof: as in the previous case (5.1.1.).

4. Terrace's side openings: movable protection on the side-openings is necessary to protect the terrace from direct solar radiation on the warmer periods of the year and wind-driven rains.

5.2. Key Findings

The sample of referential cases indicate a few common features that dominate the self-built environment of the *favelas* in the cities Sao Paulo and Rio de Janeiro. In this context, common problems that contribute to potential high risks of overheating are: 1. The lack of facade treatment, revealing ceramic or solid earth brick walls without external rendering and paint. External rendering would help in reducing heat gains from impinging solar radiation on walls and roofs (by reducing U Values), whilst adding material protection against the typical tropical rain.

The U value of bare solid bricks is 3,70 $W/m^2.K$ (very close to the recommendations), whereas the perforated ceramic brick without render is 2.93 $W/m^2.K$, reducing to 2,48 $W/m^2.K$ with render, improving the insulation; 2. Reasonable small windows (the same standardized aluminum-ased frame windows used for social housing developments across the country), with inefficient opening for the necessary ventilation, particularly during the warm periods of the year [5] and; 3. When covering open terraces, the negative impact of such thermally fragile roof construction is less but can still pose a threat to thermal comfort due to long-wave heat irradiation.

On a more positive note, the shading of roof-terraces creates a value opportunity to be outdoors and scape from the likely overheated internal spaces during days and nights, particularly during the warmer periods of the year. In addition, the occupation of terraces to expand the possibilities of daily life activities (such as those related to the kitchen) and allowing conventional indoor functions to happen in semi-outdoor spaces, points out to the need and preference for well ventilated spaces (whether they are indoors or outdoors) and; the application of perforated ceramic (and concrete blocks) create facades which are permeable to sun, daylight and air movement, whilst provide protection against the impact of solar radiation – a typical design strategy of iconic examples from the so called Brazilian Bioclimatic Modernism [4].

6. FINAL CONSIDERATIONS

As a final product of the workshop *Social Housing: Pictures and diagnostics in communities before and after Covid-19*, an on-line open-access library was made available with the outcomes of the technical critical assessment of existing situations and the associated recommendations [2]. In this way, this project aligns with another current initiative -the *Change* (in Portuguese: *Mude*) digital platform, including design recommendations for daylight, ventilation and other aspects from thermal performance in the domestic space [9].

As previously explained, the recommendations were based on both existing adequate features as well as new solutions where changes are needed to improve internal thermal and daylighting conditions. Overall, the recommendations for the interventions in the building fabric and components are applicable to residential buildings in other informal and self-built settlements in the cities of Sao Paulo and Rio de Janeiro (where the references are from) as well as in other places of similar climatic conditions if material resources are compatible to the suggested building strategies. Ultimately, this pilot project demonstrates the practical efficiency of a participatory approach that addresses a socio-environmental and inclusive design agenda, at the domestic level of local self-built communities. In this sense, the recommendation technically adequate simple and specific building interventions are opportunities for the occupants to choose from to improve their own living conditions. In sum, the main effort of this technical assistance was to incentivize and support the favela residents to "Change!" [9].

ACKNOWLEDGEMENTS

The authors would like to thank the UN-Habitat programme *ONU-Habitat Circuito Urbano 2020* for supporting this pilot project. Thanks to FAUUSP and to ArqXp for providing technical support.

REFERENCES

1. ABNT (2021). NBR15220-3, Parte 3: Zoneamento bioclimático brasileiro e diretrizes construtivas para habitações unifamiliares de interesse social.
2. ArqXp (2020). Habitacao Popular: Retratos e Diagnosticos. Available at: https://arqxp.com/habitacao-popular-retratos-e-diagnosticos-nas-comunidades-antes-e-depois-da-covid-19/
3. DaSilva, E.N.; Ribeiro, H. (2006). Alterações da temperatura em ambientes externos de favela e desconforto térmico. *Rev Saúde Pública*, 40, 663-70p.
4. Gonçalves, J. C. S. et al (2018). Revealing the thermal environmental quality of the high-density residential tall building from the Brazilian bioclimatic modernism. *Energy and Buildings*, p. 17-29, 2018.
5. Gonçalves, J. C. S. (2014). O conforto térmico como um processo de adaptação ambiental: repensando os padrões da habitação em São Paulo. Contraste. Sao Paulo, p.260 – 266.
6. Gonçalves, J.C.S.; Pizarro, P.E.; Mulfarth, R.C. K.; Carucho, C. (2014). Examining the Environmental and Energy Challenges of Slums in São Paulo, Brazil. *Proceedings of PLEA 2014*, Ahmedabad.
7. ONU-HABITAT (2020). Circuito Urbano 2020. Para um Futuro Urbano Melhor. Available at: https://www.circuitourbano.org/edicoes-anteriores/
8. Peel, M.C.; Finlayson, B.L.; Mcmahon, T.A. (2007). Updated world map of the Köppen–Geiger climate classification. *Hydrol.Earth Syst. Sci*. 11: 1633–1644, 2007.
9. Pizarro, E. P. (2020). Mude! (Change!). Available at: https://www.eduaopizarro.com/change/
10. Pizarro, E. P.; Gonçalves, J. C. S. (2018). Everyday House: Redesigning the Informal Housing in Subtropical Climates, the Case of Paraisópolis Favela in São Paulo. *In: PLEA 2018*, Hong Kong.
11. Ribeiro, Darcy (1995). O Povo Brasileiro: A formação e o sentido do Brasil. São Paulo: Companhia das Letras.
12. Trading Economics, [Online], Available: https://population-living-in-slums-percent-of-urban-population-wb-data.html/ [16 August 2020].
13. UN Human Settlements Programme (2007). *What are slums and why do they exist?* Available at: http://www.unhabitat.org/downloads/docs/4625_51419_GC 21 What are slums.pdf/
14. UN (2019). The Sustainable Development Goals Report 2019. Available at: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf/
15. World Population Review [Online], Available: https://world-cities/ [16 August 2020].

PLEA SANTIAGO 2022
Will Cities Survive?

Microclimate evaluation method for urban planning in Legal Amazon region

JOÃO CARLOS MACHADO SANCHES[1] RENATA MANSUELO ALVES DOMINGOS[2] EMELI LALESCA APARECIDA GUARDA[2] ELEONORA SAD ASSIS[3]

[1] Universidade do Estado de Mato Grosso
[2] Universidade Federal de Santa Catarina
[3] Universidade Federal de Minas Gerais

ABSTRACT: With the uncontrolled growth of urban agglomerations, cities have expanded urban planning requirements. This growth has directly reflected in the urban microclimate with severe consequences for the population. Thus, this work aims to analyse the climatic variables of temperature and relative humidity of the central part of a medium-sized city in the Amazon region. The methodology uses mobile transect to obtain data from the variables studied in two well-defined seasons, being dry and wet. Measurements took place in three different periods on three consecutive days. Based on the data obtained, maps of temperature and relative air humidity distribution were made. Thus, from the measurements by mobile transect, it can be observed that in the dry season in the afternoon, more significant variations in temperature and relative air humidity were recorded between the analysed points, with an average of 2.6 ºC of temperature and 4 % of air relative humidity. There was slight variation between the points; however, temperatures of up to 35.4°C and humidity of 26.4% were recorded. Therefore, it is possible to draw guidelines that aim to minimize these high temperatures found through climatic knowledge.
KEYWORDS: Urban climate, Climate change, Sinop city center.

1. INTRODUCTION

It is clear that population expansion, which occurred mainly from the Industrial Revolution, contributed to changes in local climatological factors since it increased the consumption of natural resources and industrialization. In a disorderly way, this expansion alters the balance of the natural climate, contributing to the formation of the local urban climate.

The main factors related to climate change, such as an increase in temperature and a decrease in relative humidity, are mainly characterized by the thermal properties of construction materials, urban morphology, and the proportion between green and built areas. In addition, these climate changes produce adverse conditions for human health since bioclimatic stress can harm the productivity and health of the population due to thermal discomfort [1].

Thus, it becomes necessary to monitor meteorological aspects in urban areas, in the interior, and the surroundings of cities. This monitoring should contain climatological data that contribute to urban design tools and guidelines for different climatic zones and land use classes [2].

Based on the above, since Sinop is a city located in the north of Mato Grosso and is undergoing a process of accelerated growth, it is necessary to obtain climatic knowledge of this region in order to develop strategies for urban planning that minimize the harmful effects of climate change on the urban environment.

It is important to note that the concept of scale in studies related to urban climate is fundamental for carrying out analysis of measurements, "so that they become representative tools of the meteorological environment, rather than the climate in general, and provide data and support to the application needs in urban design and planning" [3].

According to these authors [3], the changes imposed by the urban climate can be observed at various scales. They recognize that studies of this type use a hierarchical order of scope, often framed in the regional climate scale, or macroscale, related to meteorological properties; the scale of changes due to orography, or mesoscale; and scale of changes caused by buildings, or microscale.

Here is presented the case of Sinop city, located in the Legal Amazon region in Brazil, which is undergoing an accelerated growth process, pointing the necessity to obtain climate information, in order to develop strategies for urban planning that minimize the harmful effects of climate change in the urban and rural environment that has been taking place.

This article aims to evaluate the possibility of using a specific methodology to obtain climatological data from on-site measurements, supported by mapping the conditions of use and occupation of urban land, according to the method proposed by Sanches (2015).

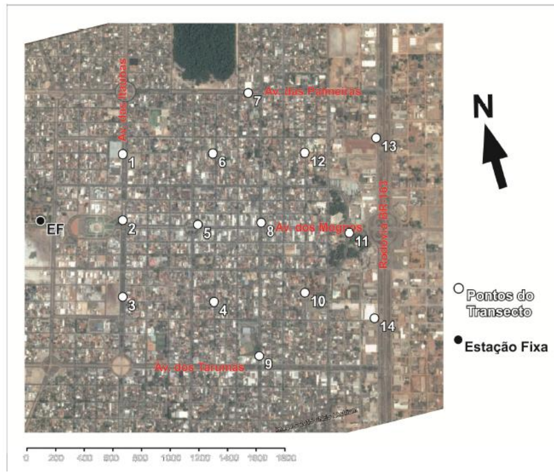
2. MATERIALS AND METHODS

The municipality of Sinop is located in the northern region of the State of Mato Grosso, with a latitude of 11.86°S and a longitude of 55.5° W. Belongs to the area known as Legal Amazon. However, it is also influenced by the Cerrado (Savanah) biome.

The research is based in this city through the methodology developed by Sanches (2015) [4], making it possible to produce maps of the temperature and relative humidity of Sinop through a mobile transect (Figure 01).

The mobile transect path is determined from the characterization of the region based on WMO (2008) [5] according to studies by Professor T. R. Oke. In this classification, essential characteristics are observed, aiming at aspects related to the land use and occupation, the presence of vegetation and water bodies, the presence of infrastructure, building layout, soil cover, permeability, and population density [4].

Figure 1:
Distribution map of measurement points for the Sinop city center transect. [4]



The measurements of the meteorological variables took place in two representative seasons for this region. Firstly, in the hot and dry season characterized by July and August of 2013 and later in the hot and humid season represented by February and March of 2014.

The survey took place over three working days with stable weather conditions. The route lasted approximately 35 minutes for three consecutive days in each season under analysis. The times defined for the measurements were at 08:00, 14:00, and 20:00 hours, representing the periods after sunrise, the hottest period of the day, and the period after sunset.

The equipment used for the mobile measurements was a compact set of sensors from the Vantage Pro2 station by Davis Instruments. This station comprises two main units, an integrated set of sensors, and a console for presenting and recording the data obtained. The communication between these two units takes place through a "wireless" system with a maximum range of 300 meters [6].

This integrated set of sensors contains a rain collector, a temperature/humidity sensor and an anemometer. The temperature/humidity sensor is mounted inside a radiation shield to minimize the impact of solar radiation on the readings.

Based on the information produced in the analysis of the city, the hottest area with the highest concentration of urban activities is identified. Therefore, it is sought to conduct specific research in this delimited area and use a more significant number of measurement points (Figure 2).

It starts with the characterization of this region, observing aspects related to the use and occupation of the soil, the presence of vegetation and bodies of water, the presence of infrastructure, building layout, soil cover (with emphasis on permeability), and density populational.

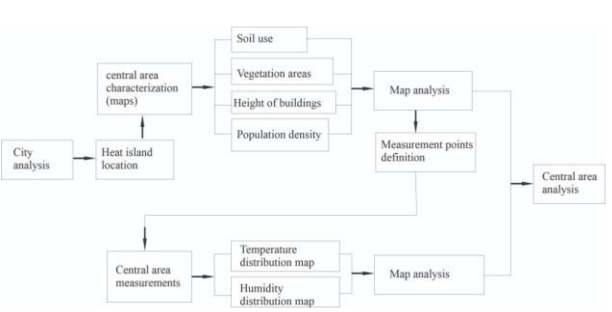
Again, the maps, graphs, and arguments produced from the information collected are analysed. This analysis derives the definition of measurement points representative of the different spatial configurations in the selected area. A new transect is then carried out, recording the same variables described above, with subsequent data processing and making maps of the behaviour of temperature and relative humidity.

A new analysis of the conditions found in the delimited area is made, with the same premises described above, in order to show, on a smaller scale and in greater detail, influences of the built environments in the formation of microclimates in the city.

It is important to emphasize that this step was disregarded in elaborating maps for climate analysis and recommendations for urban planning, as will be discussed later.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

Figure 2:
Diagram of the proposed methodology on the scale of the central region of the city.



Measurements were made at each season and at a given time, with the car at a speed of 40 km/h, requiring at least two minutes to wait at each point of analysis to stabilize the equipment. After this period, the value of the temperature and relative humidity variables and the exact minute of the record are recorded, which are shown through the console inside the car.

Subsequently, after collecting and correcting the data, maps were generated using the kriging method, using the SAGA GIS geostatistics software, in which the corrected temperature and relative humidity averages of the three days of measurements in each period were inserted. In this way, temperature and humidity distribution maps were obtained separately for the three morning, afternoon, and night periods.

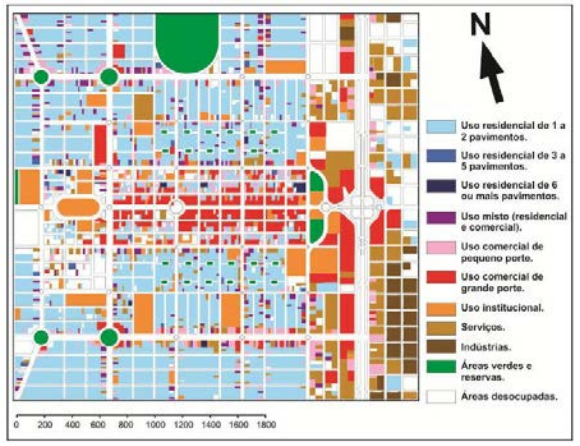
Therefore, from the information of the land use and occupation map, the density map of the studied area, and the maps of distributions of air temperature and relative humidity of the three periods, it was possible to verify the points with more considerable climatic alterations in the center of the city of Sinop-MT.

3. RESULTS

3.1 Analysis Sinop city center

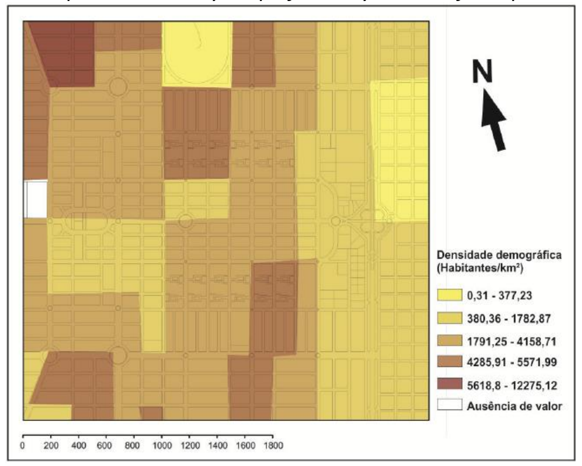
From the analysis of the land use and occupation map of the central part of the city of Sinop-MT (Figure 3), it was observed that Av. dos Mognos and the adjacent streets concentrate the most significant number of commercial establishments. In the other blocks, residential use is intense. It was also noted a large number of unoccupied lots in this region, evidencing the real estate speculation, present even in the oldest and busiest region of the city.

Figure 3:
Land use maps of downtown Sinop-MT



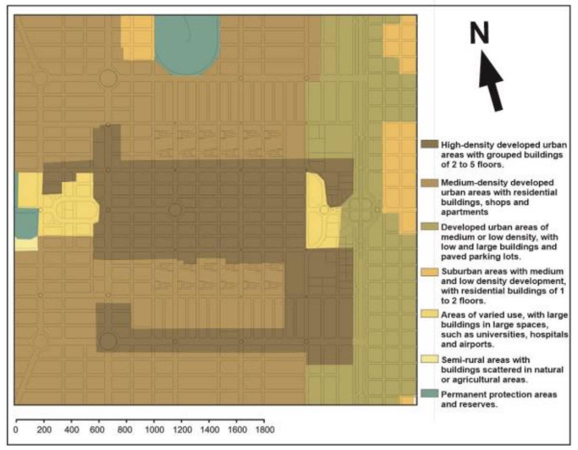
Regarding the population density map (Figure 4), it is evident that the region is no longer densely occupied by inhabitants; however, it is observed that, in all the censused sectors, there is always the presence of dwellings, even along Av. dos Mognos (predominantly commercial). Mixed-use (commercial and residential in the same unit) is also quite frequent, contributing to the central region's occupation, even if small.

Figure 4:
Population density map of the city center of Sinop-MT.



The map of urban structures, organized according to their ability to impact the climate (Figure 5), shows that in the city center, there is a relative heterogeneity of occupations. Mainly along the axis of Av. dos Mognos and adjacent streets, along the axis of Av. dos Tarumãs, there are the most developed areas with the highest density. On the other hand, open areas are still found, with scattered buildings and a specific concentration of vegetation, as is the case of the city's Cathedral and Bíblia square.

Figure 5:
Map of urban structures with impact on climate for Sinop city center.

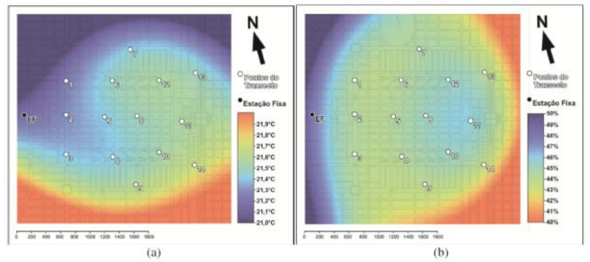


3.2 Climate Analysis

In the dry season in the morning period, slight variation was observed in the average values of air temperature between the points of the transect. Point 14 recorded 21.7°C and point 1, 21.2°C on average, the difference being only 0.5°C. The most significant temperature difference recorded between the measurement days took place on 08/29/2013 when point 14 recorded 20.4°C, and point 1 recorded 19.5°C, with a difference of 0 .9°C, also significantly reduced. This panorama is repeated with the values of relative humidity of the air. Only 3% on the average variation was observed, between points 11 and 14.

From the observation of the maps of average distribution of temperature and relative humidity, for the morning period in the dry season (Figure 6), it is possible to verify the tendency of temperature increase in the South of the central region, influenced by Av. dos Tarumãs, and a decrease in relative humidity values to the East, influenced by Highway BR-163. Noted the formation of a small region with lower temperatures to the West of the Center (near the UNEMAT Reserve), covering points 1 and 2, and a small region (in Bíblia square), covering points 10 and 11. In all cases, it is observed that such changes are very mild, almost imperceptible, demonstrating the low impact of land use and human activities on this evaluation scale and in this period.

Figure 6:
Maps of average distribution of air temperature (a) and distribution of relative humidity (b) for the Sinop city center on the average of measurement days in the morning period of the station

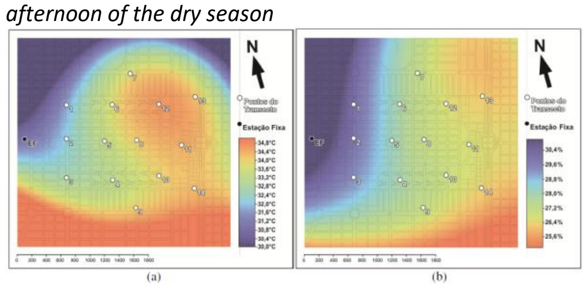


In the afternoon of the dry season, more significant variations are observed in the average values of temperature and relative humidity of the air between the transect points. Point 14 recorded 34.2 °C and pointed 1, 31.6 °C on average, with a difference of 2.6 °C. The most considerable temperature difference recorded between the measurement days occurred on the second day, when point 11 recorded 35.4 °C, and point 1 recorded 32.0 °C, with a difference of around 3.4 °C. Quite expressive. Regarding the relative air humidity values, 4% of the average variation was observed between points 1 and 14, with the most significant difference recorded on the third day of measurement, when, between points 1 and 14, the difference was in the order of 6%.

The maps of the average distribution of temperature and relative humidity in this period (Figure 7) show the trend of increasing temperature to the south of the central region and a warmer region covering points 6, 7, 8, 11, 12, and 13. On the other hand, the trend of decreasing relative humidity values is configured in the Southeast direction, in the same way as in the surroundings of point 13.

Here we can see the evident influence of the UNEMAT Reserve and the Forest Park in the decrease in temperature values and the increase in relative humidity values.

Figure 7:
Maps of average distribution of air temperature (a) and distribution of relative humidity (b) for the Sinop city center on the average of measurement days in the afternoon of the dry season

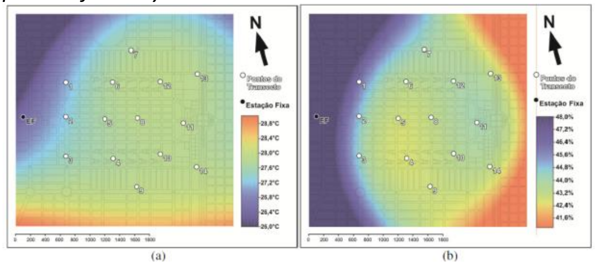


At night, few variations are observed in the average temperature and relative humidity values between the transect points. Point 10 recorded an average of 27.9 °C and pointed 1, 27.0 °C, with a difference of 0.9 °C. The most considerable temperature difference recorded between the measurement days was recorded on the second day when point 10 recorded 28.3 °C, and point 1 recorded 27.2 °C, the difference being 1.1 °C, not very expressive. Regarding the relative air humidity values, a 3% average variation was observed between points 1 and 14, with the most significant difference recorded on the second day of measurement and between points 1 and 14, with a difference of 5%.

Observing the maps of the average distribution of temperature and relative humidity in this period (Figure 8), it is possible to verify the tendency of temperature increase in the south of the central region and the tendency to decrease the relative humidity values in the east direction. Once again, the apparent influence of the UNEMAT Reserve and the Florestal Park in the decrease in temperature values and the increase of relative humidity values are verified.

Figure 8:

Maps of average distribution of air temperature (a) and distribution of relative humidity (b) for the Sinop city center on the average of measurement days in the night period of the dry season.



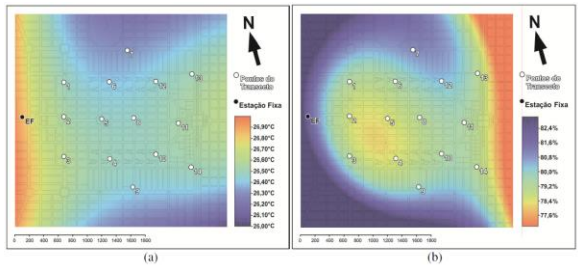
In the rainy season, there was also a slight variation in the average air temperature values between the transect points in the morning. Point 3 recorded 26.6°C and point 7, 26.3°C on average, the difference being only 0.3°C. The most significant temperature difference recorded between the measurement days took place on 03/19/2014 when point 3 recorded 27.6°C, and point 10 recorded 27.0°C, with a difference of 0 .6°C, also significantly reduced. This panorama is repeated concerning the values of relative humidity of the air. Only 3% of the average variation was observed between points 4 and 7.

From the observation of the maps of the average distribution of temperature and relative air humidity, for the morning period in the rainy season (Figure 9), it is possible to verify the tendency of increase of temperature to the West of the central region and of decrease of the values of relative humidity to the East, influenced by Highway BR-163. Noted the formation of a small region with lower relative humidity covering points 2, 4 and 5, in the vicinity of Plínio Callegaro square.

As in the previous season, it is observed that such changes are very mild in the morning, almost imperceptible, demonstrating the low impact of land use and human activities on this assessment scale and in the evaluated period.

Figure 9:

Maps of average distribution of air temperature (a) and distribution of relative humidity (b) for the Sinop city center on the average of measurement days in the morning of the rainy season.



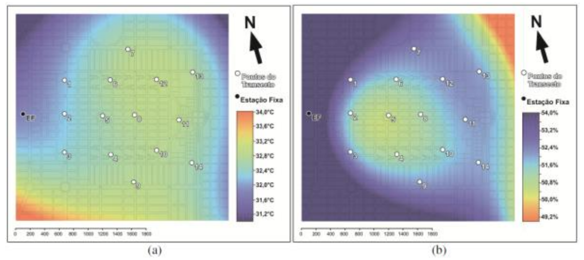
In the afternoon of the rainy season, there are few variations in the mean values of temperature and relative humidity between the transect points. Point 12 recorded 32.8°C and point 1, 32.1°C on average, with a difference of 0.7°C. The most significant temperature difference recorded between the measurement days took place on 03/17/2014 when point 12 recorded 32.9°C, and point 1 recorded 31.7°C, with the difference in the order of 1.2°C. Regarding the values of relative air humidity, an average variation of 3% was observed, between points 1 and 5, with the greatest difference recorded on 03/17/2014, when, between points 1 and 5, the difference was on the order of 5%.

The maps of the average distribution of temperature and relative humidity in this period (Figure 10) show the trend of increasing temperature in the South of the central region and decreasing relative humidity values in the East direction, forming a less humid region encompassing points 2, 4, 5, 6, 8, and 10.

Once again, the evident influence of the UNEMAT Reserve and the Florestal Park on the decrease in temperature values and the increase in relative humidity values can be observed.

Figure 10:

Maps of average distribution of air temperature (a) and distribution of relative humidity (b) for the Sinop city center on the average of measurement days in the afternoon of the rainy season.

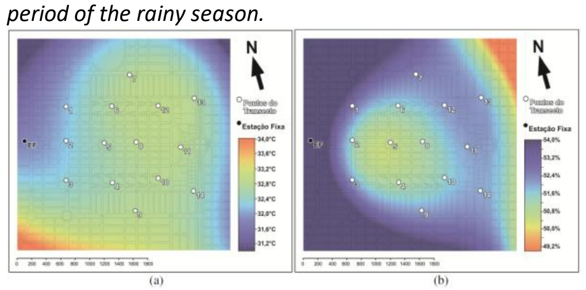


At night, few variations are observed in the average temperature and relative humidity values between the transect points. Point 1 recorded an average of 27.7 °C and point 14, 27.2 °C, with a difference of only 0.5 °C. The most significant temperature difference recorded between the measurement days was recorded on 03/18/2014 when point 1 recorded 28.6 °C, and point 14 recorded 27.2 °C, with a difference of 1.4 °C, very close to that recorded in the dry season. Regarding the relative humidity values, there was an average variation of 3%, between points 1 and 14, with the largest difference recorded on 03/18/2014, also between points 1 and 14, in a difference of an order of 8%.

Observing the maps of the average distribution of temperature and relative humidity in this period (Figure 11), it is possible to verify the trend of temperature increase and decrease relative humidity values in the North of the central region. It is also possible to observe the low influence of the UNEMAT Reserve and the Florestal Park on the decrease in temperature values and the increase in relative humidity values, with a notably wetter region encompassing points 11, 12, 13, and 14.

Figure 11:

Maps of average distribution of air temperature (a) and distribution of relative humidity (b) for the Sinop city center on the average of measurement days in the night period of the rainy season.



4. CONCLUSION

Since the measurements carried out took place in two well-defined stations in the municipality of Sinop, it was clear in this research that the option for data collection at the height of the dry and rainy periods represents regional climatic differences.

In addition, the methodology developed by Sanches (2015) [4] for assessing the urban climate of small cities using mobile transects, to assess the climatic differences of smaller portions of the city was effective.

Finally, it was found that there was little variation in temperature and relative humidity between the points, both in the dry and in the rainy season. However, high temperatures and low relative humidity were recorded in the central part of the city, so, based on this climate knowledge, it is possible to elaborate guidelines that aim to reduce harmful weather effects in this area.

REFERENCES

1. ASSIS, E. S. DE. Estudo Integrado da Ilha de Calor em Áreas Urbanas e sua Contribuição ao Planejamento: O Caso de Belo Horizonte, MG. *Fórum Patrimônio*, v. 4, n. 1, p. 69–83, 2011.

2.GRIMMOND, S. *Climate of cities*. In: Atmospheric observation panel for climate. Sixteenth session. Geneva, 2010.

3. Barbirato, G. M.; Souza, L. C. L.; Torres, S. C. (2007) Clima e cidade: a abordagem climática como subsídio para estudos urbanos. EDUFAL. Maceió.

4. SANCHES, João Carlos Machado. Uma metodologia para a inserção do clima como critério *para o planejamento urbano*: análise da cidade de Sinop-MT. Rio de Janeiro, 2015. Tese (Doutorado em Urbanismo) – Programa de Pós-graduação em Urbanismo – PROURB/FAU/UFRJ, Universidade Federal do Rio de Janeiro, 2015.

5. WMO. WORLD METEOROLOGICAL ORGANIZATION. *Guide to Meteorological Instruments and Methods of* Observation. WMO, Report No. 8. 7th Edition, 2008.

6. DAVIS INSTRUMENTS. Vantage Pro2 Console Manual. Davis Instruments Corp., (2012). Available: ttp://www.davisnet.com/product_documents/weather/manuals/07395-234_IM_06312.pdf

PLEA SANTIAGO 2022
Will Cities Survive?

Optimization of a social housing model in Brazil

The EPS application to reduce the impact of climate change on buildings' thermal-energy performance

ALEXANDRE SANTANA CRUZ [1], LEOPOLDO EURICO GONÇALVES BASTOS[1], AXEL BESSON[2]

[1] Universidade Federal do Rio de Janeiro - UFRJ
[2] Institut National des Sciences Appliquées de Lyon – INSA Lyon

ABSTRACT: The aim of this paper was to assess the efficiency of thermal insulation application for thermal-energy performance of Brazilian social housing. This study evaluated through computer simulation a representative project designed with Expanded Polystyrene (EPS) application for the building's envelope while addressing the impact of climate change. The performed simulations were based on the EnergyPlus software coupled with jEPlus parametrization and jEPlus+EA Optimization tools. The Climate Change World Weather File Generator tool was used to produce weather data for future climate scenarios. The multi-objective optimizations, using the Non-dominated Sorting Genetic Algorithm II (NSGA-II), focused on improving indoor thermal comfort whilst reducing the building energy demand. The building envelope optimization considered different parameters as the building's orientation, glazing solution, and EPS thickness. Thus, the intent was to show that the EPS application in the building envelope can provide indoor thermal comfort and energy savings, for Brazilian climate regions that mainly require cooling systems.
KEYWORDS: Optimization, Thermal Insulation, Social Housing, Climate Change, Energy Efficiency

1. INTRODUCTION

In Brazil, it is estimated that the country has a deficit of 6 million housing units (Fundação João Pinheiro, 2018). Thus, in 2009, the Federal Government created the "My House, My Life" program to facilitate house access for low-income families (Hehl et al., 2014). The program focused on a standardized model for the whole country to reduce costs and accelerate the construction process. Consequently, the result led to low quality buildings, which do not meet the users' needs in many ways, especially in terms of thermal comfort and energy performance (Dalbem et al., 2019).

Discussions about energy efficiency in Brazil are extremely recent (Cruz et al., 2020). The NBR 15220 was the first Brazilian standard published in 2005 that provides constructive guidelines and bioclimatic strategies to assess the social housing thermal performance (ABNT, 2005). Later, the NBR 15575, published in 2008, established the requirements and performance criteria applicable to residential buildings in the project phase (ABNT, 2013). Finally, the Technical Quality Regulation for the Energy Efficiency Level for Residential Buildings (RTQ-R), published in 2010, indicates technical requirements for building classification from the highest to the lowest energy efficiency, on a scale rank from "A" to "E", respectively (RTQ-R, 2012). Although regulations have evolved in recent years, buildings represent 50% of total electricity demand in Brazil, with residential sector as the largest consumer, accounting for 25% (MME, 2019).

Parallel to this, there is a growing concern about climate change as a potential threat to increase buildings' energy demand and dependence on the HVAC system (Lamberts et al., 2014). Based on simulations using future weather files, several studies have shown that the use of adaptation measures, such as windows with shading devices, low solar absorptances for the envelope coating and the use of insulation, are essential to reduce the impact of climate change on building' thermal-energy performance (Cruz & Cunha, 2021; Invidiata & Ghisi, 2016; Triana et al., 2018).

Thermal insulation is one of the most effective ways of saving energy in buildings (Lamberts et al., 2014). For the envelope, Expanded Polystyrene (EPS) is a common approach worldwide, and stands out for numerous advantages like being recyclable, its lightness, its easy application, the prevention of mould and moisture, and it does not spread flame (Smakosz & Tejchman, 2014). Modular prefabricated EPS panels can provide low thermal transmittance values, and reduce heat exchange with the external environment, acting as a passive design strategy to reduce HVAC energy demand. But at the same time, high levels of thermal insulation can promote overheating by blocking the indoor heat dissipation in regions that are mainly requiring cooling systems, unless appropriate measures to improve thermal comfort are adopted (Cruz & Cunha, 2021).

Therefore, the objective of this study was to assess the efficiency of thermal insulation application for the thermal-energy performance of Brazilian social housing. This study considered computer simulations for a single-family housing with EPS application while addressing the impact of climate. The performed simulations were based on EnergyPlus software coupled with jEPlus parametrization and jEPlus+EA Optimization tools. The Climate Change World Weather File Generator tool was used to provide future climate weather data. The multi-objective optimizations employed the Non-dominated Sorting Genetic Algorithm II (NSGA-II) focused on improving indoor thermal comfort, whilst reducing building' energy demand. The building envelope optimization considered some parameters as building's orientation, glazing solution, and EPS thickness. Thus, the intent was to identify if the application of EPS in the building envelope can provide both indoor thermal comfort and energy savings, for Brazilian climate regions that mainly require cooling systems.

2. METHOD

As a case study, it was analyzed a representative single-family housing project from the Brazilian program "My house, my life", located in the city of Rio de Janeiro – Brazil. The method followed presented four sections. The first one (2.1), by means of the CCWorldWeatherGen tool, the weather files were modified and evaluated for future climate scenarios such as 2050, and 2080. The next section (2.2) concerned the base case simulation using the EnergyPlus software. The thermal envelope solution met the minimum requirements established by the NBR 15575 standard, in order to verify its thermal-energy conditions. In the third section (2.3), using the EnergyPlus software coupled with jEPlus parametrization and jEPlus+EA Optimization tools, the energy model was optimized for a future climate (2080), besides the current climate scenario. The established optimization process varied three parameters for the envelope from the base case: building's orientation, glazing solution, and thermal insulation thickness of the wall and roof. Based on the NSGA-II algorithm, the multi-objective simulation focused on minimizing the cooling energy demand and discomfort hours of the model. The last section (2.4), introduced a comparison and analysis for the three models' simulations performed with the future weather file (2080): NBR 15575 model; optimized model for the current scenario (TRY format); and the optimized model for this future scenario (2080).

2.1 Future climate scenarios

This research considered future climate scenarios to evaluate the impact of climate change. According to previous studies (Cruz & Cunha, 2021; Invidiata & Ghisi, 2016; Triana et al., 2018), the tool known as CCWorldWeatherGen can be used to generate future climate scenarios (SER Group, 2012). The tool is a Microsoft Excel based instrument that uses EnergyPlus Weather file (EPW) files to generate future weather data for any location in the world, in the A2 emissions scenario for 2020, 2050, and 2080. The research was based on the A2 scenario from the IPCC Third Assessment Report that is considered to be the current trend in the world (high emission scenario) (Triana et al., 2018). Following the NBR 15220, the Brazilian territory presents eight Bioclimatic Zones (BZ), being BZ 8 classified as the hottest zone (ABNT, 2005). To evaluate the effects of climate change in Brazilian hottest regions, it was considered the city of Rio de Janeiro located in the BZ 8. The weather files from Rio de Janeiro - Brazil in Test Reference Year (TRY) format available at Energy Efficiency in Buildings Laboratory (LABEE, 2021) was inserted into CCWorldWeatherGen tool. The Rio de Janeiro climatic parameters are presented in Table 1.

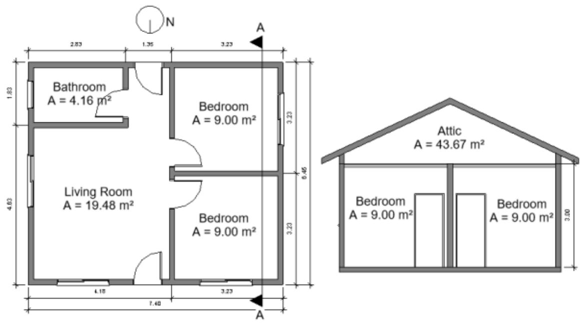
Table 1:
Weather data of Rio de Janeiro (LABEEE, 2021).

Koppen Geiger	Dry bulb temperature (°C)			Relative humidity (%)
	Average	Max	Min	Average
Aw	25	30	21	78

2.2 The NBR 15575 model

The chosen project of a single-family housing typology for the low-income sector come from previous studies (Hehl, 2014; Triana, 2015). The house has a net area of 43 m² which is equivalent to the minimum area set by the "My House, my Life" program. The one-floor house model consists of 2 bedrooms, a living-room, a bathroom, a ceiling height of 3m, facing north-south, and a fenestration area of 6m². Figure 1 showed the social housing floor plan, and section of the single-family house.

Figure 1:
Low-income housing model.



The assumed envelope characteristics as thermal transmittance, solar absorptance, and solar factor values for the project are shown in Table 2. All of them followed the Brazilian guidelines for BZ 8, and configurated the base case, named here as the NBR 15575 model (ABNT, 2013).

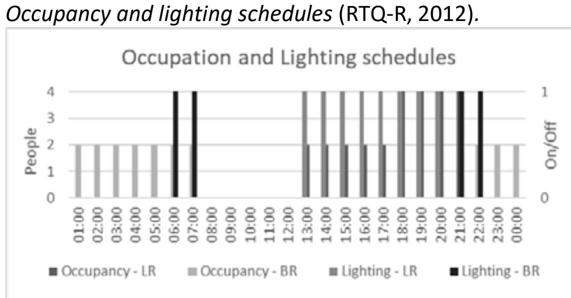
Table 2:
NBR 15575 model description (ABNT, 2013)

Element Description	U (W/m^2K)	SA (%)	SF (%)
Wall - ceramic brick with plaster	2.50	20	-
Glass - 3mm	5.80	-	86
Floor - Concrete slab + ceramic tiling	3.40	20	-
Roof – Cement fiber sheet with ceiling wood	2.20	60	-

Note: U = Thermal transmittance; SA = Solar absorptance; SF = Solar Factor

The numerical model was configurated with the standard values presented in the RTQ-R for: occupancy, lighting, equipment, natural ventilation and air-conditioning system (RTQ-R, 2012); and five thermal zones: living-room, bathroom, bedroom 1, bedroom 2, and the attic. It was also considered a minimum occupancy of two people per bedroom (BR) and four people in the living room (LR). The lighting schedule followed the occupancy schedule for each room according to Figure 2, respectively.

Figure 2:
Occupancy and lighting schedules (RTQ-R, 2012).



The people's metabolic rates considered for the living room and bedrooms were 108 W/person, and 81 W/person, respectively. The installed power density for lighting considered in the living room and bedrooms were 5 W/m^2, and 6W/m^2, respectively. In addition, a constant internal load density of 1.5 W/m^2 for the living room was considered for the period of 24h (RTQ-R, 2012).

Two conditions were configured based on RTQ-R guidelines: a) naturally ventilated mode; and b) air-conditioned mode. The naturally ventilated model is done using the airflow network object in EnergyPlus defined as happening 24h per day throughout the whole year. In order to feature the ASHRAE Adaptive Comfort model (ASHRAE, 2013), window opening occurs automatically when the indoor air temperature is equal or greater than the thermostat trigger temperature, 20°C ($T_{int} \geq T_{setpoint}$), and when the internal air temperature is higher than the external temperature ($T_{int} \geq T_{ext}$) (Dalbem et al., 2019). Regarding to the second simulation mode, an air-conditioning system was configured to predict the energy demand for the whole year and identify building's dependence of air-conditioning to achieve thermal comfort conditions. This mode came from the package Terminal Heat Pump available in EnergyPlus and established for all main rooms. The air-conditioning system was defined for a long-stay room occupation similar to the occupancy schedule with a setpoint of 20°C for heating and 25°C for cooling, according to the regulation RTQ-R. The heating and cooling system had a performance ratio (COP) of 3.00 (RTQ-R, 2012).

2.3 Optimization process

As mentioned before, two conflicting objectives were involved simultaneously during the optimization process. The intent was to minimize the amount of discomfort hours and the cooling energy demand for the case study based on design variables. The simulation process utilizes EnergyPlus software coupled with jEPlus parametrization and jEPlus+EA optimization tools.

The NSGA-II algorithm, employed in this study, creates a random population based on the design variables ranges given as model inputs (Gou et al., 2018). It evaluates the fitness functions obtained with the initial population and ranks solutions based on non-dominated sorting. Afterward, the algorithm crossovers and mutates selected solutions to create the next generation, and applies elitism to the best individuals from parents' chromosomes. Individuals with a higher rank and a larger crowding distance are selected as the new parents for crossover and mutation to generate the new generations of children (Gou et al., 2018; Linczuk & Bastos, 2020). The process runs until it reaches a final condition or stops if the number of solutions found is enough. In the applied NSGA-II algorithm, the population size of 50 was chosen with crossover rates equal to 1, mutation rates equal to 0.2, tournament size equals to 2, and generations set to 100, respectively (Linczuk & Bastos, 2020).

For the optimization process, two climate scenarios were considered: the current climate scenario (TRY format) and the future climate scenario (2080). Thus, two distinct optimization processes were performed considering the design variables described in Table 3.

Table 3:
List of design variables used in the optimization process.

id	Description	Box constraints
0	Building long axis azimuth (º)	0 - 315 (step 45)
1	Glazing U-value (W/m^2K)	1.02, 1.64, 2.27, 2.89,3.51, 4.13, 4.76, 5.38, 6
2	Glazing SHGC	0.19, 0.28, 0.37, 0.46, 0.54, 0.63, 0.72, 0.81, 0.90
3	External walls EPS thickness (m)	0.00, 0.06, 0.08, 0.10, 0.12
4	Roof insulation thickness (m)	0.00, 0.06, 0.08, 0.10, 0.12

3. RESULTS

3.1 Future climate of Rio de Janeiro - Brazil

The average values of air temperature, relative humidity, and global horizontal radiation, respectively for the TRY, 2050, and 2080 climate files of the city of Rio de Janeiro generated by the CCWorldWeatherGen tool are indicated in Table 4.

Table 4:
Weather data for future climate scenarios.

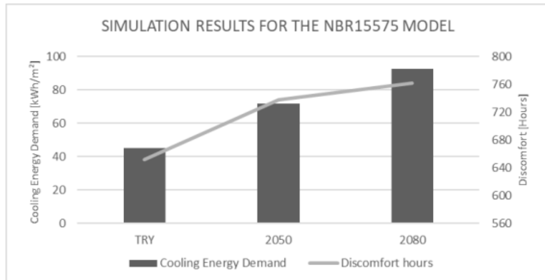
Climate metric	TRY	2050	2080
Dry Bulb Temperature (◦C)	23.5	25.2	26.5
Relative Humidity (%)	82.6	89.1	93.4
Global Horizontal Radiation (Wh/m^2)	207.9	214.7	220

The annual mean outdoor air temperature will increase by 3°C, the annual mean relative humidity will decrease by 10.8%, and the annual mean global horizontal radiation will increase by 12.1 Wh/m^2, until 2080.

3.2 The NBR 15575 Model performance

Following the described method, the results for the thermal-energy performance of NBR 15575 model for current and future climates, under natural ventilation and using a HVAC system, are indicated in Figure 3. For the natural ventilated mode, the metric evaluated was the yearly discomfort hours (h), and when considering the HVAC system, the metric evaluated was the yearly cooling energy demand (kWh/ym^2).

Figure 3:
Cooling energy demand and discomfort hours for the low-income house and RTQ-R model.

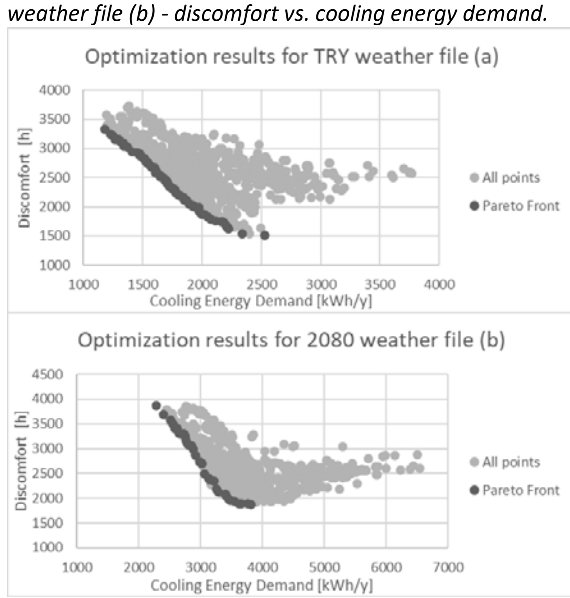


As expected, the number of discomfort hours will increase in the coming decades, and consequently, the dependence on the HVAC system. The annual discomfort hours will increase about 100 hours and the cooling energy demand will double by 2080.

3.3 Optimization process

The multi-objective optimization was performed to find optimal design solutions for the NBR 15575 model in terms of comfort hours and energy demand. The multi-objective optimization study considered the TRY weather file and the 2080 future scenario by generating a series of optimal solutions called Pareto-front. All results and optimal solutions in the Pareto-front are presented in Figure 5. At first, it is possible to conclude that in 2080, despite the design solution, residents will consume more energy and suffer more discomfort than in the TRY scenario.

Figure 5:
Optimization results for TRY weather file (a) and 2080 weather file (b) - discomfort vs. cooling energy demand.



Based on parallel coordinates, Table 5 complemented Figure 5 and showed the results for the three best solutions configurations depicted from the Pareto-front for the TRY and 2080 scenarios.

Table 5:
The three best solutions configurations from the Pareto-front for the TRY and 2080 weather files.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

id	TRY			2080		
	1º	2º	3º	1º	2º	3º
0	180	180	180	225	225	225
1	4	6	6	1	1	1
2	0.5	0.5	0.6	0.3	0.5	0.6
3	0.06	0.08	0.08	0.1	0.12	0.08
4	0.06	0.08	0.06	0.1	0.1	0.1

In all solutions, using EPS as thermal insulation in the roof and walls was preferred. Based on Table 5, in the future, the thickness increase for thermal insulation will ensure better performance. Moreover, high-performing glass, greater sun protection (SHGC), and low thermal transmittance (U-Value) will be essential in residential projects.

3.4 Comparative analysis of the Models

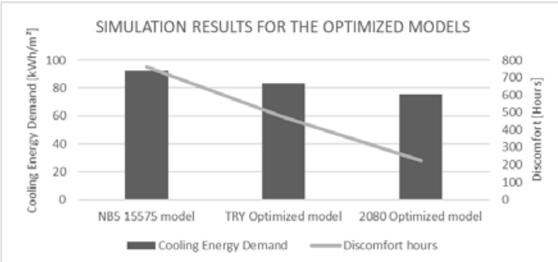
Finally, the three models were examined by simulation means, for the future weather file (2080): the NBR 15575 model; the best optimized model for the current scenario (TRY format); and the best optimized model for the future scenario (2080). The configuration of these models is described in Table 6.

Table 6:
The final solutions configuration.

id	NBR 15575 Model	TRY Optimized Model	2080 Optimized Model
0	0	180	225
1	5.8	4	1
2	0.86	0.5	0.3
3	0	0.06	0.1
4	0	0.06	0.1

The thermal-energy performance for each model: under natural ventilation and the use of an HVAC system, are presented in Figure 6. Similar to the first section, the metrics evaluated are the yearly discomfort hours (h), and the yearly cooling energy demand (kWh/ym²).

Figure 6:
Cooling energy demand and discomfort hours for the Optimized models.



As expected, Figure 6 presented the optimized model of 2080 as the one with the best performances. These results confirmed that future climate scenarios are required to evaluate new design solutions. In addition, both optimized models indicated a decrease of discomfort hours and energy consumption compared to the NBR 15575 model. The TRY Optimized model and the 2080 Optimized model were able to reduce discomfort hours by 28% and 54%, respectively. In terms of cooling demand, the models were able to reduce the energy demand by 10% and 17%, respectively. This optimization study emphasizes a revision of the construction guidelines of NBR 15575 to consider future climate scenarios. Furthermore, the adoption of thermal insulation on walls and roof, combined with high-performance glass, proved to be a promising alternative for climate change in the Brazilian climate regions that mainly require a cooling system like the city of Rio de Janeiro.

4. CONCLUSION

Discussions about energy efficiency in Brazil are extremely recent, and although regulations have evolved in recent years, the residential sector is still the largest consumer of electricity in the country. Parallel to this, there is a growing concern about climate change as a potential threat to the increasing buildings' energy demand and dependence on HVAC system. Thus, the purpose of this paper was to optimize the application of thermal insulation in social housing located in Rio de Janeiro - Brazil to reduce the impact of climate change on the thermal-energy performance of the residential sector.

As considered, the first section consisted of using the CCWorldWeatherGen tool, to modify weather files for future climate scenarios. By 2080, there would be: an increase of 3°C for the annual mean outdoor air temperature, 10.8% increase for yearly mean relative humidity, and 12.1Wh/m² increase for the yearly mean global horizontal radiation. In the second section, thermal-energy performance of the NBR 15575 model for current and future climates were assessed. Results indicate a 10% increase in the number of discomfort hours and the double by 2080 for the cooling energy demand if we continue to follow the Brazilian standards. The third section, related to multi-objective optimization emphasized optimal design solutions for the NBR 15575 model. Thus, it was possible to say for the future climate conditions, the increase of the thermal insulation thickness will ensure better building performance. In addition, high-performing glass, greater sun protection (SHGC) and low thermal transmittance (U-Value) will be essential in residential projects. Finally, in the last section, focused on the simulation of three models under a future scenario (2080): NBR 15575 model; best optimized model for the current scenario (TRY format); and best optimized model for 2080. Results indicated that future climate scenarios are required to evaluate buildings' performance with new design solutions. Moreover, both optimized models showed a reduction of discomfort hours and energy consumption when compared with the NBR 15575 model. The TRY Optimized Model and the 2080 Optimized Model were able to reduce discomfort hours by 28% and 54%, respectively. In terms of cooling demand, the models were able to reduce the energy demand by 10% and 17%, respectively. The optimization developed indicated the need to review the constructive guidelines of NBR 15575 based on the future climate impact. Furthermore, the adoption of EPS thermal insulation on walls and roof, combined with high-performing glass, proved to be a promising alternative for Brazilian climate regions that are mainly requiring a cooling system like the city of Rio de Janeiro.

ACKNOWLEDGEMENTS

The authors would like would like to thank the Higher Education Improvement Coordination (CAPES) - BRAZIL.

REFERENCES

1. ABNT. (2005). *NBR 15220: Thermal Performance for Social Interest Housing, Part 2: Calculation Method of Thermaltransmittance, Thermal Capacity, and Termal Lag of Building Componentes.*
2. ABNT. (2013). ABNT NBR 15575-4:2013 - Edificações habitacionais - Desempenho Parte 4 : Sistemas de vedações verticais internas e externas. In *Associação Brasileira de Normas Técnicas*.
3. *Arquivos climáticos em formato TRY, SWERA, CSV e BIN | Laboratório de Eficiência Energética em Edificações*. (n.d.). Retrieved March 31, 2021, from https://labeee.ufsc.br/downloads/arquivos-climaticos/formato-try-swera-csv-bin
4. ASHRAE. (2013). Thermal Environmental Conditions for Human Occupancy. In *ASHRAE STANDARD 55*. https://doi.org/10.1016/0140-7007(79)90114-2
5. Cruz, Alexandre S., de Carvalho, R. S., & da Cunha, E. G. (2020). Passive house alternative proposal for the Brazilian Bioclimatic Zone 8. *International Journal of Sustainable Development and Planning*, *15*(6), 827–833. https://doi.org/10.18280/ijsdp.150605
6. Cruz, Alexandre Santana, & Cunha, E. G. da. (2021). The impact of climate change on the thermal-energy performance of the SCIP and ICF wall systems for social housing in Brazil. *Indoor and Built Environment*, *0*(0), 1–15. https://doi.org/10.1177/1420326X211038047
7. Dalbem, R., Grala da Cunha, E., Vicente, R., Figueiredo, A., Oliveira, R., & Silva, A. C. S. B. da. (2019). Optimisation of a social housing for south of Brazil: From basic performance standard to passive house concept. *Energy*, *167*, 1278–1296. https://doi.org/10.1016/j.energy.2018.11.053
8. FUNDAÇÃO JOÃO PINHEIRO. (2018). *Déficit Habitacional no Brasil 2015: Estatística & Informações, Demografia e Indicadores Sociais*. http://www.bibliotecadigital.mg.gov.br/consulta/consultaDetalheDocumento.php?iCodDocumento=76871
9. Gou, S., Nik, V. M., Scartezzini, J. L., Zhao, Q., & Li, Z. (2018). Passive design optimization of newly-built residential buildings in Shanghai for improving indoor thermal comfort while reducing building energy demand. *Energy and Buildings*, *169*, 484–506. https://doi.org/10.1016/j.enbuild.2017.09.095
10. Hehl, R., Angelil, M. M., & Something Fantastic. (2014). *Minha casa - nossa cidade: innovating mass housing for social change in Brazil* (Issue February). https://doi.org/3944074092
11. Invidiata, A., & Ghisi, E. (2016). Impact of climate change on heating and cooling energy demand in houses in Brazil. *Energy and Buildings*, *130*(2016), 20–32. https://doi.org/10.1016/j.enbuild.2016.07.067
12. Lamberts, R., Dutra, L., & Pereira, F. O. R. (2014). *Eficiência Energética na Arquitetura* (3ª). Eletrobras.
13. Linczuk, V. C. C., & Bastos, L. E. G. (2020). Otimização multiobjetivo orientada ao desempenho térmico para o projeto de edificações de baixo consumo de energia na Região Sul do Brasil. *Ambiente Construído*, *20*(4), 509–529. https://doi.org/10.1590/s1678-86212020000400485
14. MME, M. of M. and E. (2019). *Brazilian Energy Balance*.
15. RTQ-R. (2012). Regulamento Técnico da Qualidade para o Nível de Eficiência Energética Edificações Residenciais (RTQ-R). *Aleph*. http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC001788.pdf
16. Smakosz, Ł., & Tejchman, J. (2014). Evaluation of strength, deformability and failure mode of composite structural insulated panels. In *Materials and Design* (Vol. 54, pp. 1068–1082). https://doi.org/10.1016/j.matdes.2013.09.032
17. Sustainable Energy Research Group - University of Southampton. (2012). Climate Change World Weather File Generator for World-Wide Weather Data. In *CCWorldWeatherGen*. http://www.energy.soton.ac.uk/ccworldweathergen
18. Triana, M. A., Lamberts, R., & Sassi, P. (2015). Characterisation of representative building typologies for social housing projects in Brazil and its energy performance. *Energy Policy*, *87*(December 2014), 524–541. https://doi.org/10.1016/j.enpol.2015.08.041
19. Triana, M. A., Lamberts, R., & Sassi, P. (2018). Should we consider climate change for Brazilian social housing? Assessment of energy efficiency adaptation measures. *Energy and Buildings*, *158*, 1379–1392. https://doi.org/10.1016/j.enbuild.2017.11.003

PLEA SANTIAGO 2022

Will Cities Survive?

City Lab

Support Infrastructure

MANUELA CARDONA BETANCOURTH [1] JUAN CAMILO AGUIRRE ARANGO[2] GUSTAVO CORREA VANEGAS, JUAN CARLOS GONZALES CEBALLOS

[1] Universidad Católica de Pereira

ABSTRACT: The current situation we live in worldwide, the pandemic, inequality and climate change highlight the crisis in health and security, a fact that evidences the fragility in the city models we occupy, generating collapses in the way of living, working, and recreating as human beings, demanding to rethink a different panorama for our present-day city.

For this reason, the object of study focuses on the city of Pereira, Colombia, which has been the epicenter of the arrival of immigrants in the current crisis, where more than 5,591 people arrived in the city in search of refuge, a fact that generated an increase of 78.5% triggering overcrowding in informal settlement housing.

Given this, it is to understand the city as a laboratory, which allows to understand the present and rethink it towards the future by identifying the shortcomings from the quality of life factors, that is how City Lab arises in the activation of the center of Pereira where different disused buildings that have become places of informal shelter are gradually identified to form a network of sustainable infrastructure to serve as a meeting point and in case of health emergencies as supply centers.

KEYWORDS: City, Shelter, Supply, Infrastructure, Disuse, Urban regeneration.

1. INTRODUCTION

The present condition we are experiencing worldwide, between the pandemic, social inequality and climate change, highlights the fragility of the current city models in which we inhabit, this is generating collapses in the ways of living, working, and recreating as human beings, demanding to reconsider a different way of city´s design.

For this reason, the object of study focuses on the city of Pereira, Colombia, which emerged in 1863 as a result of different migrations located between the center of Bogota, Medellin and Cali, this area that we know as the golden triangle, which because of its strategic position has been the epicenter of arrival of immigrants in the current crisis where more than 5,591 people came to the city in search of refuge and a better quality of life, a fact that generated an increase of 67.3% in the housing of informal settlements.

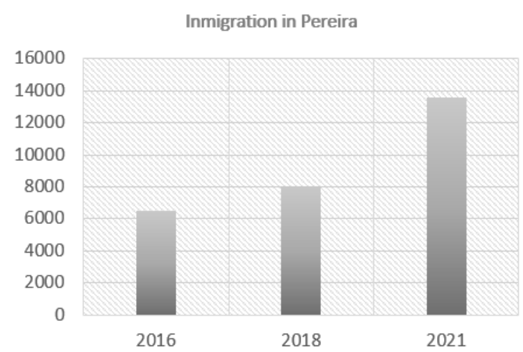


Figure 1 Pereira Immigrants.

generated situations of overcrowding in housing, making it more difficult to live in a pandemic. (Pereira cómo vamos,2020)

According to the study of the city's indicators, it is evident that in recent years the conditions of work, recreation and habitability have decreased, generating an imbalance in the configuration of the city.

Figure 2 Percentages of quality of life inhabit

Figure 3 Percentages of quality of life to work

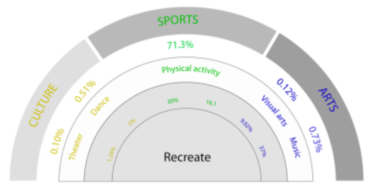


Figure 4 Percentages of quality life to recreate

2. ANALYSIS OF THE CITY

Pereira is a city that has been transforming and growing through different migrations, therefore, informal settlements have been a key factor to the development of the construction of the city, over time. The city´s layout was positioned on the old railroad track as a lineal city, in search of a better connectivity and tactical location turning as we know today as Av. 30 de Agosto (current name) in the center of historical memory because it is surrounded by the main commercial and dwelling neighborhoods that in its beginning were developed as an informal settlement, on the other hand Pereira has a main water resource known as the Otún river, thanks to its environmental and livelihood situation has been an attractive place to become the main refuge for displaced people on their banks and slopes, it also has a total accessibility to another of the main roads of the city known as Av. Del Rio.

This is how both roads and the river become axes of construction of the city center, where through public galleries, commercial passages, cultural activities generated a civism typical of Pereira, which because of the accelerated and unplanned growth began to segregate, in addition to this up-to-date coronavirus epidemic situation has ended with the few cultural spaces and commercial exchange its function as typical use of the city. New functions into the urban fabric seeks to enhance the main connectors through the occupied limit as a research project for reconfigured places, generating different enclosures that make the city.

Faced with this uncertain panorama that is related to the pandemic, the city is understood as a laboratory, which allows to understand the present and rethink it towards the future, seeking to generate different approaches that allow to cure the city of the segregation that imposes its ever-changing population.

Based on the understanding of the city as a laboratory. An example of analysis as references is made by the Exodus project (figure 5) , where Rem Koolhaas' Exodus shows us how the deconstruction of the limit becomes the element of integration of the city, and Constant's New Babylon (figure 6) shows us how the understanding of the city is given through a network of enormous links that are in movement and point to a society that congregates from leisure and recreation.

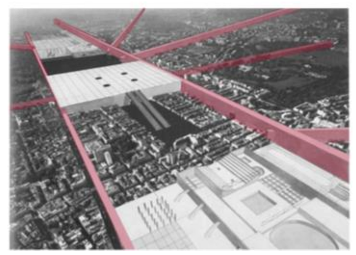


Figure 5 Exodus_Rem Koolhaas

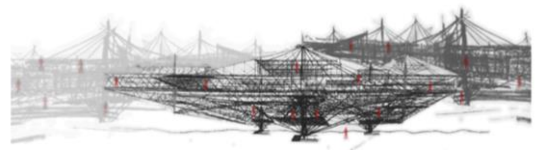


Figure 6 New Babylon_Constant

Based on the idea of society in movement and the prospect of the city of Pereira is facing as an uncertain panorama, which is a product of its constant migrations, movements, and its accelerated growth, the city is understood as follows:

The configuration of the urban hull as an automated city model that is interrupted by the covid situation, and suffering incidents due to climate change, and social inequality which has generated overcrowding in informal settlements and disconnecting society from collective spaces fact that triggers an unstable city model that unbalances the condition of inhabiting.

For this reason, the project is developed in the center of Pereira where different unused properties have been identified with potential to be centers of shelter, supplies and recreation in order to begin to recycle the abandoned structures avoiding a more unbridled growth within the city. These three (3) main properties have been chosen to introduce a change, as a seed of adjusting the recent situation. These properties are recognized as the longstanding convent of the Carmelitas, the old clinic Saludcoop and the non-used Carrefour supermarket; where a perimeter ring is generated that covers the two main roads of the city of Pereira. This ring becomes a limit that allows generating new developments and ways of living within the urban space that is contained and activated, where it seeks to improve the conditions inside the urban area by enhancing connectivity between the different infrastructures and breaking with the automated model of the configuration of the center of Pereira.

In order to select these properties, the explicit conditions of the land use plan (POT) were reviewed, and the following considerations were taken into account:

- Being located within the regulatory sectors, each property responds to an area of multiple activity, which allows us to generate a mix of uses that configure the disused properties in structures for housing, commerce, leisure, and culture where in case of health emergencies (pandemic) they can become the main source of supply and also because of its centrality and scale can become a meeting point. (POT,2016)

- In order to acquire the lots that are under the domain of private entities, the income tax that covers the different properties was reviewed, where it is proposed to the owner of the property under article 255 and 257 to cede the lot for the common good and 25% of the value of the property tax will be paid. (POT,2016)

In addition to this, the POT regulations allow us to carry out a macro project to recover the lost areas within the city and to recover the different collective activities that have been lost within the city due to the emergence of covid-19.

To complement the development of the boundary within the contained space, we begin to select support infrastructures in smaller scale lots that allow an expansion within the same contained space, becoming a network of links that improve the habitat.

3. DEVELOPMENT OF THE PROPOSAL.

Thinking about the situation of COVID-19 and the future of city in the face of this new state of uncertainty and the tangible arrival of new immigrants and more sanitary emergencies, the strategy of recycling infrastructures through a new dynamic of **"building on what is built"** *arises with the objective of seeking a joint improvement in different variables of habitability. The actual urban structures cannot stay rigid, unmoved they need to play and active roll as we upgrade the urban infrastructure, and services or more necessities arise.*

Developing the configuration of the structures in relation to the pandemic, it is proposed to generate within the volumetrics congregation spaces that become cultural nodes and allow to empower the community in order to heal both the city and society, this is proposed because the city of Pereira presented an increase of 78% in rates of anxiety and depression by citizens during the compulsory (Pereira cómo vamos 2020) isolation, being able to meet and arrange the city for these meetings in safe spaces will begin to integrate the entire support infrastructure with different civic activities of the city.

On the other hand, the strategy also seeks to enhance the rates of tree planting and public space in the city through the use of green roofs that allow the development of home gardens, as well as central spaces where they are implemented, thus generating easily accessible supply centers; the vegetation implemented also seeks to enhance the existence of courtyards as connecting points in the city.

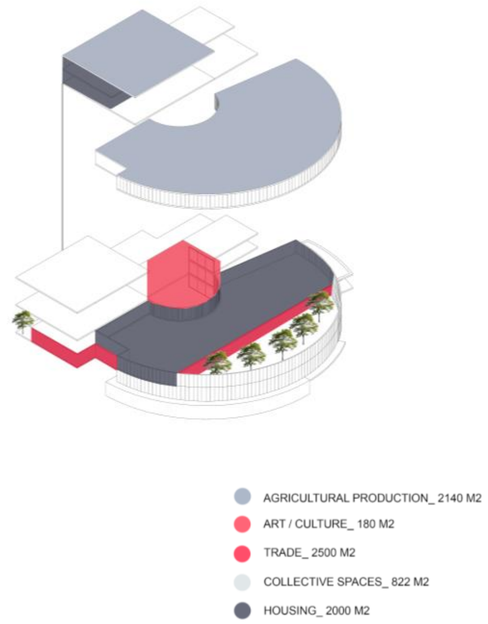
Each infrastructure seeks to enhance the quality of life indexes, which is why different recreational, supply and housing activities are included that are directly related to production, culture and shelter, each of which are developed in the following manner:

3.1 SALUDCOOP CLINIC:

The Saludcoop clinic, is a building that belonged to one of the entities of the private health system in Colombia (Saludcoop). It has two main naves and a central atrium that allows the reception and distribution of activities in the building. In this building, which is still in good condition, its renovation is planned and elaborated as follows:

A series of subtractions are generated (views from the section) allowing double heights in the spaces, a spatial continuity of the void and working with it. The first level is completely freed to strengthen this spatial permeability as public, which is attached from the city to the interior of the building, and where leisure activities, culture, commerce and generating green areas begin to occur. The residential areas and

Figure 7 Axonometric View and Indenxes of Saludcoop's regeneration proposal



collective spaces are located from the second to the fourth floor, allowing a subdivision of the private and the public. Finally, we propose the location of the agricultural production areas on the roof, which are located as residual spaces in the building, thus seeking to take advantage of natural lighting and rainwater for the conservation and production of plants and products.

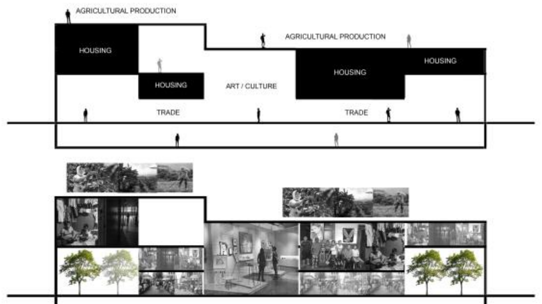


Figure 9 Formal Saludcoop Setup

Through the infrastructure of the former Saludcoop clinic, 2,500 m2 of commerce and public space are developed, which are directly complemented by 180m2 of areas for art and culture. In addition, 2,140m2 of orchards are being provided, which contribute to the production of the area, within the proposal, the m2 of housing is also increased, where 2,822m2 are provided. 822m2 that are complemented in turn with common areas, to generate mixed complexes that can respond to the different activities of the place, focusing on the development of generating a large network of shelter that unfolds throughout the saludcoop sector

3.2 THE CARMELITE CONVENT:

The Carmelitas is a convent that was founded in 1946 on 30 de Agosto Avenue in the city of Pereira, the building today is in a high state of deterioration and abandonment since 1999 earthquake with epicenter in the city of Armenia, which affected surrounding areas including sectors of Pereira, and for this reason, decided to move the convent to another part of the city. Thus, this building is taken as the object of study and work in search of a reconstruction and consolidation of this as a strategic point and articulating enclave of the supporting infrastructure and the city itself.

Now, the convent is made up of two volumes, the first with colonial typology, which is based under a central courtyard that allows the internal spatial distribution and is established in the infrastructure as a point of agricultural production.

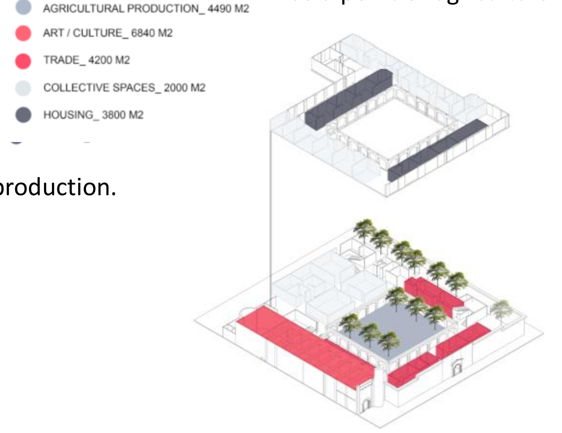


Figure 10 Axonometric and Indenxes of the Carmelita's proposal

Likewise, the rest of the second floor is consolidated as a commercial area and public space, projecting itself as a space of congregation of the city. On the second floor the private spaces (residence and collective spaces of the dwellings) are proposed. On the other hand, the second nave corresponds to the church of the convent, in which

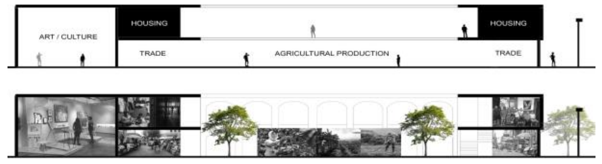


Figure 8 Formal Configuration Carmelita's

the conformation of an art and culture space is proposed, which is consolidated as an articulator of the city towards the building.

For the Carmelite convent is proposed to generate an infrastructure that contributes to the indexes from a public, civic and cultural development as it seeks to continue with the historical memory that contributes to the great infrastructure, for this different spaces are proposed that will allow the meeting in open places with good air flow to be able to congregate different amounts of people, In it there will be 423m2 of common areas that will be developed along with 288m2 of art and culture, in turn 221m2 of commerce will be developed, in addition 236m2 of green areas and 380m2 of home gardens will be implemented to generate large and healthy spaces for face-to-face meetings, also generating a housing space of 400m2 as a temporary housing for different immigrants.

3.3 CARREFOUR SUPERMARKET:

Carrefour was conceived from the Bavaria Partial Plan, an urban planning project that aimed to renovate and consolidate this forgotten and deteriorated area (since the Bavaria factory ceased production in 2001) developing a mixed use, which would allow the sector to be inhabited from housing (which was never executed), public space and commerce (former Carrefour). Due to this, a social problem is concentrated due to the abandonment of the area and due to the tolerance neighborhoods adjacent to the building.

In this sense, the intention is to condense within the building the different variables that were initially conceived for the Partial Plan but interrelating them to consolidate the building as an epicenter for social and urban improvement. Carrefour is the building with the largest scale within the support infrastructure, which will house the largest number of people and may have a far-reaching impact on

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

the problems of its sector (the river avenue). In this way, the two upper floors are consolidated as one where the residential areas of the project will be located. Subtractions are generated to establish a grid of voids where green areas of trees will be located in the lower part (basement).

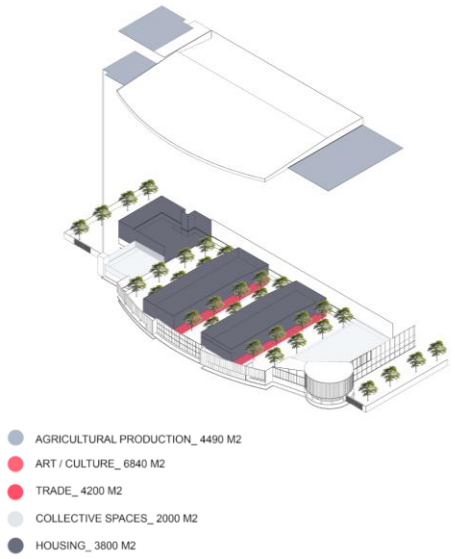


Figure 11 Axonometric and indexes Carrefour's Proposal

Likewise, the basement will be a completely open space which will have commerce to complement the public space. Finally, the roofs of the side volumes of this building will also be used for the development of vegetable gardens to enhance agricultural cultivation and economic and environmental sustainability.
Carrefour sector that closes our perimeter ring where 6,840m2 of complementary cultural spaces are developed with green areas, 3,000m2 of common areas, 4,200m2 of commerce and work activities that are unified with 5,800m2 of housing.

Figure 12 Formal Carrefour Configuration

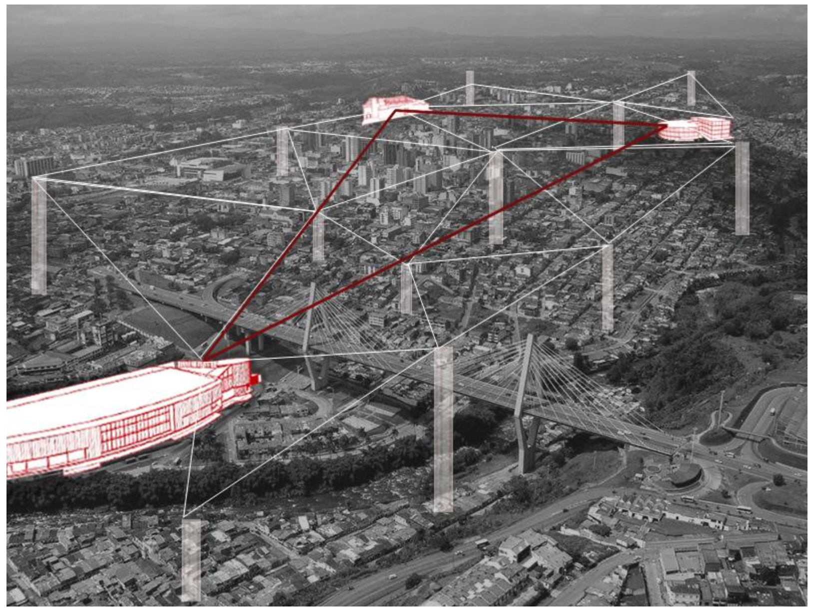
4.CONCLUSION.

When we ask ourselves the question: How will cities survive? City lab arises as an immediate response to the crisis by the covid 19 that we have been going through although the problems are evident in our cities it is recognized that society must also intervene, so city lab arises as the answer to improve the different living situations that were intervened because of the mandatory isolation, but also arises as a criticism of our model of city occupation where there are no spaces to meet and that allow a healthy mental development in the inhabitants, for this, City lab also proposes an alternative that can be replicable in different contexts because it seeks to recycle the structures in disuse and start building on what is built, thus avoiding the unbridled growth that does not contribute something positive to the constant problem of climate change and generating an awareness of what is no longer used in the city.

Through the boundary generated by the 3 projects developed, it is possible to change the ways of living in the city to spaces that are productive and recreational, which begin to contribute to the city an index of controlled housing with easy access and centrally located.

The strategy of recycling what exists arises not only from the need to begin to generate changes in the face of climate change, but also arises as a way to heal the city through a partnership, as both will survive as long as they work together, so the perimeter ring that is generated between Av. 30 de Agosto and Av. Del Rio, smaller scale infrastructures that cover the center and become the activating support of the 3 main ones, generating a limit that is contained but at the same time expands, finding that one of the keys for the city to survive the crisis is to guarantee the collectivity of society and its sustainability, city lab seeks to be that experimental space that allows its different abandoned infrastructures to contribute to the construction of the city. See figure 13 below to map dual city infrastructure of proposed projects and new interventions in relationship with other projects in disuse and the urban fabric of the city of Pereira

Figure 13 Existing Network City Lab Support Infraestructure



REFERENCES

1. Planeación Municipal (2016) Plan de Ordenamiento Territorial (POT).
2. Koolhaas Rem (1978) Delirious New York
3. Samper Germán (1997) urban enclosure, the humanization of the city
4. Pereira cómo vamos (2020) informe de calidad de vida.
5. Jerez Fernando (2012-2013) Estrategias de Incertidumbre, sistemas y máquinas interactivas.
6. Koolhaas Rem (1995) Ciudad Genérica.
7. Koolhaas Rem (2005) Espacios Basura.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

Daylight priority in apartment room-layout design when daylight access is limited due to dense urban surroundings

A case from Dhaka city

SAIFUL ISLAM[1] MOHAMMED FARHAZ UDDIN[2]

[1] Department of Architecture, North South University, Bangladesh
[2] S3 Architects, Bangladesh

ABSTRACT: Daylight requirements are usually ignored in residential design in compact urban contexts in developing countries. Dhaka is not an exception. It reviewed apartment room-layout design of forty-five residential projects. Master bed room, dining room and kitchens were examined in terms of their daylight accessibility. A daylight proximity scale DPS (1 being the best & 6 being the worst) was established and used to review their plans. Majority dining rooms scored 5 to 6, majority kitchens scored 4 to 6, and majority bed rooms scored 1 to 2. These results do not compliment IESNA guidelines because it suggests 300 lux for kitchen and dining, and 100 lux for bed rooms. For further investigation, daylight autonomy for these three types of rooms were simulated using Daysim. Simulation results also confirmed that none of the dining rooms ever get 300 lux, a few square feet area of a handful kitchens receive 300 lux for only 30% time of the year, and majority master bed rooms receive the target value for 75% time of the year. Therefore, based on both DPS scale and daylight autonomy analysis, this study argues that daylight priority is significantly absent in apartment room-layout design of Dhaka city.
KEYWORDS: Daylight, Density, Apartment room-layout

1. INTRODUCTION

This paper presents part of a study that explores possibilities of improving daylight condition in apartment buildings of Dhaka city. Daylight requirements are usually ignored in residential design in compact urban contexts in developing countries [5]. Dhaka is not an exception [3]. This part of study examines whether daylight goal is an important criterion in apartment design of Dhaka city.

Compared to detached houses, ensuring access to daylight for majority rooms is difficult for multi-storey apartment buildings in dense urban environment. Due to land scarcity in dense urban environment, apartment buildings are built close each other. For these apartment buildings, only street sides have relatively better access to daylight. The rest three sides are bound to face narrow alley-canyons unless the lot is a corner one. Narrow rear setback (typically 1.5m) and side setbacks (typically 1.0-1.25m) allowed by Dhaka's building codes made it inevitable [1]. Moreover, typical apartment buildings are seven to nine story tall hence these side and rear alleys are deep narrow canyons with darkness as its common characteristics. Therefore, not all rooms in typical Dhaka apartment have same level of access to daylight.

However, according to IESNA recommendations, not all rooms in a residence need same level of daylight either. Dining and kitchen require 300 LUX, living rooms require 200 LUX and bed rooms require 100 LUX [8]. Therefore, daylight access is more critical for dining and kitchen than it is for bed rooms. However, the authors' initial assumption is that existing condition is the opposite of the recommendation. This paper examines whether layout design of typical Dhaka apartments follow the stated hierarchy of daylight preferences or is it the opposite. If this part of the study finds a deviation, the next part would then examine the reasons of deviation. These parts will eventually lead to identify pragmatic solutions for daylight improvement in apartment buildings of Dhaka city.

2. METHODOLOGY

For this paper, the most common room types in apartments have been studied - Master Bed room, Dining room and Kitchen. The study intends to find which room type gets the most priority in terms of daylight. To determine it, one option is to examine daylight availability in these room types in significant number of residences. However, field measurements were not possible due to pandemic situation. Besides, the time and resources needed to conduct the field measurements was not available. Instead, a three-stage method has been adopted.

For the first stage, a large pool of drawings of residential projects were reviewed. These drawings are part of student assignments submitted to the first author in earlier semesters. For several semesters, the author has been guiding his students to critically evaluate their residence designs in terms of daylight availability. For their evaluation, site plan, satellite image, floor plans and sections through neighbouring buildings were required. These drawings and images created a rich pool of information that helps to identify typical pattern of apartment room layout in the context of limited access to daylight. Out of this pool, based on completeness in required information, forty-five residential projects have been selected for final review. These projects represent the typical apartment buildings of Dhaka city as students are from all parts of the city and together, they represent the upper-middle income group of the city who are the primary buyers of these apartment units.

For the second stage, Daylight Priority Scale (DPS) (Table 1) has been established and used which is based on relative position of rooms considering their daylight accessibility. To establish DPS, in terms of daylight accessibility, first hierarchy in surrounding canyons has been established. Based on the work of Strømann-Andersen and Sattrup, street canyons have been given the priority over alley-canyons as the former's canyon aspect ratio is low [9]. Second, hierarchy in room type has been established. As corner rooms have higher chance of having bilateral windows, it has given priority over in-between rooms [4]. Thus, a corner room facing the street has more chances to get better daylight than an in-between room facing the alley-canyon. Moreover, primary investigation had identified a few other variations in room location and exposures. There are rooms that are at the centre of apartment unit. Sometimes they are surrounded by other enclosed rooms. Sometimes other open space type rooms like family space or dining keep them away from exterior walls. These relative positions and exposure are depicted in the Daylight Priority scale in Table 1. This scale has been used to judge apartment room layout to identify daylight preference among its Master Bed room, Dining and Kitchen.

The third stage used computer simulation to validate the results gathered through the use of DPS. This study used Daysim as a tool for computer simulation. It was developed by the National Research Council Canada. Daysim uses the engine of Radiance which has been widely recognized for validity during the last 25 years [3]. Radiance is a backward ray-tracer that simulates individual light rays to calculate luminous distribution within a room. It is capable of predicting internal illuminance and luminous distribution in buildings under different sky conditions. It uses the concept of daylight coefficient utilizing the sky luminance models developed by Perez and Tregenza [6]. According to Reinhart, for daylight coefficient method, the celestial sky is theoretically divided into disjoint sky patches and contribution of each of them is calculated for illuminance at a specific point in a room [6]. This approach was found successful in modelling indoor illumination of a full-scale office with complex shading devices [7].

Table 1:
Daylight Priority scale (DPS)

Scale	Room description
1	Street facing corner room
2	Street facing in-between room
3	Alley facing corner room
4	Alley facing in-between room
5	Centre rooms away from window
6	Centre rooms surrounded by other rooms

Note: 1 being the highest order.

To perform simulations, the most common values found in the 45 residents have been used. Plot size of 5 katha (1 katha=720 sq. feet) has been chosen since 69% of the residents were constructed on this size of plot. Building height of eight story has been selected since it reflects the recent trend of apartment development. Side and rear setback have been selected based on the building code which is four feet and six feet respectively. Window to floor area ratio has been kept to 15% based on building codes too. The most common size of bed room is fifteen feet by fifteen feet; dining room is twelve feet by fifteen feet; and the kitchen is eight feet by ten feet.

For the simulations, surface reflectance values of interior wall, floor and ceiling were set according to IESNA guidelines (Rea, 2000). Table 2 shows the selected reflectance values for different surfaces along with IESNA guidelines. For exterior wall, reflectance values were also 50% as the subsequent reconnaissance survey found no significant difference between indoor reflectance values to that of the exterior one. Ground reflectance was 20% which is the default value of Daysim tool. Single pane window was chosen as it was still the prevailing trend in residential buildings at DRA. Visual transmittance for glazing set at 90%, and visual transmissivity was set at 98%.

Table 2:
Surface reflectance values used in simulations

Type of surfaces	IESNA Guidelines for reflectance values (%)	Reflectance values selected for simulations (%)
Ceiling	60-90	90
Wall	35-60	60
Floor	15-35	20

Table 3:
Radiance Simulation Parameters considered in this study

Parameters	Min	Accurate	Max	Used
Ambient bounces	0	2	8	5
Ambient accuracy	0.5	0.15	0	0.1
Ambient resolutions	8	128	>	300
Ambient divisions	0	512	4096	1000
Ambient super-samples	0	256	1024	20

This study chose Daylight Autonomy (DA) as daylight performance indicator. According to Reinhart (2006), the daylight autonomy at a point in a building is defined as the percentage of occupied hours per year, when the minimum illuminance level can be maintained by daylight alone. Therefore, using DA data, the simulations showed how much time in a year the kitchen and dining rooms get a minimum of 300lux and bed rooms get 150lux.

3. RESULTS

A total of forty-five residential projects have been reviewed. All six room types listed in the Daylight Priority Scale were found among these projects at certain degrees. For better understanding, a typical apartment building layout is shown in Figure 1 where two apartment units are placed side by side. All six room types are found in these two apartment units and room types from DPS are marked in red dots. Dot 1 is a street facing corner room, dot 2 is street facing in-between room, dot 3 is an alley facing corner room, dot 4 is an alley facing in-between room, dot 5 is a centre room away from window, and dot 6 is a centre room surrounded by other rooms.

For all forty-five projects, Master bed room, dining room and kitchens were examined through the DPS. It has been found that master Bed rooms get the highest priority in terms of daylight. Kitchens get the second level of priority and dining rooms get the least priority. These findings are shown in Figure 2, Figure 3 and Figure 4 respectively.

Figure 1:
A typical apartment plan showing all six room types listed in the Daylight Priority Scale (DPS)

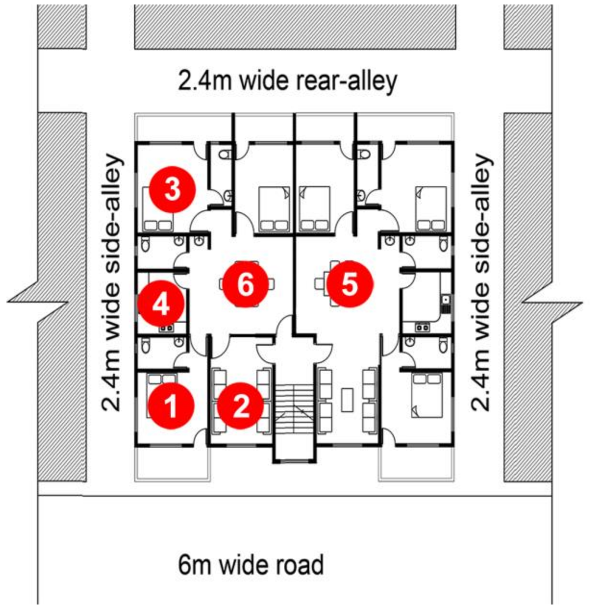


Figure 1 shows that if daylight is concerned, master bed rooms get the highest priority. Sixty four percent master bed rooms found to be the street facing corner rooms which represents the best score in DPS. Only three percent master bed rooms were alley facing corner rooms that represents the third level in DPS. The remaining thirty three percent master bed rooms are street facing in-between rooms which has the second highest score in DPS. Therefore, it is found that master bed room gets the highest priority if daylight is a concern.

Figure 3 shows that kitchens do not get as much priority as master bed rooms although kitchens require almost tripple amount of daylight for its functionality. Seventy six percent of observed kitchens are alley facing in-between rooms which is the fourth level in DPS scale. Twenty two percent kitchen found to be in a better situation than these seventy six perceta kitchens. They are alley facing corner rooms.

According to Figure 4, dining rooms get the least priority in terms of daylight. Unfortunately, dining rooms require same daylight as kitchen and three times the daylight needed for bed rooms. Forty two percent observed dining rooms has no access to daylight since they are surrounded by other rooms. This is the worst level in DPS scale that is six. Twenty percent dining rooms scored five and thirty two percent scored 4 in DPS scale.

Figure 2:
Identified level of daylight priority for master bed rooms in the studied apartment buildings

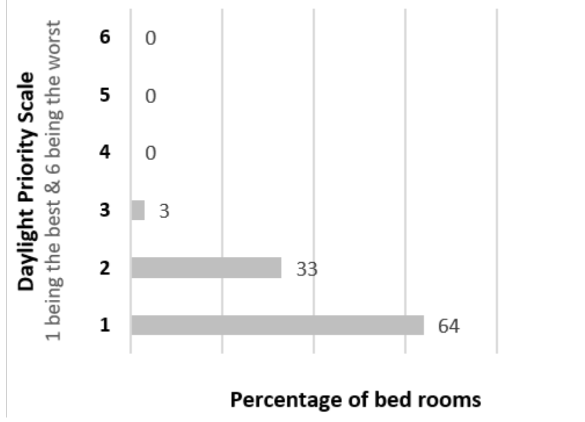


Figure 3:
Identified level of daylight priority for kitchens in the studied apartment buildings

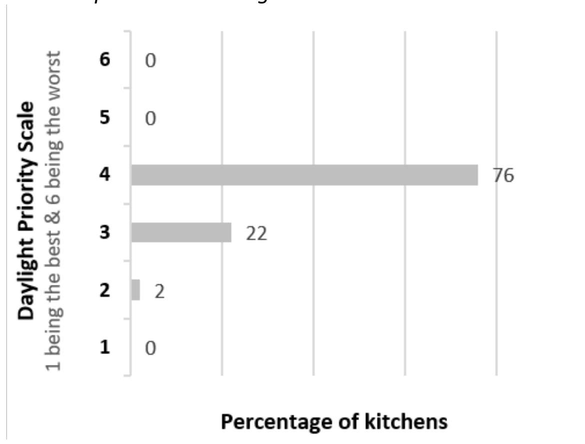
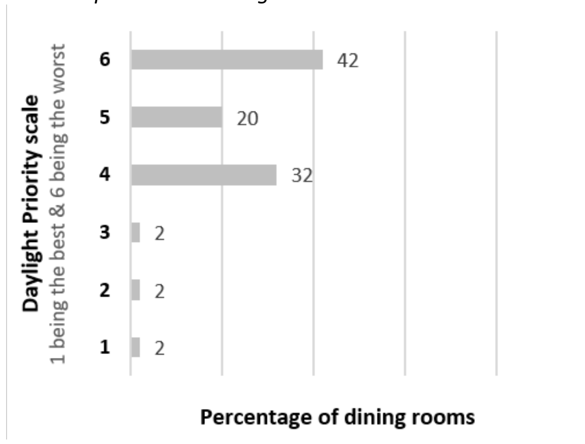


Figure 4:
Identified level of daylight priority for kitchens in the studied apartment buildings



From the above discussion and figures it is clear that for apartments in Dhaka, access to daylight is not a priority in kitchen and dining although they both requires 300 lux of daylight. From the DPS scale, relative chances of getting daylight can be assumed. However, forecasting amount of daylight received in a particular room is not its objective. For this reason, Daylight Autonomy was simulated for six room types listed in the DPS scale. Among them, three are for master bed room, two are for kitchen and one is for dining room. These simulations were carried out for bottom floors only. It was done because bottom floors experience the most difficulties in getting daylight. Figure 5 shows Daylight autonomy simulated for three cases of master bed room. As it was discussed in previous sections, 100 lux was set as minimum criteria for bed rooms. It is seen (middle part of Figure 5) that most part of master bed room receive 100 lux for more than 75% of the year. When the master bed room is a street facing in-between room, about 40% of the room receive 100 lux for less than 50% time of the year. This become even worse when master bed room is a rear-alley facing corner room. Only a few square feet area next to the window receives 100 lux but only for 15% time of the year.

For kitchen and dining rooms, minimum value for daylight autonomy has been set as 300 lux. From Figure 6 it is seen that daylight autonomy for kitchens are poor. When kitchens are alley facing in-between rooms (top of figure-6), daylight autonomy is zero. When they are alley facing corner rooms (middle of Figure-6), a few parts of them receive 300 lux for 30% time of the year. For dining rooms surrounded by other spaces no simulation was needed as it is easy to forecast the result. Even when dining rooms are at centre but have access to daylight through a distant window (bottom of Figure 6) daylight autonomy found to be zero.

4. CONCLUSION

References This study examined apartment room-layout design of forty-five residential projects in Dhaka city. Master bed room, dining room and kitchens were examined in terms of their daylight accessibility. A daylight proximity scale DPS was established and used to review their plans. DPS is a six segments scale where 1 represents the best and 6 represents the worst scenario. 1 stands for street facing corner room, 2 is for street facing in-between room, 3 is for alley facing corner room, 4 is for alley facing in-between room, 5 is for Centre rooms away from window, and 6 is for Centre rooms surrounded by other rooms.

This study found that master bed rooms get the highest priority in terms of daylight. Kitchens get the second level of priority and dining rooms get the least priority. Forty two percent dining rooms fall under DPS scale of 6. They do not get any light

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

since they are surrounded by other rooms. Seventy six percent kitchens fall under DPS scale of 4. Sixty four percent master bed rooms fall under DPS scale of 1- and thirty-three percent fall under DPS scale of 1. These findings do not compliment IESNA guidelines where 100 lux is suggested for bed rooms and 300 lux for dining and kitchen.

Figure 5:
Daylight autonomy simulated for three cases of master bed room

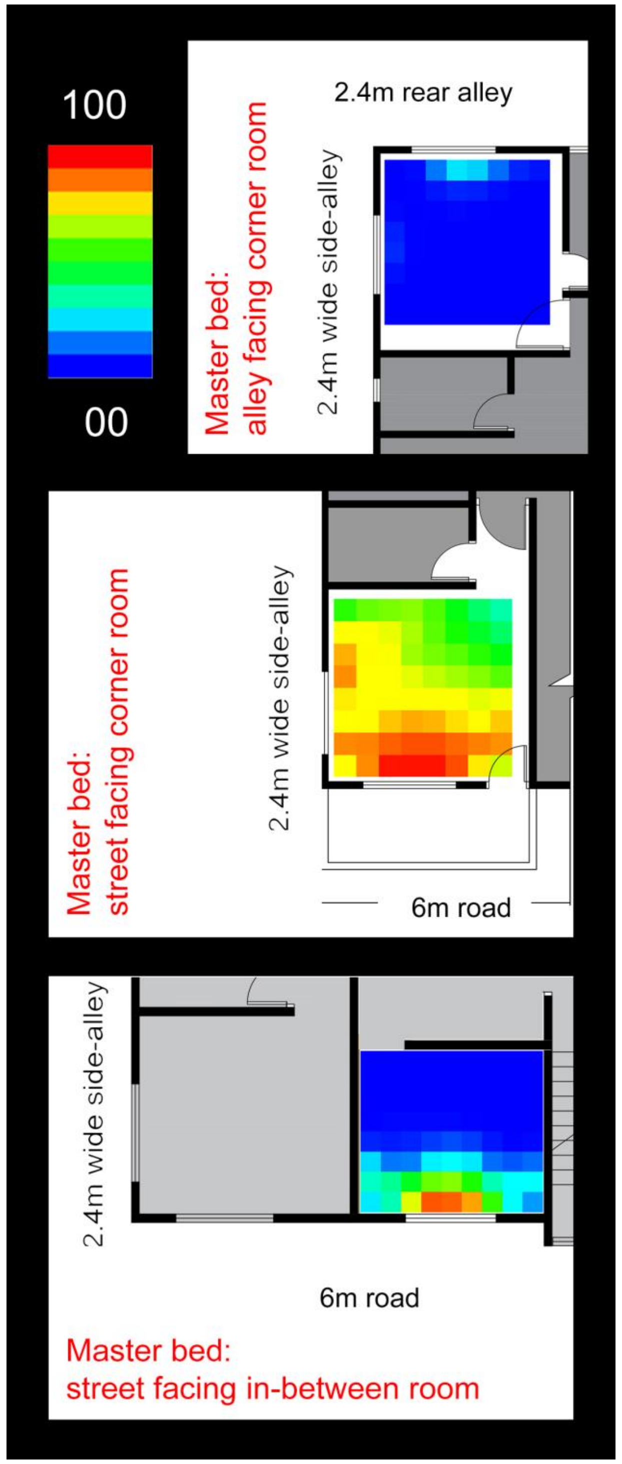
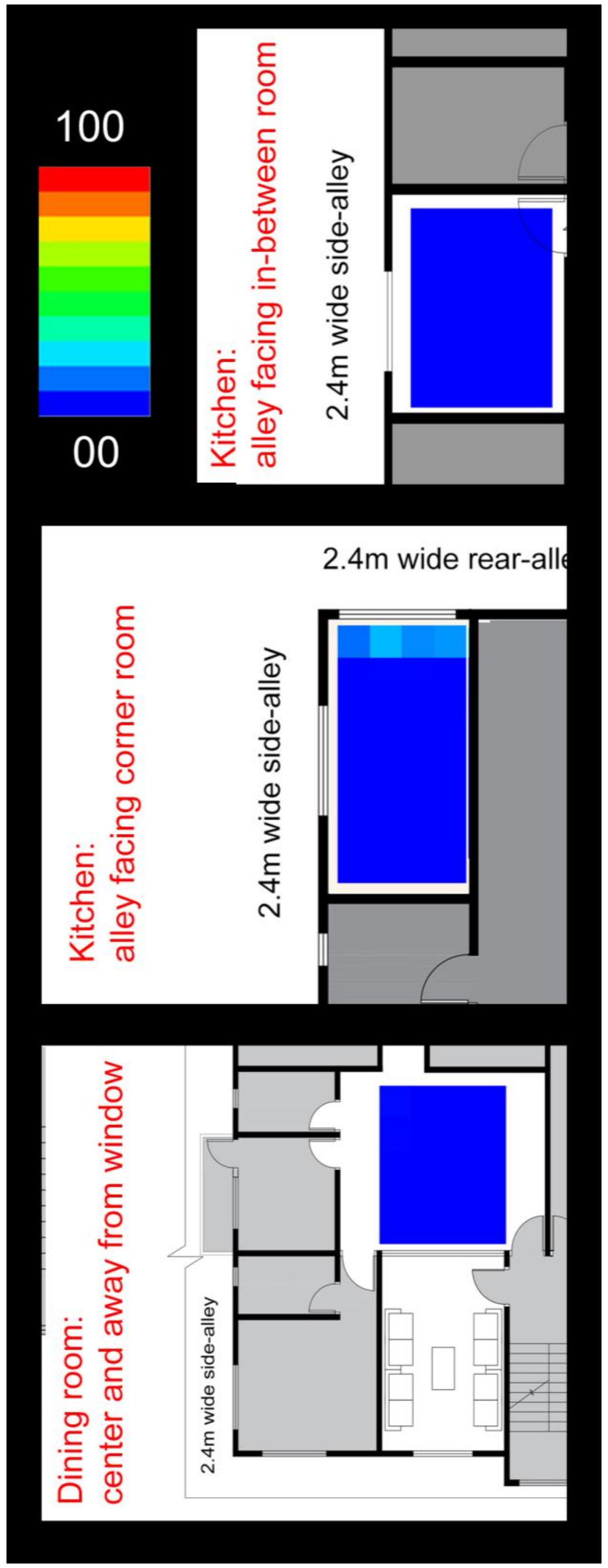


Figure 6:
Daylight autonomy simulated for two cases of kitchen and one case of dining room



For further examination, daylight autonomy for these three types of rooms were simulated using Daysim. Seventy-six percent kitchens never get 300 lux in any time of the year. A negligible area of kitchens those are alley facing corner rooms get 300 lux but only for 30% time of the year. Dining rooms found to be the worst as sixty two percent of them are placed at the centre of apartment unit. Out of these sixty-two, forty two percent do not get any daylight as they are surrounded by other rooms. The remaining twenty percent also do not get 300 lux for any time of the year. Daylight autonomy in bed rooms compliment DPS scale findings.

Therefore, using both DPS scale and daylight autonomy analysis, this study argues daylight priority is significantly absent in apartment room-layout design of Dhaka city.

REFERENCES

1. Bangladesh, G. o. (1996). Imarot Nirman Bidhimala (Building Construction Ruless)1996. Dhaka, Bangladesh: Ministry of Housing and Public Works Retrieved from http://www.rajukdhaka.gov.bd/rajuk/frmactsHome?type=acts
2. Jacobs, C., Singh, T., Gorti, G., Iftikhar, U., Saeed, S., Syede, A., Siderius, C. (2019). Patterns of outdoor exposure to heat in three South Asian cities. Science of the Total Environment, 674, 264–278.
3. Jenks, M., & Burgess, R. (Eds.). (2004). Compact Cities: Sustainable Urban Forms for Developing Countries. London and New York: Taylor & Francis.
4. Lechner, N. (2015). Heating, Cooling, Lighting, Sustainable Design Methods for Architects (4th ed.). New Jersey: John Wiley & Sons.
5. Mehjabeen, S. (2020). Daylighting in Density: A Parametric Study of High-Rise Residential Buildings and Urban Street Canyon Configurations in Dhaka, Bangladesh. (Masters of Science), The Pennsylvania State University,
6. Reinhart, C. F. (2006). Tutorial on the Use of Daysim Simulations for Sustainable Design. Canada: Institute for Research in Construction.
7. Reinhart, C. F., & Walkenhorst, O. (2001). Validation of dynamic Radiance-based daylight simulations for a test-office with external blinds. Energy and Buildings, 33.
8. Rea, M. S. (2000). The IESNA lighting handbook: reference & application (9th ed.). New York: Illuminating Engineering Society of North America.
9. Strømann-Andersen, J., & Sattrup, P. A. (2011). The urban canyon and building energy use: Urban density versus daylight and passive solar gains. Energy and Buildings, 43(8), 2011-2020.doi:https://doi.org/10.1016/j.enbuild.2011.04.007

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE BUILDINGS AND TECHNOLOGY

DAY 01
16:00 — 17:30

CHAIR
CARLOS ESPARZA

PAPERS
1221 / 1561 / 1421 / 1661

13TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

Comparative study of two passive cooling systems

Indirect evaporative cooling vs. radiant-capacitive cooling

EDUARDO MANUEL GONZALEZ-CRUZ, EDUARDO KRÜGER [1]

[1]Universidade Tecnológica Federal do Paraná - UTFPR, Curitiba, Brazil

ABSTRACT: The aim of this study is to compare the thermal performance of two passive cooling systems. On one hand, an indirect evaporative cooling system (IECS), consisting of a shaded and naturally ventilated roof pond (RP) and on the other hand, a low energy consumption Radiant-Capacitive Cooling System (RCCS), made up of a Radiant-Capacitive Module (RCM) and fed with chilled water from nocturnal radiative cooling. Test cells fitted with both systems each have been monitored during a warm period at the Federal University of Technology of Paraná, located in Curitiba, Brazil. The systems were experimentally evaluated using three small test cells. Results obtained with the experimental RCCS demonstrated its applicability for indoor cooling even under conditions that were not the most promising for night-time radiative cooling. The RCCS has a thermal performance comparable to, or even higher than, the RP. In general terms, when faced with high ambient temperature conditions and relatively favourable sky conditions for nocturnal radiative cooling, the system has a thermal performance very close to that of an indirect evaporative cooling system.
KEYWORDS: Radiant-capacitive system, radiant cooling, night sky cooling, indirect evaporative cooling, experimental study.

1. INTRODUCTION

One of the greatest problems related to climate change is that a large part of the greenhouse gas (GHG) emissions that cause it are due to the generation of electricity used in the construction sector. Buildings account for around 40% of primary energy consumption in Europe and in most developed countries [1]. Much of that energy is used to heat or cool buildings in order to provide comfort to building occupants. Over 76% of all US electricity usage and more than 40% of all US energy use and associated greenhouse gas (GHG) emissions are destined to providing comfortable and well-lit residential, commercial and industrial, in many cases with electric lighting and space conditioning [2]. Energy use for indoor cooling has doubled since 2000, making it the fastest growing end use in buildings, driven by a combination of higher temperatures and increased indoor activities [3]. In this context, the global energy demand for air conditioning is expected to triple by 2050 [4].

Progresses in the development and application of passive cooling systems or those with low energy consumption are greatly needed. With the purpose of developing, testing and improving low-cost passive systems for tropical areas, we focus here on natural cooling systems based on water evaporation and radiative heat exchange, having water as heat transfer medium.

The aim of this study is to compare the thermal performance of two passive cooling systems. On one hand, we tested an indirect evaporative cooling system (IECS), consisting of a shaded and naturally ventilated roof pond (RP) and on the other hand, we evaluated a low energy consumption Radiant-Capacitive Cooling System (RCCS).

2. METHODOLOGY

The systems in the experimental setup (Figure 1) were evaluated using three small test cells: a Control Cell (CC), an experimental test cell with the hydronic Radiant-Capacitive Module (RCM) and an experimental test cell fitted with a Roof Pond (RP).

Figure 1:
Experimental setup with the CC, RCM and RP test cells and other system components.

Monitoring data correspond to three experimental series carried out during a warm period of the year, from November 16, 2019 to January 20, 2020. Data were sampled at 5 min intervals with indoor temperatures in the three test cells, outdoor conditions and water temperatures in the components of the RCCS.

Equipment used consisted of previously calibrated HOBO U12-012 loggers with two external sensors each (TMC20-HD), HOBO S-THB-M002 and two TMC20-HD, which were connected to a HOBO weather station U12-001.

The systems have been monitored at the Federal University of Technology of Paraná, located in Curitiba, Brazil, at 25° 26' 33.6” S and 49° 21' 14.14” W, at an elevation of approximately 953 m a.s.l. Local climate can be classified as Cfb (temperate maritime humid climate), according to the Köppen-Geiger classification

Comparisons between both systems have been drawn, in terms of their thermal performance, characteristic temperatures and correlations between them and the control cell, as well as key performance indicators such as the depression of the maximum and average temperatures, and the daily Mean Cooling Potential (MCP) of the systems, relative to outdoor climate exposure conditions.

2.1 The Radiant-Capacity Cooling System (RCCS)

The RCCS has three components (Figure 2): an indoor Radiant-Capacitive Module (RCM) powered by a Sky Radiator (SR), which takes advantage of the night sky as a heat sink, and a cooled water storage tank or Thermal Energy Storage (TES).

The system is hydronic, i.e. it uses water as a heat transfer medium that runs through the system’s components in a closed loop and without any water expenditure. The RCCS cools water from the TES during the night in the SR by long wave radiation losses and circulates it through the RCM, located in the indoor space of the experimental cell, and back to the TES (closed-loop circuit 1).

During daytime, the water cooled during the night and stored in the TES can be eventually tapped to the RCM through a separate loop (from TES through RCM and back, Figure 2), so as to remove indoor heat gains indoors during the day.

The test cell (800 mm x 800 mm x 530 mm high), with the RCM (Figure 3a), is made with 18 mm thick marine plywood with a 50 mm extruded polystyrene insulation layer in the internal part of walls and floor. Within the test cell, the radiant-capacitive module (RCM) acts as a ceiling, consisting of a 670 mm x 670 mm x 65 mm metal container, completely filled with water, with an inside heat exchanger (aluminium serpentine) and insulated by a 85mm polystyrene layer covered with plywood.

The SR is composed of 10 hollow extruded aluminium profiles combined, measuring 895 mm × 95 mm × 8.3 mm each, yielding a total surface area of 0.85 m2. Each one of the profiles is covered by a black matte finish and has three internal channels through which water circulates (by a low-power pump) during the night and is cooled by a combination of heat losses due to long-wave radiation exchange with the sky and natural convection.

The thermal energy storage (Figure 2) consists of a polyethylene water tank with a diameter of 560 mm and a height of 1090 mm, lined with a double layer of polyethylene wool insulation and filled with water up to a height of 930 mm (approximately 230 litters of water).

More details of the construction, dimensions and materials of the Radiant Capacitive Module (RCM) and the sky radiator (SR) can be seen in [5].

Figure 2:
Scheme with the three components of the RCCS: Sky Radiator (SR), Thermal Energy Storage (TES), Radiant-Capacitive Module (RCM) with the two closed-loop circuits depicted (circuit 1–dashed line; circuit 2–continuous line).

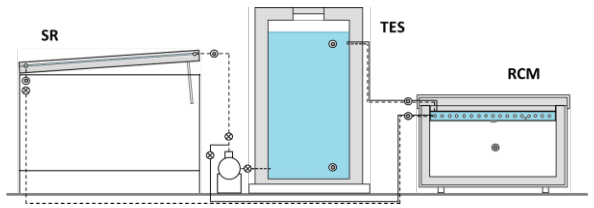
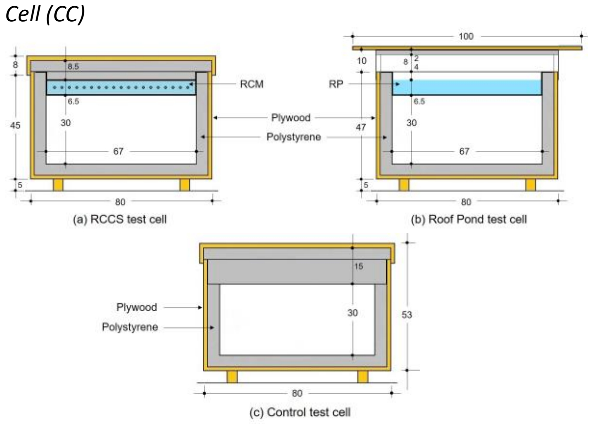


Figure 3:
Schematic diagram of the test cells: (a) Radiant –Capacity Cooling System (RCCS), (b) Roof Pond Cell (RP) (c) Control Cell (CC)



2.2 The Indirect Evaporative Cooling System (IECS)

The “roof” of the experimental cell with the IECS (Roof Pond - RP) (Figure 3b) consists of a water pond made of 1.2 mm thick galvanized steel sheet and painted white, similar to the one developed by González and González [6] for thermal performance studies in Maracaibo, Venezuela. Indoor space and dimensions of the remaining elements (walls, floor) are identical in all three cells.

The roof pond was filled with water to a height of 65 mm (29 l) in series 1 and 2 and with 100 mm (45 l) in the third experimental series.

The roof pond is shaded by a 15 mm thick plywood board, with a dimension of 1.00 m x 1.00 m, painted white and insulated on its inner face with a 20 mm thick polystyrene sheet. An air gap of 100 mm allows permanent ventilation of the water and a 100 mm overhang creates extra shading (figure 3b).

The evaporation of water in the RP leads to a continuous loss of heat from the mass of water to adjacent air. Heat gains from the cell's walls are dissipated through the roof pond.

2.3 The Control Cell (CC)

The Control Cell has exactly the same dimensions and physical characteristics as the two experimental cells in terms of walls and floor. The roof element has a 150 mm thick polystyrene thermal insulation underneath the 15 mm thick plywood board that significantly reduces heat exchanges with the outdoor environment (figure 3c). Its walls and floor, as in both experimental cells, have an inner layer of 45 mm thick polystyrene sheets.

3. RESULTS

3.1 Characteristic temperatures in the RCCS and the RP

In order to analyse the characteristic temperatures recorded with the two systems, the results of three experimental series (Series 1, 2 and Series 3, which yielded the maximum mean cooling potential in both systems, as described in the next section) carried out during 50 summer days are presented (November 16, 2019 through January 20, 2020). In the RCCS the pumping period spanned 11 hours, between 7 pm to 6 am, with a flow rate of 28 l/h. The radiator was fully exposed (surface area of 0.85 m²) to the sky hemisphere and TES was at its full capacity of 220 l). Table 1 shows a synthesis of the characteristic temperatures in the CC, RCCS, RP and outdoors during the experimental series.

Three continuous days in December and in January (Series 3) are represented in Figure 4. The intention was to evaluate the cooling performance of the RCCS system when no heat is removed from indoors by pumping cooled water from the TES during the day.

Due to the cooling of the water that circulates through the RCCS, there is a decrease in the daily indoor average temperature in the RCM test cell relative to the outdoor average (mean offset 1.1 K, with a maximum difference reaching 4.0 K). A high temperature depression in the maximum indoor temperatures with respect to outdoors is also noticed (mean 5.0 K, peaking at 8.3 K).

Because of the continuous 24-hour evaporative cooling in the RP, a decrease in the indoor average temperature is also noticed relative to the outdoor average (mean offset 1.7 K, with a maximum difference reaching 5.9 K). Likewise, a strong drop of the maximum indoor temperature in the RP is observed with respect to outdoors (average 4.0 K, with a peak of 7.9 K).

In contrast, temperatures in the control cell (CC) closely follow the outdoor pattern. On sunny days, the daily maximum temperature is somewhat higher than the ambient, while the minimum temperature at the end of the night is in general slightly lower than outdoors. As a result, the mean indoor temperature in the CC (used here as a reference for assessing the Mean Cooling Potential - MCP) is generally a few tenths of a degree higher than the ambient mean. In the RCCS, due to the added thermal mass with the RCM, minimum indoor temperatures are higher than outdoors.

Figure 4:
Temperatures measured at CC, RCCS, RP and outdoors in Series 3 (27-29 December 2019 and 9-11 January 2020).

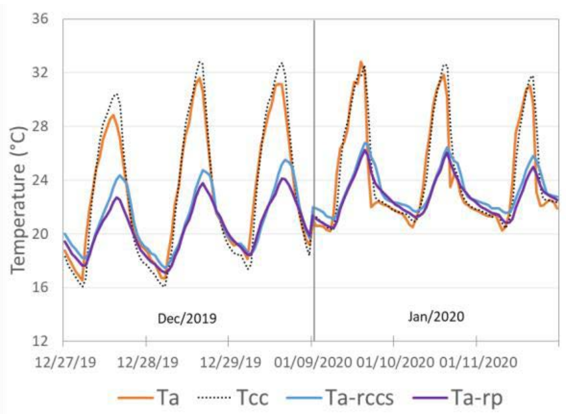
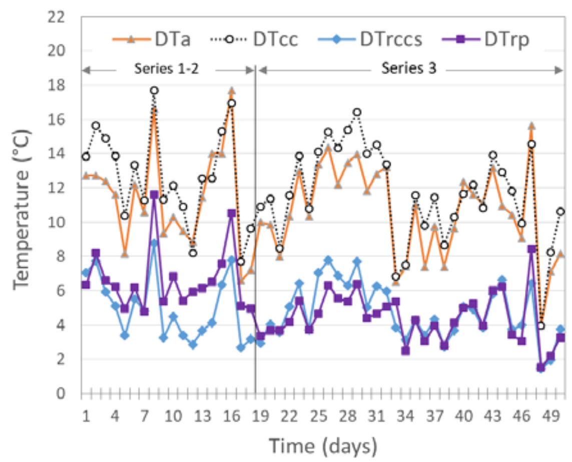


Figure 5:
Temperature swing in CC, RCCS and RP and outdoors.



Comparing the daily temperature swing (DT) in the RCCS with that of the RP module (Figure 5), a somewhat larger amplitude is observed in RP during Series 1-2. However, in Series 3 their amplitudes are very similar, except in the first days when the RP results in lower values. This is in part due to the difference in thermal mass between the two systems and to the heat gain/loss in each case.

The indoor temperature swing is another factor that is positively affected by the RCM and the RP relative to outdoors. The decrement factor (ratio between the indoor and the outdoor temperature swing) is, for the three series, on average 0.44 and 0.46, in the RCCS and in the RP, respectively (with standard deviations of 0.08 and 0.12), which are fairly close. However, as shown in Figure 5, due to the difference in the amount of water in the roof pond (29 l in Series 1-2 and 44 l in Series 3) in the first two series, the RP has a mean decrement factor higher than that of the RCCS (0.58 vs. 0.44). However, during Series 3, both systems present very similar decrement factors, 0.42 and 0.44 in the RCCS and in the RP, respectively.

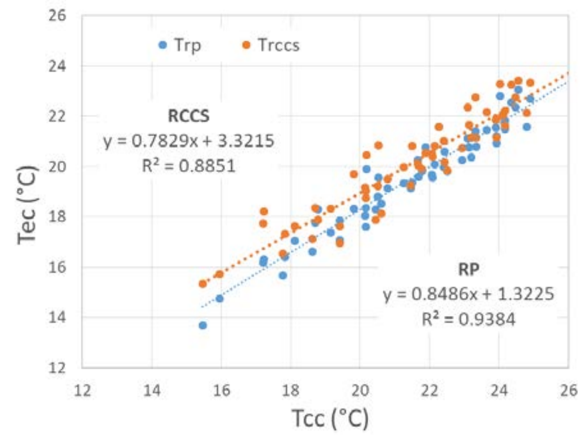
These values correspond to an average indoor temperature swing in the RCCS of 4.1 K, ranging 2.5-5.7 K, and in the RP of 5.2 K, ranging 3.3-7.7 K. Thus, significant thermal stability is achieved in both systems.

Figure 6 shows high correlation between the mean daily temperatures measured in the control cell and those in the two experimental cells RCCS and RP (R^2 of 0.885 and 0.938, respectively). The generated trend lines suggest that the efficiency of both systems tends to be similar for increasing mean daily temperatures in the control cell.

Table 1:
Characteristic temperatures in the control, experimental cells and outdoors.

Series	Ambient			Control Cell			RCCS			RP			DT(cc-rccs)	DT(cc-rp)
	Tavg (°C)	Tmax (°C)	Swing (K)	Tavg (°C)	Tmax (°C)	Swing (K)	Tavg (°C)	Tmax (°C)	Swing (K)	Avg (°C)	Tmax (°C)	Swing (K)	DTavg (K)	DTavg (K)
1	19.7	27.0	11.8	20.0	28.4	13.6	18.5	21.8	5.7	17.9	21.8	6.7	1.5	2.1
2	18.6	25.7	11.1	19.0	26.6	11.8	17.7	20.3	4.3	17.3	21.2	6.7	1.3	1.6
3	22.2	28.8	10.6	22.4	29.8	11.6	21.1	23.9	4.7	20.5	23.0	4.4	1.3	1.9
Avg	**21.1**	**27.9**	**10.9**	**21.4**	**28.9**	**12.0**	**20.0**	**22.9**	**4.8**	**19.5**	**22.5**	**5.2**	**1.34**	**1.92**

Figure 6:
Correlations between indoor temperatures measured at CC versus RCCS and RP.



3.2 Cooling potential

The daily Mean Cooling Potential of the two systems (MCP), given in Wh/m².day, was assessed. MCP was calculated based on the difference of the average daily temperatures obtained in the two experimental cells (EC) relative to those registered in the control cell (CC). A large positive offset between Tcc and Tec means a high cooling potential. MCP can be calculated according to the following equation (1) [6]:

$$MCP = (UAg \times (Tcc - Tec) \times 24) / A \quad (1)$$

Where UAg is the global thermal transmittance of the control module (W/K), estimated as 1.5 W/K, and for both EC and CC, since both have the same dimensions and typology as the test cells used and tested by González and González (2013). Tcc and Tec are the average daily temperatures in the control and experimental test cells, respectively, and A is the effective area of the ceiling, i.e. the internal area of the ceiling (m²).

Figure 7 shows daily values of MCP and the main variables that influence the cooling potential of the systems: wet bulb temperature depression (Dwbt), average ambient temperature (Ta.avg) and metal plate temperature depression (DTr).

The RP presents during most of the time higher MCP values than the radiant-capacitive system. The average MCPrccs is 106.2 Wh/m².day (with an average of 136.9 Wh/m².day in December and 74.9 Wh/m².day in January), whereas the MCPrp is 152.5 Wh/m².day (50.6% higher than that of MCPrccs), 183.5 Wh/m².day in December and 129.5 Wh/m².day in January. Taking a series of days between December 19, 2019 and January 1, 2020 for a comparative analysis, the cooling potential of the RCCS reaches 78% of the cooling potential of the roof-pond.

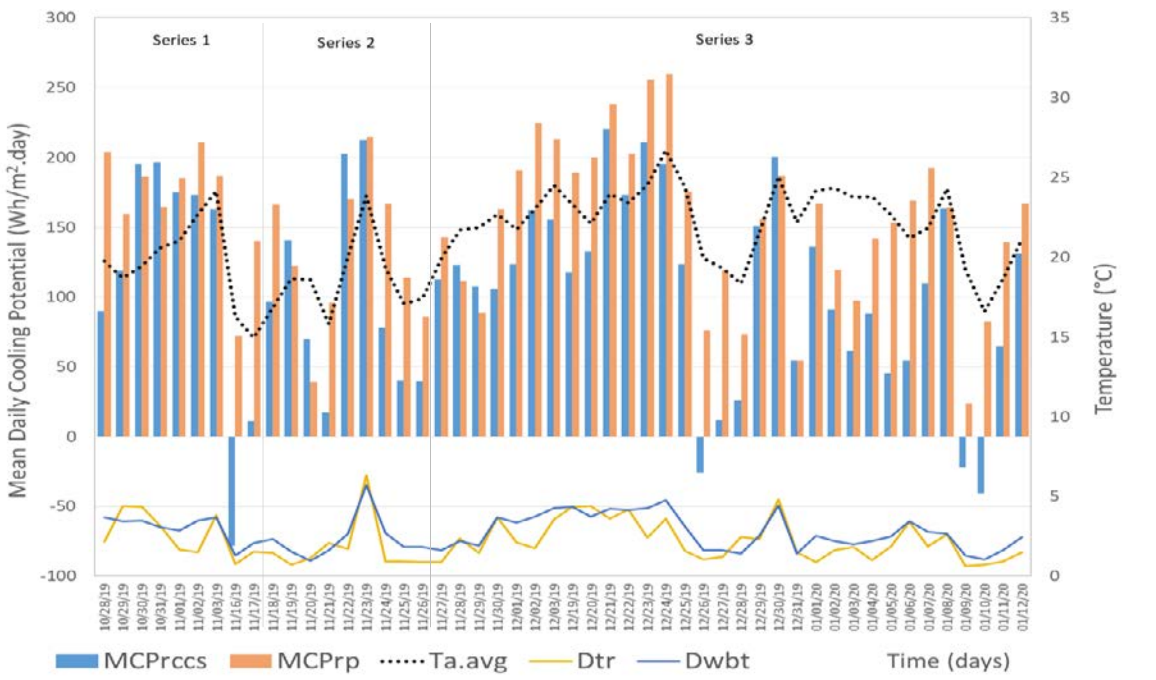
While the thermal performance of the roof pond depends largely on the wet-bulb temperature depression, i.e. the difference between the dry bulb and the wet bulb temperature, throughout the 24 hours of the day (MCP is strongly correlated with the DWBT, with r-square 0.79), the nocturnal sky temperature depression alone does not suffice to explain the RCCS' performance on a 24-hour cycle.

As the RCCS benefits from night-time radiative cooling, the cooling efficiency of the system primarily depends on the atmospheric conditions of the night sky. Cooling output is governed by cloud cover and moisture content of the atmosphere, along with existing pollutants and particulates that might affect the system's performance. The radiative cooling potential of the location can be estimated according to Berdahl and Martin [7] in terms of the sky temperature depression (DTsky), which is the difference between the ambient air temperature (Ta) and the sky temperature (Tsky). The clearer the sky hemisphere and the less moisture the ambient air contains, the greater the potential for radiative cooling and the greater the overall efficiency of the system.

In the RCCS, however, during daytime, the system's performance is a function of the set of climatic conditions it is exposed to, ultimately responsible for heat gains through the module's envelope. Therefore, in terms of the MCP, the thermal performance of the RCCS is much more complex to explain than that of the roof pond system.

It is important to highlight the reason for the negative values of MCP in Figure 7. In those cases, the average daily temperature of the RCCS was higher than that of the CC. This is observed on days when there is a sudden drop in outdoor temperature (as in cold fronts) and the temperature at CC drops faster than at the RCCS due to its higher thermal mass.

Figure 7:
Mean Cooling Potential per day during experimental series and corresponding mean ambient temperature (Ta.avg), wet bulb temperature depression (Dwbt) and temperature depression of a metal sheet concurrently exposed to the sky during measurements (Dtr).



3.3 The Thermal Performance Mean Ratio

One way to evaluate the thermal performance of the RCCS in relation to the RP is by means of the ratio of the relationship between mean and maximum temperature depression reached in the test cells (RCCS and RP) with respect to the CC. As already pointed out, the depression of the mean temperature in the RCM with respect to the CC allows us to determine the mean cooling potential of the system. By dividing this by the same depression, yet using that obtained for the RP module, a ratio can be obtained that gives us a performance index for comparing both systems.

The mean temperature depression in the RP (DTrp.avg) is equal to the difference between the mean indoor temperature at the CC and at the RP, as follows:

DTrp.avg = Tcc.avg - Trp.avg (2)

Analogously, the mean temperature depression in the RCCS (DTrccs.avg) is equal to the difference between the mean indoor temperature at the CC and that at the RCCS:

DTrccs.avg = Tcm.avg - Trccs.avg (3)

The Thermal Performance Index (TPI), understood as the ability of the RCCS to reach the mean temperature depression achieved by the RP module is given by:

TPI (avg) = Tcc.avg - Trccs.avg / Tcc.avg - Trp.avg (4)

By the same reasoning, we can comparatively analyse the performance of both systems in terms of the daily maximum temperatures, as follows:

TPI (max)=Tcc.max-Trccs.max/Tcc.max- Trp.max (5)

Where: Tcc.max = Daily maximum temperature at the CC; Trccs.max = Daily maximum temperature at the RCCS; Trp.max = Daily maximum temperature at the RP.

TPI values can be less than, equal to or greater than 1. A TPI value equal to 1 means that the RCCS has a thermal performance equal to that of the RP taken as a reference.

For the TPI (avg), the average value reached in the 50 days of these experimental series was 0.63. However, during 33 of the 50 days values higher than 0.6 are observed (with a TPI (avg) = 0.90). If the 11 days of these Series of rapid drop in temperature due to cold fronts are withdrawn from the analysis the PTI is higher than 0.8 reaching a maximum of 1.8, which means a greater cooling capacity than the RP. In 12 of the 50 days (24%) the TPI is equal to or greater than 1. Thus, when climatic conditions are moderately stable, without large temperature differences from one day to the next, the TPI (avg) is around 0.84, as is the average between the first 13 days of Series 3 (Figure 10).

On the other hand, regarding the TPI (max), the average in these experimental Series was 0.95 with a maximum value reaching 1.72 and a standard deviation of 0.2. This means that the ability to reduce maximum temperatures of the RCCS with respect to the CC is very close to that of the RP and sometimes may even exceed it.

Finally, it is interesting to note that during the first two experimental series the TPI max was 1.1 (the roof pond had 6.5 cm of water), while in Series 3 (the roof pond with 10 cm of water) TPI avg was 0.95. This points to the importance of the amount of thermal mass in the RP for improving its thermal performance.

4. CONCLUSION

The results obtained with the experimental RCCS show that, although it is necessary to deepen the characterization and evaluation in full scale, indicate cooling potentials and the capacity to reduce internal temperatures for the thermal conditioning of buildings even in conditions that, as in the case of Curitiba, are not the most conducive to nocturnal radiative cooling.

Based on the analyses performed with both passive systems, we conclude that the RCCS has a thermal performance comparable to, or even higher than, the RP. In general terms, under conditions of high ambient temperature and relatively favourable sky conditions for nocturnal radiative cooling (clear sky with low humidity content), the system has a thermal performance greater than 80% of that of an indirect evaporative cooling system.

One last point, in full scale, the RCCS will have more promising results provided that the building already has substantial thermal mass.

ACKNOWLEDGEMENTS

This research was carried out within the framework of EDITAL Nº 11/2018 - PROPPG - Visiting Professor (PV) of the Department of Civil Construction, Federal University of Technology of Paraná - UTFPR, Curitiba, Brazil.

REFERENCES

1. IEA-Net Zero by 2050 A Roadmap for the Global Energy Sector, IEA-2021. https://www.iea.org/reports/net-zero-by-2050 (accessed June 21, 2021).
2. Chiesa, G., Huberman, N., Pearlmutter, D., Grosso, M., (2017) Summer discomfort reduction by direct evaporative cooling in Southern Mediterranean areas. Energy Procedia 111 (2017) 588–598.
3. IEA. Cooling. https://www.iea.org/fuels-and-technologies/cooling (Accessed June 21, 2021).
4. IEA. Air conditioning use emerges as one of the key drivers of global electricity-demand growth. https://www.iea.org/news/air-conditioning-use-emerges-as-one-of-the-key-drivers-of-global-electricity-demand-growth (Accessed June 21, 2021).
5. Gonzalez, E. Krüger, E. (2022). Experimental study on a low energy radiant-capacitive heating and cooling system. Energy and Buildings 255 (2022) 111674. https://doi.org/10.1016/j.enbuild.2021.111674
6. Gonzalez, E., González, S. (2013). Estudio experimental sobre el comportamiento térmico de un nuevo tipo de techo-estanque para el enfriamiento pasivo en clima húmedo. Ambiente Construído, Porto Alegre, Vol. 13, No. 4, pp. 149-171, out./dez. https://doi.org/10.1590/S1678-86212013000400011
7. Martin, M., & Berdahl, P. (1984). Characteristics of infrared sky radiation in the United States. Solar energy, 33(3-4), 321-336. https://doi.org/10.1016/0038-092X(84)90162-2

Thermal Performance of Ceramic Claddings Used on Vertical and Horizontal Urban Surfaces

ANA JÚLIA PILON CASTELLO[1] MARCIUS FABIUS HENRIQUES CARVALHO[1] CLÁUDIA COTRIM PEZZUTO[1]

[1] Pontifical Catholic University of Campinas, Brazil

ABSTRACT: Many investigations document the thermal performance of urban roofs and pavements. However, few studies have related the impact of vertical covering in urban warming. This paper therefore fills this gap by evaluating the thermal performance of colored ceramic materials used on urban horizontal and also on vertical surfaces. The results evaluate the influence of physical characteristics such as color, texture and finish, as well as the thermal and optical behavior of the study samples. The thermal measurement of the claddings exposed to solar radiation was registered on a typical summer day in February, 2022. The surfaces temperatures were observed each two hours throughout the day, under the influence of current weather conditions, and then the database was configured to develop statistical analyses. The solar reflectance of the samples was collected with a portable spectrometer. Throughout the experiment, the horizontal plane had the highest maximum temperatures. The results show that the white sample (WH_SP) reached the lowest surface maximum temperatures, 43.3°C and 38°C, horizontal and vertical surfaces, respectively. On the other hand, the black sample (BL_SP) reached the highest temperatures, 63.9°C and 41.8°C, horizontal and vertical plane, respectively. The results showed the considerable influence of position, color and solar reflectance on the thermal performance of urban claddings.
KEYWORDS: Thermal performance, Solar reflectance, Urban envelopes, Facades, Microclimate

1. INTRODUCTION

Urban regions can be characterized by several microclimates according to the surfaces that compose them, such as asphalt, vegetation, and especially a wide range of building envelope materials that impact on the urban albedo result [1].

In general, higher temperatures are observed in cities compared to the surrounding rural areas, this is known as heat islands. However, cities can reverse this phenomenon by considerably increasing the albedo of materials, being able to reduce the air temperature from 2°C to 4°C according to studies [2].

Heat islands studies are always in progress because implies issues of climate change and population growth in cities. The sixth report of the Intergovernmental Panel on Climate Change (IPCC) declares that global warming is likely to exceed the range of 1.5°C and 2°C in the 21st century and reports the importance of engagement from user to scientist to decision-making on mitigation and risk management process [3]. The implementation of heating mitigation measures is a way to prepare cities and buildings for the impacts of future urbanization, in addition to reducing future cooling demand [4].

Cool or highly reflective materials are materials with high solar reflectance and high infrared emittance [5-6].

In general, the use of more reflective materials can reduce up to 39°C in the surface temperature of the facades [7], 41°C on roofs [8] and 32°C on floors [9], comparing extreme situations of surface heat gains.

Many investigations documented the thermal and optical performance of roofs and pavements [10]. Although, a few studies related the impact of vertical covering in urban warming.

As soon, the objective of this paper is to evaluate the thermal potential of a group of ceramic coverings, understanding the influence of their optical and thermal properties and physical characteristics, such as reflectance and color, and also to analyze the difference of the heating of study samples, in the horizontal and vertical planes.

2. MATERIALS AND METHODS

This work presents an experimental study to analyze envelope materials commonly used in Brazilian buildings. Thus, an outdoor experiment was carried out under solar radiation in a typical summer week, in the southeast region of Brazil, in February 2022, using various colored ceramic claddings with different textures and finish, measuring 240mm x 116 mm and 9mm thick (Table 1).

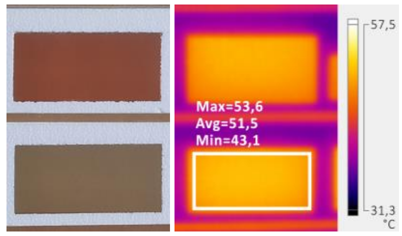
Table 1:
Classification of materials according to their characteristics observed.

Sample code		Surface color	Surface texture	Surface finish
BL_SP		Black	Smooth	Polished
DB_SP		Dark blue	Smooth	Polished
RED_SP		Red	Smooth	Polished
LB_SP		Light blue	Smooth	Polished
YE_SP		Yellow	Smooth	Polished
BE_SP		Beige	Smooth	Polished
WH_SP		White	Smooth	Polished
TE_SM		Terracotta	Smooth	Matte
CO_SM		Concrete	Smooth	Matte
BE_SM		Beige	Smooth	Matte
TE_RM		Terracotta	Rough	Matte
CO_RM		Concrete	Rough	Matte
BE_RM		Beige	Rough	Matte

In this experiment, the sample was fixed on a horizontal and vertical platform made of MDF (Medium Density Fiberboard) and coated with EPS (Expanded Polystyrene), 40mm thick, working as adiabatic limit with respect to the conductivity of other samples or MDF boards. Both panels were positioned in the southern orientation, because this position the solar incidence is lower in most of the year. The horizontal was inclined according to local latitude, 23°, and the vertical 90°.

The surface temperature measurement of each unit was collected using a Fluke Ti110 thermographic camera (Fig. 1). They were observed every 2 hours, from 6am to 4am of the following day. The measured hourly surface temperatures of each unit correspond to the average temperature values of the total surface. These values are estimated automatically by selecting the specific area on the infrared images (Fig. 1), using the software Fluke SmartView Classic 4.4.

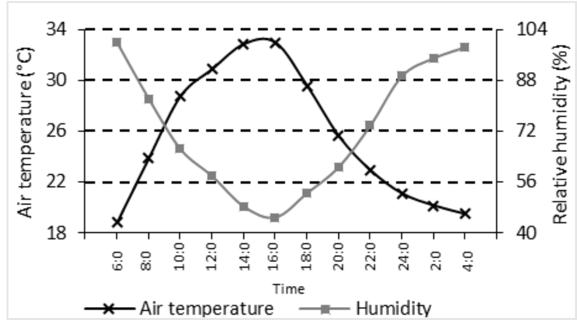
Figure 1:
Visible and infrared image of selects samples.



The emissivity value of 0.9 was set in the IR camera and in the thermometer, as indicated in studies [11].

Stations ported with Testo 174H Data Loggers were installed on site for climate monitoring (Fig. 2), recording air temperature and relative humidity every 10 minutes.

Figure 2:
Air temperature and relative humidity during the measurement day.



Optical characteristics of the sample were also collected. The solar reflectance of the claddings was calculated following the procedures and methods proposed by studies [12-13], using the ALTA II Spectrometer, developed by the Lunar and Planetary Institute, in Houston-Texas, to obtain the radiation emitted in 11 wavelengths, between 470 and 940 nanometers (7 in the visible region and 4 in the infrared region). Several studies report good reliability of this instrument [13-14].

Solar elevation, azimuth and solar chart from the day of thermal measurement were collected on SunEarth's website. It is a tool for consumers and designers of solar energy. The data are according to the specific local coordinates (22°43'S and 46°51W) and in the GTM-3 time zone.

3. RESULTS

This section presents results of the measurement of the sample surface temperatures (°C), from the horizontal and the vertical experiments. The daily maximums and minimums are provided (Table 2 and Fig.3). The highest maximum temperature recorded in this research

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE BUILDINGS AND TECHNOLOGY

was 63.9°C, for the black sample (BL_SP) in the horizontal platform. On the contrary, the white sample (WH_SP) in the vertical platform, presented the lowest maximum temperature, 38°C. Therefore, there is 25.9°C of difference between the data extreme.

In the horizontal position, the black and white samples (BL_SP and WH_SP) obtained, respectively, an increase of 22.1°C and 5.3°C in the maximum temperatures in relation to the vertical position. That is, more heat accumulates in the horizontal plane, and dark materials are more influenced by the position of the coating. Dark roofs and floors can reach high temperatures, as they are under the direct influence of solar radiation.

The difference of maximums and minimums and the daily averages are also provided (Table 2). The difference ranged from 29.5°C to 49.8°C in the horizontal panel and from 20.5°C to 24.2°C in the vertical panel. From a first point of view, samples heat up more and cool down more in the horizontal experiment. But another observation is that considering the total averages, the vertical study with 27.6°C remains hotter throughout the day, even not reaching the maximum temperatures of the horizontal study, which has a total average of 23.2°C.

Table 2:
Reflectances and daily surface temperatures (maximums, minimums, *differences and averages*)

Code	Reflectance (%)	Horizontal Platform (°C)				Vertical Platform (°C)			
		Maximum	Minimum	Difference	Average	Maximum	Minimum	Difference	Average
BL_SP	0.3	63.9	14.1	49.8	21.0	41.8	17.6	24.2	28.6
DB_SP	3.6	63.4	14.0	49.3	20.7	41.1	17.4	23.7	28.3
RED_SP	16.2	55.7	14.0	41.7	20.2	39.4	17.3	22.1	27.5
LB_SP	20.6	51.3	13.8	37.5	19.8	39.1	17.4	21.7	27.6
YE_SP	29.6	50.7	13.9	36.8	20.0	38.3	17.1	21.1	27.0
BE_SP	30.9	49.7	13.9	35.8	19.8	39.0	17.1	21.9	27.5
WH_SP	50.4	43.3	13.8	29.5	19.2	38.0	17.5	20.5	26.7
TE_SM	11.6	56.6	13.9	42.7	51.5	40.4	17.5	22.9	27.9
CO_SM	10.4	56.6	14.5	42.0	21.8	40.8	17.1	23.7	27.9
BE_SM	25.4	52.8	14.6	38.1	21.5	40.3	17.3	23.0	27.7
TE_RM	10.0	59.6	14.3	45.2	22.5	39.7	17.5	22.2	27.4
CO_RM	10.3	58.4	14.3	44.1	22.1	39.6	17.1	22.5	27.4
BE_RM	24.5	53.8	14.8	38.9	21.9	38.6	17.6	21.0	27.3

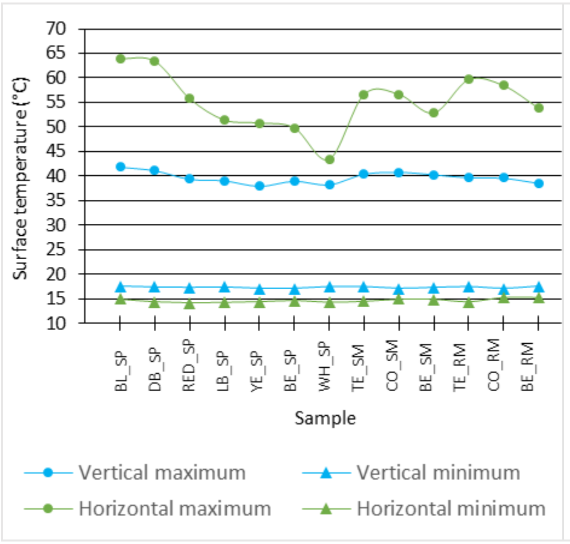
Note: The average of each sample was taken from all data measured throughout the day.

Observing the minimum temperatures (Fig. 3), the values do not show significant differences between the samples. Additionally, during the night period the performance of the samples is strongly affected by the infrared emittance [10].

However, it was found that all the polished claddings on the horizontal platform recorded the daily minimum temperatures at 22:00, while all the matte ones at 6:00 (Fig. 3 and 7). That is the polished samples cooled down faster.

The white coating (WH_SP) presented the best thermal performance of all, and dark color claddings such as black, blue and terracotta, presented the worst performances and high amplitudes. These results reinforce the discussion about the thermal performance of claddings in the known literature. White coating was also considered a suitable material for covering buildings as they provide good thermal comfort for outdoor environments, improving the urban microclimate [8-10]. Overall, research reports the low efficiency of dark-colored surfaces [7,9,15].

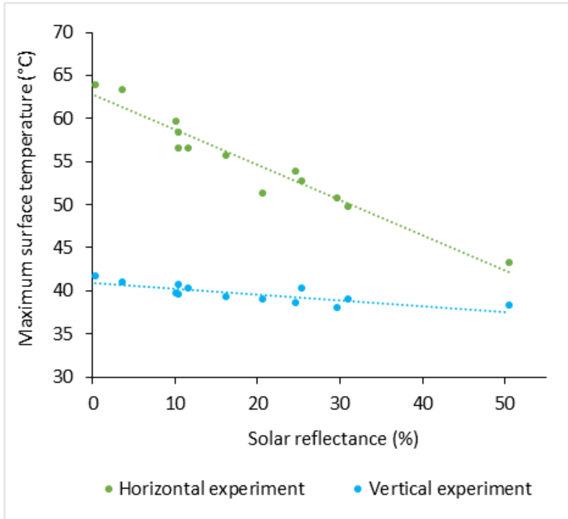
Figure 3:
Daily maximum and minimum surface temperatures, from the horizontal and vertical coverings.



The most unfavorable facade coating is black. The surface temperature difference found between this coating and the white, with the highest performance, was 17.5°C, in another study [7]. In this work, the difference between the maximum temperatures of the sample BL_SP and WH_SP is 20.6°C, horizontally. And 3.8°C, vertically.

In the comparison between solar reflectance and maximum surface temperature, the claddings with the highest values of solar reflectance, as expected had the lowest surface temperatures. The samples with the best thermal performances, WH_SP, LB_SP, BE_SP, BE_SM, BE_RM and YE_SP, have the highest percentages of solar reflectance, 50.4%, 20.6%, 30.9%, 25.4%, 24, 5% and 29.6%, respectively. The reflectances of the other claddings varied in a low range, from 0.3% (for the black coating) to 16.2% (for the red coating). It is possible to affirm, like other studies [6-11], that the main factor that affects the thermal performance of the sample during the day is the solar reflectance (Fig. 4). The correlation between solar reflectance and maximum temperature is -0.97 for the horizontal experiment, and -0.80 for the vertical one. There is a strong inverse correlation. It is important to remember that several studies also evaluate the interference of weathering over time, which can cause changes in solar reflectance [16-17-18].

Figure 4:
The correlation between maximum daily surface temperature and the solar reflectance, from horizontal and the vertical experiments.

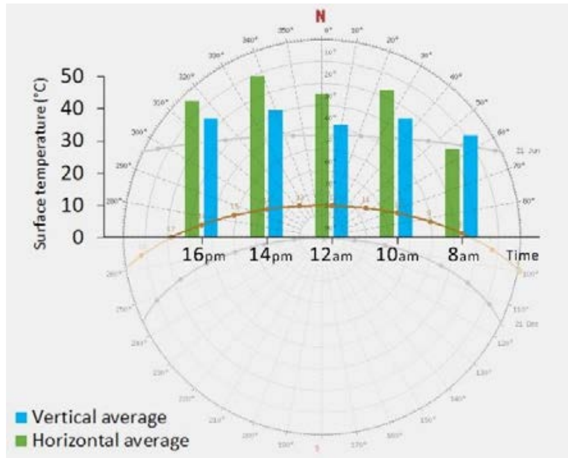


The following data describe the solar elevation and the solar azimuth of the thermal measurement day (Table 3). The hourly average temperatures of both experiments, during the influence of solar radiation (from 8am to 16pm), were plotted in graphs and overlapped on the solar chart (Fig. 5). It is possible to observe the solar trajectory in comparison with the thermal measurement data of the claddings.

Table 3:
Data of solar position from the thermal measurement day.

Hour	Solar Elevation (°)	Azimuth (°)
6:00	1.03	99.76
8:00	26.24	88.57
10:00	53.52	72.92
12:00	75.03	19.82
14:00	62.2	296.69
16:00	35.55	275.86
18:00	7.91	264.08

Figure 5:
Average surface temperatures and the solar trajectory, from horizontal and vertical experiments.



At 8am, the vertical experiment heated up more quickly, but at 10am the horizontal study already registered greater heating. According to the analysis of climatic conditions, at 12am there was a small drop in temperature, reflecting the heating of the samples. As a result, a reduction of up to 2.4°C occurred in relation to the previous measurement, at 10am. In this analysis, south facades indicated low heating potential and lower differences of surface temperatures, good to thermal balance externally and internally.

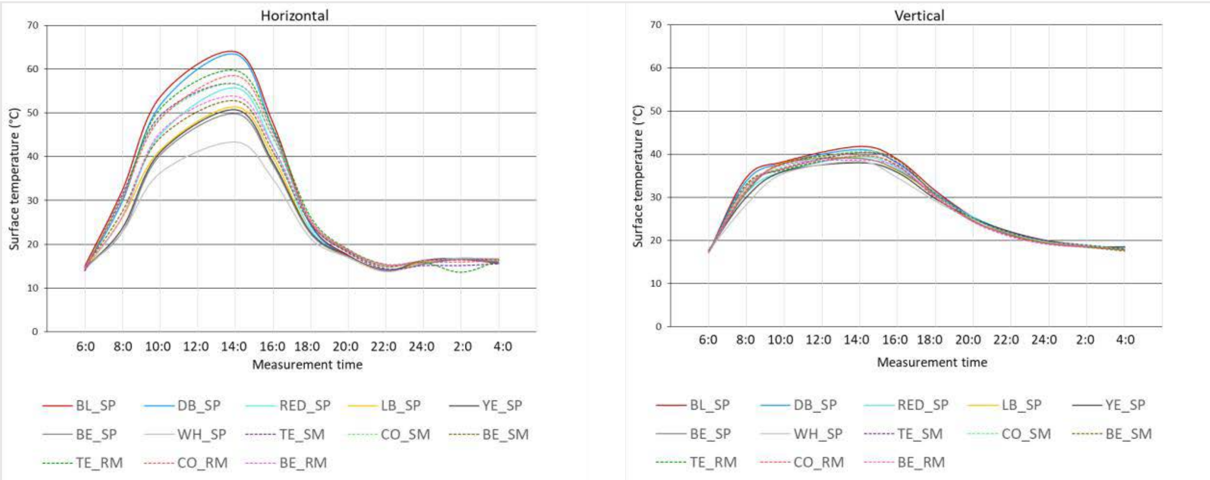
By observing heating and cooling at different times, from 6am to 10am, from 10am to 2pm, from 2pm to 6pm, and from 6pm to 10pm, was verified the thermal difference of the experiments (°C/hour). The greatest heat gain occurred from 6:0 to 10:0 in the horizontal study (+30.6°C), noting that the azimuth is close to 90° in this period. On the other hand, it presented the highest heat loss from 2pm to 6pm (-9.3°C). At 2pm there is the highest solar azimuth (296.7°).

Table 4:
Heat gain and heat loss, from horizontal and vertical experiments.

Period	Horizontal (°C)	Vertical (°C)
6:0 to 10:0	+30.6	+18.9
10:0 to 14:0	+9.3	+3.1
14:0 to 18:0	-29.3	-8.5
18:0 to 22:0	-10.0	-9.4

Finally, it is possible to notice the behavior of the samples considering the temperatures measured every two hours during the day and night (Fig. 7), highlighting again the samples with the best and worst performance in both experiments (WH_SP and BL_SP). In summary, the horizontal experiment recorded greater differences between the surface temperatures, as the vertical experiment is more constant, but the average surface temperature is high.

Figure 6:
Distribution of surface temperatures every two hours, from horizontal and vertical experiment.



3. CONCLUSIONS

Optical properties affect mainly the thermal balance of the evaluated ceramic claddings. In general, the greater is the reflectivity of the sample to solar radiation (during the day), the surface temperature reached lower values. This correlation is very evident on the horizontal and on the vertical experiment. This research also showed how the surface coating applications (horizontal and vertical orientation) influences on the thermal performance of urban envelopes. It should be noted that on the horizontal experiment the variables solar reflectance, surface color, and finish demonstrated influence. The higher the solar elevation and the closer the azimuth is to the facade normal, the higher the surface temperature, considering both experiments. In any case, the materials present in the facades of urban buildings absorb solar energy and infrared radiation. Heat accumulates on their surfaces and dissipates it into the atmosphere. Then the use of claddings with better thermal performance plays an important role in mitigating heat islands and cooling in urban areas. Of all the sample considered in this study, WH_SP is the best, followed by the beige, yellow, and light blue samples (BE_SP, YE_SP, LB_SP), all polished. As expected, the best thermal performance is associated with light-colored materials. On the contrary, dark claddings, such as black, dark blue and terracotta, absorb more heat and their use in urban constructions can cause thermal discomfort to pedestrians on the streets and sidewalks.

This research will be continued by estimating the thermal performance for other solar orientations such as north, east and west and for different weather seasons.

All the information and conclusions obtained in this experiment are useful to formulate architectural strategies and even urban guidelines to deal with urban warming and mitigate the extreme events of climate change.

REFERENCES

1. P. A. Coppin, B. W. Coppin, C. L. Penney, and P. Schwerdtfeger, "Zonal characteristics of urban albedos," *Urban Ecol.*, vol. 3, no. 4, pp. 365–369, 1978, doi: 10.1016/0304-4009(78)90039-6.
2. H. Taha, "Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat," *Energy Build.*, vol. 25, no. 2, pp. 99–103, 1997, doi: 10.1016/s0378-7788(96)00999-1.
3. IPCC, "SIXTH ASSESSMENT REPORT - Conference Slides," *Press Conf. Slides*, pp. 01–48, 2021, [Online]. Available: https://www.ipcc.ch/report/ar6/wg1/downloads/outreach/IPCC_AR6_WGI_Press_Conference_Slides.pdf.
4. S. Garshasbi *et al.*, "Urban mitigation and building adaptation to minimize the future cooling energy needs," *Sol. Energy*, vol. 204, no. March, pp. 708–719, 2020, doi: 10.1016/j.solener.2020.04.089.
5. M. Santamouris, "Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments," *Sol. Energy*, vol. 103, pp. 682–703, 2014, doi: 10.1016/j.solener.2012.07.003.
6. A. Synnefa, M. Santamouris, and K. Apostolakis, "On the development, optical properties and thermal performance of cool colored coatings for the urban environment," *Sol. Energy*, vol. 81, no. 4, pp. 488–497, 2007, doi: 10.1016/j.solener.2006.08.005.
7. N. L. Alchapar and E. N. Correa, "Optothermal properties of façade coatings. Effects of environmental exposure over solar reflective index," *J. Build. Eng.*, vol. 32, no. May, p. 101536, 2020, doi: 10.1016/j.jobe.2020.101536.
8. MUNIZ-GÄAL, L. P. et al. Eficiência térmica de materiais de cobertura. Ambiente Construído, v. 18, n. 1, p. 503–518, 2018.
9. N. L. Alchapar, E. N. Correa and M. A. Cantón, "Classification of building materials used in the urban envelopes according to their capacity for mitigation of the urban heat island in semiarid zones," Energy and Buildings, v. 69, p. 22–32, 2014.
10. A. L. Pisello, "State of the art on the development of cool coatings for buildings and cities," *Sol. Energy*, vol. 144, pp. 660–680, 2017, doi: 10.1016/j.solener.2017.01.068.
11. L. Doulos, M. Santamouris, and I. Livada, "Passive cooling of outdoor urban spaces. The role of materials," *Sol. Energy*, vol. 77, no. 2, pp. 231–249, 2004, doi: 10.1016/j.solener.2004.04.005.
12. E. I. Santos, D. L. Marinoski, and R. Lamberts, "Influência do ambiente de medição sobre a verificação da absortância de superfícies opacas utilizando um espectrômetro portátil," *X Encontro Nac. e VI Encontro Lat. Am. Conforto no Ambient. Construído*, pp. 660–669, 2009.
13. C. D. Pereira, D. L. Marinoski, R. Lamberts, S. Güths, and E. Ghisi, "Relatório de Avaliação do Espectrômetro Portátil ALTA II.," 2015.
14. K. A. Dornelles and M. Roriz, "Métodos alternativos para identificar a absortância solar de superfícies opacas," *Ambient. Construído*, no. 16, pp. 109–127, 2007.
15. N. L. Alchapar, E. N. Correa and M. A. Cantón, "Índice De Reflectancia Solar De Revestimientos Verticales: Potencial Para La Mitigación De La Isla De Calor Urbana," Ambiente Construído, v. 12, n. 3, p. 107–123, 2012.
16. N. L. Alchapar and E. N. Correa. "Aging of roof coatings. Solar reflectance stability according to their morphological characteristics," Construction and Building Materials, v. 102, p. 297–305, 2016.
17. K. Dornelles, R. Caram, and E. Sichieri. "Natural weathering of cool coatings and its effect on solar reflectance of roof surfaces," Energy Procedia, v. 78, p. 1587–1592, 2015.
18. L. F. Kowalski. "Envelhecimento de pavimentos de concreto pigmentado e consequências sobre o albedo," Revista de Arquitetura IMED, v. 10, n. 1, p. 126, 30 dez. 2021.

Reversible building design
Viewing a building as a material bank

FELIPE OSSIO [1], RENATO D'ALENÇON[2], MORITZ RÜCKER[2], MATÍAS AHUMADA[1]

[1] Escuela de Construcción Civil. Facultad de Ingeniería. Pontificia Universidad Católica de Chile
[2] Escuela de Arquitectura. Facultad de Arquitectura, Diseño y Estudios Urbanos. Pontificia Universidad Católica de Chile

ABSTRACT: Reversible Design leads to efficient use of raw materials, as well as, a CDW reduction by: making flexible and adaptable designs favourable for new uses and programs; and recovering both the built surface and its construction components for new uses, in order to create a materials reserve. At the same time, a Reversible Design also has several restrictions to consider (structural, economic, environmental, and various others) that differ with the project's location. To be able to advance towards a Reversible Design, we need to ask ourselves How reversible are our dwellings?. This study determinate the reversibility for the most abundant archetype of Chilean housing by analysing there structure's adaptation, circularity of components, and deconstruction and disassembly potential. The study shows the low reversibility of Chilean housing and gives clues on how to improve it. The method, which can be replicated in other contexts, makes it possible to take an X-ray of the existing housing stock with a view to improving its reversibility.
KEYWORDS: housing; transformable architecture; adaptable buildings; sustainable architecture

1. PROBLEM STATEMENT
In recent years, national and international politics have paid special attention to sustainable concepts associated with construction projects, creating the need to reduce their environmental impact, as well as conduct enhanced and more efficient resource management. The design of sustainable projects requires a paradigmatic change, allowing for development to not be a synonym for squander that is typically provoked by uncontrolled misuse and disposal, but rather replacing linear production cycles with circular cycles (Bedoya, 2011). The development of processes to reduce the quantity of material necessary for building construction, along with the reintegration of residual scraps into the system, are required in order to reduce waste resulting from said activity.
Nevertheless, the current approach to building design and construction has a high environmental impact. In particular, the generation of Construction and Demolition Waste (CDW) represents a serious problem for cities worldwide. In fact, the global CDW generation rate is disconcertingly high; the waste generated by the European construction industry constitutes 36% of Europe's total waste (Eurostat, 2019). In Chile, it is estimated that the construction industry generates 7,1 millions tons of annual CDW, with the Metropolitan, Valparaiso, and BioBio regions being the largest generators of the annual residential CDW (Molina-Ramírez, Ossio, & Urria, 2019).
The mismanagement of CDW has caused multiple impacts in the country, including the need to have ground prepared for appropriate disposal, and required management costs (Jin et al. 2017; Valdés & Rapimán 2007). Additional impacts include those derived from CDW transportation and poor disposal, such as: occupying land suitable for other uses, urban problems, visual impact, risks of massive removals or landslides, soil contamination due to gypsum accumulations and their mixture with organic residues, increased fire risks due to the discharge of hazardous and/or combustible residues, contamination of surface waters and groundwater due to leaching caused by CDWs coming contact with rain water, risks before catastrophes, damage to public health, and impact to flora and fauna (Acosta, 2002). This situation is aggravated given the slow degradation of CDW compared to its accumulation rate (Asociación Española de Reciclaje de Residuos de Construcción y Demolición, 2019), as well as its low capacity for recycling or reintegration into the economic cycles.
As the high generation of CDW is a multifactorial problem, involving all the key players in the construction industry (especially architects and builders, researchers, suppliers, as well as users), anticipation from as early as the design stage is essential for the environmentally sound management of CDWs. In fact, adequate anticipation of the end of life for building accounts for the limitations and needs related to the useful lifespan of the projects, their reversibility even in the design phase, and the end of life for the materials.
The above takes relevance when considering the volatile changeability of the needs of the users, and those living with the built environment, leading to an accelerated obsolescence of buildings, and consequently, to high CDW generation. In fact, building obsolescence is in part caused by physical phenomenon (deterioration of materials) as well as the result of human activities where functional and economic factors play an important role. In doing so, the technical useful life of projects (durability of the materials) can be greater than the functional useful life (use for which the property is intended) or the economic useful life (period in which its use is economically profitable). It is in this regard that the adaptability of buildings intended from design commencement is especially relevant (Galle, Vandervaeren, De Temmerman, et al., 2019).
Finally, the lack of resources, along with environmental problems, raises the question of whether the construction industry, which is responsible for using 40% of virgin materials mined worldwide (Enshassi, Kochendoerfer & Rizq, 2014), should have a more active role in this issue. The existing residential building stock represents the largest financial, physical, and cultural asset in the industrialized world. This existing building stock also represents our future material stock to be reused or to be recycle (Gobbo, 2015). A sustainable society is not possible until this key resource can be managed sustainably. The demolition of buildings in order to erect new structures, without considering their life cycle, results in an inefficient practice with negative economic, energy, and social impacts. The existing constructions should incorporate the circular economy via: a Reversible Building Design approach integrating flexible and adaptable designs for new uses and programs; a subsequent reduction in CDWs and efficient use of virgin resources; as well as the revaluation of its construction components as a materials reserve (Gobbo, 2015).

2. BACKGROUND
The concept of a Reversible Building Design is related, either directly or indirectly, to many terms that have gained momentum among architects and academics, applicable in different phases throughout the life of the project.
Concepts that aim to extend the building-use stage include: Design for Longevity (Sassi, 2004; Morgan & Stevenson, 2005) that aims to guarantee a long life to the building through strategies that allow it to adapt to programmatic changes and facilitate its maintenance and improvement; Design for Change (Webster, 2007; Heidrich et al., 2017) that refers to designs that recognize that the needs and aspirations of users evolve, therefore seeking building designs that adapt to these changes in the most effective way; or Design for Adaptability (Basta, Serror, & Marzouk, 2020; Giorgi, Lavagna, & Campioli, 2020; Gosling, Sassi, Naim, & Lark, 2013; Heidrich et al., 2017; Morgan & Stevenson, 2005; Rios, Chong, & Grau, 2015; Webster, 2007) that corresponds to a design strategy that aims to anticipate the future rehabilitation of a building and allow it to be easily reconfigured for another use.
All these strategies are related to Reversible Building Design, and consider the evolution of operational buildings through intermediate transformations to extend their total life cycle. Likewise, this design allows us to make the energy and material consumption more efficient by reducing the generation of CDW.
In a building's final end-of life phase, concepts related directly to the notion of reversible design include: Design for Deconstruction (Akinade et al., 2017; Basta et al., 2020; Buyle, Galle, Debacker, & Audenaert, 2019; Eckelman et al., 2018; Morgan & Stevenson, 2005; Rios et al., 2015; Webster, 2007) that corresponds to a design strategy permitting the easy separation of its materials and components to better facilitate recycling and reuse, or Design for Disassembly (Aguiar, Vonk, & Kamp, 2019; Basta et al., 2020; Buyle et al., 2019; Giorgi et al., 2020; Heidrich et al., 2017; Klinge A, Roswag-Klinge E, Paganoni S, & Lehmann, 2019; Morgan & Stevenson, 2005; Rios et al., 2015; Stephan & Athanassiadis, 2018) that corresponds to a design strategy used to create construction elements that can be easily disassembled without causing any damage so that the components can be reused.
Faced with this multiplicity of terms and notions, it is difficult to establish a clear understanding of the exact nature of Reversible Design. According to Oxford Advanced Learner's, reversible signifies the capability to return its original state or situation. Thus, the Reversible Building Design concept refers to the "integration of disassembling possibilities from the initial design of a project or product. It integrates a reflection on the mounting methods, the compatibility between layers and the life spans of the construction elements" (Trachte, Gobbo, & Massart, 2019). Reversible Design is essential to achieve an enhancement of existing buildings and new projects through adaptive design, scheduled disassembly, and CDW reuse.
To such a degree, the Reversible Building Design integrates notions of adaptability and flexibility, as well as the notion of reversible connections, connections that can be disassembled without damaging the components they connect, whether forming part of a building's structure, function and/or envelope. The reversibility of the

connections has a great influence on the potential of environmentally sound management of CDWs at the project's end-of-life and is considered a prerequisite for deconstruction.

Furthermore, the Reversible Building Design requires the consideration of several restrictions (structural, economic, environmental, among others) which differ depending on the location of the project (each country has its own environmental, economic, and local regulations). Therefore, it is pertinent to analyze, on the one hand, the national regulatory framework (constructive and environmental) governing the entire life cycle of construction materials or elements, including possible reversibility and construction reuse, with the aim to identify and understand the opportunities and obstacles of a complex legislative framework on the application of Reversible Building Design in Chile. And on the other hand, to analyze the Reversible Building Design evaluation systems, allowing us to determine the potential reversibility of current architectural designs considering reversible connections that are applicable according to the legal regulatory framework.

2. RESEARCH QUESTION AND OBJECTIVES

Studies have shown that a Reversible Design leads to efficient use of raw materials, as well as, a CDW reduction by: making flexible and adaptable designs favorable for new uses and programs; and recovering both the built surface and its construction components for new uses, in order to create a materials reserve. (Debacker et al., 2015; Durmisevic et al., 2017; Vefago & Avellaneda, 2013). At the same time, a Reversible Design also has several restrictions to consider (structural, economic, environmental, and various others) that differ with the project's location (each country has their own set of environmental and economic limitations, along with local regulations).

This is particularly true in Chile, a country that is divided into 16 administrative regions located in different climatic zones. The housing stock in said zones comprises up to 6 million units whose characteristics vary according to local weather conditions, and availability and accessibility of construction materials. A recent study showed that 496 archetypes can be used to represent 100% of the housing stock in Chile and only 8 can represent 35% of the stock. (Molina, Kent, Hall, & Jones, 2020).

To be able to advance towards a Reversible Design, we need to ask ourselves "How reversible are dwellings in Chile?" By analyzing the adaptation, circularity of components, and deconstruction and disassembly potential of structures that use existing designs, and based on what has already been mentioned, we should be able to moving towards new reversible designs.

Consequently, this study aims to determinate the reversibility for the most abundant archetype of Chilean housing by analyzing there structure's adaptation, circularity of components, and deconstruction and disassembly potential.

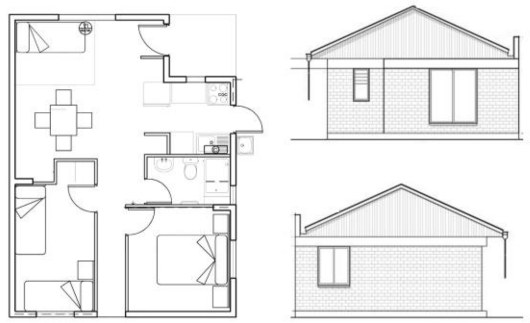
3 METHOD

The method divides itself into four main stages, namely: (3.1) Archetype Characterization; (3.2) Assessment of the potential adaptability; (3.3) Assessment of circularity of components and (3.4) Assessment of the deconstruction and disassembly potential.

3.1 Archetype Characterization

The archetype analyzed corresponds to the most abundant archetype in Chile. It represents 6.8% of the stock (Figure 1). It is a detached single-storey uninsulated house, constructed with clay bricks in central cities of the country, prefabricated panels in northern cities, and wooden panels in southern cities (Molina et al., 2020). The detailed analysis required technical documentation and quantification of the materials used. In order to do this based on the characteristics; representative model of the same type was through buildings permits and documentation that are currently present in the municipalities.

Figure 1:
Floor plans and of the reference archetype.



Note: The design is based on the available information in (Molina et al., 2020).

3.2 Assessment of the potential adaptability

The functional adaptability for the archetype was evaluated on a scale of 0 to 100, considering aspects such as Space efficiency, Ceiling height, Building depth, Floor layout, Structural Flexibility, and Technical Building Service Flexibility, by means of an instrument provided by the DGNB Certification System belonging to the German Sustainable Construction Council (DGNB System, 2017).

3.3 Assessment of circularity of components

The archetype's percentage of inclusion of materials and components with circular attributes was determined using the methodology proposed by the World Business Council for Sustainable Development (2021). The circularity of components is calculated as the average of circular inputs and outputs in mass. For the circular inputs, the percentage renewable or non-virgin percentage (no distinction is made between them) of the material/element/product is considered. On the other hand, circular outputs are calculated as the multiplication between the percentage recoveries potential (reflects the company's capacity to design appropriately) and the percentage actual recovery (reflects the capacity of the ecosystem to take over).

3.4 Assessment of the deconstruction and disassembly potential

Disassembly security was determined following the recommendations in the ISO/DIS 20887 standard: Sustainability in buildings and civil engineering works - Design for disassembly and adaptability - Principles, requirements and guidance (International Organization for Standardization, 2020), using a scale from 0 to 100.

4. RESULTS AND DISCUSSION

The archetype analyzed represents 6.8% of the stock (4.7 million units). It is a detached single-storey uninsulated house, constructed with clay bricks in central cities of the country (180.744 units), prefabricated panels in northern cities (61.713 units), and wooden panels (77.261 units) in southern cities. It has two bedrooms, two bathrooms and a separate kitchen. Its heating and cooking fuel is generally gas. Its mean household is 3.4 persons whose average socioeconomic status ranges from the 2nd decile (by population) in the centre-south of Chile to the 7th decile in the capital region (Molina et al., 2020).

The mass of the archetype varies depending on its main materiality. Thus, the clay bricks house weighs 57 ton, prefabricated panels house weighs 48,8 ton and wooden panels house weighs 30,2 ton.

Space efficiency, Ceiling height, Depth of floor plan, Floor layout, Structure and Building services were considered to determine the potential for adaptability. Therefore, it is not dependent on the main materiality of the dwelling and is a unique value for the archetype under study.

Table 1:
Potential for adaptability

Indicator	Potential for adaptability (%)
Space efficiency	0%
Ceiling height	30%
Depth of floor plan	100%
Floor layout	100%
Structure	50%
Building services	77%
Total	**59%**

As shown in Table 1, the potential for adaptability in the archetype analyzed is 59%. The adaptability is strongly influenced by Depth of floor plan and Floor layout and to a lesser extent by Building services.

To increase the adaptability potential of the analysed archetype, it is necessary to improve the Space efficiency, i.e. to improve the ratio of usable area to total area.

As shown in Table 2, the circularity of the components in the archetype analyzed varies between 1.4% and 10.3%, depending on the representative materiality.

Table 2:
Circularity of Components

Materiality	Circular Input (kg)	Circular Output (kg)	Circularity Components (%)
Clay Bricks	879	682	1,4%
Prefabricated Panels	3.027	1.428	4,6%
Wooden Panels	3.833	2.397	10,3%

The percentage of circularity of the components considers both the incorporation of materials with such attributes (Circular Input), as well as the possibility that these materials have of re-entering the economy at the end of the project's life cycle (circular output).

Although low, the percentage of circularity of components (Table 1) is strongly influenced by circular inputs. This is due to the fact that the dwellings, despite having possibly valuable materials, are in a context that is not normally applied, and lose practically all of their value during the demolition stage (a process that is currently destructive).

On the other hand, the circular entries depend only on the attributes of the material, so their influence on the percentage obtained is less obstructed, unlike the circular outputs, which depend on the material, its potential for valorization and the current rate of valorization on the market.

Standardization, ease of access to components and services, safety of disassembly, simplicity, independence and avoidance of unnecessary treatments and finishes were considered to determine the potential of the deconstruction and disassembly. Therefore, it is dependent on the main materiality of the dwelling.

As shown in Table 3, the potential of the deconstruction and disassembly in the archetype analyzed varies between 49% and 54%, depending on the representative materiality

Table 3:
Potential of the deconstruction and disassembly

Materiality	Potential for deconstruction (%)
Clay Bricks	49%
Prefabricated Panels	49%
Wooden Panels	54%

The difference between the archetypes is not significant and in all of them, the potential for deconstruction is strongly influenced by the rigidity of the structure. Thus, improving the standardization, ease of access to components and services, and simplicity of structure would have a significant effect on the potential for deconstruction.

4. CONCLUSION

Reversible Design leads to efficient use of raw materials, as well as, a CDW reduction by: making flexible and adaptable designs favorable for new uses and program. In Chile, the most representative archetype of the housing stock has a under potential for reversibility.

In terms of potential for adaptability, the archetype analyzed is 59% adaptable. Improving the depth of floor plan and Floor layout and to a lesser extent by Building services would have a significant effect on the potential for adaptability.

The inclusion of materials with circular attributes is rather low; increasing the inclusion of such materials requires an ecosystem to provide them and a policy framework to encourage it.

Finally, the potential for disassembly may increase as design strategies are taken to make the structure more flexible.

As a conclusion, the reversibility of the archetype studied can still be improved by applying the principles of the circular economy to the design.

ACKNOWLEDGEMENTS

This work was financed by the Agencia Nacional de Investigación y Desarrollo (ANID) of Chile, through the project: ANID FONDECYT INVESTIGATION N° 11200688. The research described in this article has not been subjected to any review by the ANID funding institution so it does not necessarily reflect their views, and therefore no official endorsement should be inferred.

REFERENCES

Acosta, D. (2002). Reducción y gestión de residuos de la construcción y demolición (RCD). Tecnología y Construcción, 18(2), 49–68.

Aguiar, A., Vonk, R., & Kamp, F. (2019). IOP Conference Series: Earth and Environmental Science BIM and Circular Design. IOP Conf. Ser.: Earth Environ. Sci, 225, 12068. https://doi.org/10.1088/1755-1315/225/1/012068

Akinade, O. O., Oyedele, L. O., Ajayi, S. O., Bilal, M., Alaka, H. A., Owolabi, H. A., … Kadiri, K. O. (2017). Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills. Waste Management, 60, 3–13. https://doi.org/10.1016/J.WASMAN.2016.08.017

Asociación Española de Reciclaje de Residuos de Construcción y Demolición. (2019). RCD Asociación. Retrieved March 29, 2019, from http://www.rcdasociacion.es/

Basta, A., Serror, M. H., & Marzouk, M. (2020). A BIM-based framework for quantitative assessment of steel structure deconstructability. Automation in Construction, 111, 103064. https://doi.org/10.1016/j.autcon.2019.103064

Bedoya, C. (2011). Construcción Sostenible para volver al camino. Medellín: Cátedra UNESCO de sostenibilidad. Biblioteca Jurídica Diké.

Buyle, M., Galle, W., Debacker, W., & Audenaert, A. (2019). Sustainability assessment of circular building alternatives: Consequential LCA and LCC for internal wall assemblies as a case study in a Belgian context. Journal of Cleaner Production, 218, 141–156. https://doi.org/10.1016/j.jclepro.2019.01.306

Debacker, W., Galle, W., Vandenbroucke, M., Wijnants, L., Chung Lam, W., Paduart, A., … De Weerdt, Y. (2015). Veranderingsgericht bouwen: ontwikkeling van een beleids- en transitiekader [Change oriented construction: the development of a policy and transition framework]. 247. Retrieved from http://www.ovam.be/sites/default/files/atoms/files/TWOL Dynamisch Bouwen_ EINDRAPPORT_finale versie_OVAM1_LR.pdf

DGNB System. (2017). DGNB System - Certificate for sustainable and green building. Retrieved March 29, 2019, from https://www.dgnb-system.de/en/system/certification_system/

Durmisevic, E., Berg, M. C., & Atteya, U. (2017). Design Support for revisable buildings with focus on visualizing and simulating transformation capacity during initial design phase. International HISER Conference on Advances in Recycling and Management of Construction and Demolition Waste, (June), 264–270. Retrieved from http://www.bamb2020.eu/wp-content/uploads/2017/07/Design-Support-for-revisable-buildings-with-focus-on-visualizing-and-simulating-transformation-capacity-during-initial-design-phase.pdf

Eckelman, M. J., Brown, C., Troup, L. N., Wang, L., Webster, M. D., & Hajjar, J. F. (2018). Life cycle energy and environmental benefits of novel design-for-deconstruction structural systems in steel buildings. Building and Environment, 143, 421–430. https://doi.org/10.1016/J.BUILDENV.2018.07.017

Enshassi, A., Kochendoerfer, B., & Rizq, E. (2014). An evaluation of environmental impacts of construction projects Evaluación de los impactos medioambientales de los proyectos de construcción. Revista Ingeniería de Construcción, 29(3), 234–254. https://doi.org/10.4067/S0718-50732014000300002

Eurostat. (2019). Waste statistics - Statistics Explained. Retrieved June 17, 2019, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics/es

Galle, W., Vandervaeren, C., De Temmerman, N., Herthogs, P., Poppe, J., Tavernier, I., … Lanckriet, W. (2019). Building a Circular Economy. Buildings, a Dynamic Environmente (V. A. E. Vrije Universiteit Brussel, Ed.). Brussels.

Galle, W., Vandervaeren, C., Poppe, J., Cambier, C., Elsen, S., Lanckriet, W., … koen. (2019). Building a Circular Economy. Design Qualities to Guide and Inspire Building Designers and Clients. Brussels: Vrije Universiteit Brussel, VUB Architectural Engineering.

Giorgi, S., Lavagna, M., & Campioli, A. (2020). Circular economy and regeneration of building stock: policy improvements, stakeholder networking and life cycle tools. In Research for Development (pp. 291–301). https://doi.org/10.1007/978-3-030-33256-3_27

Gobbo, E. (2015). Déchets de construction, matières à conception : analyse des stocks et flux de matières dans le cadre des opérations de rénovation énergétique en Région de Bruxelles-Capitale. Université catholique de Louvain.

Gosling, J., Sassi, P., Naim, M., & Lark, R. (2013). Adaptable buildings: A systems approach. Sustainable Cities and Society, 7, 44–51. https://doi.org/10.1016/j.scs.2012.11.002

Heidrich, O., Kamara, J., Maltese, S., Re Cecconi, F., & Dejaco, M. C. (2017). A critical review of the developments in building adaptability. International Journal of Building Pathology and Adaptation, 35(4), 284–303. https://doi.org/10.1108/IJBPA-03-2017-0018

International Organization for Standardization. ISO/DIS 20887 Sustainability in buildings and civil engineering works -- Design for disassembly and adaptability -- Principles, requirements and guidance. , (2020).

Jin, R., Li, B., Zhou, T., Wanatowski, D., & Piroozfar, P. (2017). An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. Resources, Conservation and Recycling, 126, 86–98. https://doi.org/10.1016/j.resconrec.2017.07.034

Klinge A, Roswag-Klinge E, Paganoni S, & Lehmann, R. L. (2019). IOP Conference Series: Earth and Environmental Science Design concept for prefabricated elements from CDW timber for a circurlar building Design concept for prefabricated elements from CDW timber for a circurlar building. IOP Conf. Ser.: Earth Environ. Sci. https://doi.org/10.1088/1755-1315/323/1/012022

Molina-Ramírez, J., Ossio, F., & Urria, D. (2019). Construction and Demolition Waste Generated in the Annual New Housing Stock in Chile. Santiago.

Molina, C., Kent, M., Hall, I., & Jones, B. (2020). A data analysis of the Chilean housing stock and the development of modelling archetypes. Energy and Buildings, 206, 109568. https://doi.org/10.1016/j.enbuild.2019.109568

Morgan, C., & Stevenson, F. (2005). Design for Deconstruction. Building for a Future, 14(4).

Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for Disassembly and Deconstruction - Challenges and Opportunities. Procedia Engineering, 118, 1296–1304. https://doi.org/10.1016/J.PROENG.2015.08.485

Sassi, P. (2002). Study of current building methods that enable the dismantling of building structures and their classifications according to their ability to be reused, recycled or downcycled. International Conference for Sustainable Building. Oslo.

Sassi, P. (2004). Designing buildings to close the material resource loop. Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 157(3), 163–171. https://doi.org/10.1680/ensu.2004.157.3.163

Stephan, A., & Athanassiadis, A. (2018). Towards a more circular construction sector: Estimating and spatialising current and future non-structural material replacement flows to maintain urban building stocks. Resources, Conservation and Recycling, 129, 248–262. https://doi.org/10.1016/j.resconrec.2017.09.022

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size—or Why the P Value Is Not Enough . Journal of Graduate Medical Education, 4(3), 279–282. https://doi.org/10.4300/jgme-d-12-00156.1

Trachte, S., Gobbo, E., & Massart, C. (2019). MMG Réemploi – TACHE 2 : Cadre réglementaire Rapportage. Louvain la Neuve.

Valdés, G. A., & Rapimán, J. G. (2007). Propiedades físicas y mecánicas de bloques de hormigón compuestos con áridos reciclados. Informacion Tecnologica, 18(3), 81–88. https://doi.org/10.4067/S0718-07642007000300010

Vefago, L. H. M. C., & Avellaneda, J. (2013). Recycling concepts and the index of recyclability for building materials. Resources, Conservation and Recycling, 72, 127–135. https://doi.org/10.1016/j.resconrec.2012.12.015

Webster, M. D. (2007). Structural Design for Adaptability and Deconstruction: A Strategy for Closing the Materials Loop and Increasing Building Value.

Characterization of native macroalgae

"Pelillo" (Agarophyton chilense) and "Lamilla" (Ulva lactuca) for the development of a prototype thermal insulating material

CARLOS ROJAS [1,2], JUAN PABLO CÁRDENAS-R [2,3]

[1] Facultad de Arquitectura, Construcción y Medio Ambiente, Universidad Autónoma de Chile, Temuco, Chile.
[2] Departmento de Ingeniería de Obras Civiles, Universidad de La Frontera, Temuco, Chile.
[3] Scientific and Technological Bioresource Nucleus, Universidad de La Frontera, Temuco, Chile

ABSTRACT: Air pollution is a problem that affects the health of the world's population. One cause is that buildings have poor or not thermal insulation, which generates a high energy consumption for heating, which is supplied with the combustion of biomass in low efficiency appliances, releasing into the environment a large amount of particulate matter. In this context, thermal insulating materials are key allies to reduce energy demand in buildings, which is why progress must be made in the sustainable development of these materials. In this work, a characterization of two algae present in the Chilean coasts was carried out, in order to revalue them and generate a prototype of a natural and sustainable material. Their physicochemical properties were analyzed and the results show the algae has excellent thermal insulation qualities, with an average thermal conductivity of 0.036 [W/mK]. This result is comparable to expanded polystyrene (EPS), a material widely used in the Chilean market, which has an average thermal conductivity value of 0.038 [W/mK]. In addition, the algae presented good thermal stability and its morphology contributes to the development of a bulk material, since it has a porous structure with air chambers between the fibers.
KEYWORDS: Energy efficiency, natural thermal insulation, low environmental impact material, sustainability.

1. INTRODUCTION

In several cities around the world, high concentrations of fine particulate matter ($PM_{2.5}$) have been evidenced, causing serious respiratory diseases, being the residential park one of the main responsible for such emissions [1, 12]. In addition, it has been shown that buildings consume over 40% of the energy worldwide, which is why it is essential to analyze the energy efficiency of buildings, specifically in the design, since it is at that time where appropriate thermal insulation materials can be specified to reduce energy consumption in buildings and thus reduce emissions of particulate matter and greenhouse gases worldwide [8, 9, 11, 20]. In Chile, among the strategies proposed by the "Ministerio de Vivienda y Urbanismo" (MINVU) is to "improve the thermal insulation standards of housing" in order to reduce the demand for heating, however, this brought an increase in the demand for thermal insulation materials where the market is dominated by synthetic products with high environmental impacts in their life cycle [5, 13, 16].

Several studies have showed the possibility of generating and using new thermal insulating materials with low environmental impact with residual natural fibers or recycled products [14, 21], which allow maintaining thermal comfort conditions and reducing energy consumption in the operational stage of buildings; among them is the development of a natural polymer got from the Hydrangea Macrophylla plant, where thermal conductivity results comparable to traditional insulating materials were got [2, 13, 15, 17].

In this work, a physicochemical characterization of the algae Pelillo (Agarophyton chilense) and Lamilla (Ulva lactuca) was carried out in order to generate a prototype of thermal insulating material with low environmental impact to reduce heat energy losses in buildings.

2. MATERIALS AND METHODS

2.1 Materials

The algae were collected from the shores of the coasts of the island of Quinchao, belonging to the Chiloé archipelago, on beaches authorized for harvesting the material, in the Putique sector, Figure 1 shows the algae in the extraction meadow.

Figure 1:
Pelillo and Lamilla in extraction meadow.

The algae were then dried on both sides at room temperature on the same beaches and the excess sand was removed and taken to the laboratory for measurement and testing.

2.2 Moisture

Moisture content was obtained using a BOECO moisture analyzer, model BMA H50, with a power of 400 [W], which works with a halogen light in a temperature range of 10-40°C and delivers results with an accuracy of 0.001%. The equipment generates a gradual heating process with time intervals in which the changes in mass experienced by the samples are measured until the meter detects constant mass.

2.3 Density

This property was determined by relating the mass of algae that could be deposited (without compacting) in a cylindrical polyvinyl chloride specimen with a volume of 393.55 [cm^3]. The cylindrical specimens serve as the basis for measuring the thermal conductivity of the samples.

2.4 Thermal conductivity

This measurement was performed with the Decagon "KD2 Pro" instrument, which is based on the "Transient Line Heat Source" method and complies with the specifications of the IEEE 442-1981 standard and ASTM D5334-08.

In order to study in greater depth the thermal behavior of the algae, triplicate measurements were made at different density levels of the samples, where Pelillo was analyzed between 60 - 80 [kg/m^3], while Lamilla was analyzed between 50 - 70 [kg/m^3].

2.5 Thermal stability

The algae were previously prepared by drying in an oven at a constant temperature of 40°C and then crushed until homogeneous samples were obtained. Measurements were performed on a TGA/DSC STA6000, Perkin Elmer, USA. The purge gas and carrier gas used was nitrogen (N2) at 40 ml/min. The temperature program used was as follows: a heating from 25 - 120°C at a heating rate of 50°C/min; then held for 3 minutes at 120°C; heating from 120 to 950°C at 100°C/min; cooling from 950 to 450°C at 100°C/min, gas change to oxygen at a flow rate of 40 ml/min; heating from 450°C to 800°C at 100°C/min and finally a 3-minute isotherm at 800°C.

2.6 Surface analysis (Morphology)

The morphological visualization of the samples was performed by scanning electron microscopy (SEM), with a VP-SEM SU 3500 Hitachi-Japan microscope, considering the following magnification conditions: 40-100-200-500X, BSE detector, 10KeV, WD~12 (mm), 30 (Pa).

3. RESULTS AND DISCUSSION

3.1 Moisture

Under normal conditions, algae can absorb and eliminate moisture quickly, which is why their moisture content must be measured and controlled so as not to affect their thermal performance [19]. Table 1 shows the details of the fiber measurements, where the Pelillo samples had an average moisture content of 12.02%, while Lamilla had an average moisture content of 14.91%. These results are attributed to the open porosity of the fibers and in the case of Lamilla it has a much more porous structure than Pelillo, which is why it has a higher moisture content. Although the percentages are higher with respect to other fibers, such as those of lignocellulosic composition that border 6% [15], they are comparable with traditional insulating materials, therefore, it is a quite favorable result for the thermal conductivity of algae and its possible use as thermal insulation materials in buildings [7, 10].

Table 1:
Moisture content of the samples [%].

Sample	S1	S2	S3	AVG	SD
Pelillo	11.80	11.92	12.33	**12.02**	0.28
Lamilla	15.68	12.96	16.10	**14.91**	1.70

3.2 Density

The density for the Pelillo samples ranged between 60-80 [kg/m^3], while for Lamilla the density ranged between 50-70 [kg/m^3]. These results are similar to the densities of traditional thermal insulating materials such as glass wool, mineral wool, polyurethane foams and expanded polystyrene that vary between 10-90 [kg/m^3] [5, 6, 18]. On the other hand, the results for both algae are lower than other lignocellulosic fiber materials whose densities range from 105-130 [kg/m^3] [16]. Table 2 shows some comparative density data between materials.

Table 2:
Material density.

Material	Density [kg/m³]
Pelillo	60-80
Lamilla	50-70
Expanded polystyrene	10-30
Mineral wool	40-90
Glass wool	10-47
Wheat straw	105-115

3.3 Thermal conductivity

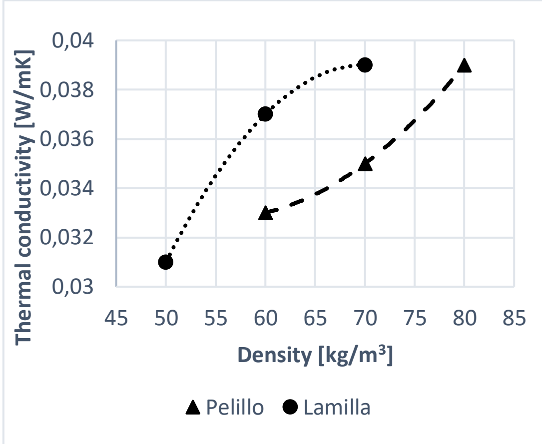
The thermal conductivity measurement is shown in Figure 2 and is the same procedure for each sample of each fiber, and it is indicated that Pelillo obtained an average of 0.036 ± 0.003 [W/mK], while Lamilla obtained a value of 0.036 ± 0.004 [W/mK].

Now, when comparing these data with the other materials, it can be observed that the algae present thermal conductivities similar to the conventional ones and higher than wheat straw, corn husk and hybrid composites, since these present results of 0.046, 0.047 and 0.072 [W/mK] respectively, while expanded polystyrene varies between 0.036 and 0.043 [W/mK] [5, 10, 11, 13, 16, 17].

Figure 2:
Thermal conductivity measurement of samples.

In both fibers, the best results for this property are generated at minimum densities, i.e. 60 [kg/m³] for Pelillo and 50 [kg/m³] for Lamilla, which can be seen in Figure 3. This behavior is inverse to what was shown in the work of Gnip I., et al., in 2012, since expanded polystyrene and other materials improve their thermal conductivity with increasing density. On the contrary, in algae fibers it occurs inversely due to the fact that, as the density of the samples increases, the internal air chambers of the material decrease, this being the fundamental quality of thermal insulating materials [4, 8, 21].

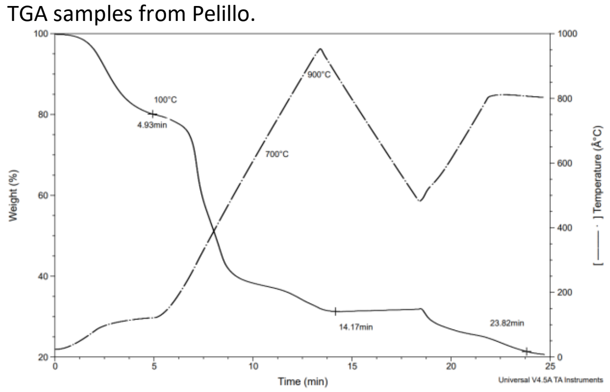
Figure 3:
Thermal conductivity and density ratio.



3.4 Thermal stability

The thermogravimetric analysis of the Pelillo samples is shown in Figure 4, where it is observed that in the first 5 minutes of the test, around 100°C is reached and 19.78% of mass is lost, which corresponds to the moisture of the algae, while the greatest loss of mass is found between the 5th and 14th minute at a temperature of 120 - 700°C with 48.71% of its mass and is associated with volatile solids. Once cooling begins, under an oxygen environment it consumes a large part of the organic matter, identified as fixed carbon, and which corresponds to 10.17% of the sample. In the last heating stage, after approximately 24 minutes, ash is obtained in a percentage of 20.94% of the total sample. Accordingly, it is indicated that this algae has a thermal stability of around 120°C, therefore, the processing of the fiber for its production as a thermal insulating material should not exceed this value to avoid damaging the structure of the material.

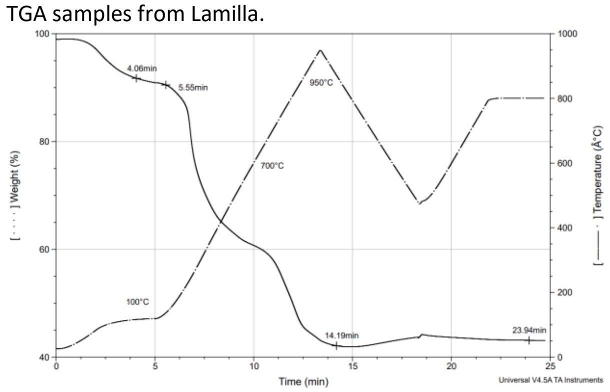
Figure 4:
TGA samples from Pelillo.



The thermogravimetric analysis of the Lamilla samples is shown in Figure 5, where it is observed that in the first 4 minutes of the test, around 100°C is reached and 7.74% of mass is lost, which corresponds to the moisture of the seaweed, then, between the 6th and 14th minute at a temperature of 200 - 700°C there is a loss of mass of 30.02% and it is associated to volatile solids. Once cooling begins, under an oxygen environment, it consumes a large part of the organic matter, identified as fixed carbon, which corresponds to 16.66% of the sample. In the last heating stage, the greatest loss of mass is observed, which corresponds to ashes in a percentage of 43.17% of the total sample. Accordingly, it is indicated that this algae has a thermal stability around 200°C, therefore, the processing of the fiber for its production as a thermal insulating material should not exceed this value to avoid damaging the structure of the material.

For both cases, it is indicated that the results are similar to those of other traditional fibers and insulating materials that have a thermal stability of around 150°C [3, 20].

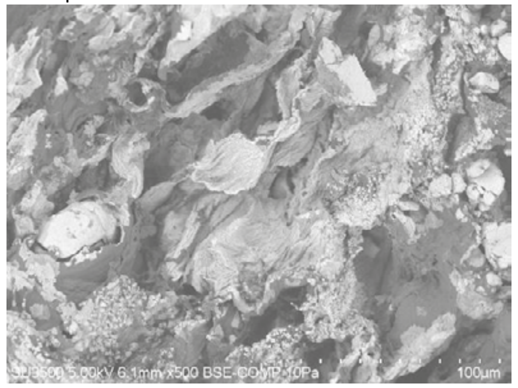
Figure 5:
TGA samples from Lamilla.



3.4 Surface analysis (Morphology)

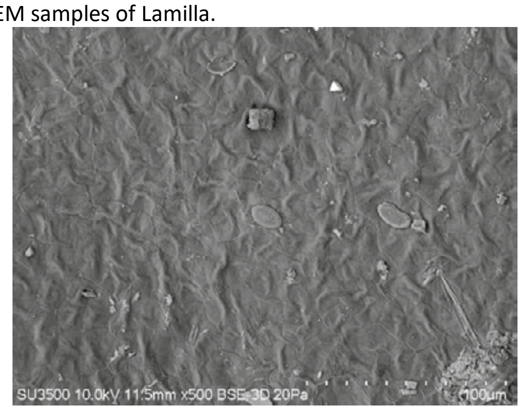
The morphological analysis of the samples was carried out in 3 planes, transversal, longitudinal and superficial, Figure 6 shows the longitudinal section of Pelillo where cellular structures of porosity between 400 and 500 microns can be observed, which is lower than the porosity of traditional insulation materials, which have a much more open porosity [22]. In addition, a high content of crystallized salts is observed and the leaders within the chemical composition are identified, where Carbon (C) leads with 49.1% of the total mass tested, followed by Oxygen (O) with 24.6%.

Figure 6:
SEM samples of Pelillo.



On the other hand, Figure 7 shows the Lamilla analysis where a homogeneous surface with small pores between 50 and 100 microns is observed, however, neither longitudinal nor transversal cuts were performed, since it does not have a tubular morphology to which a direction and sense could be given. In addition, it is identified that within the chemical composition, Oxygen (O) leads with 35.6% of the total mass tested, followed by Carbon (C) with 36.4%.

Figure 7:
SEM samples of Lamilla.



4. CONCLUSION

The characterization in fiber format of the algae provided the necessary information to demonstrate the feasibility of a thermal insulation prototype based on native algae, since they present thermal conductivities averaging 0.036 [W/mK], comparable to traditional materials commercialized in the Chilean market, such as expanded polystyrene, glass wool or mineral wool.

In this work, both algae are highlighted, since they are abundant in the Chilean coasts, their value is low and the cultivation, drying and partial cleaning technique is mastered by the personnel that performs the labor on site, therefore, their acquisition would not generate a large investment.

Finally, it is indicated that a process of defiberization of the algae could be interesting to evaluate, since the algae present roughness and absence of pores, which would allow obtaining long fibers with low diameters, generating a homogeneous material similar to fiber wools, such as sheep's wool or glass wool.

ACKNOWLEDGEMENTS
The authors would like to thank the Energy Efficiency Laboratory of Department of Civil Works Engineering and the Scientific and Technological Nucleus in Bioresources (BIOREN) of Universidad de La Frontera for allowing the use of their facilities and equipment for the measurements performed in this research.

REFERENCES
1. Brauer, M., Casadei, B., Harrington, R. A., Kovacs, R., Sliwa, K., Davaakhuu, N., … Vedanthan, R. (2021). Taking a Stand Against Air Pollution—The Impact on Cardiovascular Disease: A Joint Opinion from the World Heart Federation, American College of Cardiology, American Heart Association, and the European Society of Cardiology. Journal of the American College of Cardiology, 77(13), 1684–1688. https://doi.org/10.1016/j.jacc.2020.12.003.
2. Cárdenas-R, J. P., Cea, M., Santín, K., Valdés, G., Hunter, R., & Navia, R. (2018). Characterization and application of a natural polymer obtained from Hydrangea macrophylla as a thermal insulation biomaterial. Composites Part B: Engineering, 132, 10–16. https://doi.org/10.1016/j.compositesb.2017.07.086.
3. Chetehouna, K., Belayachi, N., Rengel, B., Hoxha, D., & Gillard, P. (2015). Investigation on the thermal degradation and kinetic parameters of innovative insulation materials using TGA-MS. Applied Thermal Engineering, 81, 177–184. https://doi.org/10.1016/j.applthermaleng.2015.02.037
4. Domínguez-Muñoz, F., Anderson, B., Cejudo-López, J. M., & Carrillo-Andrés, A. (2010). Uncertainty in the thermal conductivity of insulation materials. Energy and Buildings, 42(11), 2159–2168. https://doi.org/10.1016/j.enbuild.2010.07.006.
5. Gnip, I., Vejelis, S., & Vaitkus, S. (2012). Thermal conductivity of expanded polystyrene (EPS) at 10 °c and its conversion to temperatures within interval from 0 to 50 °c. Energy and Buildings, 52, 107–111. https://doi.org/10.1016/j.enbuild.2012.05.029.
6. Hung Anh, L. D., & Pásztory, Z. (2021). An overview of factors influencing thermal conductivity of building insulation materials. Journal of Building Engineering, 44. https://doi.org/10.1016/j.jobe.2021.102604.
7. Jerman, M., & Černý, R. (2012). Effect of moisture content on heat and moisture transport and storage properties of thermal insulation materials. Energy and Buildings, 53, 39–46. https://doi.org/10.1016/j.enbuild.2012.07.002.
8. Kalhor, K., & Emaminejad, N. (2020). Qualitative and quantitative optimization of thermal insulation materials: Insights from the market and energy codes. Journal of Building Engineering, 30(October 2019), 101275. https://doi.org/10.1016/j.jobe.2020.101275.
9. Kasaeian, A., bahrami, L., Pourfayaz, F., Khodabandeh, E., & Yan, W. M. (2017). Experimental studies on the applications of PCMs and nano-PCMs in buildings: A critical review. Energy and Buildings, 154, 96–112. https://doi.org/10.1016/j.enbuild.2017.08.037.
10. Khoukhi, M. (2018). The combined effect of heat and moisture transfer dependent thermal conductivity of polystyrene insulation material: Impact on building energy performance. Energy and Buildings, 169, 228–235. https://doi.org/10.1016/j.enbuild.2018.03.055.
11. Khoukhi, M., Abdelbaqi, S., Hassan, A., & Darsaleh, A. (2021). Impact of dynamic thermal conductivity change of EPS insulation on temperature variation through a wall assembly. Case Studies in Thermal Engineering, 25(January), 100917. https://doi.org/10.1016/j.csite.2021.100917.
12. Mardones, C. (2021). Ex-post evaluation of residential insulation program in the city of Temuco, Chile. Energy for Sustainable Development, 62, 126–135. https://doi.org/10.1016/j.esd.2021.04.003.
13. Mawardi, I., Aprilia, S., Faisal, M., & Rizal, S. (2022). Investigation of thermal conductivity and physical properties of oil palm trunks/ramie fiber reinforced biopolymer hybrid composites as building bio-insulation. Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.01.249.
14. Ng, S., Jelle, B. P., Sandberg, L. I., Gao, T., & Alex Mofid, S. (2018). Hollow silica nanospheres as thermal insulation materials for construction: Impact of their morphologies as a function of synthesis pathways and starting materials. Construction and Building Materials, 166, 72–80. https://doi.org/10.1016/j.conbuildmat.2018.01.054.
15. Rojas, C., Cea, M., Rosas-Díaz, F., & Cárdenas-R, J.P. (2018). Physical, chemical and mechanical characterization of a prototype insulating material based on eucalyptus bark fiber. IEEE Latin America Transactions, 16(9). https://doi.org/10.1109/tla.2018.8789566.
16. Rojas, C., Cea, M., Iriarte, A., Valdés, G., Navia, R., & Cárdenas-R, J.P. (2019). Thermal insulation materials based on agricultural residual wheat straw and corn husk biomass, for application in sustainable buildings. Sustainable Materials and Technologies, 17, e00102. https://doi.org/10.1016/j.susmat.2019.e00102.
17. Soto, M., Vera, M., Parra, K., Rojas, C., & Cárdenas, J. P. (2020). Potential of the Residual Fibers of Pisum Sativum (PS), for use in a Development of a Thermal Insulator Material. IOP Conference Series: Earth and Environmental Science, 503(1). https://doi.org/10.1088/1755-1315/503/1/012084.
18. Wang, X., Qin, D. H., Ren, J. W., & Wang, F. T. (2021). Numerical estimation of thermal insulation performance of different coverage schemes at three places for snow storage. Advances in Climate Change Research, 12(6), 903–912. https://doi.org/10.1016/j.accre.2021.10.003.
19. Wang, Y., Liu, K., Liu, Y., Wang, D., & Liu, J. (2022). The impact of temperature and relative humidity dependent thermal conductivity of insulation materials on heat transfer through the building envelope. Journal of Building Engineering, 46(13), 103700. https://doi.org/10.1016/j.jobe.2021.103700.
20. Wi, S., Yang, S., Yeol Yun, B., & Kim, S. (2021). Exterior insulation finishing system using cementitious plaster/microencapsulated phase change material for improving the building thermal storage performance. Construction and Building Materials, 299, 123932. https://doi.org/10.1016/j.conbuildmat.2021.123932.
21. Zhang, T., Yang, Y. L., Liu, S. Y., & Wang, C. J. (2021). Evaluation of thermal conductivity for compacted kaolin Clay-Shredded tire mixtures as thermal insulation material. Construction and Building Materials, 308(September), 125094. https://doi.org/10.1016/j.conbuildmat.2021.125094.
22. Zhao, Y., Wagstaff, E., Gage, S., Payne, D., & Turchi, C. (2022). Chemical compatibility of hollow ceramic cenospheres as thermal insulation for high-temperature thermal energy storage applications with molten nitrate salt. Solar Energy Materials and Solar Cells, 238(February), 111597. https://doi.org/10.1016/j.solmat.2022.111597.

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 01
16:00 — 17:30

CHAIR
CHRIS WHITMAN

PAPERS
1156 / 1224 / 1534 / 1496 / 1165

14TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Adaptation of passive heating strategies in the Peruvian Mesoandean Zone

Thermal improvement in social housing

DIANA KAREN PARI QUISPE[1] JOÁRA CRONEMBERGER RIBEIRO SILVA[2] CAIO FREDERICO E SILVA[3]

[1] SICAC Research Group, University of Brasília, Brasília DF Brazil
[2] Laboratory of Environmental Control and Energy Efficiency - LACAM, University of Brasília - Brasília DF Brazil
[3] Postgraduate Program of Architecture and Urbanism, University of Brasília - Brasília DF Brazil

ABSTRACT: Housing projects in Peru generally employ the same construction materials across the country. The energy deficit that is driven by the selection of these construction materials at a daily basis results in energy poverty and low thermal quality to the housing's interiors. In this sense, this research showcases the potential of passive heating strategies through thermo energetic simulations. The city of Puno, located on the shores of Lake Titicaca, will serve as a case study for this research's method. First, a representative housing typology was determined in a proposed area. Then, the current thermal behaviour was simulated. Finally, three intervention proposals of combined variables were simulated, with emphasis on thermal envelope enhancement and indigenous materials using the Design-Builder tool version 6.1.0. The ASHRAE 55-2017 standard was used to evaluate the comfort level at 80% acceptability. As a result, when compared with the current state at 0.0% of percentage of hours occupied in comfort (POC), the three intervention proposals show reasonable rates, highlighting the combination with sheep's wool and Ichu, which shows 100% comfort; and Totora, with 87.5% comfort. Strategies to improve the thermal enclosure can be potentially introduced in the rehabilitation of existing homes and the design of new buildings.
KEYWORDS: Thermal comfort, Social housing, Passive solar heating, indigenous materials.

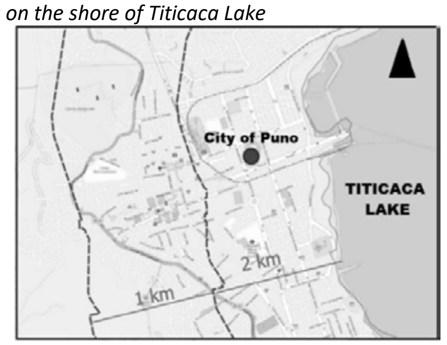
1. INTRODUCTION

The Mesoandean is one of the various high-altitude zones in Peru, since it ranges from 3,500 to 4,000 meters above sea level. Moreover, it can be classified as a bioclimatic zone with a cold and dry climate, especially in the months of June and July [1,2]. In Peru, housing projects usually employ the same construction materials across all regions, resulting in housing that does not suit climate-related needs. As a result, daily energy deficiency leads to energy poverty and poor thermal quality indoors. The health of the residents is heavily influenced by the quality of housing and the minimum circumstances that allow for well-being within, particularly in surroundings of long-term permanence (LTP). The usage of construction materials that contribute to an optimal temperature fluctuation could help improve current energetic conditions in housing. Solar energy can partially contribute to the energetic conditions by providing around 706 W/m^2; and the use of indigenous materials for thermic insulation are also potentially attractive for housing in the context of the study area. Furthermore, the appropriation, adaptation and appreciation of ancestral techniques can help identify the occupants with their environment. In this context, the selected housing typology for this study is a two-story house with a backyard, predominantly constructed with brick material and without thermal insulation. The worst-case climatic scenario, a house with a South-North orientation, was analysed for this study.

2. METODOLOGY

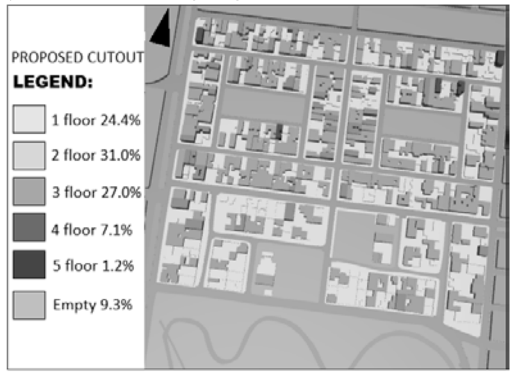
The proposed methodology aims to adapt the inclusion of passive heating strategies in existing social housing. This research focuses in the city of Puno, located at the edge of the Titicaca Lake (Fig. 1).

Figure 1:
The city with the most extensive social housing and closer to the area on the shore of Titicaca Lake



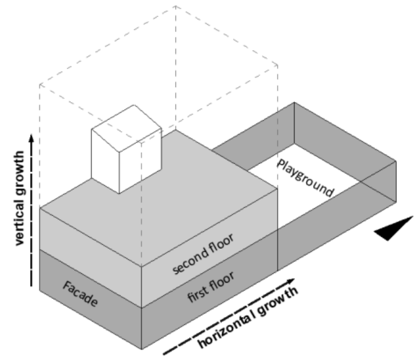
A buffer of 1 km and 2 km from the coastline was defined (Fig. 1). Within the 1 km strip there are fifteen towns, and in the 2 km strip, there are three towns. These towns correspond to the altitude level of the Mesoandean zone, of which the largest and most populous of them is the City of Puno. A sector with existing social housing was located in this strip. A representative typology was then determined in the proposed area. For that, it was necessary to separate the houses by levels and determine the predominant materials. The dwellings range from one to five stories, with a two-story dwelling predominating with 31% of the total (Fig. 2).

Figure 2:
Proposed cutout building height



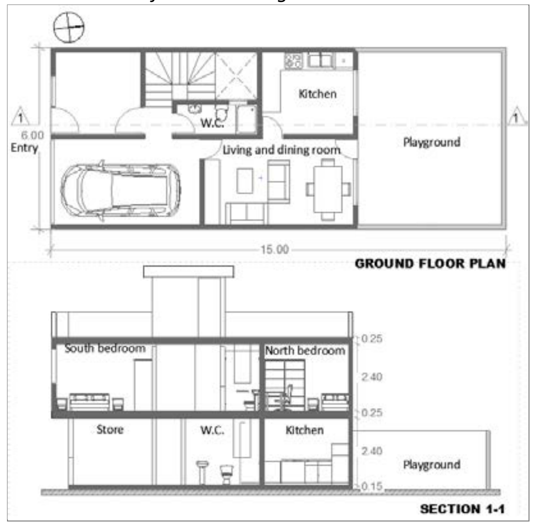
The predominant material in walls is ceramic brick 75%, in the case of ceilings the concrete slab is observed in 80% of the total, the floors are 100% concrete slab, the doors are sheet metal in 67% of the cases, and simple glass windows conform 54.0% of all houses. This typology tends to extend horizontally and vertically since its introduction in the zone, with a maximum height of five floors and a proclivity to occupy the entire lot (Fig. 3).

Figure 3:
Proposed typology for modelling



Then, the representative housing typology was defined. This typology is composed of a two-level dwelling with a backyard, the total area is 90 m^2, facing South, and neighbouring houses with greater height, which is least favourable context. In ground floor plan, the LTP living-dining room considered for the study is observed (Fig. 4).

Figure 4:
Plan and section of social housing

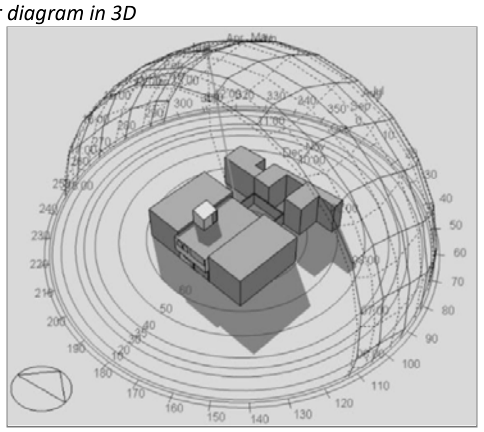


2.1 Simulations in their current state

The current thermal behaviour of the housing typology was then simulated, considering the climatic characterization and including the construction and urban aspects determined in the previous stage, using the Design-Builder version 6.1.0 tool. This tool uses the calculation engine of the EnergyPlus program (version 8.9). In the analysis, the data of the operating temperature (OT) and the external air temperature (ET) were used. For the typical day of the coldest winter month (July), 744 total hours were averaged. An outside temperature of 1.22 °C, upper limit of 21.70 °C, a comfort zone of 18.20 °C and a lower limit of 14.70 °C were considered. For the annual range, the average ET of the previous seven days was taken for each day of the year at 8,760 hours. Once the maximum and minimum acceptable temperatures for 80% of environmental acceptability of the users were determined, the percentage of hours spent in comfort (POC), maximum limit (hot), and minimum limit (cold) were computed. An outside temperature of 5.80 °C, upper limit of 23.10 °C, a comfort zone of 19.60 °C and a lower limit of 16.10 °C was considered.

The current state was replicated in the software using these characteristics. The solar diagram in 3D and its neighbors are shown in (Fig. 5).

Figure 5:
Solar diagram in 3D



The simulation parameters were provided in a hierarchical manner, delimited by exteriors (neighbors) and interiors (thermal zone) with the features of the envelope enclosures. Thermal properties for the outside walls, roof, and floor composition were included (Table 1).

Table 1:
Thermal properties

Thickness in mm	Conductivity	Density	Specific heat	U value
	λ w/m.K	ρ (kg/m³)	C (J/kg.K)	U (W/m²k)
Wall of 150 mm				
Internal plaster: 12.5	0.72	1.860	1.200	2.22
Brick: 125	0.47	1.045	800	
External plaster 12.5	0.72	1.860	1.200	
Ceiling (Mezzanine): Total thickness 250 mm				
Subfloor 50	1.15	2.000	1.000	1.72
Concrete slab 50mm	1.15	2.000	1.000	
Hollow ceiling brick 120 mm	0.44	720	800	
Gypsum plaster 30 mm	0.35	900	870	
Floor: Total thickness 150 mm				
Concrete: 100 mm	1.75	2.200	1.000	3.81
Underlayment 50 mm	1.15	2.000	1.000	

The house has an occupancy of five people between the ages of 18 and 60 years, an activity factor of 1.0 MET and 1.0 Clo. The home appliances are associated with domestic use with the absence of air conditioning equipment.

All the thermal zones for this typology were modelled and simulated, however, only that coincide with the long term permanence (LTP) permanence was considered. The studied LTP is the living-dining room, located on the first level of the dwelling. The hours of occupation are from 7:00 hrs to 24:00 hrs considering 5 days a week. The following characteristics are considered: the room lighting is 6 W/m^2, infiltration of 1.00 AC/h with a Crack template classified as "very poor". Exterior metal and interior wooden doors. Simple glazing of 4 mm with solar transmission SHGC=0.847, light transmission=0.816, U=5.871 W/m²k with aluminium carpentry, with a percentage of an open area of 10%, both for interior and exterior windows.

The following is observed from this configuration:

- The annual POC of 3.5% comfort, the percentage of hours of discomfort due to cold is predominant at 96.5%. The average ambient temperature is 11.4 °C.
- The POC for the typical day is 0.0% comfort and 100% cold discomfort hours. The average ambient temperature is 8.2 °C.

In both cases there is no heat discomfort. It is observed in the figures are below the comfort limits in the current state (Table 2).

Table 2:
Percentage of comfort and OT in the current state

% Cold discomfort	% Comfort	% heat discomfort	OT		
			Max	Min	Mean
Annual results living-dining room					
96.5	3.5	0.0	13.6	8.0	11.4
Typical day results living dining room					
100.0	0.0	0.0	11.5	4.8	8.2

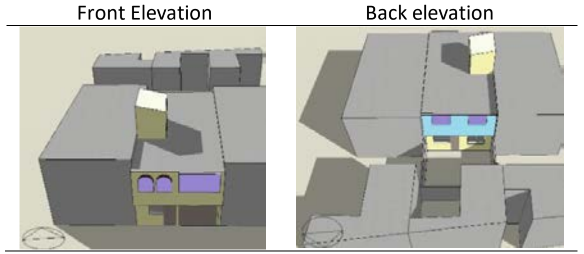
In the LTP, the need to improve the thermal envelope is evident. Heat loss is primarily through the walls, external air and floor.

2.2 Improvement proposal

Three intervention approaches were simulated in this section, each consisting of groups of combined variables and emphasizing the usage of indigenous materials. The environment cannot be changed because these are semi-detached residences with near neighbors. As a result, interventions that do not require the modification of the interior distribution while seeking to maintain its functionality must be proposed (Fig. 6).

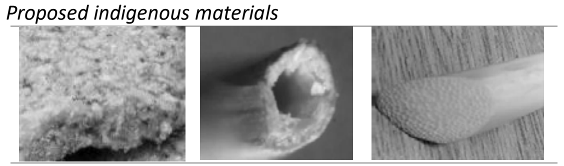
Adaptive comfort and the ASHRAE 55-2017 standard for naturally conditioned spaces controlled by the occupant were used for the evaluation [3]. Active heating systems are not considered into account.

Figure 6:
Front and back elevation for the improvement proposal



For wall insulation, it is proposed to add three compositions using indigenous materials with low thermal conductivity, such as: sheep wool [4], Ichu [5] and Totora [6]. The floor and mezzanine adaptations are isolated with conventional materials (Table 3).

Table 3:
Proposed indigenous materials

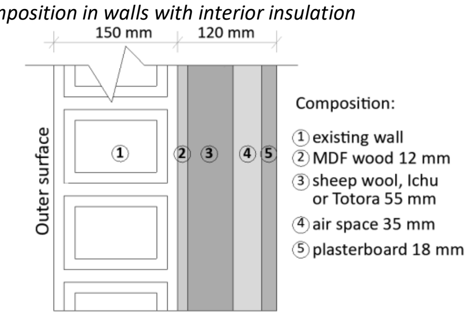


Sheep wool: 0,040 w/m.K	Ichu: 0.0473-0.1130 w/m.K	Totora: 0.049-0.0540 w/m.K

2.3 Design Strategies Employed

The proposed strategies are with what was suggested by the authors [7,8] such as; using the improvement strategies of the thermal envelope. Thermal insulation was considered using insulated sandwich-type shutters; plywood, sheep's wool and plywood, with opening hours between 8:00 hrs and 18:00 hrs. The composition in walls is towards the interior, with a total thickness of 270 mm (Fig. 7).

Figure 7:
Composition in walls with interior insulation



The use of solar heating (SH) by windows and skylights in favor and a semi-direct wall system, using an inertial wall in second floor bedrooms facing North is part of the accounted strategies, taking advantage of the backyard of the house as a heat storage element. Furthermore, the increase in hermeticity in frames to avoid infiltrations with an "excellent" crack template assures that the researched typology does not show cracks and perform better.

Because the materials are locally available, the practicality of the suggested solutions with native materials is achievable. In the case of sheep wool, the Puno region is Peru's leading producer. It is necessary to employ 1.1 kg per m^2, which necessitates prior processing, which includes washing the wool, saturation with boron salts, carding, and dry felting, resulting in a blanket or roll of sheep's wool [9]. In the instance of Ichu, a wild straw found throughout the American Andean South plateau, straw bales were utilized for the first time to build dwellings by Nebraska settlers at the end of the nineteenth century [10,11]. Due of its proximity to Lake Titicaca, the Totora can be collected and purchased locally, potentially creating jobs for inhabitants who extract the Totora blankets, also known as "Kesanas". The Titicaca National Reserve has 16,000 ha of reeds of which 30% is used as cattle feed, 15% is used as handicrafts and tourism, 40% contributes to natural regeneration, and 15% which is equivalent to 120,000 tons of reeds not used. In 2016, 5,000 ha were burned, equivalent to 1 125,000 Kesanas [12].

Integration to current construction practices is possible because sheep wool, Ichu and Totora panels can be placed on a support structure in wood or metal to contain the insulating material attached to the interior.

3. RESULT AND DISCUSSION

The variables shown were selected as the ones that could be better assimilated by the local inhabitants. From the standpoint of the thermal envelope and solar heating (SH) improvement strategy, and after analysing them individually by isolated variables, it was feasible to determine which ones may increase the ambient temperature to a higher or smaller extent. As a result, for the analysed LTP, the use of isolated shutters (A), management of infiltrations (B) and wall insulation (I, II and III) were more important than the other variables (C, D, E, F, G and H) since which presented a greater increase in OT, because it made it possible to reduce heat fluxes and keep the heat inside. The variables analysed showed an increase in OT both for the typical winter day and annually and others made no difference individually (Table 4).

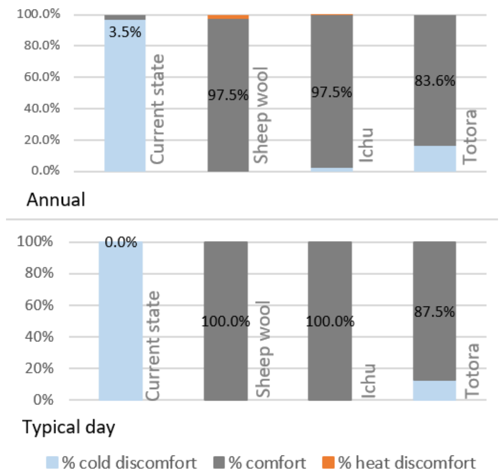
Although increases in OT have been observed, in all cases they are still below the comfort range considered for the area studied. Based on these results, the need to proposed combinations alternating the variables on the wall with the others.

Table 4:
Isolated variables and increase in OT

Va	Thermal envelope + SH	Typical day	Annually
I	Sheep wool walls U=0.50 W/m²k	2.23 °C	2.11 °C
II	Ichu walls 0.72 W/m²k	1.76 °C	1.68 °C
III	Totora walls 0.95 W/m²k	1.35 °C	1.29 °C
A	Insulated shutters 50 mm, U=0.64 W/m²k	3.25 °C	2.84 °C
B	Infiltrations change to 0.20 AC/h	3.42 °C	2.45 °C
C	Vertical circulation double ceiling (4 mm glass+20 mm air+4 mm glass) U=2,74 W/m²k	0.01	0.00
D	1st level floor (EPS + ceramic) U=1.71 W/m²k	0.34	0.19
E	Insulated mezzanine 88 mm, 0.61 W/m²k	-0.18	-0.17
F	28 mm double glass windows, U=2.74 W/m²k	-0.05	-0.03
G	Insulated doors U=0.64 W/m²k	0.04	0.08
H	Inertia wall with 100 mm air chamber	-0.19	-0.05

The current state shows a 0.0% percentage of hours occupied in comfort (POC) for the typical winter day and 3.5% annually, for the three proposed combinations it shows good percentages, highlighting the combination with sheep wool and Ichu that presents 100% of comfort for the typical day and 97.5% annually (Table 5).

Table 5:
POC for typical winter day and annual



The constructive solution in its current state has limitations to provide thermal comfort to the house, especially in the early morning and at night. The improvement of the thermal envelope has enabled constant internal temperatures, decreased heat loss when used on the exterior walls of the typology operating in both the warmer and colder months.

The combined intervention proposals are then compared to the current state of the house, which alternates the material in the walls with sheep wool, Ichu, and Totora and includes the variables A to H. It should be emphasized that these isolations did diminish the area of the internal LTP. This arrangement was chosen to avoid material deterioration owing to its organic origin, as well as contact with external agents such as rain, insects, etc.

The results indicate that the three interventions, on average for the typical day, increase by 9.5 °C from the current state of 8.2 °C, reaching 17.7 °C (Table 6). Moreover, annually increase by 7.5 °C, concerning the current state of 11.4 °C, reaching 18.9 °C (Table 7).

Table 6:
Operative temperature and comfort zone for the typical winter day

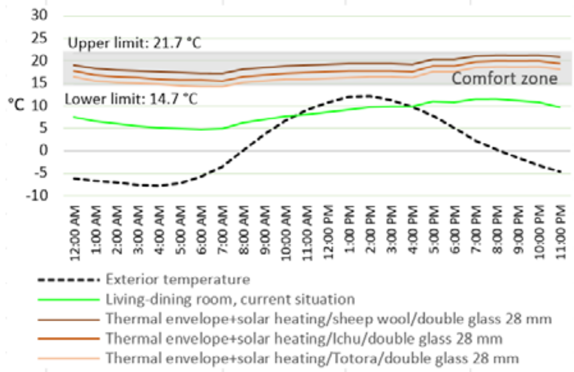
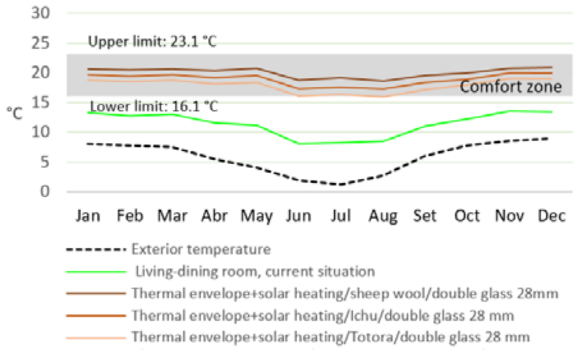


Table 7:
Operative temperature and annual comfort zone



The reduction in infiltrations from 1.00 to 0.20 AC/h determined by the hermetic characteristics of the envelope aided in closing the energy conservation cycle. It is understood that the value utilized is difficult to attain in the case of social housing, but the importance of ensuring that these buildings are as hermetic as possible is evident, clearly indicating the path to be used to obtain better thermal performance.

The management of the SH by an inertia wall proved to be ineffective for this environment due to its location in the upper floor and the solar interference of the adjacent neighbours, as well as the area's vertical solar incidence. It should be noted that the North-facing backyard provided better thermal performance, so its configuration would be the most appropriate. It is necessary to give it due importance in order to maintain its permanence on the lot and facilitate solar entry, despite the vertical growth of the adjoining neighbours.

It was possible to achieve an OT within the established comfort range by combining several interventions. This emphasizes the significance of implementing the improvement strategies of the thermal envelope strategies in direct relation to the thermal performance of dwellings in the Meso-Andean zone, which may be used both in the retrofitting of existing dwellings and in the design of new buildings.

4. CONCLUSION

This article examines an LTP of a representative typology of social housing in the Mesoandean zone in its current state and how it could be improved using combined intervention approaches. This comprises of variable groupings that feature a set of three autochthonous materials used in instances of local vernacular architecture since ancient times. Because of their availability in the study area, they are regarded good thermal insulators with socio-cultural and environmental benefits.

The increase in thermal insulation properties was effective by using natural fibers, the applications in this study were convenient since they are resistive materials with thermal conductivities lower than 0.06 W/m.k. Totora and Ichu are low-energy recyclables because they can be reused for soil fertilization if damaged during their life cycle.

The local dwellings depend greatly of the solar gains through the glazing, which influence positively the thermal behaviour of the environment in order to increase the internal comfort. The suggestions seek to bring alternatives that may be appropriate for social housing in the same region while also providing a better responsiveness to climatic conditions. The results are favourable, especially when the improvement of the thermal envelope, the use of isolated shutters, and the infiltration management are considered.

The Peruvian regulations must accommodate a wider range of materials with construction potential. In cold climates such as Puno, the introduction of passive strategies and the use of alternative construction systems for thermal improvements in social housing should be researched further in the Mesoandean zone, where they can be introduced both in the rehabilitation of existing homes and in the design of new buildings.

REFERENCES

1. Presidencia del Consejo de Ministros. (2019). Plan multisectorial ante heladas y friaje 2019-2021. In Decreto Supremo N° 015 (p. 114).
2. MVCS. (2014). EM. 110 Confort térmico y lumínico con eficiencia energética. In Reglamento Nacional de Edificaciones (p. 50). Diario el Peruano.
3. ANSI/ASHRAE 55. (2017). ANSI/ASHRAE Standard 55-2017 : Thermal Environmental Conditions for Human Occupancy. ASHRAE Inc., 2017, 66. Available from: https://doi.org/ISSN 1041-2336
4. Ghavami, Khosrow; Herrera, P. (2018). Non conventional materials and technologies (M. R. Proceedings, Ed.; 1st ed.). Materials Research Proceedings.
5. Charca.S. (2015). Assessment of Ichu fibers as non expensive thermal insulation system for the andean regions. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 53(9), 1689–1699. Available from: http://publications.lib.chalmers.se/records/fulltext/245180/245180.pdf%0Ahttps://hdl.handle.net/20.500.12380/245180%0Ahttp://dx.doi.org/10.1016/j.jsames.2011.03.003%0Ahttps://doi.org/10.1016/j.gr.2017.08.001%0Ahttp://dx.doi.org/10.1016/j.precamres.2014.12.
6. Aza, L. (2016). La totora como material de aislante térmico: potencialidades. Universidad Politécnica de Catalunya. Available from: https://core.ac.uk/display/46605991.
7. Olgyay, V. (1998). Arquitectura y clima, manual de diseño bioclimático para arquitectos y urbanistas (G. Gili, Ed.; 15va ed.). Gustavo Gili.
8. Neila, J. (2004). Arquitectura bioclimática en un entorno sostenible (M. Laria, Ed.; p. 223).
9. MCVS. (2019). Suplemento Materiales y Procesos. Aislamiento Termoacústico 2019. Lima-Perú. Available from: https://issuu.com/construccionyvivienda/docs/suplemento_termoacustico_2019.
10. Othman, A. R., Sahidin, N., Martinez, L. A., Sifferlen, C., Study, C., Cole, P., Wimmers, G., & Pitts, A. (2009). Passive Design Toolkit: For Homes. In M. R. U. Design (Ed.), Sustainability (Switzerland) (1ra ed., Vol. 222, Issue January 2010). Matthew Roddis Urban Design. Available from: https://vancouver.ca/files/cov/passive-home-design.pdf%0Ahttp://dx.doi.org/10.1016/j.sbspro.2016.05.185.
11. CASBA. (2019). Straw bale building details, an illustrated guide for design and construction (1 st). New Society Publishers.
12. PUCP. (2021). Charla | Vivienda altoandina. Enfrentar las heladas con tecnologías constructivas ecológicas, bioclimáticas, sismorresistentes y materiales naturales locales. Available from: https://educast.pucp.edu.pe/video/12312/charla__vivienda_altoandina_enfrentar_las_heladas_con_tecnologias_constructivas_ecologicas_bioclimaticas_sismorresistentes_y_materiales_naturales_locales.

Thermal performance of traditional courtyard houses in a warm humid climate

Case study of Colima, México

M. GABRIELA TORIS-GUITRON[1] CARLOS J. ESPARZA-LÓPEZ[1] CARLOS ESCOBAR-DEL POZO[2]

[1]Facultad de Arquitectura y Diseño, Universidad de Colima, Coquimatlán, México.
[2] Facultad de Ingeniería Mecánica y Eléctrica, Universidad de Colima, Coquimatlán, México.

ABSTRACT: The current climate crisis has highlighted the importance of buildings design that can reduce energy consumption for heating and cooling. In this regard, the courtyard is an architectural element that can create a microclimate and thus influence the thermal performance of its immediate spaces. The aim of this study is to analyze the integral thermal performance of a representative courtyard house in a warm humid region. This is proposed to have a better understanding of its thermal capabilities in this climate, as well as to developed conclusions that could guide to further improvement and reinterpretation of this building type. Through field measurements, temperatures of different spaces inside the house were registered along different seasons. The findings showed that this building type allows a wide range of thermal conditions that vary depending on the time and orientation. Nevertheless, it was observed that the courtyard does not contribute to a better thermal performance of the house during the day, since it allowed higher exposure to solar radiation and consequently raised the temperature of the corridors. On the other hand, the possibility for cooling through natural ventilation in the enclosed rooms was identified and different ventilation strategies were compared.
KEYWORDS: Courtyard houses, thermal performance, warm humid climate, passive cooling.

1. INTRODUCTION

The increasing environmental concerns and the scarcity of fossil fuels have demand attention on buildings designs that can reduce energy consumption for heating, cooling, and ventilating. In this regard, the courtyard is an architectural element that can create a microclimate and influence the thermal performance of its immediate spaces inside the building, and thus lead to less annual energy demand [1].

The performance of courtyard varies from one climate to another and depends on the configuration of its design variables such as form, height, proportions, and glazing [2-4]. Regarding this, some results have demonstrated courtyards are more energy efficient in hot-dry and hot-humid climates than in temperate and cold climates [3].

1.2 Courtyards in warm humid climates

Courtyard buildings have a higher surface to volume ratio in comparison to other building types. This indicates that the building is more exposed to the outdoors environment, and has higher possibilities for natural ventilation, solar radiation, day lighting, heat gains and heat losses [5]. In a warm humid climate, enhancing continuous and efficient ventilation is a desirable strategy for promoting thermal comfort. Nevertheless, higher exposure to solar radiation should be avoid as well as the increase of indoor temperatures during the day [6].

Regarding the suitability of courtyard houses in this climate, Rapoport suggested that the appearance of courtyards in hot humid climates it's an anticlimactic solution [7] and other researchers coincide that this building type is not appropriate because of the narrow daytime temperature variation [5]. Furthermore, the findings of Doctor-Pingel et al. 2019 showed that this strategy led to elevated indoor temperatures in a warm humid region, as in the summer months, temperatures in this space get higher due to direct solar radiation on the exposed courtyard floor [8].

Despite courtyard houses have not been commonly related to warm humid climates, they have also been part of the constructive tradition in these regions. Therefore, some authors have explored its thermal performance and passive cooling possibilities related to different design parameters. For instance, courtyard´s height plays a significant role in enhancing thermal comfort, as it determines the solar exposure this space receives [9] and consequently, the daily maximum air temperature [10]. As height increases, better thermal performances are obtained because of increment in shaded areas that lower duration of excessive solar radiation [2, 11-12]. On the other hand, when natural ventilation is considered, Tablada pointed out that cavity ratios (Width/Height) of 1.0 and 0.7 can promote better ventilation because of the geometry that causes the development of a strong vortex and high velocity magnitudes [13].

Another proportion that influences the exposure to solar radiation is the relation between courtyards width and length. According to some researchers, the least solar radiation gains and irradiation were observed in squared courtyards compared with rectangular ones [4,12]. This also decreases the amount of energy required for cooling during summer periods [4]. In addition, the orientation can also influence the heat gains of the buildings, especially in rectangular plan courtyards. Better performances were observed when orienting the long axis of the courtyard along northeast–southwest [2, 12] and east-west [14].

The findings from Kubota et al. showed that courtyards perform different according to its type. For instance, the courtyard types where air flow was almost absent during the day (<0.2 m/s), the air temperatures in the courtyard and the immediate spaces maintained relatively low values compared to outdoor temperature. Contrary to this, the types with higher indoor wind speeds also had air temperature increases [10]. This highlights the importance between ventilation and thermal performance of this building form. Related to this, Toe & Kubota identified two cooling strategies of the courtyards. The first one is to improve radiative and ventilative cooling during the night, and the other, to reduce cross ventilation and avoid vertical airflows between indoors and outdoors during day [15].

Through this review of literature, it was possible to have a better understanding of how courtyard dwellings generally respond to a hot humid climate, as well as how certain design parameters influence its thermal performance. It was identified that solar radiation should be diminish and natural ventilation should be enhanced only in certain moments of the day, so that this building form could have a better thermal performance. In addition, previous studies also provided a background to support the current study and to carry out the assessment of results.

2.BACKGROUND

The study area is in Colima, located in western México at 19° 14′ N, 103° 43′ W and 484 m above sea level. According to Köppen's classification, it is an equatorial savannah climate with dry winter (Aw) [16]. The average annual temperature is 25.5 °C with 14°C thermal swings and annual rainfall of 970mm.

The morphological and typological characteristics that determine the traditional courtyard houses of Colima were identified through a review of the historical evolution and field sampling. The houses dated from the XIX and XVIII centuries, and its origins were greatly influenced by Spanish culture. They are characterized mostly by one storey, with a rectangular or square central courtyard surrounded by corridors and enclosed rooms in the periphery. The length of the courtyards varied from 4.5 m to 22.6 m and the width from 1.7 m to 26.6 m. In accordance with the urban layout, the possible facades orientations are northwest, northeast, southwest, or southeast.

Regarding building materials, walls were made of adobe or brick with thicknesses ranging from 0.4 m to 1.1 m, depending on the material and the construction period. At first, sloping roofs predominated, but later the use of flat roofs increased. The main roofing materials consist of wood and clay tiles, but in subsequent interventions even concrete has been used.

3. METHOD

The present work is part of an ongoing systematic research to study the thermal performance of traditional courtyard houses, so that it could guide to further improvement and reinterpretation of this building type. The aim of this work is to analyze the integral thermal performance of a representative courtyard house through field measurements in a warm humid region. Additionally, computer simulations were carried out to compare different ventilation strategies and their effect in operative temperatures inside the rooms.

From the field sampling, a representative courtyard house in Colima was selected for field measurements. The one storey house dates from the XIX century. It has a squared plan courtyard placed in the centre of the building with an area of 110.25 m^2 and height of 4.5 m. The courtyard is surrounded by corridors on each of its sides and enclosed rooms are immediate to them. The building materials consists of brick walls and reinforced concrete flat roofs over wooden beams and clay tiles. The courtyard floor is covered with stone and the indoor floors with clay tiles. As it is naturally ventilated, no heating or cooling systems affected the measurements.

The monitoring periods were determined by three main seasons defined as mild semi-humid (December to March), warm semi-humid (April to May) and warm humid (June to November). The house was monitored hourly for 7 days each season. Dry bulb temperatures were recorded using Onset Hobo dattaloggers with an accuracy of ±0.35°C. The equipment was placed at 1.1 m height in the courtyard, corridors, and rooms in each one of the orientations (see Fig. 1). The windows of the rooms remained closed during the measurements. Outdoors environmental variables such as solar radiation, air temperature, relative humidity, wind speed, and wind direction were also measured to develop the weather file for the simulation.

Figure 1:
Left: courtyard house section and plan with the measurement points. Right: photography of the house taken from one of the corridors.

The computer simulation was conducted using DesignBuilder, which is a graphical interface for EnergyPlus. To validate the accuracy of the model, sets of hourly simulated and measured air temperature data were compared for different spaces. The differences in mean temperatures were not greater than 1ºC, the coefficients of determination (R^2) were higher than .94 and the RMSE values were lower than 1.31 for all the spaces. Based on this evaluation, it was determined that the model was accurate.

4. RESULTS AND DISCUSSION

The assessment of data obtained in the field measurements is mainly concerned in comparing the differences between the temperatures of the spaces in each season. The comparison is based on observing the differences between average thermal swings and maximum temperatures of the spaces. In addition, an analysis of the representative days in each season was conducted to have a better understanding of the thermal performance.

The results showed similar thermal swings in the courtyard and outdoors, but the courtyard maximum and minimum temperatures remained slightly higher. In the corridors, thermal swings and maximum temperatures vary depending on the season and the orientations. Among the indoor spaces, the rooms registered the lower maximum temperatures with thermal swings smaller than 1.6 ºC. Regarding the orientations, the southwest corridor and rooms had the lower maximum temperatures in most of the seasons.

When comparing the results obtained in different seasons, the higher maximum temperatures were observed in May, during the warm semi-humid season. In the monitored period, the average maximum temperatures of the courtyard and outdoors reached 37.9ºC and 36.2ºC, respectively. Conversely, lower maximum temperatures were registered in February. In this period, the thermal swings of the courtyard and outdoors were 14.2ºC on average (refer to table 1).

Table 1: *Average maximum temperatures in the different measurement points of each season.*

Maximum Temperatures (ºC)	Mild semi-humid February	Warm semi-humid May	Warm humid October
Outdoors (T0)	32.0	36.2	34.2
Courtyard (T1)	33.1	37.9	34.7
Corridor SE (T2)	30.3	39.3	33
Corridor SW (T3)	29.3	35	32.4
Corridor NW (T4)	37.1	34.4	40.1
Corridor NE (T5)	37.1	35.1	37.5
Room SE (T6)	26.1	30.2	30.2
Room SW (T7)	25.8	30.3	29.6
Room NW (T8)	26.4	32.8	31.1
Room NE (T9)	27.2	31.4	31.5

In the corridors, the maximum temperatures vary according to each season. For instance, in the mild semi-humid (February) and warm humid (October) seasons, corridors oriented north presented higher maximum temperatures and thermal swings while the ones oriented south presented lower maximum temperatures than outdoors. This can be explained since in February and October the sun path is similar. During this season, the sun rises from the southeast and sets in the southwest. Therefore, solar radiation affects the temperature of the northwest corridor during the morning, and of the northeast corridor in the afternoon. On the other hand, in warm semi-humid season, the higher temperatures were measured on the southeast corridor. Given that the sun path in May promotes a higher exposure to solar radiation in this orientation, especially during the afternoon.

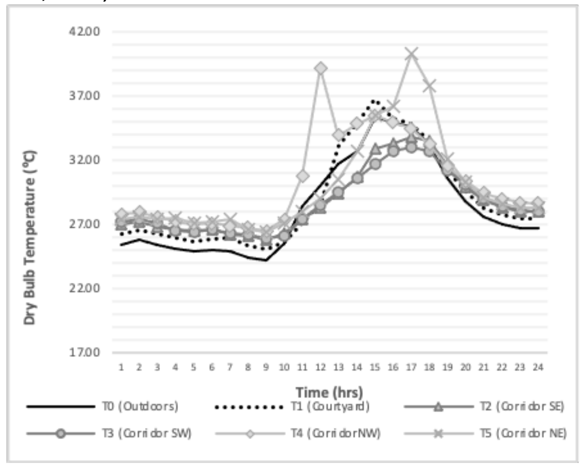
As in the outdoor temperatures, the rooms had lower maximum temperatures in February compared to the other seasons. In May and October, the temperatures inside the rooms had similar maximum temperatures, but higher thermal swings in May.

4.1 Thermal performance of corridors and courtyard in a representative day

For a more detailed analysis about the influence of the courtyard in the corridors, a representative day for each season was selected. For this, the two parameters considered were the average outdoors temperature and the thermal swings, the latter to include the relative humidity variable. The representative day consisted of the one in which its temperature and thermal swings performed more similarly to the ones of each season.

In the warm humid season, the courtyards openings cause that the north corridors received direct solar radiation. This contributed to an increase of 3.8ºC in maximum temperatures of the northwest, that was registered 3 hours in advance, compared to outdoors. During the afternoon, the maximum temperature in the northeast was recorded with an increase of 4.9ºC and a thermal delay of two hours. Meanwhile, the south corridors had lower temperatures than the courtyard and outdoors with a thermal delay of two hours. Outdoors and on the courtyard, both maximum temperatures were reached at the same time (figure 2).

Figure 2:
Dry bulb temperatures of the courtyard and corridors in a 24-hour thermal cycle. Warm humid season. (October 23rd, 2020).



In the representative day of the mild humid season, the corridors oriented north were also exposed to solar radiation. The northwest showed an increase of 3.8ºC in the morning, four hours before the maximum temperature of the exterior. In the northeast the increase was of 5.8ºC without a thermal delay. The maximum temperatures in the south corridors were registered with a delay of one hour (figure 3).

On the contrary, measurements from the warm semi humid period indicated higher temperatures (3.8 ºC) in the southeast corridor than outside. This was observed with a thermal delay of two hours. In this season, there was no thermal delay between the other corridors and outside (figure 4).

Figure 3:
Dry bulb temperatures of the courtyard and corridors in a 24-hour thermal cycle. Mild semi humid season (February 21st, 2021).

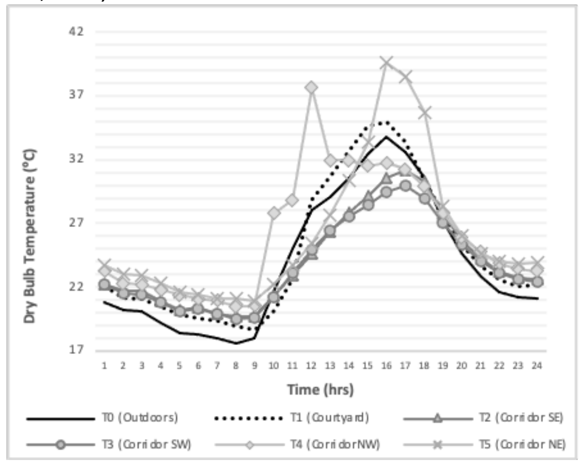
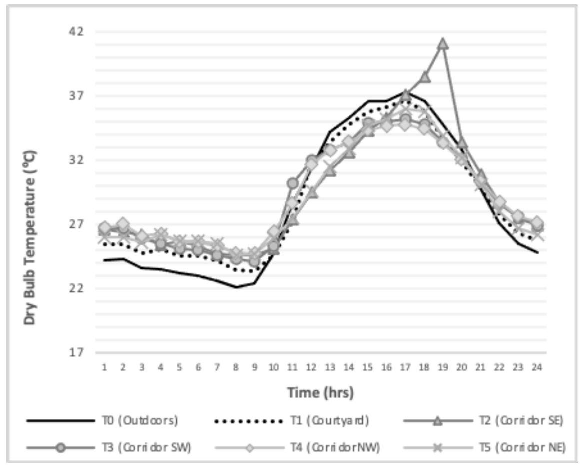


Figure 4:
Dry bulb temperatures of the courtyard and corridors in a 24-hour thermal cycle. Warm semi humid season (May 29, 2021).



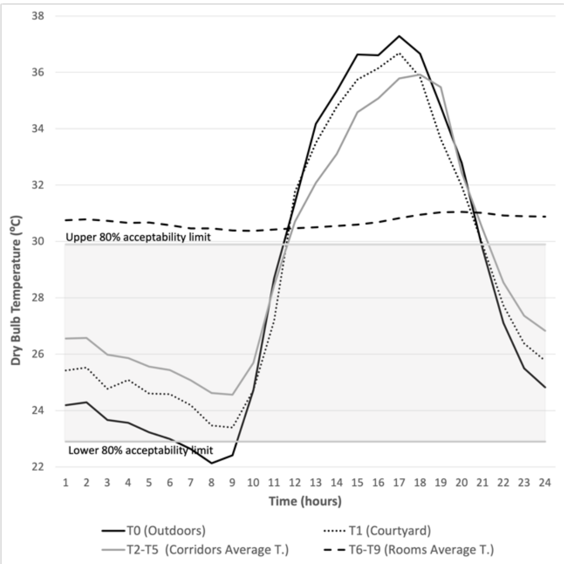
4.2 Detailed analysis of a critical period

Among all the monitoring periods, the warm semi humid season turned out to be the most critical since it experienced the highest outdoor temperatures. Figure 5 shows the 24-hour thermal cycle of different spaces in a representative day of the season. The temperature in the rooms and corridors correspond to the average of all the orientations. In addition, the thermal comfort zone for the 80% of acceptability was calculated according to international standard ASHRAE 55-2017 [17].

In this season during the day, approximately from 10 hrs. to 21 hrs., the courtyard contributes considerably to the increase in heat gains of the building. This can be seen in the temperatures of the corridors, especially during the afternoon. In this interval of hours, it is not desirable for the rooms to be ventilated since this can contribute to an increase in their temperatures. After 21 hrs. until the early hours of the morning, the courtyard allowed a decrease in the corridors temperatures as well as in the rooms, because it enhance a higher exposure to outdoors conditions. As the rooms had closed windows, the difference in minimum temperatures with the courtyard were approximately of 7ºC. This difference suggests the possibility that the inhabitants could open the windows to promote passive cooling of these spaces during this time lapse.

Furthermore, if the thermal comfort limits for the 80% acceptancy are taken as a reference, during most part of the day (from 11 hrs. to 21 hrs.) the corridor and the courtyard temperatures exceed the upper limit of comfort. In warm humid regions, with air velocities between 1.5 y 2.0 m/s, the thermal comfort limits could only be extended if outdoor temperature does not exceed 32ºC [18]. In this season, outdoor temperatures were higher than 32ºC from 12 hrs. to 19 hrs, this prevents the possibility of promoting thermal comfort as well as increasing heat gains in the building.

Figure 5:
Dry bulb temperatures of different spaces in the courtyard house in a 24-hour thermal cycle of the critical season. Thermal comfort limits were set as a reference.



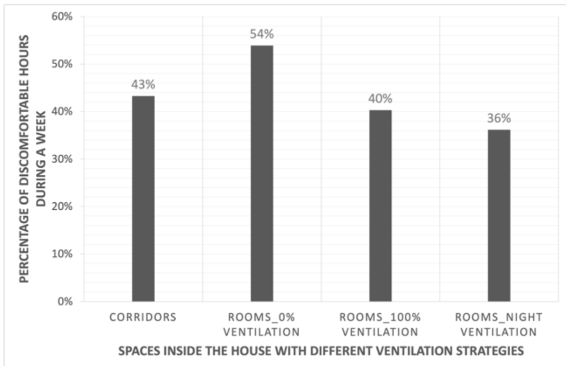
Note: Thermal comfort boundaries were calculated according to international standard ASHRAE 55-2017 [17]. This is an adaptative model developed for naturally conditioned spaces that relates the temperature ranges, for the 80% of acceptability, to outdoor climatic conditions.

4.3 Ventilation strategies in a critical week

When comparing the thermal performance of the spaces inside the house, great differences between the maximum and minimum temperatures of the corridors and the enclosed rooms were observed. The temperature of the rooms had lower thermal swings due to its enclosure, the thermal properties of its envelope and the limited windows that remained closed during the field measurements. This configuration prevented temperatures from rising during the afternoon but limited the potential benefits of a night-time ventilation strategy.

To explore the possibility for cooling during the night and early morning, three different ventilation strategies were proposed varying the opening of the windows. The first consisted of keeping the windows closed, the second considered an opening of 100% during all day, and the third modified the opening from 0% during the afternoon to 100% during night and early morning (0:00 to 12:00 hrs). These ventilation strategies were compared through computer simulation using DesignBuilder software. Results of operative temperatures were obtained for a representative week of the warm semi humid season, that was considered as the most critical period from the field measurements. Furthermore, the percentage of discomfortable hours was calculated using operative temperatures of the spaces inside the house. For this, the operative temperatures of each type of space in different orientations were averaged.

Figure 6:
Percentage of discomfortable hours during a representative week of the critical season (Warm semi humid) in the corridors and rooms with different ventilation strategies.



Note: The percentage of discomfortable refers to the number of hours that the temperature is outside the thermal comfort boundaries during a week (168 hr). Thermal comfort boundaries were calculated according to international standard ASHRAE 55-2017 [17].

The maximum percentage of discomfortable hours (54%) was registered when the rooms windows had an opening of 0%. The discomfort percentage for the corridors, the rooms with windows 100% opened and the rooms with night/early morning ventilation were 43%, 40% and 36%, respectively (see Fig.6). The latter ventilation strategy prevents the increase of maximum temperatures in the rooms and enhance lower temperatures by 1.9ºC, compared to when the windows where closed.

5. CONCLUSION

From the results obtained through this research, it can be determined that this case study traditional courtyard does not contribute to enhance passive cooling inside the house during the day. On the contrary, this courtyard configuration allowed higher exposure to solar radiation and consequently raised the temperature of the corridors, especially during the afternoon. In some cases, the difference between a corridor exposed to direct solar radiation and those that were not, almost reached 10ºC. Meanwhile, during the night, no significant temperature drops were observed. However, the possibility for cooling through natural ventilation in the enclosed rooms was identified. The best ventilation strategy to promote lower percentage of discomfortable hours was to open the windows (100%) during the night and early morning. This diminishes the percentage of discomfortable hours in a week by 18%, compared to when the windows remained closed.

The current study allowed a better understanding of the thermal performance of the spaces inside a courtyard house along different seasons. The findings showed that this building type allows a wide range of thermal conditions that vary depending on the time, space, and orientation. Nevertheless, further research may be need considering different courtyard designs so that it could protect better from solar radiation and increase shaded areas. Likewise natural ventilation would need to be consider to enhance an adequate thermal performance in a warm humid climate.

REFERENCES

1.Taleghani, M. (2014). Dwelling on Courtyards. Exploring the energy efficiency and comfort potential of courtyards for dwellings in the Netherlands. *Rotterdam: Architecture and the build environment.*
2.Muhaisen, A. (2006). Shading simulation of the courtyard form in different climatic regions. *Building and Environment,* 41: p. 1731–1741.
3. Aldawoud, A. (2008). Thermal performance of courtyard buildings. *Energy and Buildings,* 40: p. 906–910.
4.Yasa, E. and Ok, V. (2014). Evaluation of the effects of courtyard building shapes on solar heat gains and energy efficiency according to different climatic regions. *Energy and Buildings,* 73: p. 192–199.
5.Ratti, C., Raydan, D., and Steemers, K. (2003). Building form and environmental performance: archetypes, analysis, and an arid climate. *Energy and Buildings*, 35: p.49-59.
6. Givoni, B. (1976). Man, climate and architecture. 2nd ed. *London: Applied Science Publishers.*
7. Rapoport, A. (2007) The nature of the courtyard house: a conceptual analysis. *Traditional Dwellings and Settlements Review, 18.* p. 57-72.
8.Doctor-Pingel, M., Vardhan, V., Manu, S., Brager, G., and Rawal, R. (2019). A study of indoor thermal parameters for naturally ventilated occupied buildings in the warm-humid climate of southern India. *Building and Environment, 151:* p. 1-14
9.Ghaffarianhoseini, A., Berardi, U., Ghaffarianhoseini, A. (2015). Thermal performance characteristics of unshaded courtyards in hot and humid climates. *Building and Environment, 87: p.* 154-168.
10. Kubota, T., Zakaria, M. A., Abe, S., and Toe, D.H.C. (2017). Thermal functions of internal courtyards in traditional Chinese shophouses in the hot-humid climate of Malaysia. *Building and Environment, 112: p.* 115-131
11. Almhafdy, A., Ibrahim, N., Ahmad, S.S., and Yahya, J. (2013). Analysis of the Courtyard Functions and its Design Variants in the Malaysian Hospitals. *Procedia - Social and Behavioral Sciences, 105: p. 171-182.*
12. Rodríguez-Algeciras, J., Tablada, A., Chaos-Yeras, M., De la Paz, G., and Matzarakis, A. (2018). Influence of aspect ratio and orientation on large courtyard thermal conditions in the historical centre of Camagüey-Cuba. Renewable Energy, 125: p. 840-856
13.Tablada, A. (2006). Shape of new residential buildings in the historical centre of Old Havana to favour natural ventilation and thermal comfort. *Katholieke Universiteit Leuven. Thesis submitted for the degree Doctor of Architectural Sciences*.
14. Taleghani, M., Tenpierik, M., and van den Dobbelsteen, A. (2014) Indoor thermal comfort in urban courtyard block dwellings in the Netherlands. *Building and Environment, 82: p.* 566-579
15. Toe, D., and Kubota, T. (2015). Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot–humid climate of Malaysia. *Solar Energy*, 114: p. 229-258.
16.Kottek, M., Greiser, J., Beck, C., Rudolf, B., and Rubel, F. (2006). World map of the Köppen- Geiger climate classification updated. *Meteorol Z, 15.*
17.ASHRAE standard 55-2017 (2017) Thermal environmental conditions for human occupancy. *Atlanta, GA.*
18. Givoni, B. (1994). Passive and Low Energy Cooling in Buildings. *Los Angeles: Van Nostrand Reinhold.*

PLEA 2022 SANTIAGO
Will Cities Survive?

Hygrothermal comfort in school yard
A case study LEED in Rio de Janeiro

RITA DE CÁSSIA PEREIRA DA SILVA[1] VIRGINIA MARIA NOGUEIRA DE VASCONCELLOS[1]

[1] Universidade Federal do Rio de Janeiro

ABSTRACT: *The school space must be a pleasant environment that contributes to the teaching-learning process. For this, the hygrothermal comfort of students, teachers and staff must be a priority. As in the city, hygrothermal comfort in the school environment requires an understanding of the essential components of urban hygrothermal comfort, in view of the climatic reality of each region. This article aims to analyze the hygrothermal comfort conditions in a school environment, in a tropical climate, presenting as a case study the courtyards of a certified school, located in Rio de Janeiro, Brazil. The work also verifies the potential of shading elements for comfort in this climatic situation. The research, of an experimental nature, uses the post-occupancy evaluation resource to compare the results and mixed strategies used. As a result, it was observed that the free spaces intended for school life could be better used if hygrothermal comfort strategies such as cross ventilation and shading by vegetation were adopted. It is expected to contribute to the advancement of research in the area and discuss the main concerns that should be adopted in the schoolyard design, aiming at hygrothermal comfort.*
KEYWORDS: Energy, Comfort hygrothermal comfort. school architecture. Schoolyard.

1. INTRODUCTION

Climate change resulting from the urbanization process is reflected in the environmental quality of cities, harming the effective use of their spaces [1] and, in the school environment, this is no different. It is necessary that the school space is a pleasant environment, that contributes to the teaching-learning process [2]. Among so many precautions that must be taken in a school environment, concerns about the hygrothermal comfort of students, teachers and staff must be a priority. However, as in the city, hygrothermal comfort in the school environment requires an understanding of the essential components of urban hygrothermal comfort, in view of the climatic reality of each region. This work aims to analyze the conditions of hygrothermal comfort in a high school environment in a tropical climate, presenting as a case study the patios of a LEED certified school, level silver (58 points) [3], located in the city of Rio de Janeiro, Brazil. The work also verifies the potential of shading elements (built and afforestation) for comfort in this climate situation.

2. METHODOLOGY

The research, of an experimental nature, uses the post-occupational evaluation feature to compare the results and used mixed strategies. The procedures adopted for its development covered the following steps: bibliographic and field survey; measurements of climate variables; post-occupancy assessment; analysis of results; and conclusions.

2.1 Measurements of climate variables

The measurements served as support and complement to the understanding of the behavior of local climatic variables such as air temperature, relative humidity, direct solar radiation, prevailing wind speed and direction and surface temperature of the coating materials and were carried out with instruments of precision, figure 1.

Figure 1: Precision instruments used in research

The instruments used for the measurement, numbered in figure 1, were respectively: (1) a thermo-hygrometer, which measures the temperature and relative humidity of the air; (2) a digital anemometer, which measures the wind speed and makes it possible to indicate, by means of a wool line, supported on it, its predominant direction; (3) a digital solar radiation sensor; (4) a laser thermometer, which allows measuring the temperature of surfaces; (5) a digital lux meter, which measures the amount of ambient light.

The definition of the measurement points that make up the established route was determined, then, based on the criterion of use, aimed at leisure, and location, considering the distance between the points, so that the measurement points were defined and ordered according to figure 1.

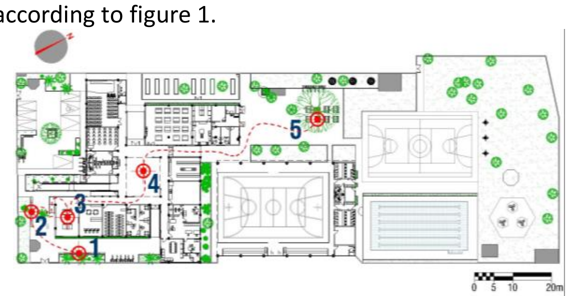


Figure 1: Measuring points maps

The measurements were carried out in the periods of solstices and equinoxes, which in Brazil correspond to January 14, March 22, July 9 and October 7, 2019, according to the College's schedule availability and environmental weather conditions.

2.2 Post-Occupation Assessment

To carry out the Post-Occupation Evaluation, it was necessary to submit the research to the Research Ethics Committee, then it was necessary to expose the research to the school community to attract interested parties to participate in its stages. Interested parties signed a consent form. After a few visits to the College, to gather a considerable sample of participants, the number of participating students who joined the survey was 28 students and 6 professors, o--ut of a total of 600 users. From then onwards, the application of the Post-Occupancy Assessment devices, applied on October 7, 2019, was scheduled. Students aged between 15 and 18 years old wore a short-sleeved shirt, jeans or shorts and sneakers, representing a clothing insulation in clo of 0.5. To calculate the adaptive comfort index, the formula developed by Humphreys (LAMBERTS et. al., 1997) is used to obtain the user's neutral temperature. Equation 1.

$$T_n = 2{,}6 + * (0{,}831 \text{ x } T_m)'$$

Equation 1 – Humphreys Neutral Temperature Equation

Where: Tn = neutral temperature in °C and Tm = average air temperature in °C

The thermal neutrality temperature was calculated for each patio, taking into account the values measured in the measurements on October 7, 2019. The average air temperature was calculated from the sum of the highest and lowest temperature measured on the day, and dividing this result by two, obtaining the result of the average air temperature and applying the result to Equation 1

Five post-occupancy assessment devices were used: Walktrough Analysis, Behavioral Map, Visual Map, Questionnaires, Interviews and Finding Matrix

The walkthrough analysis was carried out in a pre-defined route in the external areas and internal courtyard of the College, with a group of students from the student union, combining observation and interviews, which were recorded using forms prepared and adapted to the research objective, filled out. along the way and complemented by audio recordings.

The analysis of the results was carried out, at first, together with the participants in order to confirm the records; in a second moment, from the gathering of all the registration material, a results framework was formalized; in a third moment, the results were inserted, through the interweaving of data with the other POE tools, in the discoveries matrix.

The application of the Behavioral Map was given by records, in a printed floor plan, where the interactions of students in the school yards during recess were recorded, using symbols and lines, flows, activities developed, user profiles, number of users and length of stay.

The Visual Map was applied to students, in a classroom, using a floor plan of the College, with the patio areas highlighted. Students were grouped into 3 to 4 participants per plant, and they agreed on their evaluations of the patios' hygrothermal comfort, marking their evaluations by gluing stickers with five thermal sensation options - very hot, hot, comfortable, cold and very cold. The analysis of the results started from the sum of data extracted from the visual map, generating the percentages related to each degree of comfort attributed to each environment and verifying the predominance of users' perception of that environment.

Questionnaires were applied to students, who answered 3 questions related to hygrothermal comfort in the school yards. The analysis started from the sum of the extracted data, generating graphs with percentages related to the use, occupation, and level of comfort attributed to each environment.

The interviews were applied to the teachers, and were presented in a semi-structured way, with the preparation of a script and a set of questions focusing on hygrothermal comfort in the school's courtyards. The analysis of the results was made through the interweaving of data with the other POE tools, and is presented in the Findings Matrix.

The discoveries matrix was generated from the union of the results of the POE devices applied in the research in order to synthesize and validate the results obtained in each yard. The matrix presents the College's floor plan with the patios highlighted, the points of greatest discomfort pointed out in the instrument measurements, photos, captions of each POE instrument, the most relevant reports of each patio, in order to present a summary of the results of the research.

3. ANALYSIS OF RESULTS

The measurements carried out at the five points of the school's courtyards, at the hours of 9, 12 and 3 pm, in the four seasons of the year, generated a rich amount of data. The analysis was made considering, at first, the measurements of the three times in each station, and in a second moment the analysis was made considering each time in the four stations.

Summer measurements were made during a school vacation period, on January 14, 2019. Due to the interference of some objects with the measuring devices at the time of measurement, altering the results, the nine o'clock measurement was disregarded.

Among the actions aired at 9 am, on March 22, July 9 and October 7, 2019, the point that presented the highest temperatures was point 1, in patio A, which also had the lowest índices of relative air humidity. The points with the lowest temperatures, at 9:00 am, were point 5 (patio D - external patio, with fig tree), in autumn and spring, and point 3 (internal patio), in winter, which had the highest rates. relative humidity of the air, according to table 1.

9h		SUMMER 14/01/2019		FALL 22/03/2019		WINTER 09/07/2019		SPRING 07/10/2019	
COURTYARD	POINTS	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)
A	1	Discarded data		28,90	71,14	23,10	59,50	26,79	72,23
	2			28,58	73,40	21,82	62,18	26,10	74,18
B	3			27,41	77,40	21,22	64,14	25,78	76,13
C	4			26,98	75,90	21,54	62,75	26,65	73,74
D	5			26,48	80,40	22,33	59,78	25,65	76,87

Table 1. Summary of 9 o'clock air temperature and humidity measurements at 4 seasons

Among the campaigns aired at 12:00, the points that were presented as the highest temperatures were point 4 (in courtyard C - central courtyard), in summer, winter and spring, which are close to the temperatures at temperatures lowered at point 4, in courtyard A, in summer and spring, with a difference of 0.02C. In autumn, the hottest point at 12:00 was point 2, in patio A. All points with the highest temperatures also had the lowest relative humidity levels. As for the point with the lowest temperatures, 12:00h was the lowest point at 5:00 pm (patio D - external patio, in all measurements with, showing the highest relative humidity índices, according to table 2.

12h		SUMMER 14/01/2019		FALL 22/03/2019		WINTER 09/07/2019		SPRING 07/10/2019	
COURTYARD	POINTS	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)
A	1	36,74	47,21	27,76	72,87	26,18	48,50	29,85	62,92
	2	35,80	49,38	28,46	70,90	25,94	48,20	29,76	63,78
B	3	35,32	50,20	26,59	77,10	25,70	49,20	29,79	65,11
C	4	36,76	47,56	27,82	74,10	27,13	44,34	29,83	63,55
D	5	34,65	51,74	26,20	78,77	25,12	47,31	29,40	64,18

Table 2. Summary of 12 o'clock air temperature and humidity measurements at 4 seasons

As for the measurements carried out at 15:00, the point that presented the highest temperatures was point 4 (in courtyard C, central courtyard, from the skylight), which also obtained the lowest levels of relative air humidity, except in autumn, when it presented an index of relative humidity of the air in the average, among the measured points. The lowest temperatures were found at point 5 (patio D - outdoor patio), in summer and autumn; at point 3 (courtyard B – inner courtyard), in winter, and at point 1 (courtyard A – entrance courtyard), in spring. All points with the lowest temperatures had the highest levels of relative air humidity, as expected, according to table 3.

15h		SUMMER 14/01/2019		FALL 22/03/2019		WINTER 09/07/2019		SPRING 07/10/2019	
COURTYARD	POINTS	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	RELATIVE HUMIDITY (%)
A	1	39,62	45,32	25,65	77,57	24,90	56,93	27,22	70,81
	2	36,20	50,40	25,69	78,00	24,70	57,33	28,22	68,28
B	3	36,02	51,34	25,44	82,85	24,20	59,73	27,50	70,75
C	4	40,70	42,57	25,79	80,17	25,20	56,77	28,80	67,62
D	5	35,33	51,97	25,08	82,45	24,84	57,03	28,22	68,53

Table 3. Summary of 15 o'clock air temperature and humidity measurements at 4 seasons

In the analysis of the electronic model simulating the shading of the architecture and vegetation of the college, at 3 pm on January 14, March 22, July 9 and October 7, 2019, the presence of shadow is observed in all yards in a percentage greater than 50% of shading, in all of the simulated days, in the four seasons. The patio with the highest temperature at this time is the central patio.

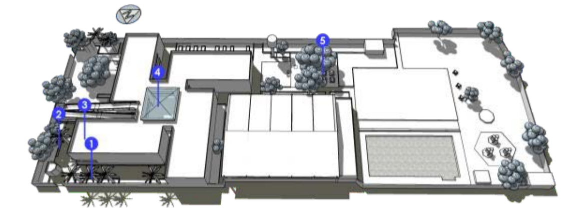


Figura 2. Shading simulation on January 14, 2019 at 15:00h

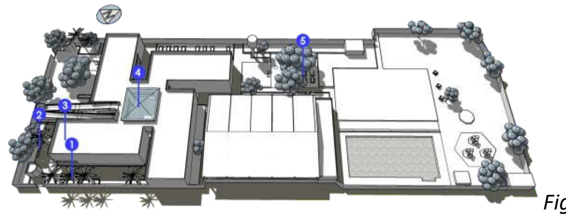


Figura 3. Shading simulation on March 22, 2019 at 15:00h

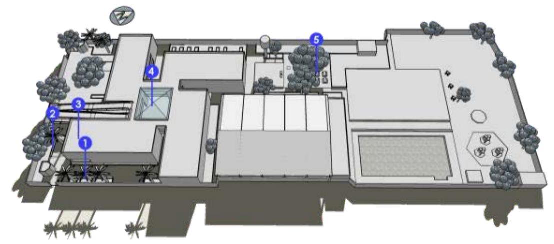


Figura 4. Shading simulation on July 9th, 2019 at 15:00h

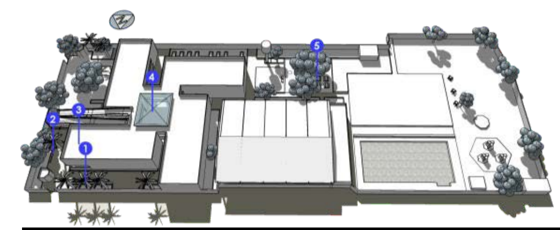


Figura 5. Shading simulation on October 7th, 2019 at 15:00h

The patios that offer the lowest temperatures are those that presented greater ventilation and shading, due to buildings or vegetation.

It is observed that the patios that offer the lowest temperatures are patio D – external patio and patio B – internal patio. It is believed that on account of good ventilation and shading.

The central courtyard has the highest temperatures. It is covered by a alveolar polycarbonate structure and does not have enough openings to escape the heat that accumulates in the place during the day, reaching the highest temperatures at 3 pm.

These data were crossed with the information obtained in the post-occupancy assessments, which will e presented below.

In the post-occupancy evaluation, the walkthrough analysis with the students of the guild and the interviews carried out with the teachers, did not only take into account the level of comfort presented on the day of the interview, but of every day of the year, with observations about certain seasons. or weather conditions.

In the questionnaires and in the visual map, the students took into account the environmental quality of that day, making it necessary to compare the result of these instruments with the measurements made exclusively on October 7, 2019.

In the post-occupancy evaluation, as a general result of all the POA devices applied, the points pointed out as the most comfortable by the students are: (1st) the inner courtyard; (2nd) the entrance patio, despite having received a lower score than the internal and external patio, obtained a higher percentage of comfort in the morning and afternoon in the questionnaires, and in the area of point 2 on the visual map; (3rd) the external patio; and in last place (4th) the central patio with the lowest percentage of comfort in all the evaluations carried out, and at all times, table 4.

	MEASUREMENTS	ADAPTIVE COMFORT	POA

								INDEX					
COURTYARD	POINTS	9h		12h		15h		Average Temp.	Neutral Temp.	Quiz		Visual	Grade
		temp.	umid.	temp.	umid.	temp.	umid.			AM	PM	Map	
A	1	26,79	72,23	29,85	62,92	27,22	70,81	28,32	26,13	74%	44%	62%	7,3
	2	26,1	74,18	29,76	63,78	28,22	68,28	27,93	25,81			69%	
B	3	25,78	76,13	29,79	65,11	27,5	70,75	27,79	25,69	78%	78%	77%	7,4
C	4	26,65	73,74	29,83	63,55	28,8	67,62	28,24	26,07	52%	22%	31%	5,8
D	5	25,65	76,87	29,4	64,18	28,22	68,53	27,53	25,47	70%	41%	69%	7,4

Table 4. Comparative table of measurements, comfort index and POA of October 7, 2019.

In the application of the adaptive comfort index, the average user neutral temperature between the five measurement points is 26°C. Since, in the afternoon, all the patios reached an air temperature above this value, the 9:00 am hour is the only one that allows hygrothermal comfort temperatures to users.

In the measurements, the points that reached the lowest temperatures were: (1st) the external patio, which only did not obtain better results at 3 pm; (2nd) the inner courtyard; (3rd) point 2, and then point 1, of the entrance yard; and, in the last place (4th) the central courtyard, which had the highest temperatures between 12 and 3 pm.

The ranking of the hygrothermal comfort responses of the post-occupancy assessment, the hygrothermal comfort index and the air temperatures in the measurements agree, only, with the last position, (4th) the central patio, as the patio with the lowest quality of hygrothermal comfort.

In the morning, the most used yards mentioned in the results of the questionnaires are the entrance yard and the inner yard. In the measurements taken at 9 am on October 7, 2019, the entrance patio was the one with the highest temperature, at point 1, with a temperature reduction at point 2, repeating its ranking in the other measurements; and the external patio and the internal patio had the lowest temperatures. The evaluation of the patios in the walkthrough analysis showed all the comfortable patios, in the morning, agreeing with the adaptive comfort index applied to the measurement results. In the interviews, the teachers mentioned the entrance patio as the most pleasant patio, in the morning, a fact justified by the proximity of the air temperature in the patio, at 9 am, with the neutral temperature of the adaptive index. Also in the interviews, the central courtyard was pointed out as the least pleasant in the morning, despite having lower temperatures than in the afternoon.

The entrance patio presented higher temperatures in the morning, due to its location to the east, receiving a higher incidence of solar radiation, however in the post-occupancy evaluation, the students rated the patio as more comfortable at this time, reaching 74% in the evaluation. What could justify this assessment of the quality of hygrothermal comfort of the entrance patio in the morning is that the temperature, despite being higher than that of the other patios, was close to the comfort level, as indicated by the adaptive comfort index.

The patios with lower temperatures in the afternoon are the external patio at 12:00, the entrance patio and the internal patio at 15:00, corroborating the data obtained in the walkthrough analysis. In the post-occupancy evaluation, the courtyard considered most comfortable in the afternoon is the inner courtyard and the least comfortable is the central courtyard, also reaffirmed in the walkthrough analysis. In the interviews, teachers reported that students complain of discomfort in the central courtyard and in the entrance courtyard, in the afternoon, and rated the central courtyard and the external courtyard, in the afternoon, as less comfortable, corroborating the measurements that point to the courtyard of entrance and the inner courtyard with the lowest temperatures.

The temperatures measured in the measurements justify the occupation of the circulations in the central courtyard, pointed out in the behavioral map and explained in the walkthrough analysis. The most shaded areas showed greater hygrothermal comfort, according to the post-occupancy assessment, such as the external patio, the internal patio and the area of point 2 of the entrance patio.

The high percentage of use of the patios, at times of worst air temperature, points to the relevance of the location and convenience of the patios for its users.

The form of the school, with its blocks configuring the blades of the weather vane, has the central courtyard as a residual result. The distribution of the circulations, which already receive heat mitigation because they are shaded, channels the wind, making the air temperature in the circulations even lower. The temperatures measured in the measurements justify the occupation of the circulations of the central courtyard, pointed out in the behavioral map and explained in the walkthrough analysis. The more shaded areas presented greater hygrothermal comfort, indicated in the post-occupancy evaluation, such as the external patio, the internal patio and the area of point 2 of the entrance patio.

The incidence of solar radiation in the central courtyard through the translucence of the skylight cover, in colorless alveolar polycarbonate, warms the atmosphere of the central courtyard. The restrictive dimensioning of the upper spans of the skylight does not allow the removal of concentrated hot air, making this space overheated, in contrast to the comfortable, shaded and ventilated circulations.

The students' performance in changing the layout of the central courtyard, changing the location of the game tables to the circulation areas in an attempt to achieve greater hygrothermal comfort, demonstrated a desire to use the space, which even with the hygrothermal discomfort, revealed both in the post - occupancy and measurement, keep the users of the site, who remain next to the central courtyard, sitting on the floor of the circulations. This fact can be explained due to the centrality of the space and the existing furniture in the place.

The discrepancy between the comfort ranking evaluated by the students in the POA and that of the measurements, and the prevalence of the use of the central patio and external patio by the students, in the afternoon, can be explained, in part, by the attractions of the patios, such as the number of available seats, level of privacy, silence, or your location. The entrance patio is made up of extensive benches and is considered by students as a quiet and reserved area, good for spending free time, studying and talking; the inner courtyard has no furniture, but it is a very reserved and silent environment, where students like to rest after lunch; the central patio is the patio with the best location due to its centrality and visibility, providing greater interaction with the other environments, despite not having a sufficient number of seats, it has several attractions such as ping-pong and foosball tables and the convenience of proximity to toilets and drinking fountains; the outdoor patio interacts with the sports courts and central patio, and is composed of tables and benches that provide greater convenience for group studies and social events, in addition to being close to the changing rooms on the court.

4. FINAL CONSIDERATIONS

As a result, it was observed that the open spaces for school life could be better used, if standards of hygrothermal comfort were respected, such as cross ventilation and shading by vegetation.

The inner courtyard is the second covered courtyard. On rainy days, its function as a shelter is not effective, but it can be solved by installing hinged awnings, allowing it to be collected on dry days. The courtyard was considered the most hygrothermal comfort of the College, but its use is practically destined for the students' rest, this use possibly relocated in a student union room or another air-conditioned indoor environment. The inner courtyard is poor in furniture, since the implementation of benches where students can gather, the relocation of the ping-pong and foosball tables, currently located in the central courtyard, would allow a better use of the space, favoring the full use, of its hygrothermal comfort conditions in the courtyard, by the students

The central patio, considered the hottest and most uncomfortable patio in the school, needs greater ventilation to allow the concentrated hot air to escape, today the height of the roof span is 40 cm, allowing inefficient ventilation, so the increase of the span would please the escape of hot air. However, to increase the height of the span, the length of the eaves must be increased, in order to protect the entry of rain. Changing the type of coverage transluced for one thermicly eficient (maintaining the characteristic of the space), is also an artifice that would contribute to thermal comfort. Today we have roofing in cellular polycarbonate with heat treatment such as reflective cellular polycarbonate that reduces the internal temperature by up to 7°C and the fully reflective cellular polycarbonate that achieves a reduction of up to 9°C, providing quality and hygrothermal comfort to the patio while maintaining its characteristics design.

The relevance of schoolyards must be considered by architects in their design exercise, removing them from the use of residual land space, and placing them at the top of the list of architectural scope needs, since in addition to being a pedagogical space contributions, the patio contributions to the well-being and rest of the students, favoring the health, concentration and development of users.

It is expected to contribute to the advancement of research in the área.

REFERENCES

1. ROMERO, Marta Adriana Bustos. Arquitetura Bioclimática do Espaço Público. Editora UNB, Brasília, 2001.
2. AZEVEDO, Giselle Arteiro Nielsen; RHEINGANTZ, Paulo Afonso; TÂNGARI, Vera Regina. O Lugar do Pátio Escolar no Sistema de Espaços Livres: uso, forma e apropriação. Rio de Janeiro: UFRJ/FAU/PROARQ, 2011.
3. ALBUQUERQUE, Rafael Tavares de. A certificação LEED na arquitetura escolar: reflexões sobre a Escola Estadual Erich Walter Heine. Dissertação de Mestrado. Rio de Janeiro: FAU/UFRJ, 2014.

PLEA SANTIAGO 2022
Will Cities Survive?

Hygrothermal Evaluation of an Indigenous Dwelling on the Andean Highlands

Evidence of how Atacameño architecture can achieve better indoor thermal standards than those set by the Chilean regulation and the average Chilean dwellings

IRENE ESCOBAR DOREN [1]

[1] Universidad Tecnológica Metropolitana

ABSTRACT: This study analyses the bioclimatic strategies underlying the indigenous architecture of the Andean Highlands. It confronts the hygrothermal performance of a Likan Antai dwelling made of liparite stone, straw, and mud with three parameters: the Thermal Regulation of the Ministry of Housing, the average indoor temperatures in Chilean houses [1] and indoor thermal comfort standards set by the Adapted Comfort Climograph [2]. Major findings show that even though temperatures in the highlands can oscillate from 42°c to -5°c in one day, indigenous dwellings provide highly stable indoor temperatures: 18°c day and night. Results evidence a hygrothermal performance that exceeds the standards set by the Chilean regulation, achieves indoor temperatures within the comfort ranges set by Neila 95% of the time; and widely exceeds the performance of the actual average housing in Chile. This comparison searches to outline the knowledge underlying indigenous architecture regarding climate adaptation and indoor thermal comfort. Therefore, this study aims to appraise the contemporary significance of this cultural heritage to contribute to preservation in areas of high material and cultural patrimony like the Andean Highlands.
KEYWORDS: Hygrothermal comfort, Andean dwellings, Caspana.

1. INTRODUCTION

Climate and architecture have always been closely related. This is evident in the materials, techniques, construction systems, and designs of primitive houses around the world. Amos Rapoport [3] highlights the amazing skills of primitive builders in dealing with climate and their ability to use minimal resources for maximum comfort. For Javier Neila [2], popular architecture represents the perfect adaptation between climate, human needs, and sustainable construction, being this the reason why he considers it the first bioclimatic architecture.

The Likan Antai or Atacameño communities that still inhabit the Andean highlands live in the oases and valleys of the Atacama Salt Flat and the Loa River Basins. The region they inhabit has a desert climate, with extreme day-night temperature variation. Their dwellings meet Jorquera's [4] definition of vernacular architecture: "It is the architecture of a place, created by a specific community and based on its knowledge of the physical and cultural environment. Their notion of environment includes climate, geography, available resources, social organization, beliefs, traditions, and productive systems. Among its most important features are the use of local building materials and the development of energy-efficient and low-impact technologies. The shape and character of the habitat and its constructions, respond to long trial and error processes, in which knowledge passes down from one generation to another. This knowledge is a timeless practical experience of building in continuous evolution seeking the best way to adapt to nature".

2. BACKGROUND

This study is based on former research entitled Sustainable Adaptation to Territory and Climate of the Indigenous Peoples of Chile. It searched for sustainable strategies underlying the settlement patterns of the 9 indigenous peoples that still inhabit the Chilean territory, and the notions of bioclimatic design underlying their construction patterns. At that moment, the hypothesis was based on a simple idea: the need for adaptation to climate and geography with simple or no technology to organize a culture and a system of beliefs implies managing daily life with local materials, available natural resources, and efficient use of energy. The focus of the investigation relied on one hand on understanding the strategies on two scales, the settlements and the buildings, and on the other hand, on the variations found between the strategies adopted by peoples of different latitudes and climates.

The present study takes a closer look at the case of Caspana, a rural Atacameño village located in the Andean Highlands of northern Chile (Fig.1), at 3264 meters over sea level and in the geographical coordinates -22.33 lat. and-68.21 long. It has a high desert climate with extreme day-night temperature variation and heavy rains in summer (Invierno Boliviano or Invierno Altiplánico).

Figure 1:
The village of Caspana in the Andean Highlands

Figure 1: Photographs of Caspana. Source: Archive of the author

The study case matches the local traditional pre-Columbian architecture of compact and rectangular enclosures (Fig.2), low height, and scarce doors and windows (Fig. 3). Walls are made of double liparite stones, 60 cm thick and 1.80 Mt high (Fig.4). Liparites are ignimbrites with more than 30% cavern component, which means that these stone walls contain air bubbles within. Local cactus wood beams (cardon) structure the ceiling and a thatched roof cover the house. The floor is made of rammed earth. The access door and the only two windows face the morning sun and all other walls have no windows or doors at all. The back of the house faces the slope, as in most houses in Caspana, and serves as a retaining wall. The enclosure is 3.5 m wide and 10 m long and faces a stone access platform that lies 1.5 meters above the street level. This platform helps protect the dwelling from floods during the rainy season. The retaining wall and staircase of this platform are also made of stone.

Figures 2,3 and 4:
Architectural plans of the case study

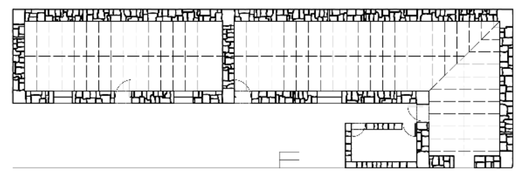


Figure 2: Floor plan of the case study. Source: Archive of the author

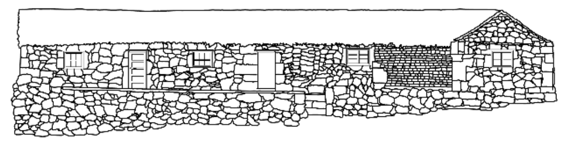


Figure 3: Elevation of the case study. Source: Own elaboration

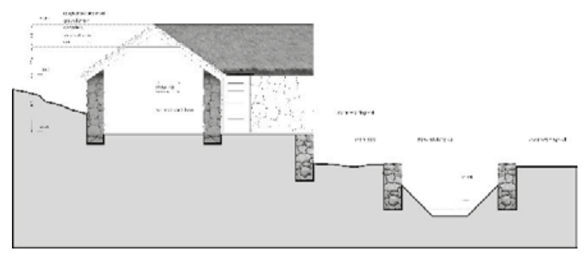


Figure 4: Cross-section of the case study. Source: Own elaboration

3. MATERIALS AND METHODS

Comfort is a complex phenomenon resulting from the combination of stimuli and sensations [5]. *Hygrothermal comfort* is achieved when the body loses heat at the right pace. It is there where a higher speed would imply a cold feeling and a lower speed, a warm feeling. At the right speed, all energy exchanges in the human body are balanced [2].

In this study, the hygrothermal performance of the study case is evaluated by comparison with three parameters: the building envelope standards set by the Chilean Thermal Regulation, the actual average indoor temperatures in Chilean dwellings, and the range of hygrothermal comfort according to Neila's Adapted Comfort Climograph. Thermal transmittance calculation is used for the first comparison and three months of hygrothermal measurements, bibliography analysis, interviews, and direct observation are used for the last two.

Fieldwork begins during the rainy season using data loggers installed inside and outside the case study house, programmed to load temperature and humidity data every 15 minutes. The three parameters of comparison are described as follows.

3.1 Thermal Regulation in Chile

In 2000, the Chilean *General Town Planning and Constructions Ordinance* includes a Thermal Regulation that sets acceptable values for the thermal transmittance of the building envelope. It defines five climate areas throughout the territory, and according to its requirements, sets standards for each one (Fig.5). Compliance with this regulation defines the admissibility of state financing through subsidies for housing construction, renovation, and refurbishment policies. Older regulatory backgrounds contain more specific climate areas and suggest harder to meet standards. Yet, they are not compulsory.

According to this Regulation, Caspana lies in the 5th Thermal Zone and sets the following acceptable U-Values for the building envelope:

Figure 5:
Minimum Thermal Transmittance for the Building Envelope according to the Climate Zone

Zone	Roofs		Walls		Ventilated mezzanines	
	U (W/ m2K)	Rt (m2K /W)	U (W/ m2K)	Rt (m2K /W)	U (W/ m2K)	Rt (m2K/W)
1	0,84	1,19	4,0	0,25	3,60	0,28
2	0,60	1,67	3,0	0,33	0,87	1,15
3	0,47	2,13	1,9	0,53	0,70	1,43
4	0,38	2,63	1,7	0,59	0,60	1,67
5	0,33	3,03	1,6	0,63	0,50	2,00
6	0,28	3,57	1,1	0,91	0,39	2,56
7	0,25	4,00	0,6	1,67	0,32	3,13

Figure 5: Minimum value for the thermal transmittance of the building envelope according to the Chilean Thermal Regulation [7]. Source: Own elaboration based on the Thermal Regulation.

The thermal transmittance of the study case's envelope is calculated (Fig.6) with data obtained from the Chilean Norm [6] and conductivity tests carried out by the Centre of Excellence in Geothermic Energy of the Andes (CEGA-University of Chile) and the University of Concepción.

Figure 6:
Calculation of the Thermal Transmittance of the Study Cases' Envelope

WALLS: Double Liparite Stone (600 mm + Stucco of Clay (50 mm)		**Thickness (meters)**	**Conductivity (W/(m/K)**	**Thermal Resistance**
Structure	**Liparite Stone**	**0,6**	**0,42**	**1,429**
Interior lining	**Clay**	**0,05**	**1,5**	**0,033**
Thermal insulation	--	--	--	--
Surface interior resistance				**0,12**
Surface exterior resistance				**0,05**
Total Thermal Resistance				**1,632 M2K/W**
U-Value of the Study Case WALL **(1/Th R)**				**0,613 W/m2K**
Minimum WALL U-Value for Zone 5 according to the **Thermal Regulation**				**1,6 W/m2K**

ROOF: Paja Brava (200 mm) + Mud (50 mm)		**Thickness (meters)**	**Conductivity (W/(m/K)**	**Thermal Resistance**
Roof	Paja Brava	0,2	0,045	4,444
Ceiling	Clay	0,05	1,5	0,033
Thermal insulation	--	--	--	--
Surface interior resistance				0,09
Surface exterior resistance				0,05
Total TR				4,618 M2K/W
U-Value (1/ Thermal Resistance)				**0,217 W/m2K**
Minimum ROOF U-Value for Zone 5 according to the **Thermal Regulation**				0,33 W/m2K

Figure 6: Calculation of the Thermal Transmittance of the study case's envelope. Source: Own elaboration.

3.2 Average temperatures in Chilean dwellings

In 2007-2008, the Chilean National Commission of Energy (CNE) and the German Agency for Technical Cooperation (GTZ) developed a study to determine the energy efficiency and hygrothermal comfort baseline of the residential sector, related to the conditioning of dwellings.

Information for the study was mainly collected from in situ surveys and measurements and considered 400 dwellings from five different regions and climates. The study defines the following ranges of hygrothermal comfort: 20°c to 26°c for 20% RH; and 20°c to 24°c for 80% RH.

Results from that study reveal, for the total winter universe, an average indoor temperature of 15.7°c. 44% of the sample registered average indoor temperatures below 15°c; 9% registered temperatures above 20°c and 67% registered 15°c or less. 91% of the sample registers 20°c or less (Fig.7).

Figure 7:
Winter Results (Indoor Temperature)

Average sample	15.7°c
44%	<15°c
9%	>20°c
67%	<15°c
90%	<20°c

Figure 7: Winter indoor temperatures in Chilean dwellings. Own elaboration with data from GTZ and the Chilean National Commission of Energy

In summer, the total universe shows an average indoor temperature of 26.4ºC. 22.4% above 30ºC and 40.5% in the range from 25ºC to 30ºC. 37.1% of registered temperatures are below 25ºC and are considered acceptable (Fig.8).

Figure 8:
Summer Results (Indoor temperature)

Average sample	26,4°c
22.4%	>30°c
40.5%	25°c – 30°c
37.1%	<25°c

Figure 8: Summer indoor temperatures in Chilean dwellings. Own elaboration with data from GTZ and the Chilean National Commission of Energy

In winter, 90% of the measured dwellings registered indoor temperatures below the range of comfort established by the study and in summer, 62.9% of the measured dwellings registered higher indoor temperatures than those defined as acceptable according to the ranges established by the study. This means that in terms of hygrothermal comfort, most Chilean dwellings provide indoor environments that are *too cold* for winter and *too warm* for summer.

3.3 Adapted Comfort Climograph

The third parameter of comparison is Neila's *Adapted Comfort Climograph*. This climograph integrates air temperature values, relative humidity, clothing, and metabolic activity to identify recommendations for architectural design that favor the feeling of hygrothermal comfort in a given climate.

In this climograph, the *comfort area* is progressive, and approaching it implies a more "pleasurable" feeling in personal order and an increase in the percentage of individuals who feel comfortable in a collective order. To alleviate the edge effect, the extended comfort areas are created in the bordering areas and are defined as those where at least 80% of the people would feel "comfortable".

To build Neila's adapted comfort climograph for the study case's climate, temperature and humidity data were obtained from the Caspana Agrometeorological Station.

Figure 9:
Adapted Comfort Climograph for Caspana

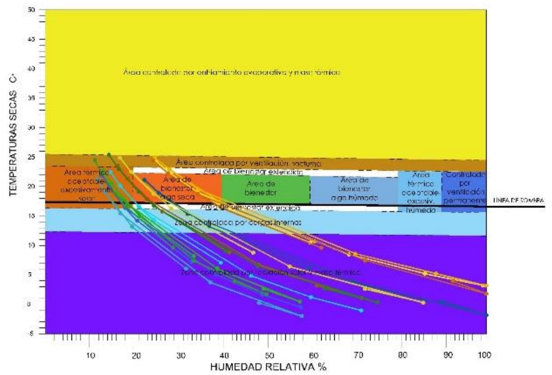


Figure 9: Adapted Comfort Climograph for Caspana. Source: Own elaboration, based on the Caspana Agrometeorological Station's database

The climograph shows that during summer, autumn, and the end of spring, daytime temperatures are within the extended comfort range, sometimes dry or excessively dry, but acceptable. In the same period at night, the temperature drops to considerably colder areas that can be controlled by internal loads. In winter and early spring months, daytime and nighttime temperatures are within this area, descending even to extreme cold areas where the need for solar radiation and thermal mass is needed.

For this climate, the extended comfort range is defined by temperatures between 16.4°c and 25.5°c and 20% to 80% relative humidity (Fig.9).

4. RESULTS

The fieldwork is carried out during the rainy season (January and February). The daily climate pattern shows a clear sunrise and rising temperatures towards 15.00 HS. In the afternoon, clouds cover the sky, and thunder is heard over the mountains. In a three-hour lapse, rain starts falling until late at night. Data recorded describes day #1 as follows: *at 8.00 HS the sky is clear with 12 °c and 60% RH. The temperature gradually increases until 15.00 HS, when 26.5 °c is registered and the relative humidity has fallen to 30%. At this time, the maximum temperature of the day has been reached and thunder sounds over the hills. At 16.00 HS, a 4 m/s wind raises, and temperature drops. At 18.00 HS heavy rain starts falling until 21.00 HS.*

Figure 10:
Indoor and Outdoor Temperatures in the Case Study

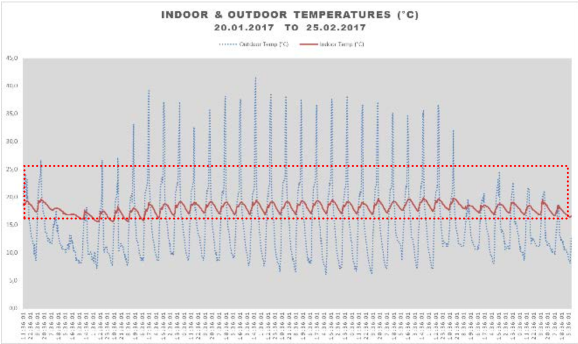


Figure 10: Indoor and outdoor temperatures from Jan 20th to Feb 25th, 2017. Source: Own elaboration

During the fieldwork, the highest outdoor temperature is 41.6°c / 6% RH. On that day, the thermal oscillation registers 34°c. The lowest outdoor temperature registered is 6.1°c / 62% RH. On this day, the thermal oscillation registers 32°c.

The highest indoor temperature registered during the fieldwork is 19.9°c / 51% RH. On that day, the indoor thermal oscillation registers 2.4°c. The lowest indoor temperature is 14.1°c /79% RH and the indoor thermal oscillation registers 2.8°c. (Fig.10)

Figure 11:
Indoor and Outdoor temperature and humidity measurements.

Outdoor				Indoor			
Temp. (°c)		RH (%)		Temp. (°c)		RH (%)	
Max	Min	Max	Min	Max	Min	Max	Min
41.6	6.1	97	6	19.9	14.1	82	42

Figure 11: Indoor and outdoor temperatures from Jan 20th to Feb 25th, 2017. Source: Own elaboration

For the complete period, the outdoor temperature oscillation reaches 38.5°c whereas the indoor oscillation reaches only 5.8°c. The average indoor temperature registers at 17.7°c (Fig. 11).

5. CONCLUSIONS

A comparison between the thermal transmittance of the building envelope and the Chilean Thermal Regulation shows that the double liparite stone wall and the straw and mud roof exchange energy with the environment at a slower pace than is required by this regulation for this climate zone. This could indicate a better performance of this traditional architecture from a material and constructive point of view.

A comparison between field results and the GTZ baseline study suggests that the case study has a higher average indoor temperature (17.7°c) than the average Chilean dwellings in winter (15.7°c) and a lower one in summer (26.4°c). In both cases, winter and summer, the study case's indoor temperatures lay closer to the comfort range set by that study than the average Chilean dwellings.

A comparison between the registered indoor temperatures and those set as comfortable by Neila's climograph for Caspana (16.4°c - 25.5°c) shows that 95% of the time, the indoor temperatures were registered as "comfortable". Only 5% of the time they proved to be "colder than" comfortable and at no time were they "warmer than" comfortable.

The stability of the indoor temperatures registered in the study case during the fieldwork could be due to the high thermal inertia of the masonry envelope that contributes to the delay of energy transmission. However, a thermal conductivity test applied to a liparite stone sample allowed us to conclude that this construction material also contributes to thermal insulation, most likely because of its 30% porosity (0,426 W/m*K).

Figure 12:
Thermal conductivity test on a liparite stone sample

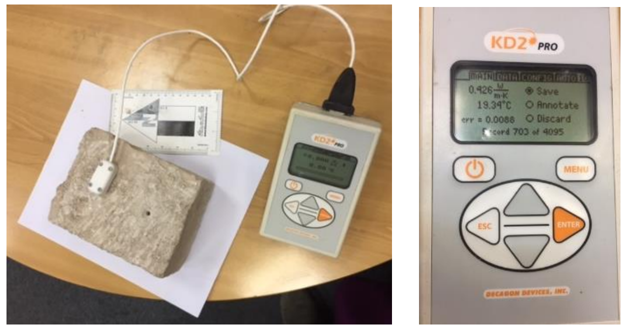


Figure 12: Results of a thermal conductivity test on a Liparite stone sample. Source: CEGA (Centre of Excellence in Geothermal Energy in the Andes, 2018)

Today, houses in Caspana are built with concrete blocks and zinc roofs (Fig.14). They not only interrupt the continuity with the landscape and the local architecture (Fig.13) but also provide poorer habitats in terms of energy use and thermal comfort. This implies an important challenge for public policies in areas of cultural heritage, given that the built-up landscape is rapidly changing while decreasing the habitability of its interior spaces

Evaluating the hygrothermal performance of both, contemporary and traditional architecture, can collaborate to appraise the present-day significance of indigenous likan antai dwellings and contribute to preservation in areas of high material and cultural patrimony like the Andean Highlands. The collection of empirical data can help focus public policies regarding construction and housing improvement plans in areas of high cultural heritage, emphasizing its ancestral values and preserving the typologies that make the place unique and unrepeatable.

Figure 13:
Traditional Dwellings in Caspana

Figure 13: Traditional dwellings in Caspana. Source: Archive of the author.

Figure 14:
Contemporary Dwellings in Caspana

Figure 14: Contemporary dwellings in Caspana. Source: Archive of the author.

6. REFERENCES

1. GTZ (2008). Determinación de Línea Base Anual para la Evaluación de la Inversión en Eficiencia Energética en el Sector Residencial Invierno 2007 - Verano 2008. Proyecto Fomento de la Eficiencia Energética (CNE / GTZ).
2. Neila, J. (2004) Arquitectura bioclimática en un entorno sostenible. Ed Munilla Leria. Madrid.
3. Rapoport, A. (1972). Vivienda y Cultura. Gustavo Gili. Barcelona.
4. Jorquera, N. (2013). El patrimonio vernacular, fuente de saberes tecnológicos y de sostenibilidad. In Cordero, E. (editor) Taller Sur. Ediciones Universidad Austral de Chile, Valdivia 175-184
5. Nelia, J & Acha, C. (2012). Bienestar Higrotérmico. Acondicionamiento Ambiental y Habitabilidad en Arquitectura. García Maroto Editores. Madrid.
6. National Institute of Normalization (2007). NCH 853 Acondicionamiento Térmico – Envolvente Térmica de Edificios – Cálculo de resistencias y transmitancias térmicas. Santiago de Chile.
7. Ministry of Housing and Urbanism (2000) Article 4.1.10 Thermal Regulation. In General Town Planning and Constructions Ordinance. Santiago de Chile.

Replacement Infill Panels for Historic Timber-Framed Buildings

Measured and simulated hygrothermal behaviour

CHRISTOPHER J WHITMAN[1], ORIEL PRIZEMAN[1], PETE WALKER[2], SOKI RHEE-DUVERNE[3], IAIN McCAIG[4], NIGEL GERVIS[5]

[1] Welsh School of Architecture, Cardiff University
[2] University of Bath
[3] Historic England
[4] Formerly of Historic England
[5] Ty Mawr Lime Ltd

ABSTRACT: The historic built environment has a fundamental role to play in the future of our cities. It has been recognised to be instrumental in achieving social, economic, environmental, and cultural sustainability. However, operational carbon emissions must be reduced, and further research is required to achieve this. This paper presents the ongoing research by the authors, evaluating the energy retrofit of historic timber-framed buildings in the UK. The paper focuses on a funded research project where monitoring of replacement infill panels under real climatic conditions, and digital dynamic hygrothermal modelling, are utilised to determine the thermal performance of four infill materials, the hygrothermal conditions within and around the panels, and assess associated risk to the historic timber frame from moisture accumulation. The four materials monitored are traditional wattle-and-daub, expanded cork board, a composite detail of woodwool and wood fibre boards, and hempcrete. The results show wood fibre as the most susceptible to moisture accumulation. The use of impermeable perimeter sealants should be questioned; however, this requires further research. The results from simulations corroborated these main findings, however interstitial condensation was predicted at the inner face of the wood fibre insulation, which to date has not been measured. The monitoring is ongoing.

KEYWORDS: Heritage Retrofit, Hygrothermal Monitoring, Hygrothermal Simulation, Timber-Frame

1. INTRODUCTION

In the face of the current climate emergency, we are challenged to rethink the design of our cities and how we inhabit them. In the majority of cases the historic built environment constitutes a valuable component of our existing urban fabric. Its role has been recognised as fundamental in achieving social, economic, environmental, and cultural sustainability. It does this through the creation of social cohesion (CHCfE Consortium, 2015), and the strengthening of citizenship (United Nations, 2017). It forms the basis for vibrant, inclusive urban economies (ibid.), whilst at the same time it has been shown to promote wellbeing (Fujiwara et al., 2014). The continuing use of its embodied carbon reduces further carbon emissions that would otherwise result from new construction (Historic England, 2020), however, its operational carbon emissions must be reduced along with those of the rest of our existing building stock (IPCC, 2018). Given the technical and philosophical complexities of retrofitting heritage buildings and those of traditional construction, it has been identified that further research is required (OJEU, 2018). This paper focuses on the currently under-researched area of the energy retrofit of historic timber-framed buildings in the UK. The paper will begin by outlining this building typology and the opportunities and challenges faced when aiming to improve its energy efficiency. It will then introduce the methodology and results for a specific experiment that has been undertaken to examine the performance and associated risks of four potential replacement infill panels. Measurements from the physical monitoring are compared to the results of digital dynamic hygrothermal simulation.

2. HISTORIC UK TIMBER-FRAMED BUILDINGS

Timber-framed buildings hold a special place in the cultural identity of the UK and more specifically England (Ballantyne & Law, 2011). With their structural frame commonly exposed both internally and externally (fig.1), these buildings have become synonymous with "Olde England" and as such have been emulated around the world (ibid.). The exposed frame was most commonly traditionally infilled with wattle-and-daub (earthen render on a woven timber lattice), although other historic infill materials such as lath and plaster, brickwork, and stone can be found (Harris, 2010). Today there are approximately 68,000 nationally designated heritage assets, built before 1850, of this typology (Whitman, 2017). Of these, 70% are dwellings and a further 14% are in use as commercial premises (ibid.). As such, the need to reduce their energy demand and increase internal hygrothermal comfort is critical.

Figure 1:
C15 timber-framed building, Lavenham, UK, showing exposed structural frame. (Lead Author, 2017)

2.1 Retrofit of historic timber-framed buildings

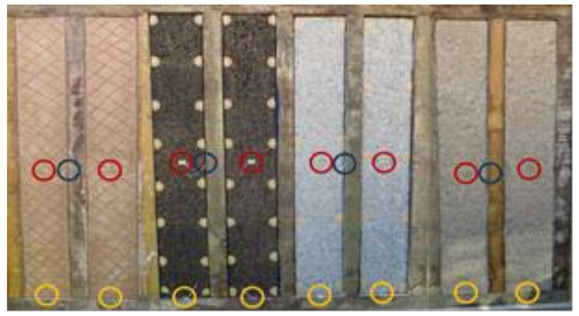
Given that the exposed frame (fig.1) is a defining part of these building's aesthetic heritage value, the energy retrofit options for their walls are limited. Nevertheless, where the historic infill panels are beyond repair, or have already been replaced, an infill material with a higher thermal resistance may be retrofitted (Oxley, 2010). However, changes to the hygrothermal performance of the infill panel may affect that of the surrounding historic fabric, raising the risk of interstitial condensation, moisture accumulation and the creation of conditions ideal for fungal decay and insect infestation. The junction between the infill material and the exposed frame presents a particular challenge in achieving airtightness and preventing water ingress. Consideration of the design of this detail, in conjunction with experienced workmanship is therefore critical to the success of the whole intervention.

3. METHODOLOGY

The research presented in this paper builds on previous research by the authors (Whitman et al., 2018, Whitman et al., 2020). To address the difficulties of undertaking *in situ* monitoring within historic walls at case study properties, and the limitations of laboratory testing, the decision was taken to monitor physical test panels exposed to real climatic conditions over an extended period (a minimum of 18 months). The panels were mounted in the north façade of a test cell located in Cardiff, Wales, UK, with the external face of the panels exposed to the Cardiff climate, and the internal environment heated (21°C) and humidified (≥60%) during the UK heating season (Nov.-Mar.). Outside of these dates, the internal conditions were free running, replicating the reality in most UK homes. The external climate (temp. (°C), RH (%), precipitation (mm), air pressure (mbar), wind speed (m/s) and wind direction) was measured using a Vaisala WXT520 mounted on the roof of the test cell. Following the failure of the integrated electronic rain gauge early in the project, this was replaced after two months with a 52202 tipping bucket rain gauge manufactured by R.M. Young. Direct solar radiation (W/m2) incident on the panels was measured using a Kipp and Zohnen® CM5 pyrometer, and the internal temperature (°C) and RH (%) of the cell with a Campbell Scientific® CS215. All sensors were wired to a Campbell Scientific® CR1000 data logger.

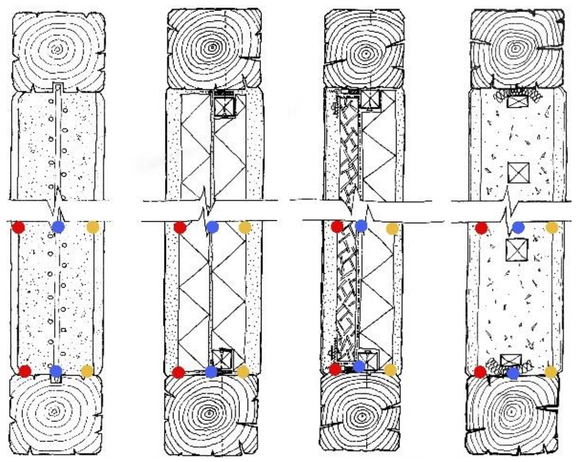
The dimensions of the panels were defined by a review of 100 historic timber-framed buildings, resulting in a typical panel size of 305 mm wide by 1830 mm high. Four different infill materials monitored were monitored (fig 2), wattle-and-daub, expanded cork board, a composite detail of woodwool and wood fibre boards (McCaig & Ridout, 2012), and hempcrete (Stanwix & Sparrow, 2014). Pairs of panels were constructed within reclaimed oak frames, with one of each finished in a render based on Natural Hydraulic Lime (NHL) 3.5 and the other in a non-hydraulic lime render with hemp shives as an aggregate (lime-hemp).

Figure 2:
Test panels prior to application of external render. Infill materials Left to right- wattle and daub, cork, wood fibre/wood wool, and hempcrete. Monitoring positions highlighted, red- centre panel, blue- vertical frame/panel junction, and yellow-horizontal frame-panel junction (Lead Author, 2019)



The thermal performance of the panels was assessed January-March 2020, and repeated November 2020-January 2021 and again November 2021-February 2022. This was undertaken using *in situ* U-value measurements according to BS ISO 9869-1:2014. Thermography following best practice guidelines (Young, 2015) was also undertaken on the 19th February 2020 and the 19th November 2020 both at 07:00, 30 minutes prior to sunrise to minimise the impact of direct solar radiation on the façade and maximise the internal/external temperature difference. Interstitial hygrothermal conditions were monitored continuously from December 2019 to December 2021 using Type T thermocouples (°C) and electrical resistance for moisture content (%). The monitoring positions as highlighted in figure 2 were located at the centre of each panel, at the horizontal junction at the base of each panel, and halfway up the vertical junction of the panels finished in NHL3.5 based render. At each position, sensors were placed at three depths (fig 3): between the internal plaster and insulation, at mid-depth, and between the insulation and external render. The sensors were wired back to the CR1000 data logger, with measurements at 30-minute intervals.

Figure 3:
Sections showing panel infill details and monitoring locations. Materials left to right- wattle and daub, cork, wood fibre/ wood wool and hempcrete. Monitoring locations Red- external (e), Blue- central (c), and Yellow- internal (i).



Following 18 months of monitoring, the measured climatic data was used to undertake dynamic hygrothermal simulations using WUFI® Pro 5.3 software and the measured and simulated results compared. Analysis of the material databases pre-existing within WUFI® Pro 5.3 (Fraunhofer Institute, 2013) was undertaken to assist with the selection of materials assigned to the components in the simulation. However, it should be noted that only in the case of the wood fibre insultation was this a precise match for the material, manufacturer, and product of the physical construction. For all other components a closest match was chosen. This was based only on limited material property data for the real materials. Additional funding is currently being sought to undertake detailed material characterisation of all materials used in the physical test panels to further improve this element of the research.

4. RESULTS

4.1 Thermal Performance

The *in situ* U-value measurements of the 103mm thick panels are presented in table 1. These show that the cork infill achieves the best thermal performance with an average U-value of 0.52W/m²K for the panels finished in the NHL 3.5 based render and 0.47W/m²K for the lime-hemp render. The worst thermal performance is seen from the wattle-and-daub with averages of 2.84W/m²K (NHL 3.5) and 2.19W/m²K (lime-hemp). Overall, the use of the lime-hemp render achieves an average 10% improvement in U-value.

Table 1. *U-values of test panel measured at centre of each 103mm thick panel according to BS ISO 9869-1:2014. For the periods Jan.-Mar. 2020 (A), Nov. 2020 – Jan. 2021 (B) and Nov. 2021-Feb 2022 (C) and average (Av.)*

Infill Material	Plaster	U-Value (W/m²K)			
		A	B	C	Av.
Wattle & Daub	NHL	2.92	2.95	2.65	2.84
	LH	2.21	2.39	1.96	2.19
Cork	NHL	0.54	0.50	0.52	0.52
	LH	0.46	0.47	0.48	0.47
Wood fibre	NHL	0.71	0.63	0.64	0.66
	LH	0.66	0.66	0.74	0.69
Hempcrete	NHL	1.56	0.94	1.12	1.21
	LH	1.22	0.99	1.39	1.20

NHL- Natural Hydraulic Lime 3.5 and LH-Lime-hemp

It had been hoped to see an improvement in the thermal performance of all panels, especially those with wet applied infill materials (wattle and daub, and hempcrete), as the panels dried out. There was however only a minimal difference in moisture content within the panels (>2%) between each of the three rounds of U-value measurements due to climatic conditions. The Hempcrete panels show an improvement in thermal performance over the first year despite displaying similar moisture contents, however this improvement is reversed by the time of the final U-value being measured. None of the U-values for this material meet the U-values of 0.67W/M²K (NHL) and 0.58W/M²K (LH) predicted based on literature for this construction technique.

Thermography (fig 4 and fig 5) undertaken in the conditions as noted in table 2, verified the results of the *in situ* U-value measurements.

Table 2: *Dates and conditions of thermography*

Date	Time	Int. Temp. (°C)	Ext. Temp. (°C)
19/02/20	07:00	20.6	3.7
19/11/20	07:00	20.5	8.7
Difference		-0.1	+5.0

Figure 4*:*
External thermography 07:00, 19/02/20. Internal temp. 20.6°C. External temp. 3.7°C. NHL- Natural Hydraulic Lime 3.5 and LH-Lime-hemp

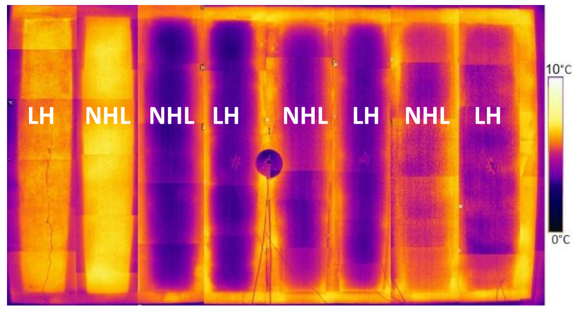
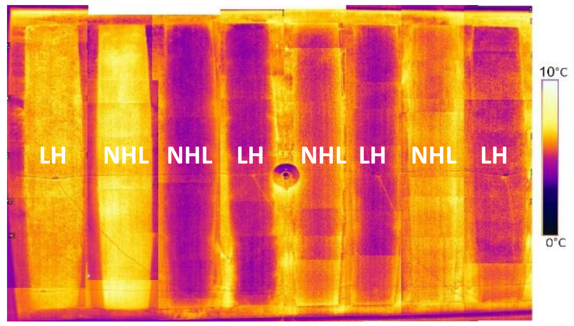


Figure 5:
External thermography 07:00, 19/11/20. Internal temp. 20.5°C. External temp. 8.7°C



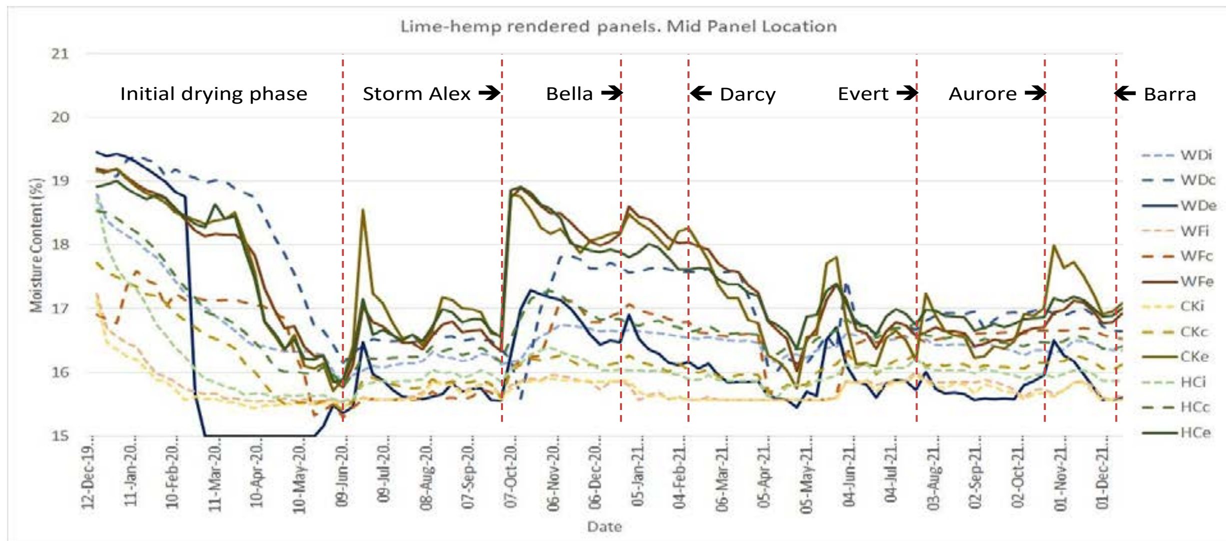
4.2 Moisture Content

The moisture content monitoring showed an initial drying period of approximately six months following construction for most monitoring positions. However, for the monitoring positions at the horizontal junction between infill and timber frame, those materials finished in lime-hemp render dried two months earlier than those finished in the NHL 3.5 based render.

This difference in drying times may be explained by the greater moisture permeability of the lime-hemp plaster. However, this would not explain why this was only detected at the horizontal junction and not at any other monitoring position. At all other positions no discernible difference in drying times was noted between panels finished with the two different renders.

These initial drying periods were then followed by a series of wetting and drying cycles (fig 6). As these cycles correspond exactly to climatic conditions, principally related to wind-driven rain during named storm events, it can be concluded that no evidence of interstitial condensation has been measured to date. Over the 18 months of monitoring a total of six named storm events took place, each with a varying degree of impact on the moisture content of the panels and timber frame. The largest impact was experienced following Storm Alex during which the wettest day since records began in 1891 was recorded in the UK (Met Office, 2020). It should be noted that at the time of the design of this experiment the frequency and intensity of these storm events was not foreseen. Although not a planned objective, the results have demonstrated the impact of such storms on the moisture content of timber-framed building elements. Climate change predictions anticipate an increase in major storms (IPCC, 2018) and as such further research is recommended into the implications of this for timber heritage in the UK and beyond.

Figure 6:
Moisture Content Measurements 12/12/2019 – 22/01/2021. (WD-Wattle & Daub, WF-Wood Fibre, CK-Cork, HC-Hempcrete. i-internal, c-centre, e-external.) Showing major increases in moisture related to storm events.



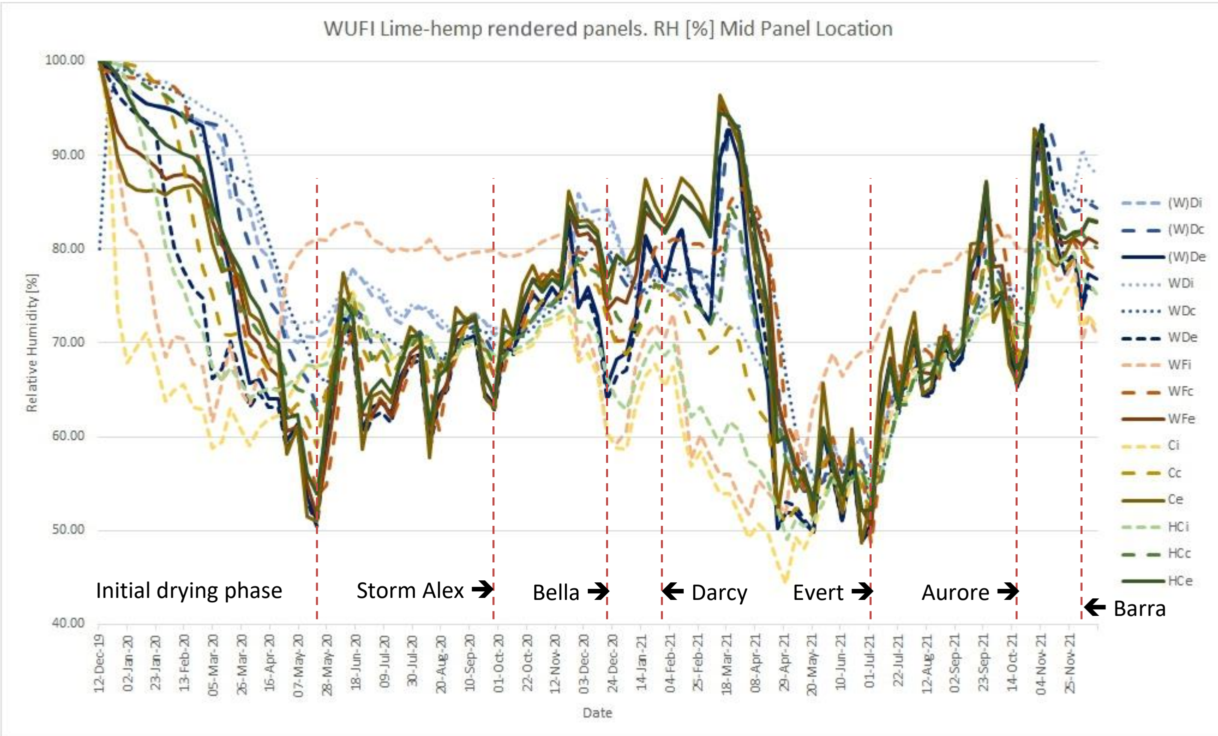
As a consequence of Storm Alex, the results from the monitoring positions at the horizontal junction between infill panel and timber frame showed a rapid increase in moisture content within the wood fibre/wood wool panels, both for those finished in the lime-hemp render and the render based on NHL 3.5. The highest moisture content was recorded at the mid-depth of these panels at this junction, with this exceeding 20% for three months and remaining over 18% for over a year. A lesser increase was also seen at the same time in the moisture content at the vertical junction for the cork infill panels, however this remained over 18% for only four months. For both these infill materials (wood fibre/wood wool, and cork) the recommended installation detail included an impermeable sealant around the perimeter. This would potentially appear to trap moisture entering the joint through capillary action. Further investigation of this is required.

4.3 Digital dynamic hygrothermal simulation

The results of the WUFI® Pro 5.3 simulations were plotted and compared with those measured. As the software package does not generate moisture content for specific monitoring positions, only for material layers, relative humidity (RH%) has been plotted as a proxy. Whilst this does not allow direct numerical comparison, it does allow profiles to be compared (fig 7.). In general, although the profiles are not exact matches, the simulations did corroborate the measured results, indicating the major changes in moisture content to result from wind-driven rain. However, they also predicted an increase in moisture content at the internal face of the wood fibre insultation which appears unrelated to any wind-driven rain, predating the first storm event. This would suggest a prediction of interstitial condensation within this construction. As previously noted, this has not been measured to date. The other notable difference between simulations and measured results is that the simulation does not demonstrate the same spread of results for the different infill materials and monitoring positions measured in reality.

WUFI® 2D simulation was attempted for the junction between the infill panels and timber frame, however the results were inconclusive and are not included in this paper.

***Figure 7**:*
Results of WUFI® Pro 5.3 simulation for Lime-Hemp rendered panels mid panel monitoring location. (WD-Wattle & Daub, WF-Wood Fibre, CK-Cork, HC- Hempcrete. i-internal, c-centre, e-external.)



5. CONCLUSION

The results show that use of cork, hempcrete and wood fibre can significantly improve the thermal performance of infill panels for historic timber-frame buildings, especially when coupled with lime-hemp finishes. Of these, the composite detail of woodwool and wood fibre boards would appear the most susceptible to moisture accumulation. The digital dynamic simulation has suggested that interstitial condensation may also be an issue for this retrofit detail, however this has as yet not been proven by the measured data.

The increase in moisture content measured at the horizontal, and to a lesser extent vertical, junctions between infill material and timber frame suggests that the use of impermeable sealants should be questioned; however, this requires further research. The role of experienced workmanship is most probably as important as the materials utilised at this critical junction, and the need for achieving airtightness is still essential for the overall thermal performance of the assembly.

The impact of wind-driven rain occurring as a result of storm events, although not anticipated, is a key finding of this research. The predicted increase in such events created by anthropogenic climate change will unfortunately create less favourable conditions for these historic buildings with or without retrofit. This is true for much of our historic built environment but may be more critical for our timber heritage. This highlights an important area for further research. Funding has recently been received for a further two years of monitoring and the authors continue to work on pursuing other related investigations.

ACKNOWLEDGEMENTS

The research covered in this paper has been made possible by Historic England funding. The authors also wish to thank Royston Davies Conservation Builders for the construction of the test cell, Hempcrete UK for the materials and construction of the hempcrete panels and Ty Mawr Lime Ltd for most of the other materials.

REFERENCES

Ballantyne, A., & Law, A. (2011). Tudoresque and the Self-Reliant Englishman. In P. Guillery (Ed.), *Built from below : British architecture and the vernacular*. Routledge.

CHCfE Consortium. (2015). *Cultural heritage counts for Europe. Full report*. https://www.europanostra.org/our-work/policy/cultural-heritage-counts-europe/

Fraunhofer Institute. (2013). *WUFI Pro 5.3*.

Fujiwara, D., Cornwall, T., & Dolan, P. (2014). Heritage and wellbeing. *Historic England*.

Harris, R. (2010). *Discovering Timber-Framed Buildings* (3rd ed.). Shire Publications.

Historic England. (2020). *Heritage Counts: There's no place like old homes. Re-use and Recycle to Reduce Carbon*. https://historicengland.org.uk/research/heritage-counts/2019-carbon-in-built-environment/carbon-in-built-historic-environment/

IPCC. (2018). *Global Warming of 1.5 ºC*. https://www.ipcc.ch/sr15/

McCaig, I., & Ridout, B. (2012). *English Heritage practical building conservation- Timber*. English Heritage ; Ashgate.

Met Office. (2020). *Record Breaking Rainfall for October* https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2020/mid-october-statistics

OJEU. (2018). *Directive (EU) 2018/844 of the European Parliment and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency* (L156/75). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN

Oxley, P. (2010). *Insulating timber-framed walls* (D. Pickles, I. Brocklebank, & C. Wood, Eds.). English Heritage. http://www.climatechangeandyourhome.org.uk/live/content_pdfs/781.pdf

Stanwix, W., & Sparrow, A. (2014). *The Hempcrete Book Designing and Building with Hemp-Lime*. UIT Cambridge Ltd. http://public.eblib.com/choice/PublicFullRecord.aspx?p=1811266

United Nations. (2017). *New Urban Agenda*.

Whitman, C. J. (2017). *The distribution of historic timber-framed buildings in the UK and the impacts of their low energy retrofit* Cardiff University].

Whitman, C. J., Prizeman, O., Gwilliam, J. & Walker, P. (2018) The impact of modernization of a 16th century timber-framed farmhouse, Suffolk, UK. The 3rd International Conference on Energy Efficiency in Historic Buildings (EEHB2018), Visby, Sweden, September 26th to 27th, 2018. Uppsala University, 182-190.

Whitman, C. J., Prizeman, O., Gwilliam, J., Shea, A. & Walker, P. (2020). Energy retrofit infill panels for historic timber-framed buildings in the UK: physical test panel monitoring versus hygrothermal simulation. Architectural Science Review, 1-12.

Young, M. (2015). *Thermal Imaging in the Historic Environment* (Short Guide, Issue. https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=088dab34-1194-43e6-af5e-a62801090992

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 01
16:00 — 17:30

CHAIR
FLORENCIA COLLO

PAPERS
1352 / 1112 / 1633 / 1139 / 1111

15TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Innovative transparent and translucent materials on façades

Non-visual effects of light

JOAO FRANCISCO WALTER COSTA[1] CLAUDIA NAVES DAVID AMORIM [1]

[1] Faculty of Architecture and Urbanism, University of Brasilia

ABSTRACT: Windows are responsible for important attributes related to the user's well-being, such as the presence of daylight and view to the outside, with visual and non-visual effects. The circadian cycle can be defined as our biological clock, which can be stimulated with the light intensity and less intensely with the spectrum. In this context, innovative materials, such as electrochromic glazing and microstructured optical components can help maximize daylight in the built environment and at the same time can filter unwanted solar radiation, protecting users from glare. From the present studies it is still unclear how the employment of these materials on facades affects non-visual effects. Therefore, the aim of the study is to give an overview of the non-visual effects of these materials on users in non-residential buildings. The method consisted of a literature review and its systematization of documents, metrics and available methods to evaluate how the employment of the electrochromic glazing and microstructured components can affect non-visual effects. It was concluded that these two materials have the potential to balance visual comfort and at the same time provide daylight. Yet it is important to extend these studies, particularly to warmer climates.
KEYWORDS: Light, non-Visual effects, electrochromic glazing; microstructured optical components.

1. INTRODUCTION

Windows, whose main component is the glass, are responsible for important attributes related to the user's well-being, such as the presence of natural light and view to the outside, with visual and non-visual effects, related to the circadian cycle [1].

According to Houser *et al*. (2021) [2] the human centric lighting is the solution for an integrated thinking about light and lighting as mediators of visual, biological and behavioral responses in humans. Some are immediate such as pupil dilation and glare perception, while others, such as mood, psychological and physiological can be delayed for hours or may not be evident for years. The circadian rhythm can be defined as our biological clock, which can be stimulated with the light intensity and less intensely with the spectrum. Design professionals are attempting to integrate this knowledge in a manner that affects people most directly, and building owners look primarily to design professionals for guidance about light and health.

Vetter *et al*. (2021) [3] summarized the physiological effects of light on human health and well-being, including a description of the processes underlying the photic regulation of the circadian rhythm. They concluded that integrative solutions that have biologically high potency light during the day and low potency during the night is perhaps the most immediate improvement to be made in order to better support applications for humans. It is also important to emphasize that daylight exposure is crucial for resetting the circadian clock.

In this context, innovative materials, such as smart windows and light redirection systems can help maximize daylight in the built environment and at the same time can filter the unwanted solar radiation, protecting users from glare [4], [5]. Smart windows are those that present the phase change property - which, in light of the luminous comfort, is the characteristic of controlling the light transmittance (LT) [6]. The Daylight Redirecting Systems are defined by those which conduct the natural light in an efficient way, guiding it deeper and with a more uniformity within two times the height of the window above the floor, against 1.5 from a conventional window [4].

Costa and Amorim (2021) [7] gave an overview of these innovative materials through the discussion of 31 academic documents including studies in Brazil. They verified through a literature review that the electrochromic glazing has a wide range to control the light transmission – from 60% to 1%. Moreover, the use of microstructured optical components allows an increased area of natural light due to its deeper penetration in the indoor environment. Nevertheless, it is important to point out that there are few studies about these systems in Brazil. From these studies mentioned it is still unclear how the employment of these materials on the facades affects the users' circadian rhythm. The investigation of these materials focused on the non-visual effects of light is the object of an ongoing doctoral thesis.

The aim of the study is to give an overview of the non-visual effects on users in non-residential buildings. The intention is to understand the metrics and calculation methods of the non-visual effects of light and how the employment of the electrochromic and microstructured optical components can affect the circadian lighting.

2. METHOD

The method consisted of a systematic literature review [8]. It consisted of four sets of searches. We wanted to know the scientific production of the last six years, between 2017 and 2022. The search was conducted in Google Scholar, Science Direct and Scopus. The first set of searches was carried out to reinforce the understanding about the theme. Then, the following keywords were inserted: *Daylight; non-visual effects of light; building; cognitive function* and *productivity; metrics*. This first set was to understand the metrics and calculation methods of the non-visual effects of light. These inserted keywords were based on the papers of Vetter *et al*. (2021) [3] and Boubekri *et al*. (2020) [3], [9]. Then the second set of searches was carried out with the same keywords as the first set, with the addition of the term "innovative glazing". In total, 2,068 results appeared. So in effect, a refinement was needed and two more sets of searches were carried out.

In the third set the following keywords were inserted: *daylight, electrochromic glazing* and *circadian*. After that 271 results appeared. In the fourth set of search the inserted keywords were *daylight, microstructured sunlight redirection, circadian*. This set had 38 results.

In total, 2,377 results were found corresponding to the mentioned keywords of the four sets of searches. As a consequence, filters and elimination criteria were added to refine the research. The first filter was carried out selecting the journals with a minimum impact factor, which had to be greater or equal to 2 and 0.292, according to Clarivate Analytics and Scientific Journal Rankings respectively.[1]

Simultaneously with this, the filter option "sort by relevance" was chosen, exhibiting the most cited or searched documents already on the first pages of the databases. The abstracts were read only when the title was related to the research's theme. These filters and criteria of elimination significantly reduced the number of selected documents, from 2,377 to 37 documents, as described in Table 1.

Table 1: *sets of searches and number of selected documents*

Set	Keywords	Results	Selected documents
1	Daylight; non-visual effects of light; building; cognitive function and productivity, metrics	1,600	17
2	Daylight; non-visual effects of light; building; cognitive function and productivity, metrics, innovative glazing	468	5
3	Daylight; electrochromic glazing; circadian	271	6
4	Daylight, microstructured sunlight redirection, circadian	38	9
	Total	**2,377**	**37**

[1] More details at: https://www.scimagojr.com/journalrank.php and https://clarivate.com/webofsciencegroup/essays/impact-factor/ . [8 March 2022].

The selected papers, which were entirely read, followed the criteria defined by Dresch, Lacerda and Junior (2015, p. 189) [10] related to the quality of the study's execution, the adequacy to the question and the focus of the review as described in Table 2. After the evaluation of these three dimensions, articles and documents which met the quality criteria "high" and "average" were selected for the discussion.

Table 2: *Criteria for assessing the quality dimensions of the primary studies*

Dimension	Quality of the study's execution	Adequacy to the question	Adequacy to the focus of the review
High	The study meets the required standards for the review	The study addresses exactly the subject of the systematic review	The study was carried out in an identical context as defined for the review
Average	The study has gaps in relation to the standards required for the review	The study partially addresses the subject of the systematic review	The study was carried out in a similar context as defined for the review
Low	The study does not meet the standards required for the review	The study only touches the subject of the systematic review	The study was carried out in a different context as defined for the review

Source: Adapted from Dresch, Lacerda and Junior, 2015, p. 192 – 193.

Then, from the 37 selected documents, 21 were entirely read, including 17 articles published in academic journals, 1 CIE International Standard, and 3 reports, which are part of the grey literature from IEA (2016; 2021) and LUCAS *et al*. (2013) [5], [11], [12].[2] After that, we identified what was the main

[2] These reports are part of the grey literature, defined by "what is produced in all government levels, academia,

contribution of each study and highlighted the gaps – non-discussed topics. We chose the articles which were entirely related to the description of the metrics and quantification of the non-visual effects of light. Regarding the innovative glazing materials, documents and articles describing the relationship between the electrochromic glazing and microstructured optical components, and the non-visual effects of light were picked for discussion.

3. RESULTS

The intention of the study was to systematize the knowledge acquired in the literature review. With this in mind, the discussion is based on what was found in the selected documents. A growing awareness has recently emerged on the health benefits of exposure to daylight and views. In this regard, windows play an important role in the users' satisfaction and there are useful methods and metrics to evaluate the non-visual effects, including the circadian stimulus [3]. In section 3.1. an overview of the non-visual effects and their quantification is described. In section 3.2. the relationship among electrochromic glazing, microstructured components and non-visual effects of light is discussed.

3.1. Non-visual effects of light and quantification

The physiological effects of light are mediated by the eye in humans. For many years, it was thought that there were only two classes of photoreceptors in the human eye: cones and rods. Nevertheless, another third photoreceptor type was discovered in the mammalian eye about two decades ago, from the present date. These photoreceptors are called ganglion cells and contain a photopigment called melanopsin and are intrinsically photosensitive to light [13]. From these moment on, many studies were directed to better understand how humans physiologically responded to light and how it could be measured.

Recent advances in photobiology have set off revolutions among both lighting researchers and the lighting industry. The physiological effects of light are mediated by the eye in humans. Light entering the eye stimulates retinal photoreceptors that convert photic information into neuronal signals, which get transmitted via ganglion cells to various regions in the brain, including the *Thalamus* and *Hypothalamus*, which regulate our biological clock. In a more detailed explanation, the intrinsically photosensitive retinal ganglion cells (ipRGCs) transmit environmental light information via the *retinohypothalamic tract* (RHT) to the central clock in the brain (SCN, *suprachiasmatic nuclei*). Other direct projections of ipRGCs include thalamic and other brain regions. The ipRGCs contain a photopigment called melanopsin and it is intrinsically photosensitive to light. The physical stimulus of our circadian clock is dependent on the timing, intensity and duration of the light exposure. Moreover, melanopsin is most sensitive to short-wavelength (blue) light, with a peak response around 480 nm. The short-wavelength sensitivity of the ipRGCs is, at least in part, reflected in the circadian, neuroendocrine and neurobehavioral responses to light described in humans [2], [3], [14], [15].

Figure 1 illustrates the pathways of light from the stimulus to the effects in the human body. At the top level, the temporal pattern relates the timing and duration of exposure to a light stimulus, spatial pattern refers to the spatial distribution of light in the three-dimensional light field, light spectrum refers to the spectral power distribution (SPD) that governs color qualities, and light level refers to the quantity of light in radiometric or photometric units. These four factors contribute to the biological potency of the light stimulus. The exact pathway from the light stimulus and circadian responses in humans are still unclear and under scientific investigation [16].

After the pathway was better identified from the stimulus in the eye to the physiological human responses, methods were developed to quantify non-visual stimulus of light. There are two to quantify light as non-visual stimulus and these are based on [11]:

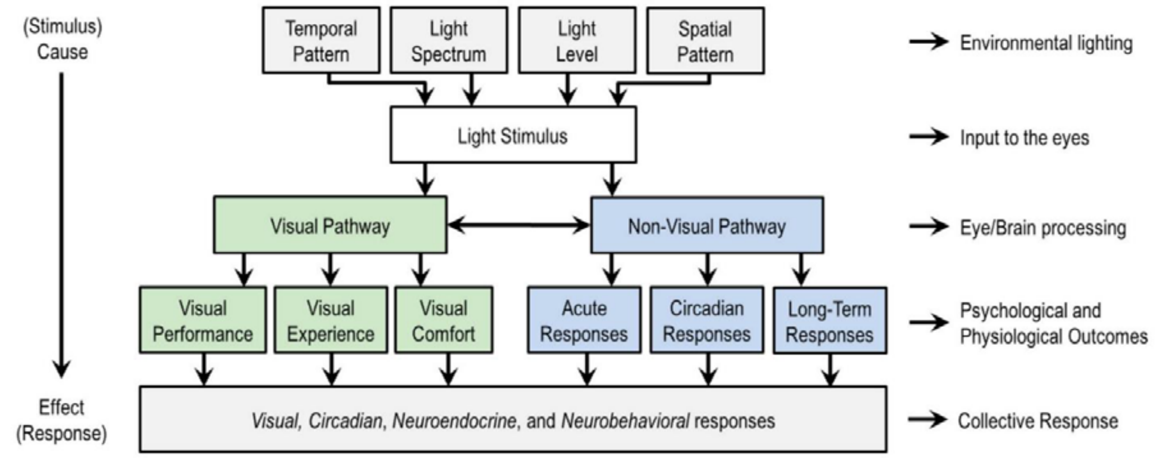
1) Spectral response of the photopigments in the rods, cones and ipRGCs
2) The nocturnal suppression of the hormone melatonin.

There are two metrics for the first method, the Equivalent Melanopic Lux (EML) introduced by Lucas *et al.* (2013) [12] and the Melanopic Equivalent Daylight Illuminance (M-EDI) proposed by CIE (2018) [17] and one tool for the second method, the circadian stimulus (CS) (REA; FIGUEIRO, 2016) [18].

CIE proposed a new quantity, the melanopic equivalent daylight illuminance (M-EDI), a new quantity that is SI compliant. The M-EDI combine the sensitivity of five photoreceptors (S cone, M cone, L cone, rhodopsin and melanopsin) with standard daylight (D65) (CIE, 2018). To calculate M-EDI the CIE has developed the "CIE S 026 α-opic toolbox", a spreadsheet in the Microsoft Excel calculator, and a user guide on how to use the toolbox, both available in the CIE website [17].

businesses groups and industry, printed or read in digital form, but is not controlled by commercial publishers" [8].

Figure 1: *Pathways of light and physiological responses in humans.*



Source: Adapted from Esposito and Houser (2021) and de Kort and Veitch (2014) [15], [16]

Units of Equivalent Melanopic Lux, EML, can be calculated by using the MS Excel workbook "Irradiance Toolbox". The toolbox provides both the photopic lux (they should be the same as measured by the illuminance meter) and the cyanopic, chloropic, erythropic, melanopic, and rhodopic lux, the first three corresponding to the three classes of cones present in the human retina, the following to the iPRGCs, and the final one to the rod photoreceptors. In the Lucas toolbox, the measured irradiance with a spectrometer is simply copy-pasted and the illuminances are calculated. For the approximate measurement with illuminance meter, the user should type the measured photopic illuminance and select the SPD from a pre-set list of light sources (e.g. incandescent, daylight, narrowband, white LED, etc.) [12].

The Circadian Stimulus (CS) can be extracted from the CS calculator, that provides a coefficient for expressing the extent to which a given light source of specific intensity and spectrum elicits circadian responses, namely the suppression of melatonin secretion. The coefficient ranges from 0 to 0.7, from no melatonin suppression (0) to maximal observed melatonin suppression (0.7), respectively. The CS Calculator is similar to the Lucas toolbox in the way, in which relative spectral power values imported from a .csv file (describing the spectral distribution of the light source) need to be introduced, or in the selection of a light source from a list with pre-set characteristics [11], [18].

The WELL building standard and Underwriters Laboratory (UL) recommend design targets for circadian lighting design. These standards are based on units of EML and Circadian Stimulus (CS). The criteria are based on the temporal pattern of light exposure (time of day and duration of exposure), light level, spectrum, and the location where the light is delivered [11], [16]. Table 3 describes the thresholds for circadian lighting design.

The issue to quantify non-visual stimulus (effects) of light was solved. On the other hand, it is not clear until to-date how the built environment influences non-visual effects in humans, particularly the configuration of the indoor spaces and the glazing materials. Xiao, Cai and Li (2021) conducted a review of 27 publications with strong relevance to theme, in which factors affecting circadian rhythm, alertness and mood were investigated. It was concluded in the review that the increase in illuminance and correlated colour temperature (CCT) at night were both positively associated with melatonin suppression, thus affecting the circadian rhythm. Additionally, high illuminance was positively correlated with alertness during daytime, increasing positive mood in the morning and decreasing it in the afternoon [14].

Alkhatatbeh and Asadi (2021) reviewed 128 papers focused on the role of architecture in creating circadian effective spaces. New buildings are better adapted to do so. However, retrofit projects can adapt some architectural and interior design features to provide circadian benefits. Easy adjustments to spaces increase the indirect component of light and boost the circadian system, such as painting surfaces with neutral colors, adding highly reflectance finishes, and adjusting the luminaires position/direction to face highly reflectance surfaces, especially the ceiling. Daylight is the best light source to provide circadian stimulation and energy efficiency [19]. In this context, the electrochromic glazing can also balance visual comfort, mitigate discomfort such as glare and provide circadian lighting [9], [20]. The following section was dedicated to discussing the application of the electrochromic glazing in two non-residential environments.

Table 3: *Thresholds for circadian lighting design.*

Standard	Temporal pattern		Lighting Quality			
	Timing of exposure	Duration of exposure	Circadian Stimulus	Equivalent Melanopic Lux (EML)	Melanopic equivalent daylight illuminance (M-EDI - Lux)	Photopic Illuminance (Lux)
Well v 2.0 Requirement for 1 point	At least between 9 a.m. and 1 p.m. Light levels must be lowered after 8 p.m.	Minimum of 4 hours	≥ 0.30 with electric light only	≥150 (if electric light only) ≥120 from electric lighting (if certain daylight criteria are met)	≥136 with electric light only ≥109 from electric lighting (if certain daylight criteria are met)	N/A
Well v. 2.0 Requirement for 3 points			N/A	≥240 (if electric light only) ≥ 180 from electric lighting (if certain daylight criteria are met)	≥218 with electric light only ≥163 from electric lighting (if certain daylight criteria are met)	N/A
UL 24480	Through the day 7 am – 4pm	Minimum of 2 hours, morning if not full period	≥ 0.30	Comply with WELL criteria listed above to achieve 1 point or 3 points	N/A	≥ 500
	3 hours before bed 5pm –7 pm	During full period	≥ 0.20		N/A	N/A
	Nighttime - sleep After 8pm		≥ 0.10		N/A	N/A

Note: All measurements are taken from the vertical plane at eye level. Source. Adapted from Ester and Esposito (2021) [16].

3.2. Electrochromic glazing and microstructured components and relationship to non-visual effects of light

Boubekri *et al*. (2020) explored the impact of optimized daylight and views on the sleep and cognitive performance of thirty office workers in Durham ID Building, in Durham, North Carolina, U.S., (35° North/78° West). They spent one week working, from Monday to Friday from 8 a.m. to 6 p.m. in each of the two office environments with identical layouts, furnishings, and orientations in November; however, one was outfitted with electrochromic glazing and the other with traditional blinds, producing lighting conditions of 40.6 and 316 equivalent melanopic lux, respectively. Participants slept 37 minutes longer and performed better in cognitive performance tests when exposed to optimized daylight and views during the day, what could be provided by the electrochromic glazing [9].

Saiedlue *et al.* (2019) carried out computer simulations in the software ALFA in a side-lit open plan office space located in Minneapolis, United States (44° North/93° West). Three glazing systems were evaluated: Double glazing and electrochromic glazing with two zones and three zones. Findings showed that the electrochromic glazing with three zones provided the best performance in creating the balance among the new metrics (i. e. Equivalent Melanopic Lux – EML and Photopic Illuminance on vertical plane at eye level) [20]. It is important to point out that these two studies considering the use of the electrochromic glazing were located in temperate climates within the United States with a limited time period, from one to seven days in November and March.

No academic paper was found about the utilization of microstructured components related to the non-visual effects of light. Yet, this system has a great potential to increase daylight in indoor environments [21]. Jakubowsky and Boer (2022) carried out illuminance measurements in two test rooms in Stuttgart, Germany (48° N/9° E), one equipped with the microstructured components and the other with conventional triple-plane glazing (reference room). Overall, measurement data were collected on 42 measurement days in the period from May 31 to September 23, 2018. On average over the measurement days, an energy saving of 58% was achieved compared to the reference room. This can be seen very clearly on sunny days. Over selected sunny measurement days, the average energy consumption for the reference room was 2.5 kWh with a relative luminous exposure of 13%. In the test room, an energy consumption of 1.2 kWh and relative luminous exposure of 69% were determined [22].

4. CONCLUSION

Since the discovery of a third photoreceptor in the human eye, the ipRGCs, studies were directed on improving the understanding of the physiological effects of light in humans. From 2013 onwards tools and metrics have been developed to quantify non-visual effects of light in the built environment. It was discovered that blue light and high CCT light at night induced delayed phase shift, and the objective alertness was reduced under the condition of lack of blue components. Additionally, high illuminance was positively correlated with alertness during daytime, increasing positive mood in the morning and decreasing it in the afternoon.

It was pointed out that the electrochromic glazing could provide visual comfort and circadian lighting in two indoor office spaces. However, the evaluation of the electrochromic glazing was only in a short period, only one day to a week in temperate climates within the United States. The microstructured components can help maximize daylight, increasing exposure to daylight. However, the study mentioned was only conducted in a temperate climate, in Stuttgart in Germany without considering non-visual effects of light. It is important to extend these studies, particularly to warmer climates.

REFERENCES

1. B. Matusiak (org.) (2018). Literature review of user needs, toward user requirements. Gdansk, 2018. Available: https://doi.org/10.18777/ieashc-task61-2020-0001 [16 September 2021].
2. K.W. Houser *et al.* (2021). Human-centric lighting: Myth, magic or metaphor? Lighting Research and Technology. v. 53. p. 97–118.
3. C. Vetter *et al.* (2021). A Review of Human Physiological Responses to Light: Implications for the Development of Integrative Lighting Solutions, LEUKOS - Journal of Illuminating Engineering Society of North America. p. 1–28.
4. I.E. Agency. Daylight in buildings, Lawrence Berkeley National Laboratory (2000). Available: https://facades.lbl.gov/sites/all/files/daylight-in-buildings.pdf [16 September 2021].
5. M. Knoop (ed.) (2016). DAYLIGHTING AND ELECTRIC LIGHTING RETROFIT SOLUTIONS, Berlin, 2016. Available: http://task50.iea-shc.org/data/sites/1/publications/Technical_Report_T50_B6_final.pdf. [25 July 2022].
6. S. Attia, S. Bilir, T. Safy, C. Struck, R. Loonen, F. Goia (2018). Current trends and future challenges in the performance assessment of adaptive façade systems, Energy and Buildings. v. 179. p. 165–182.
7. J.F.W. Costa, C.N.D. Amorim (2021). Materiais transparentes e translúcidos inovadores em fachadas: conforto visual e eficiência energética em edifícios não-residenciais no Brasil. In: Encontro Nacional de Conforto no Ambiente Construído, [ANTAC], Palmas: pp. 1–10.
8. S. Kugley *et al.* (2017). Searching for studies: a guide to information retrieval for Campbell systematic reviews, Campbell Systematic Reviews. v. 13. pp. 1–73. Available: https://doi.org/10.4073/cmg.2016.1. [22 March 2022].
9. 9. M. Boubekri *et al.* (2020). The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers, International Journal of Environmental Research and Public Health. v. 17, n. 3219.
10. A. Dresch, D.P. Lacerda, J.A.V.A. Junior (2015). Design science research: método de pesquisa para avanço da ciência e tecnologia, Bookman, Porto Alegre.
11. C.N.D. Amorim, V. GARCIA-HANSEN, N. GENTILE, W. OSTERHAUS, K. PHAM (2021). Evaluating integrated lighting projects: a Procedure to Post-Occupancy Evaluation of Daylight and Electrical Lighting Integrated Projects, Stuttgart. Available: https://doi.org/10.18777/ieashc-task61-2021-0006. [22 March 2022].
12. R. J. Lucas *et al.* (2013). Irradiance Toolbox User Guide. 19 p. Available: http://lucasgroup.lab.manchester.ac.uk/measuringmelanopicilluminance/. [22 March 2022].
13. Hattar, S., Liao, H., Takao, M., Berson, D., & Yau, K. (2002). Melanopsin-Containing Retinal Ganglion Cells: Architecture, Projections, and Intrinsic Photosensitivity. Science. v. 295 n. 5557. p. 1065-1070.
14. H. Xiao. H. Cai. X. Li (2021). Non-visual effects of indoor light environment on humans: a review. Physiology and Behavior. v. 228. n. 113195. p. 1-14.
15. Y.A.W. de Kort, J.A. Veitch (2014). From blind spot into the spotlight. Introduction to the special issue “Light, lighting, and human behaviour”. Journal of Environmental Psychology. v. 39. p. 1-4.
16. K.W. Houser, T. Esposito (2021). Human-Centric Lighting: Foundational Considerations and a Five-Step Design Process. Frontiers in Neurology. v. 12. p. 1 – 13.
17. International Commission on Illumination (2018). CIE S 026/E:2018: system for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light, Vienna.
18. M.S. Rea, M.G. Figueiro (2018). Light as a circadian stimulus for architectural lighting. Lighting Research and Technology. v. 50. n. 4. p. 497-510.
19. B.J. Alkhatatbeh, S. Asadi (2021). Role of architectural design in creating circadian-effective interior settings. Energies. v. 14. n. 20. p. 1 – 30.
20. S. Saiedlue *et al.* (2019). Assessing circadian stimulus potential of lighting systems in office buildings by simulations. ARCC Conference Repository. p. 719 – 727. Available: https://www.arcc-journal.org/index.php/repository/article/view/655/528. [22 March 2022].
21. H.F.O. Mueller (2019). Application of Micro-structured Sunlighting Systems in Different Climatic Zones. Journal of Daylighting. v. 6. n. 2. p. 52 – 59.
22. M. Jakubowsky, J. d. Boer (2022). Façade elements for room illumination with integrated microstructures for daylight redirection and LED lighting. Energy and Buildings, v. 266. n. 112106. p. 1-14.

PLEA 2022 SANTIAGO
Will Cities Survive?

Performance analysis of side lighting systems in commercial buildings in Southern Brazil

ELAISE GABRIEL [1] GIANE DE CAMPOS GRIGOLETTI [1] GABRIELA MELLER [1] BRUNA ZAMBONATO [1]

[1] Universidade Federal de Santa Maria, Brazil

ABSTRACT: This paper assessed the thermal performance of different types of glass applied on three window-to-wall ratios (WWR) in three solar orientations. The simulations were performed in the DesignBuilder software in a commercial room considering the subtropical climate. In general, the 60% WWR is the opening that allows higher energy savings, when shading devices are used, however, there are some cases that the decrease in cooling demand is balanced with the increase in lighting demand.
KEYWORDS: Window to wall ratio, Natural light, Artificial light, Energy consumption

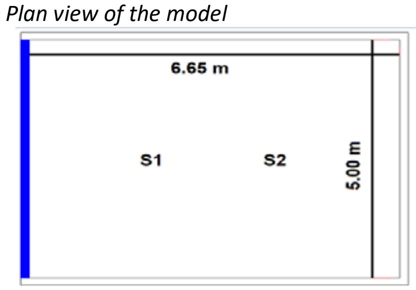
1. INTRODUCTION

In commercial buildings, daylight has a great importance due to its abundant availability during the occupation hours. However, artificial lighting in indoor environments is responsible for a large part of energy consumption, mainly because such buildings do not benefit of the integration of the two illumination systems. The amount of reflected natural light and its spatial distribution inside the building varies according to different device standards. In the case of shading devices, the number of pieces, and reflectance characteristics of their surfaces can influence the lighting performance and the use of daylight in the environment [1, 2]. The objective of this paper is to analyse the performance of side lighting systems in the consumption of electrical energy for air conditioning and artificial lighting in an office room located in Southern Brazil (characterized as subtropical climate) for four types of glass. To achieve the objective simulations were performed using the DesignBuilder.

2. METHODS

The case study is a 33.25m² office room with a ceiling height of 2.6 m, (Figure 1). S1 and S2 are the artificial light sensors, for daylight a grid at each 50 cm was considered. Table 1 shows the physical characteristics of the materials and simulation parameters [3-5]. The method is based on [5], and the simulations were divided into daylight metrics and energy consumption for the three window-to-wall ratios (WWR) (40%, 50% and 60%), three orientations, four types of glass and shading devices.

Figure 1: *Plan view of the model*



Vertical shading devices were adopted for East and West orientations, with the difference in the angle of the fins, and horizontal for North, based on the solar chart from Santa Maria – Brazil (Figure 2). South orientation was not considered since this solar orientation does not need solar protection. The WWR were defined based on the study from [5] and from the window dimensions adopted for most commercial buildings in the city.

Figure 2: *Size of shading devices*

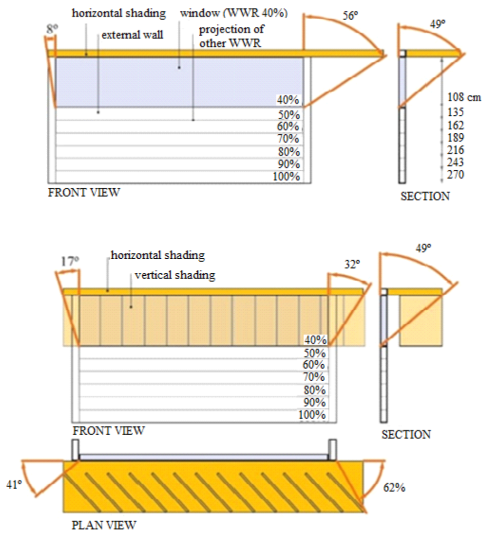


Table 1: *Material's physical properties*

Thermal transmittance (W.m^{-2}.K^{-1})		Walls	2.47
		Ceiling	2.42
Thermal capacity (kJ.m^{-2}.K^{-1})		Walls	200
		Ceiling	187
Absorptance		Walls	0.65
		Ceiling	0.70
Power density (W.m^{-2})		Lighting	4.74
		Equipment	9.70
		People	8.84
Air conditioner setpoint (ºC)		Cooling	23.5
		Heating	20.5
Type of glass	U (W.m^{-2}.K^{-1})	g-value	VT
SP	5.82	0.82	0.88
PN	5.70	0.27	0.13
GB	5.60	0.58	0.52
SKN	3.23	0.43	0.76

3. RESULTS

3.1 Energy consumption

Figure 3 shows the energy consumption for cooling, heating and artificial lighting for 40% WWR. Cooling comprehends the higher energy consumption compared to lighting and heating, for cases with and without shading, as expected.

Cooling energy increases as the thermal transmittance is higher. SP glass shows a consumption of 40.92 kWh/m²/year, for east orientation, more than two times than the SKN glass, that consumes 19.32 kWh/m²/year in this orientation. This occurs because the SP glass has a U-value of 5.82 W/m²·K whilst SKN shows a U-value of 3.23 W/m²·K. When comparing the models with shading, this difference reaches only 2.17 kWh/m²/year, due to the shading that blocks all the direct sunrays to the window, so this consumption is to keep the inside temperatures programmed by the air conditioner, and not supply the heat gains from the window. The GB and PN glasses showed intermediate consumption compared to SKN and SP glasses, varying from 18.45 to 35.26 kWh/m²/year, with and without shadings.

In terms of lighting consumption, the higher the VT, the lower the consumption. For heating, the energy consumption is considerably low for all cases. This occurs because heating is only necessary in a small percentage of hours of the year. The higher the visible transmittance, the lower the consumption. For example, PN glass has a consumption of 12.85 kWh/²/year for west orientation and 40% WWR, whilst SP glass shows consumption almost three times lower. In respect of the same models with shading, the energy consumption increased to 19.90 kWh/m²/year and 17.48 kWh/m²/year, respectively, proving again that the glasses have higher influence on windows without shading devices.

For heating, the energy consumption is considerably low for all cases, compared to cooling. This occurs because heating is only necessary in a small percentage of hours of the year in the Bioclimatic Zone 2. The heating consumption reaches its peak at 0.22 kWh/m²/year for the west orientation, 40% WWR and no use of shading.

Table 2 shows the variation (increase – positive, decrease – negative) of energy consumption between the WWR without shading devices. The column 40% to 50% indicates the decrease or increase of energy consumption between the 40% WWR and 50% WWR, and the other columns indicates the variation between 50% WWR and 60% WWR.

Figure 3: *Energy consumption x Energy consumption with shading*

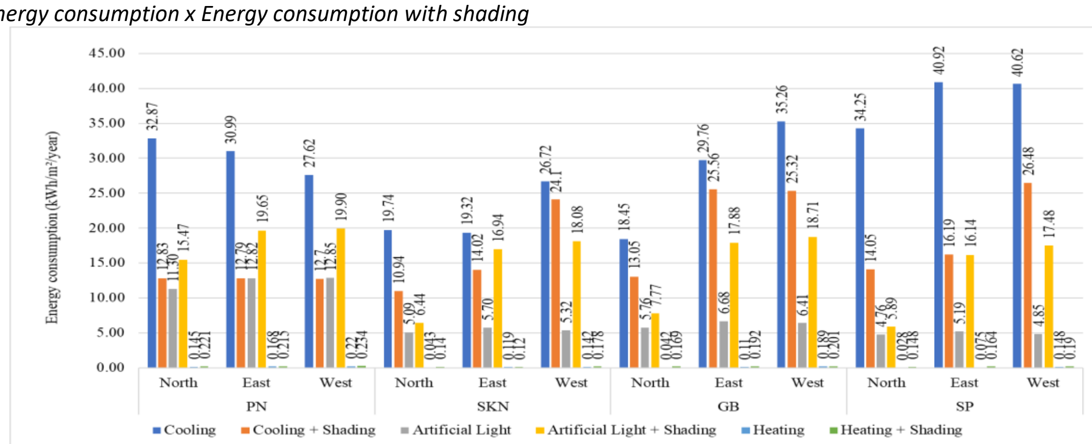


Table 2: *Percentage of variation in consumption between WWRs without shading devices*

		40% to 50%			50% to 60%		
Typologies	Orientations	Cooling	Artificial	Heating	Cooling	Artificial	Heating

			Lighting			Lighting	
PN	North	4.50%	-6.73%	-15.17%	4.16%	-4.93%	-17.07%
	South	0.10%	-7.12%	-5.11%	1.83%	-5.19%	-6.15%
	East	0.71%	-7.02%	-2.98%	4.84%	-5.37%	-9.82%
	West	2.90%	-7.78%	-6.36%	15.80%	-5.91%	-10.68%
SKN	North	66.57%	-5.11%	-83.72%	4.38%	-3.11%	-28.57%
	South	2.32%	-8.74%	-18.75%	2.91%	-5.71%	-61.54%
	East	40.99%	-7.02%	-22.69%	18.91%	-4.72%	-30.43%
	West	13.14%	-6.95%	-25.35%	6.12%	-4.04%	-14.15%
GB	North	37.51%	-6.25%	-23.81%	8.67%	-4.07%	-21.88%
	South	4.88%	-9.56%	-35.00%	5.88%	-6.89%	-9.09%
	East	19.89%	-7.93%	-27.27%	23.79%	-5.53%	-12.50%
	West	9.19%	-9.36%	-16.40%	6.44%	-6.37%	-17.09%
SP	North	2.45%	-4.41%	-28.57%	19.81%	-2.86%	-65.00%
	South	33.42%	-7.18%	-15.38%	24.74%	-4.48%	-15.15%
	East	13.83%	-6.17%	-17.33%	11.85%	-4.11%	-22.58%
	West	8.69%	-5.15%	-22.30%	7.72%	-3.26%	-25.22%

The percentages of increase in energy consumption for cooling reach its peak at 66.57%, from the 40% WWR to 50% WWR, for north orientation and SKN glass. Similar studies had shown parallel results, [6] simulated an air-conditioned cell in India, with different types of shadings on three WWR (13.33%, 26.67% and 53.33%) on south orientation. The results indicated that for the 53.33% WWR heating and lighting consumption decreased by 100% and 10.82% respectively, and cooling energy consumption increased 19.82% from the first WWR equal to 13.33%. The lower increase is equal to 0.10% for the PN glass, south orientation. In terms of lighting, the higher decreases in energy consumption happen for GB glass, west orientation between the 40% WWR and 50% WWR, equal to 9.56% of energy savings.

For the heating, the higher savings occurs for the SP glass, north orientation between the 50% WWR and 60% WWR.

The Table 3 shows the energy consumption variation between 40% WWR and 50% WWR, and 50% WWR and 60% WWR, for models with shading devices.

For the models with shading devices, the higher increase in energy consumption for cooling occurred in the north orientation for the PN glass, by increasing the 40% WWR to 50% WWR. In respect of the lighting consumption decrease, it occurred for the east orientation and SP glass, from 40% WWR to 50%. For heating, the higher energy savings happened increasing the opening from 50% to 60%, in the east orientation, with GB glass.

Table 3: *Percentage of variation in consumption between WWRs with shading devices*

		40% to 50%			50% to 60%		
Typologies	Orientations	Cooling	Artificial Lighting	Heating	Cooling	Artificial Lighting	Heating
PN	North	83.55%	-8.14%	-9.05%	2.51%	-2.18%	-7.96%
	East	6.41%	-1.63%	-10.70%	1.54%	-0.16%	-9.38%
	West	4.02%	-1.01%	-2.56%	1.74%	-0.20%	-10.96%
SKN	North	8.59%	1.40%	-22.86%	9.26%	-5.82%	-21.30%
	East	5.28%	-8.80%	-14.17%	8.40%	-1.17%	-10.68%
	West	2.90%	-6.08%	-16.85%	0.81%	-1.12%	-21.62%
GB	North	75.56%	-4.76%	-4.14%	16.15%	-1.22%	-18.52%
	East	2.15%	-6.77%	-8.85%	3.22%	-0.72%	-24.00%
	West	2.73%	-4.17%	-10.45%	3.34%	-0.78%	-0.56%
SP	North	25.77%	-3.06%	-10.14%	55.63%	-0.35%	-21.05%
	East	5.74%	-9.36%	-9.15%	6.78%	-1.64%	-0.67%
	West	3.25%	-7.55%	-2.63%	3.80%	-1.55%	-10.27%

3.2 Useful Daylight Illuminance

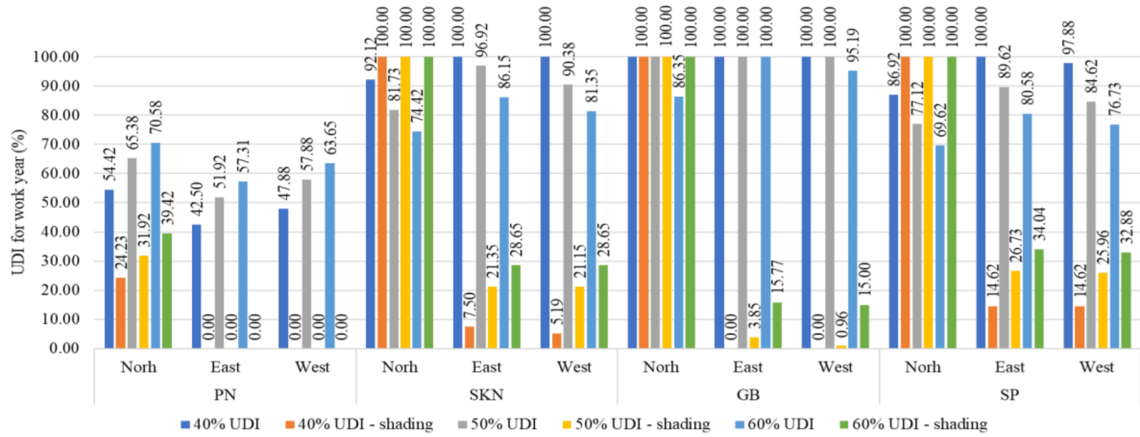
The results for UDI levels are shown in Figure 4. In relation to PN and GB glass, due to their low Visual Transmittance (VT), they showed reduced levels of UDI with the presence of shading devices, which leads to even less entry of light, when the window is covered, around 0% of UDI for 50% and 60% WWR. Some cases such as 60% WWR and north orientation presented high values of UDI with the use of shading, around 100% for GB, SP and SKN. Due to the higher solar radiation, causing UDI levels to be higher than 2.000 lux (outside the useful range), which can cause glare in the work-plane. These levels grow when the shading device is in use, lowering the range between 100 lux and 2.000 lux.

In relation to the WWR, for PN glass, the UDI value grows as the opening increases, thus, from 40% to 50%, for example, more daylight is allowed, without causing glare, due to the low VT-value, increasing the UDI from 54.42% to 65.38% for north orientation for example.

The SKN and SP glasses presented higher UDI levels with shading devices, due to higher VT higher ranges of illuminance do not cause glare and allow occupied hours whose illuminance values are in the useful range.

In relation to WWR, SKN and SP glasses behave contrary to PN and GB glasses, since due to the high VT, they already allow considerable daylight inside, by increasing the opening and, consequently, causing even more light to enter outside the useful range and decreasing the level of UDI.

Figure 4: *UDI x UDI with shading*



3.3 Daylight Autonomy

For the daylight autonomy analysis, Figure 5 shows the results. The percentage of occupied hours of the year in which a minimum illuminance value equal to 500 lux, was reached in the work-plane was lower for the models with shading devices than without shading devices. This was already expected because the shaded window allows less daylight levels. Among the solar orientations analyzed, the north presented the highest percentages of hours in the year, in which 500 lux have been reached in the work-plane, almost 100% for all openings SKN and SP glasses and above 50% for GB glass.

In relation to the glazing types, PN was the one that presents lower DA levels, since it has lower VT- value, reaching its peak at 30.96% for north orientation and 60% WWR without shading devices. The window-to-wall ratio remained an influencing factor in the levels of DA. The greater the opening, the higher the levels of DA, for all glazing types. Figure 6 shows the levels of UDI compared to DA levels, without shading devices on the windows. Considering the PN and GB glasses, the results indicated higher UDI values compared to DA, 47.88% of UDI for west orientation against 0% DA. This is justified by the lower values of visible transmittance (VT) of these glasses, which allow lower levels of daylight, less than 500 lux, generating UDI in the ranges of 100 to 500 lux. In contrast, the DA values are reduced because they only consider minimum values equal to 500 lux, in the work-plane.

For the SKN and SP glasses, which have higher visible transmittance values than the PN and GB glasses, the results indicated DA values higher than UDI, for 50% and 60% WWR. Because of the high VT, these glasses allow more daylight in the room, thus making it possible to reach bands above 2.000 lux, which result in lower levels of UDI. However, they provide higher percentages of hours of the year, in which at least 500 lux reaches the work-plane. In the South, East and West orientations, for the 40% WWR, the reverse occurs (UDI > DA), as they are orientations and opening that allow less daylight to enter.

Figure 7 shows the levels of UDI compared to DA, with shading devices on the window. For the models with shading devices, UDI levels were higher than DA levels, since shading reduces the entry of daylight, causing levels below 500 lux in most of the occupied hours. Same conclusions were made from Rocha et al. (2020), the authors developed a method for designing shading devices based on daylight autonomy and useful daylight illuminance considering energy efficiency and daylight use for 300 lux. The results shown that the higher the DA levels, the lower the results of UDI levels, this means that the daylight level at the nearest point from the window tends to stay out of the range of useful daylight illuminances (300–2000 lux), i.e., probably above 2000 lux, when the shading device allows greater daylight penetration into the room, providing an illuminance of 300 lux at the most distant point from the window.

DA levels were lower for typologies with low visible transmittance values, as is the case with PN and GB glasses, most cases resulted in 0% for east and west orientations, compared to SKN and SP glasses. Regarding the solar orientations, the north orientation presented the highest results for both DA and UDI, above 50% for all cases, and some reaching up to 100%, since in this orientation the shading is only horizontal, which allows it to obtain higher levels of illuminance, caused by solar reflections, considering that the east and west orientations do not allow direct sunlight.

Regarding the WWR, larger openings presented higher levels of UDI and DA, for example the 60% WWR for PN glass and north orientation resulted in an UDI level equal to 39.42%, almost 8% higher than the 50% WWR, and 15% higher than the 40% WWR. This occurs because the shading prevents the entry of sunlight in the bands above 2000 lux.

Figure 5: *DA x DA with shading*

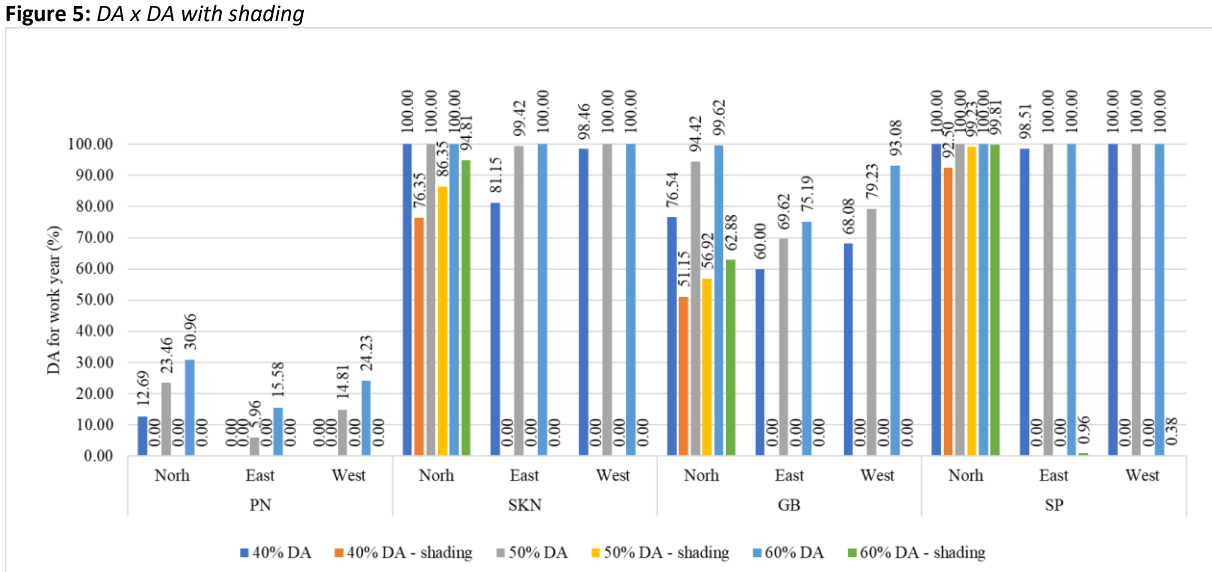


Figure 6: *UDI x DA levels*

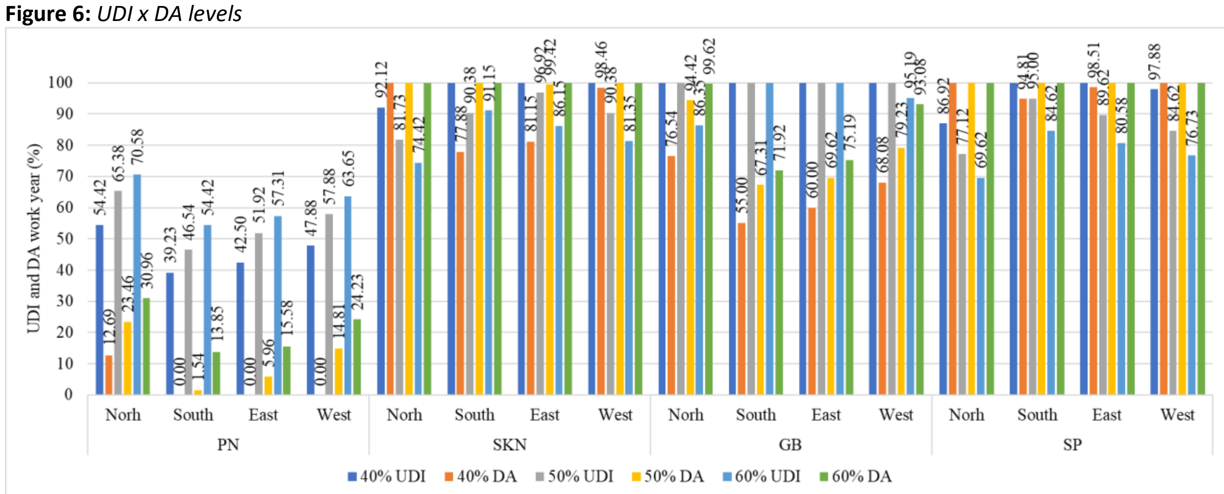
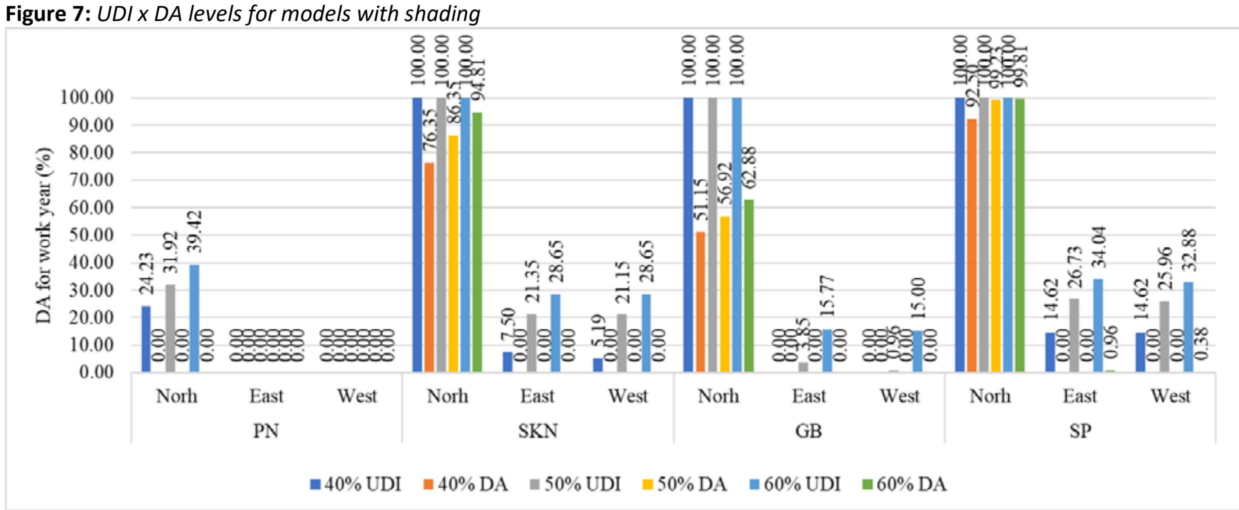


Figure 7: *UDI x DA levels for models with shading*



4. CONCLUSION

The results previously shown are valid for a specific context that includes an air-conditioned cell about 32.5 m², located at a warm and temperate climate, in bioclimatic zone 2. Also, it must be noticed that these conditions include the air conditioner set points for heating and cooling that influence on the energy consumption results. Other considerations are related to the physical characteristics of glazing, such as visible transmittance, g-value and U-value, the thermal transmittance of the façade, the shading dimensions, the radiation levels of this location, among others that contextualize this study. The results point out important relations between the glazing visual transmittance and daylight levels and energy consumption. In this sense, the definition of the glazing typology should consider not only the orientation, but window-to-wall ratio. Environments with openings aimed at orientations in which direct sunlight comes in at some time of the day showed a stronger need for shading devices, especially if the glazing presents higher visible transmittance. The research was limited to studying the relationship between the integration of artificial and natural light with cooling and heating demand, without delving into the form of calculation or the reference values of the indices. In terms of UDI levels, the shading devices increase the levels on typologies that have higher VT, keeping the daylight levels on the useful band. The opposite occurs for typologies with lower VT, in these cases, the UDI levels are lower with the use of shading. The north orientation allows the higher UDI levels, since for this orientation the shading devices are horizontal, allowing the entry of reflected sunrays. This is not the case for east and west orientation, since the shadings are vertical, covering all the direct sunlight.

The higher total energy consumption savings rotated between models without and with shading devices. In general, the 60% WWR is the opening that allows higher energy savings, when shading devices are used, however, there are some cases that the decrease in cooling demand is balanced with the increase in lighting demand, showing that individual analysis must be done in each case.

For future works, distinct spaces should be studied, including deeper or broader rooms, since the daylight behave differently in unsimilar interior spaces.

REFERENCES

1. Kim, J. T. and G. Kim, (2010). Advanced external shading device to maximize visual and view performance. *Indoor and Built Environment*, 19: 65-72.

2. Gutierrez, A.; Du, J.; Ferreira, N.; Ferrero, A.; Sharples, S. (2019). Daylight control and performance in office Buildings using a novel ceramic system. *Building and Environment*, 151: 54-74.

3. Didoné, E. L.; Wagner, A.; Pereira, F. O. R. (2014). Estratégias para edifícios de escritórios energia zero no Brasil com ênfase em BIPV. *Ambiente Construído*, 14: 27-42.

4. Ghisi, E.; Tinker, J. A. (2005). An Ideal Window Area concept for energy efficient integration of daylight and artificial light in buildings. *Building and Environment*, 40: 51-61.

5. Reinhart, C. F.; Mardaljevic, J.; Rogers, Z. (2006). Dynamic daylight performance metrics for sustainable building design. *Leukos*, 3: 7-31.

6. Ghosh, A.; Neogi, S. Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new external solar shading device in warm and humid climatic condition. *Solar Energy*, v. 169, p. 94-104, jul. 2018. Elsevier BV.

Green facades and its shading potential:

The solar radiation attenuation promoted by climber species

LUIZA SOBHIE MUÑOZ[1], MARIA SOLANGE GURGEL DE CASTRO FONTES[2]

[1] PhD Candidate in Architecture and Urbanism at the School of Architecture and Urbanism of the University of São Paulo/FAUUSP

[2] Assistant Professor of the School of Architecture, Arts and Communication at the São Paulo State University

ABSTRACT: Green facades are vertical gardens composed of climber species and can be direct, when the vegetation grows directly on the building surface, or indirect, when the vegetation grows through a support structure fixed in the building surface. They are bioclimatic strategies that can promote the thermal mitigation of the built spaces and improve the thermal performance of the buildings due to four mechanisms: shading, evaporative cooling, thermal insulation, and wind barrier. This work presents an experimental study that quantified the incident solar radiation attenuation and the Shading Potential (SP) of the indirect green facades, composed by three modules of different climber species (Passiflora edulis, Ipomoea horsfalliae and Thunbergia grandiflora). To make this possible, this work developed monitoring campaigns of incident and protected solar radiation in cold and hot weather conditions for the green facades. The results presented the better performance of Ipomoea horsfalliae, that showed a SP of 0,89, classified as "great", and attenuation values that varied between 90 and 100% during almost the monitoring campaign. These results highlight the importance of the green facades for the buildings and its application in transitional spaces, which can contribute to the thermal and comfort conditions mitigation in hot weather locations.

KEYWORDS: Green facades, Shading Potential, Solar radiation attenuation, Transitional spaces.

1. INTRODUCTION

Green facades are types of vertical gardens composed of climber species, which grow and develop vertically (5). Divided in two types, the green facades might be direct, when the vegetation grows directly on the building surface, or indirect, when the vegetation grows through a support structure fixed in the building surface or in a built element (3, 5, 10). The climber specie can be planted in a planter box or directly in the soil and it is common that exists an empty space between the green infrastructure and the building, which is called as air cavity.

The choice of suitable types of structure and plant species are important factors for the success of the indirect green facades. There are a lot of options for the structure, but the most used types are the modular trellis, cable systems and meshes (8). This process of choosing the structure must consider some aspects such as costs, possible environment impacts caused and the materials dimensions.

For the process of choosing the plant species, it is important to considerer some physiological and morphological aspects, the type of structure selected for the green facade and the climatic conditions of the local of implantation (8, 9). In addition, it is important to consider that the right choice of the plant species it is a determining factor for the good consolidation of plant cover.

Green facades are bioclimatic strategies and, when well designed, can promote the thermal mitigation of the built environment and improve the thermal performance of the buildings. This occurs due to four mechanisms: shading, evaporative cooling, thermal insulation and wind barrier (1, 7), which contribute to reduce the heat gain of the building and of its internal spaces (6).

The shading and insulation mechanisms are related to the plant coverage, which means that the greatest the plant coverage, the lower the amount of radiation that directly hits the building surface (3, 14). In addition, the air cavity effect, which create an insulation layer between the building and the green façade must be consider.

The evaporative cooling is related to a physiological function of the plants: the evapotranspiration. In this natural process, the sensible heat is consumed through the leaves and leads to the evaporation of water present in the soil and in the leaves occur, which causes an increase of the air humidity nearby (12). The wind barrier effect, in turn, makes it possible the heat flux decrease between external and internal environments of the buildings (13).

Those aspects and its results are shown on previous scientific works. In an experimental work carried out in Malaysia, it was recorded an air humidity increase nearby and decreases of 6,5 ˚C and 3 ˚C degrees for the air temperature inside the air cavity and the experiment, respectively, during the day, and 5,5 ˚C and 3,5 ˚C degrees during the night (9).

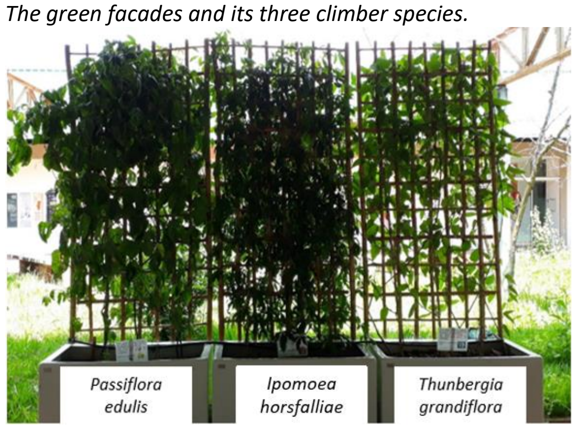
For an experiment carried out in the United Kingdom, in cold conditions and with snowfall, the vegetation promoted the test-cell insulation and its wind protection, which resulted in a difference of 3 ˚C higher between internal and external temperatures of vegetated and non-vegetated test-cells (2). During periods of frozen temperatures and heavy rain and wind, the vegetated test-cells showed from 39 % to 42 % more energy efficiency.

In this context, this work presents an experimental study that quantified the incident **solar radiation attenuation** and the **Shading Potential (SP)** of the indirect green facades, composed by three different climber species.

2. MATERIALS AND METHODS

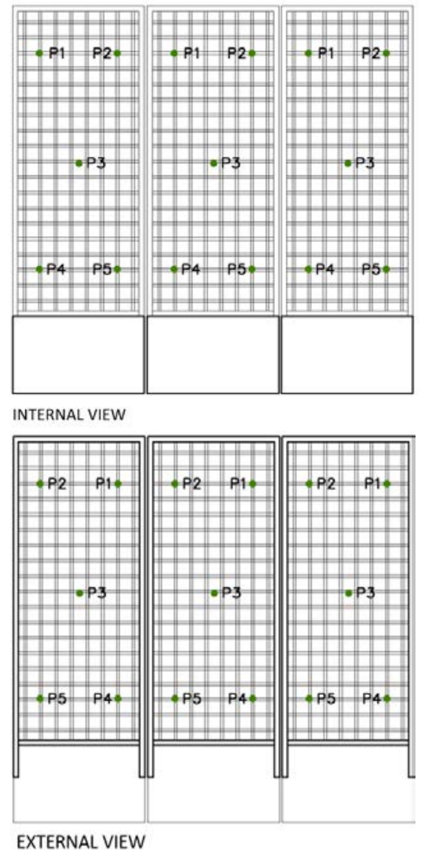
The experimental study consisted in the construction of three modules of indirect green facades located in a West orientation of a transitional space, of a university campus of Bauru, city of the São Paulo State, Brazil. The local climate is Cfa (humid subtropical), based on Köppen classification. In each module, composed by a fibre glass planter box (1,00 x 0,50 x 0,60 m) and a bamboo modular trellis to support and guides the vertical growth (Fig. 1), was planted a climber specie (*Passiflora edulis, Ipomoea horsfalliae Thunbergia grandiflora*).

Figure 1:
The green facades and its three climber species.



The monitoring campaign was started one year after the planting and aimed to identify the solar attenuation of each green façade. Thus, five measure points were located on each external and internal surfaces of the green facades as shows the Figure 2. The results allowed to calculate the solar radiation attenuation for each point and the mean values as well. For this, an equipment Instrutherm MES-100 (scale: 2000 W/m², resolution: 1W/m², precision: typically, ±10W/m²) were used for measuring the radiation, with measure every half hour in the afternoon. The campaign last for six days (three in hot weather conditions and three in cold conditions of 2018).

Figure 2:
Internal and external surfaces of green facades and its five points of radiation monitoring.



The **shading potential (SP)** of climber species (empirical parameter developed in this research), in each monitoring campaign, was calculated from arithmetic average of four factors (Table 1): VCF - Vegetal coverage factor; FTF – Foliage thickness factor; LSF – Leaves size factor; LSPF – Leaves spacing factor. The SP results vary between 0 and 1 and were classified in the following value scale: terrible (0 – 0,2), bad (0,21 – 0,4), regular (0,41 – 0,6), good (0,61 – 0,8) and great (0,81 – 1). A great SP means that this green façade can block, at least, 81% of the total incident radiation.

The calculation for the VCF factor was made from the Vegetal Coverage Proportion (VCP) in each modular trellis, which was based on previous works (4, 11). First, a picture of each green façade module was taken. Then, all the green coverage was vectorized in the software AutoCad®, the proportion between the total area of the modular trellis and the vegetal coverage were calculated (VCP) and the results were transformed into a factor (VCF), which vary between 0 and 1 (Fig. 3)

Table 1:
The values for the SP factors.

Factors	*Values*
VCF	0 – 1 – vary between 0 and 100% of vegetal coverage
FTF	0,3 - T <45cm; 0,7 – 46<T>90; 1 – T >91cm
LSF	0,3 – S>5cm; 0,7 – 5<S>15cm; 1 – S>15cm
LSPF	0,3 – SP >10cm; 0,7 – 5<SP>10cm; 1 – SP<5cm

Figure 3:
The process for calculating VCP and VCF.

3. RESULTS AND DISCUSSION

The results showed the shading potential and the solar radiation attenuation for the three indirect green façades composed by different climber species. The campaigns were realized in August 26th and 27th and September 6th (for the cold weather conditions) and December 12nd, 13th and 14th (for the hot weather conditions).

3.1 Solar radiation attenuation and shading potential in cold weather conditions

In comparison with the other measure points, the P3 point showed, for the three green facades, higher vegetal coverage proportion and foliage thickness, and the lowest values for the space between the leaves. In this point, the vegetal coverage was more uniform and denser than at the other points. These details and the SP factors for this campaign can be observed in the Fig. 4 and Table 2.

Although it presented an VCF of 0,7 and the highest LSF among all species, *Passiflora edulis* presented spaced and distant leaves and the lowest LSPF, consequently. These characteristics contributed to reduce the solar radiation attenuation. The results for the mean solar radiation attenuation for each species and points can be observed in Table 3.

Figure 4:
Plant coverage details and its monitoring points.

Table 2:
The factors for SP in cold conditions.

Climber Species	*Passiflora edulis*	*Ipomoea horsfalliae*	*Thunbergia grandiflora*
VCF	0,7	0,82	0,52
FTF	0,7	0,7	0,7
LSF	1	0,7	0,7
LSPF	0,3	1	0,7

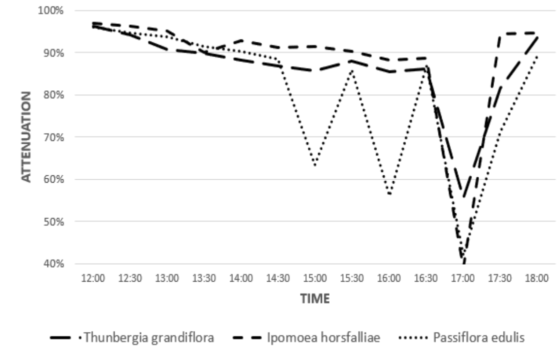
Table 3:
Results for the mean values of solar radiation attenuation (%).

Climber Species	*Passiflora edulis*	*Ipomoea horsfalliae*	*Thunbergia grandiflora*
P1	85	86	55
P2	74	77	53
P3	81	88	86
P4	65	78	71
P5	64	73	37

For *Passiflora edulis* climber, the point P1 showed the best mean of attenuation, and P5 the worst. For *Ipomoea horsfalliae* and Thunbergia grandiflora, P3 and P5 showed the best and worst mean values for the attenuation, respectively. These results are related to the plant coverage and the sun position, since P3 was the central point, where the vegetation presented more uniform and denser coverage, and P5 was the bottom point, where the plant coverage was sparse. Specially for the *Passiflora edulis*, the greater attenuation mean value at P1 is due to its location on the top of the trellis being less susceptible to solar radiation in that monitoring campaign.

In comparison, the point P3 showed the higher and more constant mean values for this parameter for the three species, which is due to a denser and more uniform plan coverage at this point, which leads to a greater shading capacity. Even though *Passiflora edulis* climber presented a good mean value for its P3 point, the space between tis leaves allowed greater passage of radiation. This relation and the solar radiation attenuation at the central points of all species can be observed in Fig. 5.

Figure 5:
Solar radiation attenuation in cold conditions at the central points.



For the other points (P1, P2, P4 and P5), all the species presented very varied results for the attenuation parameter during this monitoring campaign. This is due to variations in the plant coverage or, as the case of *Thunbergia grandiflora* P1, P2 and P5, to a lack of foliage. The *Ipomoea horsfalliae*, in turn, presented the greatest values when compared to the other species, followed by *Passiflora edulis* and *Thunbergia grandiflora*, respectively.

It is important to highlight, that at the *Thunbergia grandiflora* P3 point, the attenuation was higher than at the same Passiflora edulis point, which presented more leaves spacing and less uniform and sparse plant coverage. Nevertheless, when all five points were considered, Passiflora edulis climber presented better performance than *Thunbergia grandiflora*.

In this context and considering all parameters, during this campaign the climber species presented SP values from 0,65 to 0,81 (Table 4). *Passiflora edulis* and *Thunbergia grandiflora* SP were both classified as "good" (0,61 – 0,8) and the *Ipomoea horsfalliae* as "great" (0,81 – 1).

Table 4:
The SP in cold weather conditions.

Climber Species	*Passiflora edulis*	*Ipomoea horsfalliae*	*Thunbergia grandiflora*
SP	0,68	0,81	0,65

3.2 Solar radiation attenuation and shading potential in hot weather conditions

In this campaign it was possible to observe the same plant coverage pattern for the three green facades central points in relation to the cold weather conditions: In this way, its foliage was more uniform and denser at these points, which leads to a higher vegetal coverage proportion and foliage thickness, and the lowest values for the space between the leaves. These details and the SP factors can be observed in Fig. 6 and Table 5.

Figure 6:
Plant coverage details and its monitoring points.

Table 5:
The factors for SP in hot conditions.

Climber Species	*Passiflora edulis*	*Ipomoea horsfalliae*	*Thunbergia grandiflora*
VCF	0,72	0,88	0,6
FTF	1	1	0,3
LSF	1	0,7	0,7
LSPF	0,3	1	0,7

It is important to inform that during this campaign all the three green facades presented higher VCPs that contribute to higher VCFs, than in the cold weather conditions campaign. Even when the external surface temperature registered for the green facades reach the highest values, its solar radiation attenuation was all over 80%. In these moments, were registered 80,4%, 90,6% and 85,4% for the *Thunbergia grandiflora, Ipomoea horsfalliae* and *Passiflora edulis,* respectively. Nevertheless, Nevertheless, the points P4 and P5 of the *Passiflora edulis* and *Thunbergia grandiflora* climbers presented flaws in its plant coverage.

Although *Passiflora edulis* presented an VCF of 0,72 and maximum FTF and LSF, the space between its leaves contributes to the lowest LSPF, consequently, which causes the decrease of plant coverage shading capacity and affects the solar radiation attenuation. The results for the mean solar radiation attenuation for each species and points can be observed in Table 6.

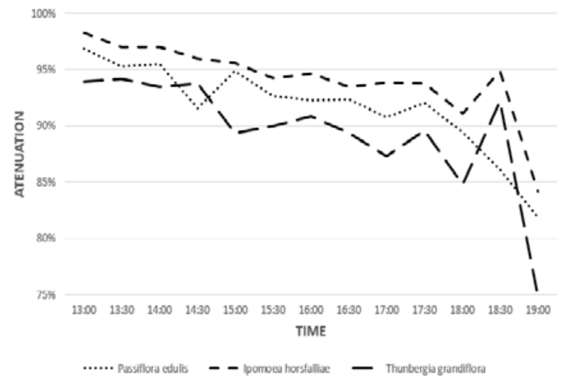
Table 6:
Results for the mean values of solar radiation attenuation (%).

Climber Species	*Passiflora edulis*	*Ipomoea horsfalliae*	*Thunbergia grandiflora*
P1	91	93	90
P2	92	92	88
P3	92	94	89
P4	74	85	64
P5	76	76	67

For *Passiflora edulis* climber*,* the greatest and worst results of attenuation were registered for the points P2 and P3 and P4. For *Ipomoea horsfalliae* these results were registered for P3 and P5, and for *Thunbergia grandiflora* in P1 and P4. All these results are related with the plant coverage, since P3 were the point where the plant coverage was more uniform and denser, while P5 and P4 presented flaws. For the *Thunbergia grandiflora,* P1 presented more uniform and denser plant coverage, which caused the higher attenuation capacity among its five measure points.

The comparative analysis between all points shows that P3 presented the highest results, even for *Thunbergia grandiflora,* which showed an irrelevant difference between this point and P3. In addition, *Passiflora edulis* and *Thunbergia grandiflora* presented oscillations for its central points results due to the sun position. This relation and performance of the three green facades central points can be observed in Fig. 7.

Figure 7:
Solar radiation attenuation in hot conditions at the central points.



To the other points (P1, P2, P4 and P5), *Passiflora edulis* and *Ipomoea horsfalliae* climbing plants presented uniform results for all these points, except for the P5, which showed more variations for its results. *Thunbergia grandiflora* showed the same tendency, but also presented flaws at the P4 and, because of this, presented some oscillations.

As for the cold weather conditions monitoring campaign, *Ipomoea horsfalliae* climber presented the greatest values when compared to the other species, followed by *Passiflora edulis* and *Thunbergia grandiflora,* respectively.

It is interesting to clarify that those valleys for *Ipomoea horsfalliae* and *Thunbergia grandiflora* solar radiation attenuation at 6 p.m. were caused by the combination between sun position and the leaves sizes, which allowed the incidence of radiation in the transitional space. For *Passiflora edulis,* this situation was different due to its leaves size, which were bigger than the other two species and could blocked more incident radiation. In this context and considering all parameters, during this campaign the climber species presented **SP** values from 0,57 to 0,89 (Table 7).

Table 7:
The SP in hot weather conditions.

Climber Species	*Passiflora edulis*	*Ipomoea horsfalliae*	*Thunbergia grandiflora*
SP	0,75	0,89	0,57

In this campaign, the results for SP were "regular" (0,41 – 0,61) for *Thumbergia grandiflora*, "good" for *Passiflora edulis* (0,61 – 0,8) and "great" for *Ipomoea horsfalliae* (0,81 – 1). It is possible to verify the same results tendency in cold conditions, whose SP of *Ipomoea horsfalliae* also presented better performance. This SP results and specific physical characteristics of each specie become even more clear and significant when the radiation attenuation results are analyzed for the hot conditions.

4. CONCLUSION

The **Shading Potential** analysis of indirect green facades, composed of three different climber species, evidences the *Ipomoea horsfalliae* better performance, which showed a "great" SP (0,81 – 1), and solar radiation attenuation of, roughly, 90% in different weather conditions (hot and cold). It is important to discuss yet the influence of the physical characteristics of the vegetation since those modules center points analyzed presented more denser and uniform foliage and vegetal coverage and, for this, they got a better shading effect. Thus, its application in green facades in transitional spaces, as balconies, can contribute to reduce the temperature and improve the thermal comfort conditions in hot weather locations.

ACKNOWLEDGEMENTS

The authors thanks to Meteorological Research Institute – IPMET, for the data provided and to the Faculty of Architecture, Arts, Communication and Design (FAAC) of UNESP, for the financial support.

REFERENCES

1. Besir, A. B. and Cuce, E. (2018). Green roofs and green facades: a comprehensive review. *Renewable and Sustainable Energy Reviews*, v. 82, p. 915-939.
2. Cameron, R. W. F., Taylor, J., Emmet, M. (2015). Hedera green façade – energy performance and saving under different maritime-temperature, winter weather conditions. *Renewable and Sustainable Energy Reviews,* v. 82, p. 111-121.
3. Hunter, A. M., Williams, S. G. N., Rayner, J. P., Aye, L., Hes, D. and Livesley, S. J., (2014). Quantifying the thermal performance of green façades: a critical review. *Ecological Engineering*, v. 63, p. 102-113.
4. Koyama, T., Yoshinaga, M., Maeda, K., Yamauchi, A. (2013). Identification of key plant traits contributing to the cooling effects of green facades using freestanding walls. *Building and Environment,* v. 66, p. 96-103.
5. Manso, M. and Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews, v. 41, p. 863-871.*
6. Muñoz, L. S., Cruciol Barbosa, M., Fontes, M. S. G. De C and Faria, J. R. G (2019). Desempenho térmico de jardins verticais de tipologia fachada verde. *PARC Pesquisa em Arquitetura e Construção*, Campinas, SP, v. 10, n. 2, mar, ISSN 1980-6809.
7. Pérez, G., Rincón, L., Vila, A., González, J. M. and Cabeza, L. F. (2011). Behavior of green facades in Mediterranean Continental climate. *Energy Conservation and Management*, v. 52, n. 4, p. 1861-1867.
8. Perini, K., Otellé, M., Haas, E. M., Raiteri, R. (2012). Vertical greening systems, a process tree for green façades and living walls. *Urban Ecosystems,* v. 16, n. 2, p. 265-277.
9. Safikhani, T., Abdullah, A. M., Ossen D. R., Baharvand, M. (2014). Thermal impacts of vertical greenery systems. *Environmental and Climate Technologies,* v. 14, p. 05-11.
10. Safikhani, T., Abdullah, A. M., Ossen, D.R. and Baharvand, M. (2014a). A review of energy characteristic of vertical greenery systems. *Renewable and Sustainable Energy Reviews*, v.40, p. 450-462.
11. Scherer, M. J. (2014). Cortinas verdes na arquitetura: desempenho no controle solar e na eficiência energética de edificações.
12. Sunakorn, P., Yimprayoon, C. (2011). Thermal performance of biofacade with natural ventilation in the tropical climate. In 2011 international conference on green buildings and sustainable cities. *Procedia Engineering,* n. 21, p. 34-41.
13. Susorova, I., Azimi, P., Stephens, B. (2014). The effects of climbing vegetation on the local microclimate, thermal performance, and air infiltration of our building façade orientations. *Building and Environment,* v. 76, p. 113-124.
14. Wong, I., Baldwin, A. N. (2016). Investigation of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region. *Building and Environment,* v. 97, p. 34-39.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Building-integrated solar technology

Learning from more than 30 years of experience with solar buildings (examples from international competitions)

KRIPPNER, ROLAND[1], FLADE, FABIAN[2]

[1] Nuremberg Institute of Technology/Faculty of Architecture, Nurmberg, Germany
[2] Solarenergieförderverein Bayern e. V. (Bavarian Association for the Promotion of Solar Energy), Munich, Germany

ABSTRACT: The "Architectural Award Building-Integrated Solar Technology" was first awarded in 2000. The aim of this prize is to make exemplary solutions at the interface between architecture and solar energy accessible to a broad public. Since then, eight competitions have been held, with around 40 prize winners and almost 600 projects submitted from all over the world. The competition entries demonstrate the great potential of coherently integrated solar technology as part of ambitious architectural and energy building concepts. In this article, examples from the competitions are used to illustrate continuous further developments and, above all, design innovations in the field of solar façades (with a focus on photovoltaics).
KEYWORDS: Building-Integrated Photovoltaics (BIPV), Solar Façades, Solar Buildings, Solar Architecture

1. ABOUT THE COMPETITIONS

The use of solar energy in and on buildings is a central aspect of energy-efficient construction – for homes, industrial and administrative buildings as well as residential complexes. The Solarenergieförderverein Bayern (Bavarian Association for the Promotion of Solar Energy – SeV) has held eight competitions on the topic of "Building-Integrated Solar Technology" since 2000, with around 40 prize winners. The aim of the competitions is to make exemplary solutions in qualitatively demanding architecture accessible to a broad public. In the years between 2000 and 2005, only a little more than a dozen entries from Bavaria and Germany were represented in each case. After the opening for European and worldwide submissions, a continuous increase in the number of participants can be observed [1].

The example of the competition activities of SeV, founded in 1997, can be used to show the increasing broad impact and establishment of the topic in the following decades. What are the continuities in the field of building-integrated solar technology and how have construction and, in particular, design strategies changed over the past 20 years? An essential feature of the "Architectural Award" is that only buildings in which the collector surface and/or the PV generator form a design-determining element of the building envelope are awarded. In the following, the focus is on solar façades (with an emphasis on photovoltaics), as some particularly striking developments can be identified here.

2. SOLAR ROOFS

Over the period of 20 years, it is noticeable that, in particular for PV roofs, a broad standard of exemplary solutions can indeed now be found both in excellent projects and in everyday architecture [2]. As a rule, standard modules are chosen for on-roof or roof-integrated systems, and only for one- and two-family houses are special products such as solar tiles or specially shaped modules sometimes used for roof integration. Very often, solar systems cover the entire roof surface, oriented to the south on a flat sloped roof facing south and north or as a prismatic structured building envelope.

Even rather simple solutions can be exemplary models. The modular plus-energy building powerHYDE (2019) by billionBricks with Architecture BRIO from Mumbai/IN convinces despite all pragmatism as an extremely sensible contribution to sustainable mass housing on the Indian subcontinent (Fig. 1).

Figure 1:
powerHYDE, Aurangabad (Architecture BRIO; ph. PHX-India/Sebastian Zachariah)

Figure 2:
Convention Center, León (Dominique Perrault Architecte; ph. JMC Berlanga)

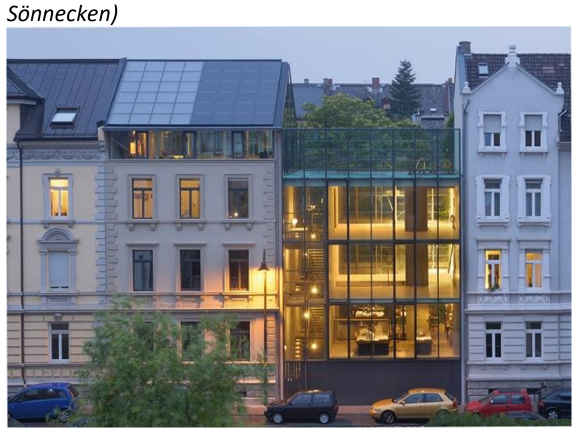
In terms of concept and design of large solar roofs, two projects stand out. At the Convention Center in León/ES (2018), Dominique Perrault Architecte succeeds in forming a multifaceted, large-scale energy roof on a flat-pitched roof nearly 300 meters long (Fig. 2). At the Energy Academy Europe in Groningen/NL (2017), Broekbakema and De Unie Architecten opted for a dense arrangement of highformat PV modules. On an elongated triangular format, six modules are placed against each other in two rows. This is not only intended to increase solar power production, but also to create a fascinatingly multifaceted three-dimensional solar roof (Fig. 3).

Figure 3:
Energy Academy Europe, Groningen (Broekbakema; ph. Ronald Zijlstra)

Large-scale roofing is also becoming increasingly important in the field of roof systems, especially in combination with electromobility. An early example is the bus station (1995) in Bad Wörishofen/DE. On an elegant steel structure, GS Schneider Architekten use semi-transparent PV modules in the southern surfaces of the roof structure. For the roofing of the carport of the waste management office (2011) in Munich/DE, Ackermann Architekten choose an innovative approach with bendable modules and foil cushions as a multifunctional roof: weather protection, use of daylight and power generation (Fig. 4). In contrast, Clayton Korte Architects are planning a filigree energy roof for the Saxum Winery (2018) in Paso Robles/US. It is an excellent example of agricultural construction that combines aspects such as minimal material use and deconstructability with aesthetic appeal. In an urban context, at the McDonald's Flagship Store – Disney (2020) in Kissimmee/US by Ross Barney Architects, the semi-transparent butterfly roof functions as weather protection on both ridge sides.

Figure 4:
Carport of the waste management corporation of Munich, (Ackermann Architekten)

Figure 5:
opusHouse, Darmstadt (opus Architekten; ph. Eibe Sönnecken)



The topic of building in the existing fabric still poses a certain challenge, especially when the requirements of historic preservation have to be taken into account. Over the years, numerous awardwinning competition entries have shown exemplary, almost self-evident implementations and demonstrate that solutions are available. In Darmstadt/DE, Opus Architekten are implementing a combined system with more conventional solar thermal collectors and photovoltaic modules in a historic ensemble (Fig. 5). In the renovation of the Pajol Hall (2013) in Paris/FR, which was slated for demolition, Jourda Architectes used the existing steel structure as weather protection for the four-story wooden building and as an energy roof (PV modules and solar collectors) for a neighborhood with offices, stores, and a youth hostel and library. In contrast, the Bernese architectural firm Halle 58 is using red PV modules in the renovation of the historic Weiherguet farmhouse (2019) in Wabern/CH.

3. SOLAR FAÇADES

In cities in particular, especially in dense structures, the possibilities for use in the area of facades are often severely limited by construction. Nevertheless, there are a number of reasons to deal with the solar activation of façades as well. For example, if the roof areas of multi-storey buildings are disadvantageously oriented, are too small in total, or are problematically cut. And last but not least, solar technology also expands the design repertoire and can become a symbolic sign for the use of renewable energies, especially in the façade [3]. This is exemplified by the Aktiv-Stadthaus (2015) in Frankfurt/DE by HHS Planer + Architekten. An outstanding project with pilot character in an inner-city environment. The architects succeeded in realizing an 8-story apartment building with 74 residential units as a PlusEnergy building on a 160 m long and only 9 m deep site under difficult urban planning boundary conditions (Fig. 6).

Figure 6:
Aktiv-Stadthaus, Frankfurt/Main (HHS Planer + Architek-ten; ph. Constantin Meyer)

In terms of construction, the dominant design is that of curtain-type, rear-ventilated façades. For example, in the almost 50 m high structure of the headquarters of the Holz-Berufsgenossenschaft (1999) in Munich/DE by PMP Architekten, poly-crystalline PV modules are arranged in a cold façade in a narrow vertical strip. In contrast, the ökotec building (1993) in Berlin/DE combines natural stone cladding with glass modules in the façade. In addition to the visible fastening, it is noticeable that the modules are formed at that time with still emphasized horizontal PV cell strips.

Figure 7:
Paul-Horn-Arena, Tübingen (Allmann Sattler Wappner; ph. SunTechnics)

The Paul Horn Arena in Tübingen/DE (2004) shows an unusual implementation for the early 2000s in terms of surface size and detailing. Allmann Sattler Wappner designed the entire south façade with vertical modules with green polycrystalline PV cells in four different sizes. A white edge, pronounced by the foil laminate on the back, structures each module and the overall appearance of the façade. Here, the visibly applied photovoltaics also perform an important role as a communicator for renewable energy (Fig. 7).

As part of the renovation of two nine-story apartment buildings (2001) in Freiburg/DE, architects Rolf + Hotz used the closed south façade for a building-high PV system. The glass/glass modules, arranged in landscape format, are attached to the aluminium substructure on the long side with visible black clamping profiles. The project shows very conclusively how PV façades can be implemented in an exemplary manner, both technically and in terms of design, even in the case of renovations (Fig. 8).

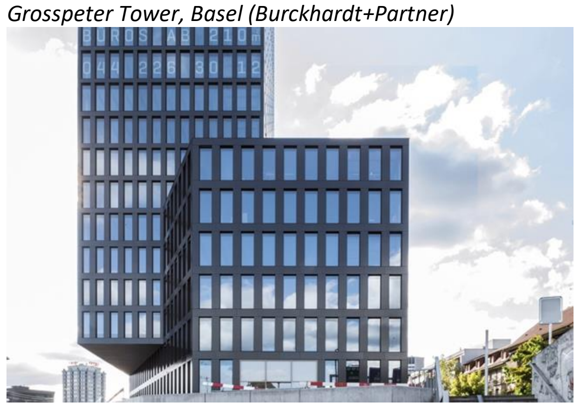
Figure 8:
Apartment buildings, Freiburg (Rolf + Hotz Architekten)

From 2010, a change begins to take place. Architects are increasingly seeking to reduce the PV cell in the total area of the module. An example of this can be seen in the children's daycare center (2014) in Marburg/DE by opus Architekten. Here, in the southwest façade, the monocrystalline cells recede in favour of a uniform surface effect; from a distance and even in close-up, a perfectly detailed glass façade is revealed. A homogeneous surface effect is created, which is an elegant and efficient alternative to natural stone and metal façades (Fig 9).

Figure 9:
Children's daycare center, Marburg (opus Architekten; ph. Eibe Sönnecken)

In the Grosspeter Tower (2017) in Basel/CH by Burckhardt+Partner, the façade is characterized all around by a clear grid structure with openings that become wider towards the top. The opaque façade surfaces consist of CIGS modules. With around 450 different façade panels, the result is a homogeneous surface effect that represents an elegant and efficient alternative to natural stone and metal façades (Fig. 10).

Figure 10:
Grosspeter Tower, Basel (Burckhardt+Partner)



However, architects are not the only ones to express increasing criticism of these dark, anthracite coloured PV modules. In recent years, solutions in other colours have been made possible by printed or coated modules, sometimes in combination with special glass. Beat Kämpfen uses PV modules with multicolor printing on the apartment building (2018) in Zurich/CH, giving the façade a reddish-brown appearance. In the Solaris residential building (2017), also in Zurich/CH by huggenbergerfries Architekten, all opaque surfaces are covered with monocrystalline modules and prismatic colored front glass despite the complex geometry of the building. The architects' goal was a "solar house that should not necessarily be recognizable as such" (Fig. 11).

Figure 11:
Solaris, Zurich (huggenbergerfries Architekten; ph. Beat Bühler)

In addition to color, important issues in façade cladding are always module dimensions or proportions and fastenings. While non-visible fastenings are now generally preferred, two projects show convincing solutions with visible profiles and hooks.

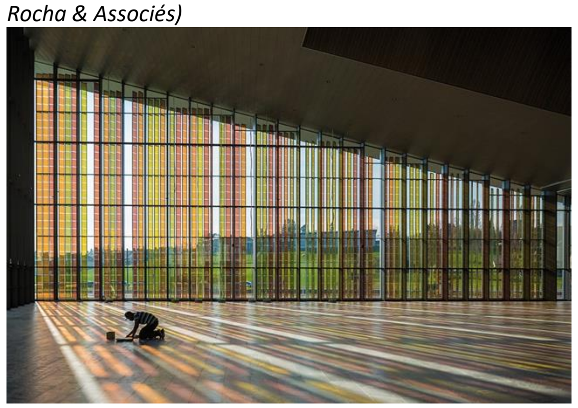
Narrow PV louvers are arranged in front of the glazed access area at the Oskar von Miller Forum in Munich/DE (2009). The frameless glass/glass modules are each held in place by linear profiles on the long sides. René Schmid Architekten choose a rather small module size for the "multi-family house with energy future" (2017) in Zurich/CH, with scaled arrangement on visible stainless steel hooks.

Figure 12:
Copenhagen International School (C.F. Møller Architects; ph. Adam Mørk)

At the International School Nordhavn (2017) in Copenhagen/DK by C.F. Møller Architects, the PV modules are mounted in metal cassettes at different angles, so that the façade changes color depending on the sunlight and the viewing angle, even though the modules are all the same color. In these projects, a few variations, both functional and constructive, within a clear overall structural concept, produce striking solutions (Fig. 12).

So far, no such variance can be observed in warm façades. The basic strategies of how crystalline cells can be used as parts of a mullion-transom construction are already shown by early examples from the SeV competitions. PV is used almost as a matter of course in insulating glazing and often serves as semi-transparent solar shading, as in the double façade of the Bane Nor office building (2020) in Oslo/NO by LPO Arkitekter. Simone Giostra & Partners expand the energy façade into a media façade at the Greenpix – Zero Energy Media Wall (2008) in Beijing/CN. The occupancy density of the PV cells varies; in addition, some panels are slightly pivoted out of the surface, giving the façade a diverse structure that attracts attention even during the day.

Figure 13:
SwissTech Convention Center, Lausanne (Richter Dahl Rocha & Associés)

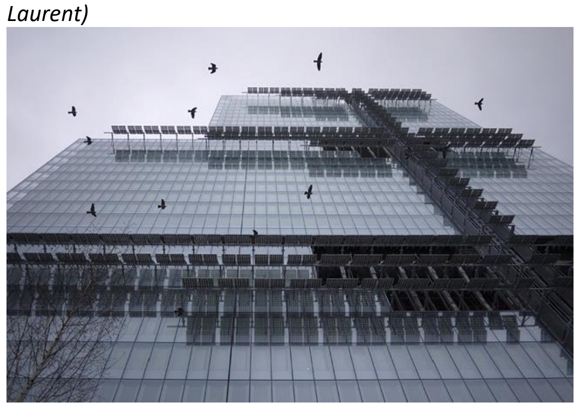


In contrast, dye cells and organic photovoltaics open up different kinds of designs. Richter Dahl Rocha & Associés used dye-sensitized solar cells in this dimension for the first time worldwide at the SwissTech Convention Center (2012) in Lausanne/CH. In the west façade, glass/glass modules with dye cells in different shades of yellow, green and red are arranged storey-high in front of the glass façade in narrow strips. These not only act as sunshades, but also create charming lighting moods in the foyer (Fig 13).

An exception is the use of photovoltaics as (movable) sun protection, even though there are instructive precursors in which PV becomes an important design-defining element. In the Sino-Italian Ecological and Energy Efficient Building (2006) in Beijing/CN by Mario Cucinella Architects, floor-to-ceiling cantilevered PV louvers serve as shading for the roof terraces (Fig. 14). In contrast, Renzo Piano Building Workshop's glass façade of the Tribunal de Grande Instance (2017) in Paris/FR uses upwardly staggered linear structures of varying lengths as solar shading (Fig. 15).

Figure 14:
Sino-Italian Ecological and Energy Efficient Building, Beijing (Mario Cucinella Architects; ph. Daniele Domenicali)

Figure 15:
Tribunal de Grande Instance, Paris (RPBW; ph. Maxime Laurent)



As early as 2000, the Nikolaus Fiebiger Center of the Friedrich Alexander University in Erlangen/DE (Erlangen University Construction Office, Christof Präg) features horizontal, single-axis tracking PV glass louvers in the façade. In doing so, the photovoltaic system blends in with the technical aesthetics of the research building in an exemplary manner. Current examples include the Hutter apartment building (2019) by Vera Gloor in Küsnacht/CH, with frameless PV modules as horizontal sliding shutters in front of a red wooden façade, and the extension of the traffic commissioner's office (2017) in Kißlegg/DE, where floor-to-ceiling vertical louvers in front of the offices act as sunshades and electricity generators.

Despite the orientation of the architecture award towards “Solar Technology“ since 2008, photovoltaics continues to dominate. And yet, time and again, exemplary solutions with solar thermal collectors can also be found in the façade. An early project is the single-family house as a PlusEnergy house (2007) in Pfarrkirchen/DE by Alfons Lengdobler, in which storey-high collectors are installed on the first floor with a clear structural relationship to the façade grid. The same applies to the elementary school (2017) in Hallwang/AT by LP Architektur ZT GmbH and to the façade of the four-story school building in Ettelbruck/LU. The detailed solutions vary, but the collectors with their dimensions and proportions complement the wooden facades in an excellent way (Fig. 16).

Figure 16:
Lycée technique pour professions de santé, Ettelbruck (Fabeck Architectes; ph. Christian Aschman)

4. CONCLUSION AND OUTLOOK

The Award of the Solarenergieförderverein Bayern with its focus on “building-integrated solar technology“ is meanwhile regarded as the leading event in its field in Europe, alongside the Swiss Solar Prize (since 1990) and the German and European Solar Prizes (since 1994). Not only the award-winning examples show that in the meantime, in addition to solar thermal collectors, photovoltaics in particular are a natural part of the building envelope of energy-efficient buildings in ambitious overall architectural concepts.

Figure 17:
Hof 8, Weikersheim/DE (Architekturbüro Klärle; ph. Brigida González)

Over a period of 20 years, it can be said that the quality of everyday architecture in the submissions has also increased significantly, even though building culture has been a seemingly negligible factor in the everyday life of many countries for decades. Here, architects are the decisive professional group for further developing the numerous positive examples and trying out new approaches.

The current challenges such as the energy turnaround and the climate crisis require creative designers and technically competent planners in equal measure. It is a matter of daring the adventure of solar architecture, worldwide at the most diverse locations and in the most diverse climatic regions, on a qualitative as well as quantitative level. This task is supported by the “Architectural Award Building-Integrated Solar Technology", which has established itself worldwide with a certain unique selling point in the field of the interface between architecture and solar technology, with important educational and informational work. [4]

Figure 18:
UmweltArena, Spreitenbach (René Schmid Architekten)

REFERENCES

1. https://www.sev-bayern.de [4 March 2022].
2. Krippner, R. (Ed.), (2017). Building Integrated Solar Technology. Architectural design with photovoltaics and solar thermal. Detail green books. Munich.
3. Herzog, T., Krippner, R., Lang, W., (3/2021). Façade Construction Manual. (2004). Edition Detail. Munich, pp. 294-321.
4. Solarenergieförderverein Bayern e. V. (Ed.), (2019), Gebäudeintegrierte Solartechnik – Architektur und Solar-energie: Aus den Wettbewerben des Solarenergie-förderverein Bayern e. V. Munich.

Application case of a bioinspired approach

Ideation, prototyping and assessment of a novel thermo-responsive and deployable building skin

TESSA HUBERT[1,2,3,4] BAPTISTE DURAND-ESTEBE[1] ANTOINE DUGUÉ[1] TINGTING VOGT WU[2] FABIENNE AUJARD[4] DENIS BRUNEAU[3]

[1] NOBATEK/INEF4, National Institute for the Energy Transition in the Construction sector, Anglet, France
[2] Institute of Mechanical Engineering (I2M), UMR CNRS 5295, Université de Bordeaux, Talence, France
[3] Ecole Nationale Supérieure d'Architecture et Paysage de Bordeaux, Talence, France
[4] MECADEV UMR CNRS 7179 - National Museum of Natural History, Brunoy, France

ABSTRACT: In the context of climate change, the design of building envelopes has become an increasing challenge. The envelope not only acts as a load bearer but also as a hygrothermal or visual barrier; it highly influences the building performance and comfort of occupants. Therefore, envelopes reacting in real time to environmental changes for an improved performance have recently been a growing interest. In particular, recent research has been focusing on inspiration from nature as a promising field for adaptive solutions. However, its practice tackles many challenges. This paper presents an experimental framework exploring several steps of design process of bioinspired building envelopes. Based on the envelope of the morpho and of the chameleon, the design emerged from this approach is a multifunctional building skin managing thermal, air and light transfers. The system is self-adaptive, as it is coated with a smart-paint, and light and air-responsive when manually triggered by occupants. A version of this principle was prototyped, integrated to a 1m² insulated box, and tested in real climate conditions. A grey-box model and optimisation algorithms were then used to assess the system.
KEYWORDS: Bioinspiration, Sensitivity analysis, Optimisation

1. INTRODUCTION

The building envelope heavily influences the overall performance of the building and the comfort of occupants. Therefore, extensive research has emerged on how to adapt to varying environmental conditions through efficient envelope systems. Facing analogous challenges, living systems must adapt to adapt external conditions through an evolutionary process.

Envelope concepts, derived from biological functions are therefore of growing interest. However, they suffer from a lack of applications in the building sector, and from unnoticed promotion as a lever to environmental issues: they are either stopped at preliminary design stages due to challenges in transferring them to technological applications (Chirazi et al., 2019), or rarely assessed in terms of performances when integrated into a building (Cruz et al., 2021), as are innovative systems in general when implemented.

2. IDEATION OF A NOVEL BUILDING SKIN

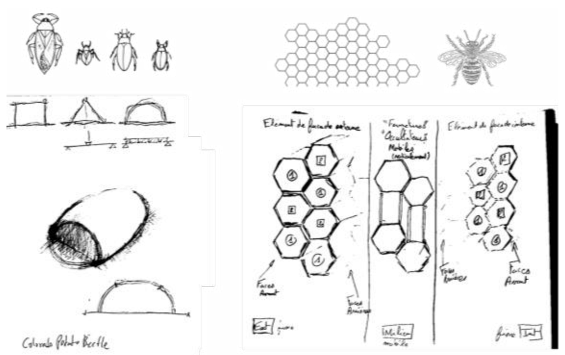
To address the challenges of the practice of bioinspiration, our work focused on the whole process of designing bioinspired building envelopes. Two main approaches were possible (ISO 18458:2015, 2015): *biology-push*, using biological functions and behaviours for inspiration as a starting point in the process, or *technology-pull*, focusing first on technical problems and then exploring how living species have overcome similar issues. As a trade-off between both approaches, we chose to focus on biological envelopes only, such as skins, stomata, scales, or animal constructions, as they are able to manage multiple functions to regulate their internal environment. With the support of biologists specialized in evolution and adaptation mechanisms, we selected and described biological models of interest for the built environment while using an architectural and functional perspective. The generated database, gathering more than a hundred models could then be handed over to designers as a tool to assist the inspiration and design of multifunctional principles. One of the proposed envelope systems was then selected and pushed towards a technological version. As the assessment of envelope systems was underlined as one of the lacks in the bioinspiration field, we built a test bench and created an experimental protocol to both validate the benefits of the emerged system in terms of performance and comfort, and retrieve feedbacks from the used framework.

2.1 A participatory bioinspired design process

Several workshops gathered engineers and architects for the ideation of bioinspired principles (Fig. 1). The biological database was provided as a datasheet including general information on the species. It also described the various stimuli that participants could undergo, such as environmental factors (heat, rain) or interactions with other species, and their effects on them (physical phenomena, behaviour).

Based on this, participants were asked to propose envelope concepts that would impact the interior indoor environmental qualities of their choice (air quality, daylight, acoustic and thermal comfort). Decision support tools, such as key features, illustrations, or tables, were included to help designers browse into the database, and select biological models of interest.

Figure 1:
Workshop envelope concepts inspired by morphological features of beetles and beehive structures.



The emerged ideas were various as some were based on morphological features and others on either physiological or behavioural characteristics. To further the design process exploration, we selected one of the proposed ideas based on its novelty.

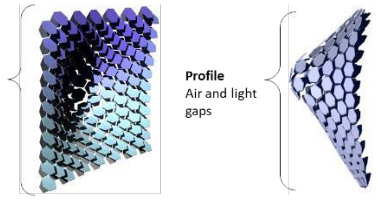
2.2 Case-study: operating principle

The selected idea is inspired by two biological models: the morpho (lepidoptera of the insect class), which demonstrates multiple functions and strategies for thermoregulation using its wings (e.g., forced ventilation, orientation towards either the environment for radiative exchanges, or adaptive emissivity of its scales (Berthier, 2005)) and by the chameleon (squamate of the reptile class), which changes colour due to a deformable crystalline network contained its derma (Teyssier et al., 2015).

The derived concept is a thermal protective system with 2 main features (Fig. 2):

- a deformable mesh supporting rotating elements for interchanging absorption properties and auto-shading;
- an auto-reactive coating of the rotating elements to a threshold temperature for adaptive emissive properties, inspired by intrinsic properties of butterfly scales (Berthier, 2005).

Figure 2:
Features of the design when deformed.



The design can be positioned in front of opaque or glazed walls, or can be installed as the envelope itself. In warm and temperate climates, when exposed to solar radiation, it prevents the envelope from overheating by changing colour. This skin can also "breathe" through openings locally generated by the deformation of the mesh, managing air and light transfers towards the buildings. The system is auto-reactive but can be modified by the users, through controlled rotations of flaps or one to several deformations, to better fit their needs.

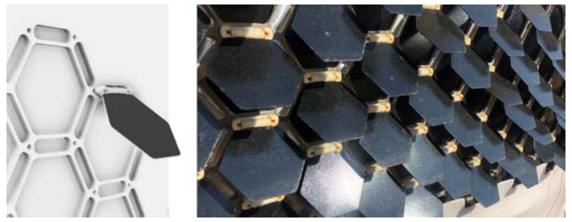
3. IMPLEMENTATION INTO A TEST BENCH

Several versions of prototypes were built in order to retrieve the proposed bioinspired features. For instance, the auto-reactivity was embedded with a thermochromic coating, formulated to change colour above and below 40°C: from one colour to a lighter one (blue to white, for instance), the absorption coefficient in the visible spectrum drops and absorbs less. Systems coupling a mesh deformation with elements deployment were built as well, using springs or string-based actuators.

However, the evaluation of such designs is rather complex, as it combines multiple physical phenomena: the effects of deformation, auto-reactivity, and deployment were therefore assessed apart from each other (Hubert et al., 2022). Only the assessment of the latter is described in this article. For this, rotating elements were built with hexagonal aluminium plates, rotating on a solid frame support through a 3D-printed plastic notched system. They were then coated with a classic black paint (Fig. 3).

For measurements of the behaviour and impact of the envelope system on an enclosed volume in real conditions, the prototype was integrated to a 1 m^3 test box (Fig. 4). The following elements were monitored: heat flows and temperatures at the different layers of the envelope, ambient temperatures, and climatic conditions such as wind velocity, and direct and diffuse solar radiation.

Figure 3:
Notched system of rotating elements (or "flaps").



Note: The plastic systems are inserted in a 4 mm thick perforated aluminium frame.

Figure 4:
Photograph of some of the sensors and of the prototype integrated to a test box in real climate conditions.

Series of measurements between January and March 2022, with a south orientation of the prototype, were performed in Talence (Nouvelle Aquitaine, France). The flaps were either in a closed position (vertical, with a rotation angle of 0°) or open (as caps, at 90° rotation angle). For each position, a 14-day measurement campaign was performed to collect data during both sunny and cloudy days.

Measurements indicate a strong correlation between the interior temperature of the box and solar radiation. A correlation between the wind speed and the variations of heat flows and temperature within the wall is observable as well. In addition, when there is wind, the surface temperature of the external flaps is higher than the temperature of the external air, and lower otherwise: it indicates that the radiative exchange with the sky dome is negligible in front of the convective exchanges by windy night.

As the measurements were performed in varying external conditions, direct comparison between the configurations does not provide information on the impact of the prototype on the box conditions. However, they can be used in a grey-box approach i.e., combining a partial theoretical structure with data to complete the model.

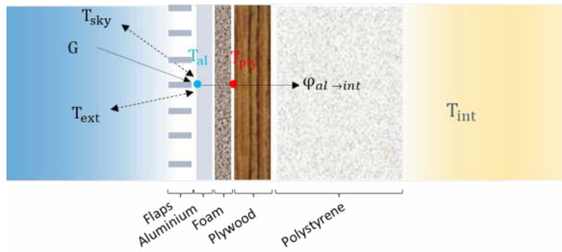
4. CHARACTERIZATION

Based on observations made from the measurements, we propose here a thermal model to characterize the system.

4.1 Thermal model

Transfers are considered to be one-dimensional between the inside and outside of the test box. The model integrates radiative heat transfers with the sky, the surrounding, and the sun, as well as conductive and convective exchanges with the ambient temperature impacted by the wind speed.

Figure 5:
Thermal balance on the outer surface of the prototype behind the flaps.



The thermal balance on the external surface T_{al} is given by Equation (1):

$$\phi_{sky} + \phi_{env} + \phi_{sol} + \phi_{conv,cond} = \phi_{al\text{->}int} \quad (1)$$

where φ_{sol} - incident solar radiation (W/m²);
φ_{sky} and φ_{env} - longwave radiative flux density from the sky and from the surrounding environment (W/m²);
$\varphi_{conv,cond}$ - conducto-convective flux density between the ambient air and the wall (W/m²);
$\varphi_{al\text{->}int}$ - conductive flux density towards the interior (W/m²).

The conducto-convective term is an affine form adapted from (McAdams, 1994) which introduces a fixed value and a variable depending on the wind velocity (Equation (2)).

$$\phi_{conv,cond} = (5.7 + f_{wind}.V_{wind}).(T_{ext} - T_{al}) \quad (2)$$

As for the longwave radiations, they are expressed in a linearized form of radiative transfers (Dugué, 2013), respectively involving variable exchange coefficients f_{sky} and f_{env} (Equation (3)). From 0 to 1, they embed the emissivity of aluminium and view factors, or an equivalent when flaps are closed:

$$\phi_{sky} = f_{sky}.\sigma.(T_{al}^2 + T_{sky}^2).(T_{al} + T_{sky}).(T_{al} - T_{sky}) \quad (3)$$

where σ - Stefan Boltzmann constant;
T_{sky} - sky temperature (K) approximated with (Duffie & Beckman, 2013).

Finally, φ_{sol} can be expressed as the sum of $\varphi_{sol,abs}$ and $\varphi_{sol,ind}$, respectively the transmitted intake from the prototype and absorbed by the aluminium, and the indirect intake absorbed through the flaps:

$$\phi_{sol,dir} = \tau.\alpha_{alu}.G \quad (4)$$

$$\phi_{sol,ind} = f_{sol}.G \quad (5)$$

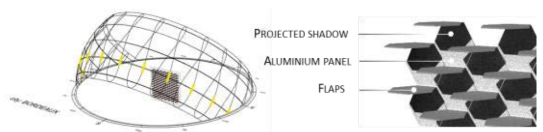
where τ - Projected sun ratio calculated with geometric models (-);
α_{alu} - Absorption coefficient of aluminium (-);
G - Incident vertical solar radiation (W/m²);
f_{sol} - Incident intake through the flaps (-).

The assessment of the prototype involves the identification of several parameters: f_{sol}, f_{sky}, f_{env}, f_{wind}. As for τ, the use of a geometrical model helped determine its value.

4.2 Geometric model

A geometric model of the prototype was made using Grasshopper in the CAD Rhinoceros software. Setting the measurement configurations (south orientation, 90° opening of flaps), we could calculate the vertically projected sun ratio τ on the tested façade (Fig. 6). A comparison of the simulations with measured projections validated the geometrical modelling.

Figure 6:
Shaded surfaces calculation using sun projection during the measurement periods.



4.3 Sensitivity analyses

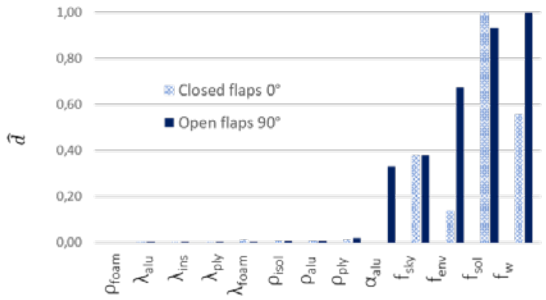
The model was simulated using the Software OpenModelica. Before identifying unknown parameters, sensitivity analyses were performed to ensures that the model is relevant and that the optimization is focused on the parameters with the greatest impact on the model error. All the parameters of the model were first included in a Morris sensitivity analysis (Morris, 1991) performed on a quadratic error cost function calculated between the measured and simulated T_{ply}. For each analysis, the used dataset is a few days of measurements demonstrating heterogeneous profiles in terms of solar radiations or wind speeds.

Results showed that only f_{sol}, f_{sky}, f_{env}, f_{wind} were to be considered in the case of a closed-flaps configuration, while the open-flaps configuration requires, as expected, optimising the absorption coefficient of the aluminium as well as shown on Figure 7.

Its impact on the model error is due to a rather high projected sun ratio τ as the tests were performed in winter in a localisation where the sun elevation is low at that time of year.

A more thorough analysis calculating estimated Sobol indexes of only impacting parameters then provided a rank of influence between the parameters. The solar, wind and environmental factors (f_{sol}, f_{wind}, f_{env}) appeared as the most influential parameters.

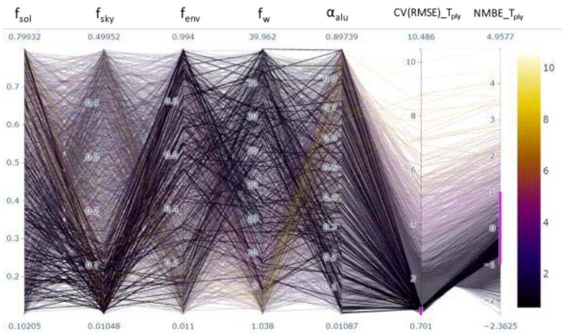
Figure 7:
Normalized Euclidean distance d between the two Morris indices (μi,σi).*



The parallel-coordinate visualization of this sensitivity analysis showed for closed flaps that simulations were under-estimating the temperature node of the model, pointing out missing information in our modelling or potential measurements errors.

For open flaps, it indicated low values of the celestial factor with rather high values for f_{env}, for "centred" estimations and low quadratic errors. The solar factor and α_{alu} seem to compensate each other as they are both impacting the solar intake (Fig. 8). Dissociating them during the optimisation may not be easy.

Figure 8:
Parallel-coordinates graph mapping all the solutions for the open-flaps configuration with their mean (NMBE) and quadratic errors (CV(RMSE)).



Note: CV(RMSE) (Coefficient of Variation of the Root Mean Square Error) is the coefficient of variance of the quadratic error indicating the results' dispersion (Ruiz & Bandera, 2017). Its value is between 0 and 1. The filtered solutions, low CV(RMSE), are color-coded by the NMBE on T_{ply}.

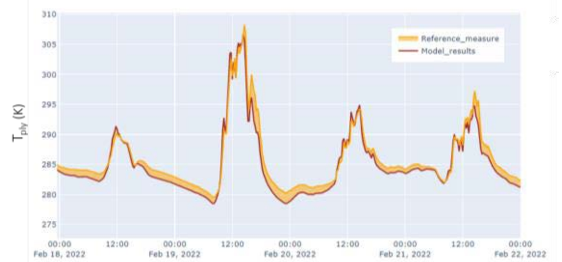
4.4 Identification

The optimization method was chosen as a stochastic approach i.e., using pseudo aleatory exploration processes. Customized programs in Python Environment were used to conduct an optimization analysis on the model with genetic algorithms, with CV(RMSE) as the cost function. Results of the optimization is given in Table 1.

Table 1:
Comparison of parameters between open and closed flaps.

	Closed flaps 0°		Open flaps 90°	
Parameter	Value	CV(RMSE)	Value	CV(RMSE)
f_{sol}	0.16		0.32	
f_{wind}	0.020	0.65%	7.1	0.61%
f_{sky}	0		0.11	
f_{env}	0.0013		0.55	
α_{alu}	N/a		0.15	

Figure 9:
Comparison of the model prediction and measurements during a validation period.



Note: The validation period is a 4-day period different from the one used for the sensitivity analysis and the calibration.

5. DISCUSSION

The two configurations showed different results. Despite closed flaps, a solar factor f_s of 0.16 means that 16% of the incident solar flux is absorbed by the aluminium layer. The total solar intake for open flaps is at least twice as high because it includes both a solar factor of 0.32 and a direct contribution from the projected sun.

The wind speed factor f_{wind} is to be compared to the index proposed by (McAdams, 1994) of 3.4, which reflects the wind protection provided by the flaps. When flaps are opened, the value of 7.1 is consistent with the reference value, showing convection due to the wind included in the energy balance of the wall. When closed, the wind factor becomes insignificant.

The optimization algorithms tend to minimize the celestial factor for both cases, whatever the initial conditions, suggesting a biased contribution of radiative exchanges with the celestial dome for the model. As expected, the radiative exchange factor with the environment indicates a very low value for closed flaps but higher when opened, with a value of 0.55 consistent with a view factor.

Unfortunately, there is a systematic error on the predicted temperature at night, foreseen by the parallel plot and an off-centred NMBE, whose origin remains unknown. In future work, the model could be discussed on its perimeter, on the modelling of the error itself or more likely on the measurement.

6. CONCLUSION

This paper presents the exploration of a bioinspired design process. We focused on understanding and describing specific biological models, and exploiting the emerged database during conception workshops. To carry the process through, we selected one of the proposed concepts and transferred it into a technological design, that we prototyped and assessed. The next steps are to test the thermo-reactive coating and assess its contribution to the actual design. On the other hand, a deformable design is currently under construction.

Delving into the whole design process of a bioinspired envelope element has been rather complex. It reinforced the observation of practical difficulties to push to the market envelope systems that combine multiple functions, as their assessment require specific modelling on a medium scale, or before/after evaluations for full scale integrations. Also, the transfer to a technical solution highlighted many challenges in terms of materials, scaling, durability issues, even for a façade test as small as 1m².

The next steps would be a full scale prototype to be integrated into existing buildings, and be controlled and manipulated by their occupants. If the colour change is intended to be auto-reactive and bring intrinsic performance, the deployment and deformation is expected to be manipulated by the building users. Their experience and acceptability are part of the successful integration of this new design into buildings, as well as the overall design performance in terms of solar protection and comfort.

If the implementation appears to be the blockchain in the design process, the earlier steps are crucial as well. In this study, we intentionally chose to prototype a concept combining many features, using both low-tech (mechanical orienting flaps) and high-tech (thermo-chromic paint) approaches. However, unless the principle is in fracture with actual building envelopes, the implementation could be eased by focusing on how to adapt existing systems during the transfer-to-technology step.

Additionally, further work on the biological database handed over to architects and engineers during the creativity phase could be done. The abstraction of a biological model into envelopes principle relied on the level of information and degree of understanding the designer got from our database. Without restricting creativity, more function- or goal-oriented solutions could emerge with the proper data structuration or angle of analysis.

ACKOWLEDGEMENTS

This research is supported by the New Aquitaine region and the French National Research and Technology Association (ANRT).

REFERENCES

1.Berthier, S. (2005). Thermoregulation and spectral selectivity of the tropical butterfly Prepona meander: A remarkable example of temperature auto-regulation. *Applied Physics A*, *80*(7), 1397-1400. https://doi.org/10.1007/s00339-004-3185-x

2.Chirazi, J., Wanieck, K., Fayemi, P.-E., Zollfrank, C., & Jacobs, S. (2019). What Do We Learn from Good Practices of Biologically Inspired Design in Innovation? *Applied Sciences*, *9*(4), 650. https://doi.org/10.3390/app9040650

3.Cruz, E., Hubert, T., Chancoco, G., Naim, O., Chayaamor-Heil, N., Cornette, R., Badarnah, L., Raskin, K., & Aujard, F. (2021). Design processes and multi-regulation of biomimetic building skins: A comparative analysis. *Energy and Buildings*, *246*, 111034. https://doi.org/10.1016/j.enbuild.2021.111034

4.Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes / John A. Duffie, William A. Beckman* (4th ed). John Wiley.

5.Dugué, A. (2013). *Caractérisation et valorisation de protections solaires pour la conception de bâtiments : Analyse expérimentale et propositions de modélisations*.

6.Hubert, T., Dugué, A., Vogt Wu, T., Aujard, F., & Bruneau, D. (2022). An Adaptive Building Skin Concept Resulting from a New Bioinspiration Process: Design, Prototyping, and Characterization. *Energies*, *15*(3), 891. https://doi.org/10.3390/en15030891

7.ISO 18458:2015. (2015). *Biomimétique—Terminologie, concepts et méthodologie* (TC 266).

8.McAdams, W. H. (1994). *Heat Transmission* (3rd Edition). McGraw- Hill.

9.Morris, M. D. (1991). Factorial Sampling Plans for Preliminary Computational Experiments. *Technometrics*, *33*(2), 161-174. https://doi.org/10.1080/00401706.1991.10484804

10. Ruiz, G. R., & Bandera, C. F. (2017). Validation of Calibrated Energy Models: Common Errors. *Energies*, *10*(10), 1587. https://doi.org/10.3390/en10101587

11. Teyssier, J., Saenko, S. V., van der Marel, D., & Milinkovitch, M. C. (2015). Photonic crystals cause active colour change in chameleons. *Nature Communications*, *6*(1), 6368. https://doi.org/10.1038/ncomms7368

PLEA STGO 2022

November 22 - 25, 2022

CHALLENGES FOR DEVELOPING COUNTRIES

DAY 02
10:15 — 11:45

CHAIR
ALEJANDRA SCHUEFTAN

PAPERS
1136 / 1345 / 1211 / 1677 / 1245

16TH PARALEL SESSION / ONSITE

WILL CITIES SURVIVE?

Roadmap towards energy-efficient buildings at a city perspective

Case of study of Florianópolis, Brazil

MARIA ANDREA TRIANA[1], MATHEUS S. GERALDI[1], ANA PAULA MELO[1], ROBERTO LAMBERTS[1]

[1] LabEEE, Federal University of Santa Catarina, Florianópolis, Santa Catarina, Brazil

ABSTRACT: This study aims to propose a roadmap to achieve nearly zero-energy and net-positive energy buildings in a Brazilian municipality as an outcome of the Efficient Cities Project case study. A general perspective of the energy consumption in the past few years is shown and associated with the building stock's floor-plan area to estimate the future condition of both building stock and its energy consumption. Three main axes were proposed to reduce the estimated energy consumption: (a) actions focused on the public sector, (b) actions focused on the private sector and (c) actions focused on building operation. The roadmap shows possible reduction on energy and emissions at the city level with the actions proposed in a significant part of the building stock and 3 scenarios for integration with renewables. The maximum reductions estimated in the best scenario in the year 2030 were 25% for the residential sector and 34% for the commercial/ services sector regarding the year 2005, showing a path to the city towards the world goals expected for the year 2050 of carbon neutrality.
KEYWORDS: Energy efficiency, Cities, Roadmap

1. INTRODUCTION

The last report of IPCC in 2021 showed that human society is already living under effects of climate change [1]. The Brazilian National Determined Contribution (NDC) to the Paris Agreement was ratified for the COP26 Conference in 2021, with the commitment to mitigate 50% of its greenhouse gas (GHG) emissions by 2030, (using the year 2005 as a baseline and the Fourth National Inventory of Emissions as a reference) and achieve carbon neutrality by 2050 [2].

Energy consumption in buildings is responsible for a significant share of carbon emissions in Brazil. According to the Brazilian National Energy Report, the residential, public and commercial buildings accounts for around 52.0% of the total electricity consumed in the country, which corresponds to around 25 $MtCO_2eq$ in 2019 (pre-pandemic Scenario) [3]. Country's public policies, as the 2030 Ten-Year Energy Expansion Plan, points out the prospects for the expansion of the sector between 2021 and 2030 [4]. The plan foresees the growth of energy demand in the residential sector and considers an increase in the importance of electricity as the main final use in the sector, with an expected growth of 3.4% per year, due in particular to a greater ownership of home appliances and a greater propensity to use conditioned environments, also induced by climate change and effects like heat waves. For the commercial and public buildings sector shows, an estimated growth in energy demand of 2.6% per year between 2019 and 2030, being the sector that was most affected by the Coronavirus pandemic. Therefore, actions to transform buildings into more energy-efficient consumers are important to reduce the environmental impacts and, consequently, achieve the intended NDCs.

Cities administrations have started taking action to mitigate climate change effects. The C40 initiative is an example of this effort led by the 40 more populated cities in the world, which aims to fight climate change and drive urban action to reduce greenhouse gas emissions and climate risks, increasing health, wellbeing and economic opportunities of urban citizens [5]. Although few guidelines tailored for cities are found in Brazil, the “Efficient Cities Project” aimed to implement energy-efficient actions in some selected Brazilian cities alongside their municipal administrations in a suitable way for their reality.

Therefore, this study aims to propose a roadmap to achieve nearly zero-energy and net-positive energy buildings in a Brazilian municipality as an outcome of the Efficient Cities Project case study. A general perspective of the energy consumption in the past few years is shown and associated with the building stock's floor-plan area to estimate the future condition of both building stock and its energy consumption. Then, three main axes were proposed to reduce the estimated energy consumption: (a) actions focused on the public sector, (b) actions focused on the private sector (that will be presented in more detail) and (c) actions focused on building operation. The roadmap shows possible reduction on energy and emissions at the city level with the actions proposed.

2. THE EFFICIENT CITIES PROJECT

The Efficient Cities project (in Portuguese "Cidades Eficientes") is an ongoing project carried out by the Brazilian Council for Sustainable Construction (in Portuguese "Conselho Brasileiro de Construção Sustentável" - CBCS) which begun in 2018. The first goal was to support municipal governments in promoting actions towards greenhouse gas emission reductions related to energy and water consumption in municipal buildings. Three cities in Brazil were chosen to join the initial phase of the project, including Florianópolis, capital of Santa Catarina State, in the south of Brazil. In November 2019, began the second phase of the project extended until June 2021 and aimed to structure elements of governance and public policies for the city administration, capable of implement permanent measures for energy efficiency of public and private buildings with reduction in greenhouse gas emissions and resilience in face of climate change. Florianópolis selected as a single case study established the Floripa Efficient City Program (in Portuguese “Programa Floripa Cidade Eficiente”). Three main subtasks were instituted: (a) developing an integrated platform for electricity and water management of the municipal building portfolio; (b) training municipality staff members in energy efficiency topics; and (c) proposing suggestions for public policy related to energy efficiency, including an energy building code to increase efficiency in public and third party buildings. A partnership between CBCS and the Laboratory of Energy Efficiency in Buildings (LabEEE) of the Federal University of Santa Catarina (UFSC) was also set up for collaboration on the project to aid in the building stock modelling process for the energy building code. The final result of the third subtask was a comprehensive roadmap to move the buildings of the evaluated city towards an energy-efficient scenario comprising nearly zero-energy or net-positive buildings considering the timeframe of 2030, which will be the focus of the presented study.

3. METHOD

3.1 City characterisation

The city of Florianópolis located in Southern Brazil, in a climatic zone Cfa (Köppen-Geiger classification), has a population of 500.973 people in 2019 [6], a territorial area of 674,844 km², Gross Domestic Product of US$ 6.9 billion in February 2015 and the Human Development Index (HDI) was 0.847 in 2010.

3.2 Data

The building stock is the organized record of the buildings. It is essential that all energy efficiency proposals for buildings at the city level have as starting point technical criteria based on analysis of the building stock contained in the municipality. Two sources of data were used to model the analysis of this study:

1. Yearly electric energy consumption at the city level broke down for use type from 2005 to 2019. It was acquired from the utility company (in kWh/year).
2. Information of the city building stock accounting all constructed area built in the city year-to-year, until 2019 (in m²), acquired from the municipality administration from two databases that account with different information: a) database of municipality’s register buildings of the Urban Planning Institute of Florianópolis (IPUF/PMF) – used to collect municipal taxes; and b) database of projects approved and licensed for construction by the Municipal Secretary of Urban Development (SMDU/PMF). With this, it was possible to identify the percentage of the main built typologies, average and median built area.

3.3 Model of the baseline scenario

The baseline scenario was modelled considering several regression analyses of both energy consumption and floor-plan area, using a interval from 2005 to 2019. A regression model with high R^2 and low root mean squared error was adopted as the baseline scenario. The equation was used to predict 2020 to 2030 yearly energy consumption and floor-plan area growing.

3.4 Strategies to reduce energy consumption

Three main axes were delineated to model strategies to reduce energy consumption considering the public sector, the private sector and the building operation (Table 1). Specific models were addressed to assess the potential impact of each action. The main impactful axis is regarding strategies for the Private Sector, which accounts for 82% (residential and commercial/services buildings typologies) of the city energy consumption [7].

Table 1: Strategies to reduce the energy consumption of the building stock.

Axis	Strategy
Strategies for the Public Sector	Internal Benchmarking
	Requirements for building construction
	Requirements for building integrated energy generation
	Energy efficient purchasing

Axis	Strategy
Strategies for the Private Sector	Requirements for building construction
	Requirements for building integrated energy generation
Strategies for building operation	Mandatory energy audits
	City-level benchmarking

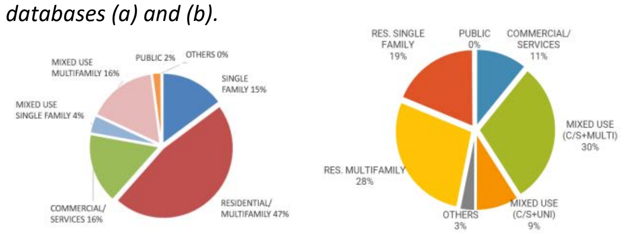
Regarding this strategy, a building stock analysis accounted for the potential impact of energy-efficient measures on the design phase of buildings for new buildings and retrofit for buildings in operation. Reduction factors according to each share of buildings' sizes were applied. Also, three scenarios of building integration with renewables energies were considered, reflecting the generation of 25%, 50% and 100% of building energy demand.

4. RESULTS

4.1 Building stock and city energy consumption

Although information from more years was available, the main focus of the built area analysis were buildings built from 2014 to 2019 that converges with the initial year of the municipality´s Master Plan last revision. 5,037 buildings from database (a) were built in the city in that period representing 5,3% of the total buildings in the city since 1,800. From database (b) 4.931 projects were approved (Figure 1).

Figure 1:
Building typology data by built area from 2014 to 2019 from databases (a) and (b).

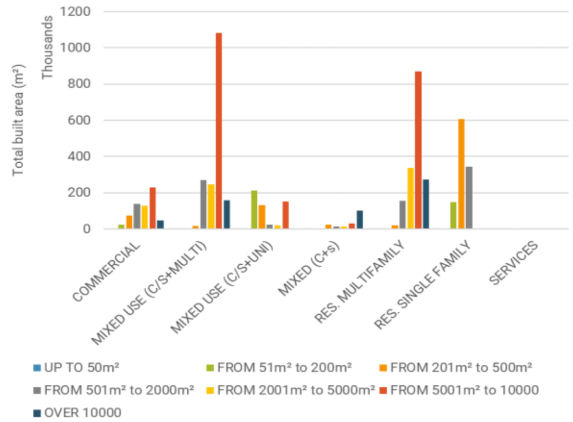


Both databases showed the preponderance of the multifamily residential typology followed by the single-family residential and commercial/services typologies, being those three typologies, the focus of the main criteria proposed in the roadmap.

An overview of the size of the existing buildings in the municipality is shown in Figure 2 that presents the buildings from database (b) organized as function of the total built area. The propositions adopted on the roadmap considered the most representative groups within each typology and allowed to determine the limits of the built area for the application of the proposed requirements of energy efficiency (Figure 2).

The ranges with the largest area and representing at least 50% of the typology stock were selected to apply the requirements proposed in the roadmap. From Figure 2, most of the built-up area consists of mixed/multifamily buildings and multifamily residential buildings in the range from 5,001 m² to 10.000 m², and single-family buildings from 201 m² up to 500 m². Commercial/services buildings have similar representation in all ranges, but from 2,001 m² onwards represent 63% of the stock.

Figure 2:
Projects from Database (b) from 2014 to 2019, distributed by frequency of occurrence of the built area range in m².

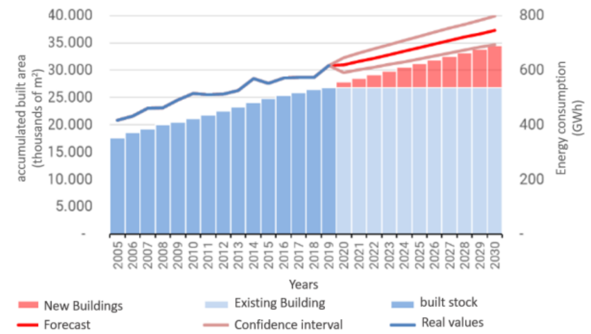


The analysis of energy consumption at the city level, showed that the entire building stock is responsible for 85% of the electricity total consumption in the municipality of Florianópolis. The remaining 15% refers to public lighting, rural and industrial consumption. The integration of database (a) with energy consumption of the municipality made possible to measure the energy consumption by typology and estimate future growth trends. Figure 3 shows information combining building stock growth data and energy consumption from 2005 to 2019, which allowed for estimating trends from 2020 to 2030 for residential (Figure 3a) and commercial/services buildings (Figure 3b). It is shown the current situation of the building´s stock in terms of built area accumulated in the municipality from 2005 to 2019 (blue bars), and its growth forecast until 2030 (red bars). From 2020 to 2030 the stock already built up to date will remain built (light blue bars). In addition, also shows the total energy consumption by the municipality's buildings registered until 2019 (blue line), and its growth trend until 2030 (red line), with a confidence interval that was calculated (light red lines).

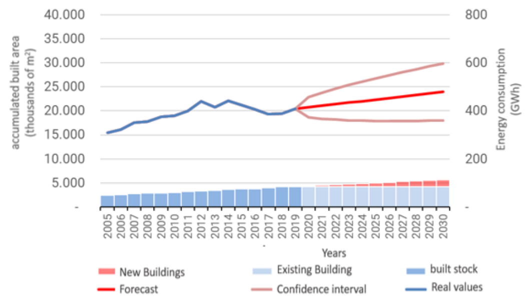
Residential buildings had a building area growth of 34% from 2005 to 2019 while commercial/services buildings was 42%. In energy consumption for the residential sector, the increase was of 32% in the same period, while in the commercial/services sector was 24%, that is, a growth of 2.3% per year for the residential sector and 2.6% per year for the commercial/services sector.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

Figure 3:
Estimate of accumulated built-up area from the stock and energy consumption of buildings in Florianópolis from 2005 to 2019 with trends for 2030. Source: Database (a) and information from CELESC - Electric Utility.



a) Residential sector



b) Commercial/services sector

From Figure 3, the commercial and service sector represent only 11.5% of the total built area from the city building stock but is responsible for 35% of the total electricity consumption in Florianópolis. The residential sector, holds 71% of the total built area, being responsible for 47% of consumption. Together, the residential and commercial/services sectors account for 82% of the municipality's total energy consumption. The focus of actions on existing buildings should start with the residential and commercial/services sector. The consumption per square meter in the commercial/services sector, regarding and average for 2005 to 2019 was 117.5 kWh/m²/year while for the residential sector was 23,1 kWh/m²/year.

It is also noteworthy in Figure 3 that the existing buildings make up a substantial portion of the built stock. In this way, actions aimed at energy efficiency of existing buildings are as necessary as for new buildings, as they represent a significant impact on the total energy consumption of buildings in the municipality.

4.2 Strategies to reduce energy consumption

Strategies for public sector buildings were established together with the city municipality and included the implementation of an online platform developed by CBCS for the management of integrated energy and water consumption in public buildings (which allows for an internal benchmarking), in addition to the creation of public policies that included guidelines for the operation of buildings by users and for energy efficient purchasing. Both the public and private sectors must follow the requirements considered in the energy code, which also includes requirements for the integration of renewable energy in buildings. And for buildings in operation, benchmarking practices and mandatory energy diagnostics linked to the sale and/or rent of commercial buildings were recommended (Table 1).

The requirements for energy efficiency in the energy code proposed considered the typologies observed as being the most significant in the study carried out. The requirements for the Private Sector apply to single-family residential buildings larger than or equal 200m², multi-family buildings larger than or equal 2,000m², commercial/services buildings larger than or equal to 2,000m². Mixed buildings follow the same requirements as the respective typology. These typologies and areas were considered for the estimated energy consumption reduction scenarios for the 2030 horizon. The criteria considered are applicable to new buildings and renovations.

The requirements addressed for residential buildings (single-family and multi-family) refer to the external elements of the building envelope (walls, roofs and windows) for thermal performance, criteria for natural lighting performance and the water heating system. It is emphasized that all new residential buildings in Brazil already must comply with the standard ABNT NBR 15575, fulfilling at least its minimum criteria, which include, among others, thermal and lighting performance criteria. The study proposed a greater requirement (beyond the minimum level) for a portion of these buildings, with the objective of increasing the energy efficiency of buildings in the municipality.

The requirements addressed for commercial/ services buildings refer to the external elements of the building envelope (walls, roofs and windows).

For both residential and commercial/services buildings, criteria for the incorporation of renewable energy, efficient equipment and prevision of charging for electric vehicles, were included on the requirements for building construction. Although for the roadmap and energy reductions calculations, only the criteria for the envelope and introduction of renewables was taken into account.

The requirements defined for the residential typology were determined based on the national thermal performance standard ABNT NBR 15575 from 2021. For commercial buildings, a study was carried out together with LabEEE based on the Energy Label Regulation for commercial buildings (INI-C).

An example of the requirements for multifamily residential buildings is presented as follow:

Buildings from 2.000 m² up to 5.000 m² - Level required considering the standard NBR 15575 for:

Thermal comfort: At least 15% of the housing units in the project must have an intermediate level

Lighting comfort: At least 15% of units must be intermediate level in their main rooms.

For energy renewable, provision for the installation of a photovoltaic energy system or other renewable energy system on site to meet at least the estimated annual electricity consumption for common areas and provision of an electrical point in at least one fixed parking space for each residential unit or a charging station for public use to serve at least 10% of the total parking spaces.

For hot water it is recommended that the water heating system follow the design and installation guidelines given by the Brazilian Labelling Program for Residential Buildings, called INI-R, considering the efficiency level A.

And when applicable for efficient lighting, the power density was limited to 5 W/m². For air conditioners, the equipment should be class A in the Brazilian Labelling Program, according to the classification given by Inmetro in 2020, equipped with refrigerant fluid that does not affect the ozone layer, or labeled with the energy conservation Seal Procel, that indicates the most efficient equipment.

For commercial buildings, results of the study carried out with LabEEE/UFSC that sought to established requirements on the building envelope for potential buildings class A level in the Brazilian Energy Labelling Program, were the base of the requirements. The criteria took into account the number of floors, window to wall ratio, solar heat gain coefficient of the external windows, thermal properties as thermal transmittance and capacity and solar absorptance for external walls and roofs. Requirements for provision of installation of renewables and electric cars were also considered, as well as requirements for efficient lighting, air conditioning and hot water system.

The compliance with all requirements is self-declaratory through a document proposed.

The potential reductions estimated with adoption of each of the measures suggested were taken into account in order to established scenarios of future behaviour. The criteria are placed by area range within each typology. A rate of renovation of the built stock of 1.5% per year was adopted based on international studies [8], due to the lack of more accurate national data. The reduction criterion was based on national studies when possible for the residential and commercial/services sector (Table 2a and b).

Table 2: Criteria for establishing scenarios and consumption targets predicted for 2030 in the city of Florianópolis.

Typology		Existing area in 2019 (accumulated)	Area expected for 2030	Criteria used to calculate impacts
Single Family Residential	Less than 200 m²	6.151.527,87	7.943.991,62	There is criteria for HIS, but it was not accounted for calculating the goals.
	De 200 a 349 m²	4.093.235,81	5.285.943,86	Reduction of 27% of the thermal load due to the requirement of NBR 15.575 (Intermediate level), considering that 40% of the final end uses of the building are due to HVAC plus reduction of 20% due to mandatory solar water heating system or efficient system
	From 350 to 499 m²	1.344.238,92	1.735.930,15	
	From 500 to 2.000 m²	956.083,58	1.234.672,12	Reduction of 55% of the thermal load due to the requirement of NBR 15.575 (Intermediate level), considering that 40% of the final end uses of the building are due to HVAC plus Reduction of 25% due to mandatory solar water heating system or efficient system.
	Acima de 2.000 m²	205.120,64	264.889,74	
Multifamily Residential	Less than 2.000 m²	1.666.296,97	2.151.831,13	Minimum level of NBR 15.575
	From 2.000 to 5.000 m²	3.119.025,53	4.027.863,19	Reduction of 20% of the thermal load due to the requirement of NBR 15.575 (Intermediate level), considering that 40% of the final end uses of the building is due to HVAC, applied in 15% of the buildings plus reduction of 20% due to efficient water heating system, applied to 15% of buildings.
	From 5.000 to 10.000 m²	3.371.409,55	4.353.788,16	Reduction of 20% of the thermal load due to the requirement of NBR 15.575 (Intermediate level), considering that 40% of the final end uses of the building is due to HVAC, applied in 25% of the buildings plus reduction of 25% due to efficient water heating system, applied to 20% of buildings.
	Over 10.000 m²	5.850.134,22	7.554.776,34	Reduction of 35% of the thermal load due to the requirement of NBR 15.575 (Intermediate level), considering that 40% of the final end uses of the building are due to HVAC, applied in 20% of the buildings plus reduction of 40% due to efficient water heating system, applied to 40% of buildings.

a) Residential buildings

Typology		Existing area in 2019 (accumulated)	Area expected for 2030	Criteria used to calculate impacts
Commercial and Service	Less than 2.000 m²	2.782.144,50	3.704.343,16	-
	Over 2.000 m²	4.287.748,24	5.709.010,04	20% reduction due to requested requirements

a) Commercial/services buildings

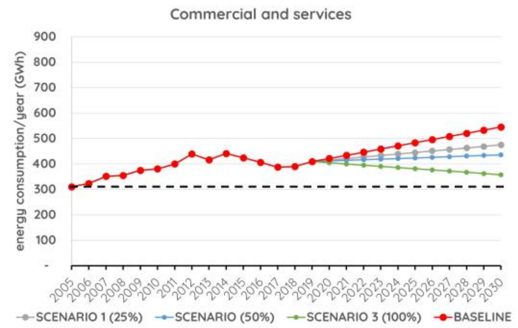
For the scenarios creation, it was considered the reduction in consumption both due to the impact of the proposed actions of energy efficiency in the building envelope and hot water system (Table 2), as well as the incorporation of renewable energy that could supply 25%, 50% or 100% of the total energy consumption in the applicable typology of buildings.

Considering the different scenarios of renewable energy in the new buildings and retrofit, it is possible to reduce the energy consumption expected for 2030 in the residential sector from 796 GWh to 722 GWh in the scenario that considers the adoption of 25% of energy renewable sources. In a scenario of 50% insertion of renewables, the estimated consumption would be 679 GWh and in the most optimistic scenario (of 100% renewable), the reduction would be to 593 GWh in 2030. For the commercial/services sector, there is the potential to reduce by 545 GWh (estimated consumption for 2030) to 475 GWh in the 25% renewable scenario, or 436 GWh in the scenario of 50% insertion of renewables, reaching up to 358 GWh in the most optimistic scenario (100% renewable).

The results can be observed in the figures for typologies residential and commercial/services, estimated for 2030 in relation to consumption in 2005 (segmented line), considering growth trend in energy consumption observed until 2019. The maximum reductions estimated in the best scenario (scenario 3) in the year 2030 were 25% for the residential sector and 34% for the commercial and services sector, as shown in Figure 4a and Figure 4b respectively.

Figure 4:
Scenarios of energy consumption in Florianópolis.

a) Residential buildings



b) Commercial/services buildings

5. CONCLUSIONS

This study aimed to propose a roadmap to achieve nearly zero-energy and net-positive energy buildings in a Brazilian municipality. A case study for Florianópolis was selected. A set of actions regarding requirements for building construction, integration with energy generation, energy benchmarking and energy audits were considered. The main conclusions were:

- Residential and commercial/services buildings, which account for 82% of the total city energy use, should be the main target for energy efficiency actions.
- An analysis of the building stock and energy consumption at the city level gives important data in order to set up and forecast goals.
- Energy efficiency criteria for retrofit is as important as for new buildings.
- Criteria for the envelope, water heating system, equipment and lighting alone are not sufficient to meet the national targets for emissions reduction and decrease the growth trend of energy consumption in buildings, being necessary the introduction of renewable energy generation within the buildings.
- Reductions from 10% to 25% in the residential sector and from 13% to 34% in the commercial/services sector in relation to 2005 consumption can be achieved with energy efficiency requirements and the introduction of renewables in order to supply from 25% up to 100% considering buildings with higher areas that represent at least 50% of the new buildings in those typologies and a retrofit renovation of 1,5% year.

Finally, the implementation of energy codes in cities is one of the most important actions of energy efficiency to make cities more sustainable.

ACKNOWLEDGEMENTS

The authors thank the municipal administration of Florianópolis that kindly contributed with indispensable information for this study. The data used in this research was made available by the Project "Cidades Eficientes", conducted by CBCS ("Conselho Brasileiro de Construção Sustentável") and financed by ICS ("Instituto Clima e Sociedade"). We also thank Clarice Degani (CBCS coordinator) and Carolina Griggs for their valuable collaboration during the project.

REFERENCES

1. IPCC (et al.) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021.
2. NDC Registry, (2021). Available at: https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx
3. BRAZIL, EPE. National Energy Balance, Report (2020). [in Portuguese].
4. BRAZIL, MME, EPE. Ten-Year Energy Expansion Plan 2030 (2021). Available at: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-490/PDE%202030_RevisaoPosCP_rv2.pdf
5. P. Mathew, R. Mitchell, T. Walter, Using Data for Policy: a manual for C40 cities, LBNL. Energy Technologies area, 2018.
6. IBGE, Brazilian Institute of Geography and Statistics. Population Estimate, (2021). www.ibge.gov.br.
7. CELESC, Energy consumption tariffs, (2018). [in Portuguese].
8. I. Artola, K. Rademaekers, R. Williams, Jessica Yearwood, Boosting Building Renovation: What potential and value for Europe?. European Parliament. Policy Department: economic and scientific policy. 2016. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU(2016)587326_EN.pdf

PLEA SANTIAGO 2022

Will Cities Survive?

Participatory learning methods to improve energy efficiency in Chilean residential sector

Public programs to support self-management

ALEJANDRA SCHUEFTAN[1,2] RENÉ REYES[2] FLORENCIA AGUILERA[2]

[1] Instituto de Arquitectura y Urbanismo, Facultad de Arquitectura y Artes, Universidad Austral de Chile
[2] Instituto Forestal, Chile

ABSTRACT: Housing deficit, poor construction quality and energy poverty are problems of high relevance in Chile, with greater incidence in the central and southern regions. In this area there is an extreme dependence on firewood for heating due to the cold climate, low energy efficiency of houses and the availability of firewood at a low price. Public programs to improve energy efficiency in existing dwellings have had a reduced impact due to several economic, behavioural and administrative barriers. This study aims to test participatory methods in a pilot retrofit program that includes practical training for households from two medium-low income neighbourhoods in the city of Valdivia in southern Chile. The training focused on simple and low-cost construction techniques to improve the thermal insulation and air-tightness of dwellings in a self-managed manner. The methodology aims to identify the key components of engagement that were used in the pilot and the effectiveness of the program based on recordings of indoor temperature before and after the retrofit. Results show that the pilot incorporated participatory components that current public programs do not consider and that, according to international experiences would encourage participation and therefore effectiveness of the programs. Furthermore, an average gain of 3.17°C in indoor temperature after the energy efficiency improvements was measured and 50% of the improved dwellings maintained an indoor temperature above the 18°C threshold during the winter.

KEYWORDS: Energy efficiency, Energy poverty, Retrofit programs, Residential sector, Chile,

1. INTRODUCTION

1.2 Chilean housing policy: impacts in energy poverty and air pollution

From 1974 onwards, housing policy in Chile underwent a deep change in response to the sharp reduction in the responsibilities assumed by the State in a highly polarized political context. Under the new neoliberal approach, a subsidiary policy was developed, aimed at reducing the country's housing deficit in the 1970s through the massive construction of low-cost social housing. These social housing projects continued to grow in the 1990's, which resulted is more than 212,000 new houses being built between 1974 and 2000 [1]. Despite the fact that this policy has reduced the housing shortage in Chile over the past decade, it also brought with it many problems in terms of living space, location, and technical quality of dwellings [2]. Furthermore, currently Chile presents an historical maximum in the number of informal settlements since 1996, with a steady increase since 2014, and a structural break since 2019 that has accelerated the process [3]. In addition, the number of unrecoverable houses increased from 0.6% to 1.5% in the period 2002-2017 [4].

In this context, energy poverty is a serious problem to the whole country and with greater prevalence in the central and southern regions. This is a consequence of the extreme dependence on firewood for heating due to the cold climate, low quality of houses and the availability of firewood at much lower prices than other fuels like electricity or gas [5,6]. In these regions the use of firewood in the residential sector rises up to more than 80% in urban areas and more than 95% in rural areas [6]. Air pollution due to the combustion of large amounts of firewood, high household expenditure in energy and low levels of comfort inside dwellings are the consequence of a significant percentage of the population living in some level of energy poverty [5,6].

Research shows that poor quality of houses with low energy efficiency are the primary cause of this problem, forcing households to use heating devices most of the day [7,8]. This can be explained due to Chile's housing policy presented above and the relatively new implementation of thermal regulations for new buildings in the country (first stage in 2000 and second stage in 2007). Therefore, nearly 70% of the houses in Chile were built before its implementation [7,8] and do not comply with thermal standards, which implies that they are not capable of maintaining an adequate indoor temperature without the use of large amounts of energy.

To address the problem of air pollution, the State has developed Atmospheric Decontamination Plans (PDAs), which define measures for the cities that have been declared as saturated areas by particulate matter ($PM_{2.5}$), as is the case of the largest cities in the south-central area of the country. These plans aim to improve air quality and include regulations regarding the use and improvement of heating systems, fuel quality, thermal quality of dwellings and education programs. PDAs have higher thermal requirements than the national thermal regulation, both for new houses and for the retrofit of existing houses. These programs align with numerous studies [8,9] which support the idea of focusing on energy efficiency in the residential sector, and particularly the retrofitting of existing dwellings. Nevertheless, these public programs have had a reduced impact because they have not been able to expand massively due to various barriers that can also be observed in energy retrofit programs in the international context.

1.2 International experiences in retrofit programs

At a global scale, retrofit programs can contribute significantly to reduce global warming, improve energy efficiency in dwellings and can also be a key factor in tackling energy poverty, especially in low-income households. In many countries, the inability of households to afford a warm house is becoming a growing problem and studies in Europe have shown that income inequality is a major factor in the rise of energy poverty. In order to pay high energy bills, poorer households may forgo basic necessities like food and medicine. Furthermore, the energy efficiency of buildings can have a negative impact on residents' mental and physical health, as well as their well-being [10].

According to the EU Commission projection (2016/547/EU), the current average building renovation rate is much lower than the 3% required to reach carbon neutrality by 2050. The average retrofit rate in Europe is 0.4-1.2% per year, with 1.0-3.0% in Germany and 0.4-1.0% in the UK. The residential sector is still a problem in many industrialized countries' energy policies. This sector's current energy efficiency gap is a consequence of market imperfections and the irrational behaviour of residential consumers. Numerous studies have examined the causes of this problem, and how to close this "energy efficiency gap" between retrofit possibilities and their implementation, particularly in low-income households [13].

Current public retrofit programs have not had the expected impact due to several economic, behavioural and administrative barriers. Economic barriers for retrofit in the residential sector include the lack of savings and the inability to get credit to upgrade inefficient appliances or infrastructure. Besides, in the face of uncertain future earnings, poorer households are more likely to be risk-averse. Low-income households may also have behavioural and informational barriers [14] and are less likely to be aware of their energy consumption and the savings that can be achieved by retrofitting [9]. Another barrier to retrofits is a lack of knowledge about available programs. Furthermore, low-income households may choose not to participate in certain programs because they do not address their particular vulnerability or because they misunderstand eligibility requirements [10]. Also, long application processes can be avoided by households, creating significant obstacles to the adoption of energy efficiency measures.

These barriers suggest that new approaches are needed to design retrofit programs. Due to the historic dependence on government support from top-down schemes, as well as the lack of technical skills and awareness among households, co-creation approaches, grassroots initiatives and community-led retrofit programs have emerged recently, approaching the challenge through mixed and community governance [15].

A key way to overcome barriers for retrofit adoption is through community-led approaches. The sharing of learnings among community-led initiatives can contribute to better engagement and to the sharing of existing knowledge, especially between initiatives that have similar focuses or are located in similar areas [15]. These initiatives are designed to engage households, address energy poverty, create local supply chains, and overcome financial obstacles. They may also empower communities to mitigate climate change, improve health and comfort, lower energy bills, and support a green economic recovery after the COVID-19 pandemic [16].

Other innovative models for retrofit programs focus on inclusive work that seek to understand homeowners' motivations and to make inclusive decisions about the retrofits [17]. This approach to decision-making can support the selection of improvements that offer substantial economic and energy benefits [15]. Before any building retrofit is implemented, it is crucial to involve the participants in the co-creation process. The residents of the houses have deep knowledge about their living environment and its problems, so participation is key to address these issues and implement measures that can produce long-lasting effects on their lives [17]. Furthermore, studies and pilot initiatives have demonstrated the importance of homeowners in cooperating and understanding the entire process and the need for energy efficiency improvements. Because of the complexity of the retrofitting process, there can be a major information barrier and the biggest failure in the energy efficiency retrofit is believed to be lack of information. Recognizing homeowners' information requirements for their engagement in the retrofitting process can increase their acceptance of energy efficiency measures [18].

Another emergent approach is the public-private-people partnership that highlights the need for sustainable development through the involvement of public administration, private actors, and citizens in a joint process. International experiences in terms of collaborative and participatory retrofit schemes that include various actors show that within the constraints of limited budgets for retrofit programs and subsidies, the redesign of the programs has the potential to achieve the greatest aggregate improvements in residential energy efficiency [10].

2. PILOT PROJECT

The methodology's first section examines retrofit programs' components, both for the pilot and for the existing public programs in Chile. It then assesses if the components have been identified as being relevant to encourage participation and engagement and, therefore, improve performance [17-18,19]. Key components for engagement were identified in the pilot as well as the potential to include them in current public programs.

The second part of the methodology evaluates the effectiveness of the pilot by comparing indoor temperature before and after the retrofit. Temperature measurements were taken for all 10 houses that underwent retrofit. They were recorded using high-resolution iBUTTON Thermochron. This technology has been very successful for this purpose [20]. The dataloggers were programmed so that they record temperature every 30 min, which allows for continuous monitoring during the months of June and July, both in 2018 and in 2021.

Based on indoor temperature measurements, energy efficiency improvements were compared in three steps:

1- Average indoor temperature between 4 and 6 am for houses in Brisas de Guacamayo 2018.
The average interior temperature of 8 standard dwellings in the neighborhood was measured during June and the first week of July 2018, between 4 and 6 am. In this time range, it is less likely that the heating device will be turned on, and therefore the thermal performance of the dwelling can be measured more clearly without interference from the heating practices of its inhabitants.

2- Average indoor temperature between 4 and 6 am for houses in Brisas de Guacamayo 2021.
The average interior temperature of 8 houses that participated in the pilot was measured, after the energy efficiency improvements. The temperature was recorded during June and the first week of July 2021, between 4 and 6 am.

3- Temperature comparison.
Based on the temperature recordings for each dwelling, the average temperature for the 4 to 6 am period was calculated before and after the imrpovements. These averages were compared to identify if the energy efficiency measures produced an increase in indoor temperature.
The houses in "Altos de Mahuiza" were not included in this comparison, since the number of improved houses was too small to obtain relevant conclusions. One house in "Brisas de Guacamayo" was not included either, due to measurement problems.

4. RESULTS

The results show that the pilot incorporates participatory components that current programs do not consider and that, according to international experiences, would allow increasing participation and therefore improvement of the effectiveness of these programs.

The following table shows the phases and components of current programs and of the implemented pilot in comparison to international recommendations studied by Zang et al. (2021).

Table 1: *phases and components of current public programs and pilot program*

International Recommendations		Current Programs	Pilot Program
Preparation Phase	-Objectives	x	x
	-Building energy data	x	x
	-Identify improvement potential	x	x
Design Phase	-Define and standardize retrofit options	x	x
	-Secure financing incentive bundles	x	x
Pilot and Commissioning Phase	-Engage with high-interest households		x
	-Revise and improve schemes		x
	-Provide financial support for more stakeholders		x
Utility Scale Implementation	-Increase market acceptance		
	-Build industry capacity		
	-Establish bridges between homeowners and professionals		x
	-Promote third party financing		x

Although the pilot considers several innovative components that promote the involvement of the participants, increase market acceptance and the building of industry capacity still needs to be addressed, but exceeded the scope of the project.

The results of the second phase of the methodology are shown in Table 2. In 2018, the average temperature of the Brisas de Guacamayo dwellings was 15.15°C during the studied period in winter, without the use of heating devices. This contrasts with the average interior temperature of 18.32°C measured in the same neighborhood after the energy efficiency improvements of 2021, without the use of heating devices.

Table 2. *Average temperature of houses in Brisas de Guacamayo between 4-6am*

Year 2018		Year 2021	
House	Temp. (°C)	House	Temp. (°C)
A*	14,95	1	17,8
B*	15,68	2 *	15,4
C	18,77	3	19,16
D*	13,91	4	19,89
E*	14,50	5	19,48
F*	13,48	6	16,41
G*	14,79	7	17,71
H	18,62	8	20,73
Average	15,15	Average	18,32

*: houses with indoor temperature below 16°C

This improvement is relevant, since it not only reflects an average gain of 3.17°C in indoor temperature after the energy efficiency improvements, but also implies a considerable reduction in the number of houses with temperatures below 16°C (from 6 to 1). This is considered a threshold below which there are strong increases in the risk of respiratory and blood pressure problems [21]. Furthermore, 50% of the improved dwellings mantained an indoor temperature above the 18°C threshold, which according to the World Health Organization is considered a healthy standard [21].

5. CONCLUSION

The results of the pilot, along with comparisons to international experiences, show that pilot programs encourage learning and produce recommendations for retrofit program design and implementation in order to overcome the barriers that were identified and presented in the previous sections (9, 14). The pilot proved that retrofit programs should be tailored to specific communities and groups to achieve the desired results. There is also an opportunity to include households in energy poverty in retrofit initiatives. These households are not usually involved in retrofit programs but are more likely to participate when participatory schemes are implemented. Pilot initiatives could facilitate the identification of the best components and the best design of the programs in order to accomplish this goal.

Although community-led retrofits are an alternative to government-managed retrofits, they will not be able to provide large-scale residential improvements without the support of a broader government program. Co-creation involves a group of diverse actors in order to create shared values, which can help overcome barriers [15], but these initiatives cannot be only self-managed in order to reach a greater scope and to maintain over time. Collaboration between local authorities and community initiatives is a way to improve efficiency and increase resources. Besides, to increase and expand programs, it is crucial to integrate top-down and bottom-up initiatives. It is also important to encourage coordination between the different institutions [17].

Furthermore, these initiatives have the potential to create other benefits, such as shared social value, democracy and empowerment of the community. It raises awareness about the link between energy use and environmental impacts, and promotes behavioural changes in households as well as in the community [18]. Pilot programs are a good way to experiment with design and implementation, as well as to include other stakeholders such professionals and contractors to help understand the scalability of the initiatives.

ACKNOWLEDGEMENTS

This project was developed by the Forestry Institute and funded by FOSIS (Social Investment Fund) with the technical collaboration of the Ministry of Energy and the Ministry of Housing and Urban Development (MINVU).

REFERENCES

1-Ministerio de Vivienda y Urbanismo (MINVU), (2011). Mapa Social de Campamentos. Santiago, Chile.
2-Rivera, A., (2012). Historia de la política habitacional en el área Metropolitana de Santiago. Revista CIS 16:p. 27-44
3-Centro de estudios socio-territoriales, (2021). Catastro Nacional de Campamentos 2020-2021: Informe Ejecutivo. Santiago, Chile: p. 15-17
4-Ministerio de Vivienda y Urbanismo (MINVU), (2020). Metodología de Cálculo del Déficit Habitacional Cuantitativo Ajustada al Censo 2017. Santiago, Chile.
5- Schueftan, A.; Sommerhoff, J.; González, A. (2016). Firewood demand for heating in South-central Chile: environmental, social and economic issues. Energy for Sustainable Development 33, 26-35.
6-Reyes, R., Schueftan, A., Ruiz, C., (2019). Controlling air pollution in a context of high energy poverty levels in southern Chile: Clean air but colder houses?. Energy Policy, 124: 301-311.
7- Schueftan, A.; González, A. (2013). Reduction of firewood consumption by households in south-central Chile associated with energy efficiency programs. Energy Policy 63, 823-833.
8- Schueftan, A.; González, A. (2015). Proposals to enhance thermal efficiency programs and air pollution control in South-Central Chile. Energy Policy 79, 48-57.
9- Schueftan, A., Aravena, C., Reyes, R. (2021). Financing energy efficiency retrofits in Chilean households: The role of financial instruments, savings and uncertainty in energy transition. Resource and Energy Economics. Volume 66.
10- Pillai, A., Tovar Reaños, M., Curtis, J. (2021). An examination of energy efficiency retrofit scheme applications by low-income households in Ireland, Heliyon, Volume 7, Issue 10.
11- Healy, J.D., Clinch, J. (2004). Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. Energy Policy 32 (2), 207–220.
12- Energy performance of buildings directive, Energy, (n.d.).
13- Dolšak,J., Hrovatin, N., Zorić. J. (2020) Factors impacting energy-efficient retrofits in the residential sector: The effectiveness of the Slovenian subsidy program, Energy and Buildings, Volume 229.
14- Chen, C., Xu, X., Day, J.K. (2017). Thermal comfort or money saving? Exploring intentions to conserve energy among low-income households in the United States. Energy Res. Soc. Sci. 26, 61–71.
15-Putnam, P., Brown, D. (2021) Grassroots retrofit: Community governance and residential energy transitions in the United Kingdom, Energy Research & Social Science, Volume 78.
16- F. Fylan, D. Glew, M. Smith, D. Johnston, M. Brooke-Peat, D. Miles-Shenton, M. Fletcher, P. Aloise-Young, C. Gorse. (2016) Reflections on retrofits: Overcoming barriers to energy efficiency among the fuel poor in the United Kingdom, Energy Res. Soc. Sci. 21
17- Xue, Y., Temeljotov-Salaj, A., Lindkvist, C. (2022). Renovating the retrofit process: People-centered business models and co-created partnerships for low-energy buildings in Norway, Energy Research & Social Science,Volume 85.
18- -Ling Jia, Queena K. Qian, Frits Meijer, Henk Visscher. (2021). How information stimulates homeowners' cooperation in residential building energy retrofits in China, Energy Policy, Volume 157.
19- Haonan Zhang, Kasun Hewage, Hirushie Karunathilake, Haibo Feng, Rehan Sadiq. (2021). Research on policy strategies for implementing energy retrofits in the residential buildings, Journal of Building Engineering, Volume 43.
20- Ruiz-Mercado, I., Canuz, E., Smith, K.R. (2012). Temperature dataloggers as stove use monitors (SUMs): Field methods and signal analysis. Biomass and bioenergy 47, 459–468.
21-OMS (2018). Housing and health guidelines. Geneva: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO.

Design research role in supporting net-zero buildings

MORENO-RANGEL, ALEJANDRO[1]; TSEKLEVES, EMMANUEL[1]; YOUNG, PAUL[1]; HUENCHUÑIR, MARCELO[2]; VAZQUEZ, JUAN MANUEL[2]

[1] Lancaster University, United Kingdom
[2] Latin American Passivhaus Institute (ILAPH)

ABSTRACT: The way we build is evolving to deliver net-zero (energy and carbon) and healthy buildings. While this has been steadily adopted in developed countries, the housing demand is expected to be greater in countries under development, where people face wide barriers and challenges to embracing the net-zero future. The Passivhaus standard has played a critical role in the net-zero building process in North America and Europe. This paper explores how design research can be used to support the net-zero evolution using the Passivhaus standard as a building design model in Latin America while supporting the Sustainable Development Goals.
Design research provides a comprehensive approach for research on net-zero and healthy buildings, construction, capacity building, and engagement activities involving academics, professionals, and policymakers. This work presents the lessons learned through different initiatives delivered in Latin America between 2020 and 2022. These initiatives developed using the Passivhaus standard are the LatamHaus Network, the Ice Box Challenge delivery in Santiago de Chile, and a workshop with academics to shape a collaboration agenda for future projects. This paper aims to present a model that can be replicated to support the decarbonisation challenges for developing countries, particularly those in the Global South.

KEYWORDS: Passivhaus, net-zero buildings, Design research, Latin America

1. INTRODUCTION

In recent years, there has been much talk about levelling up our building stock to provide a zero-carbon future, particularly with regard to the building industry. While this is plausible in the developed world, the reality is very different in developing countries. Here, the opportunities and benefits of net-zero buildings could be more meaningful as net-zero buildings approaches have been recently introduced [1] and the building stock is expected to grow above record levels [2], but they face key challenges and barriers to their uptake.

The zero-carbon building concept is based on the energy balance calculation, where the energy consumption of a building is balanced with on-site and/or off-site energy generation systems — interacting with the utility grid. The goal is to reduce the energy consumption in buildings enough so that little energy produced on-site is needed for their upkeep. The Passivhaus Standard has been demonstrated as a method to achieve this goal around the globe [3], and even to be a positive energy building.

A Passivhaus is "*a building for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air* [4]." The Passivhaus centres its design around five key principles: 1) adequate insulation, 2) thermal bridge-free construction, 3) airtight building envelope, 4) use of high-performance doors and windows, and 5) adequate ventilation, usually provided through Mechanical Ventilation with Heat Recovery (MVHR) systems (Figure 1). In the case of warmer climates, where solar radiation is considerable, such as those in Latin America, it is also suggested to take into consideration solar shading as a 6th principle to avoid overheating [5].

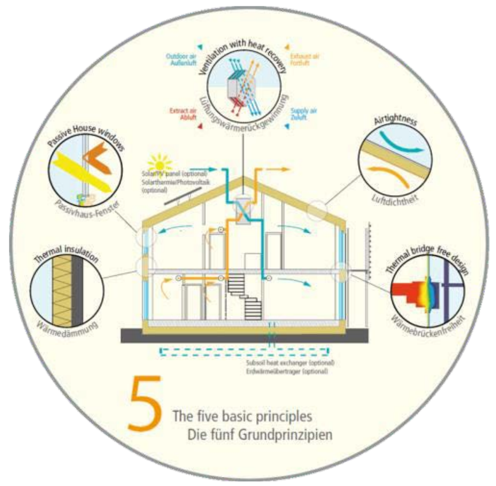


Figure 1: Passivhaus principles. Source: Passive House Institute (https://passivehouse.com/).

In recent years, the Passivhaus has started to expand outside of Central European climates where it was first born. Nowadays, there are Passivhaus examples in China, New Zealand and Latin America. The Passivhaus uptake in Latin America started in 2013 with an office building in Chile, followed in 2014 with the first home in Mexico City [1]. Since then, other buildings have followed, which have been extensively studied. These studies show evidence of thermal comfort [6], [7], energy [8], [9], economic [10], [11] or environmental [12] performance, as well as the feasibility [13], [14] of Passivhaus buildings in Latin America.

Nonetheless, the uptake of the Passivhaus in Latin America faces several barriers and challenges. The most important are economic, social acceptance, local building regulations and the lack of energy-efficient targets in these countries [[1]. Latin American stakeholders had also identified these barriers in the work presented here. Between May 2020 December 2020, the authors of this present paper have been working on developing an approach using design research methods to identify barriers and solutions and agents of change through a series of a series of initiatives planned for delivery between January 2021 and December 2022: 1) developing a network to support the Passivhaus in Latin America called LatamHaus (already in place), 2) the Ice Box Challenge in Santiago de Chile during the COP 26, and 3) an international workshop that brings academics to develop research projects that support the net-zero future.

This paper does not intend to provide detailed insights on the planning, delivery and findings of these activities. Instead, it seeks to provide a framework for approaching challenges for net-zero buildings in developing countries throughout these three main steps. It also provides an overview of the insights and the lessons learned from activities 1 and 2. Therefore, this paper presents the framework so that it could be used and applied as a reference to support the decarbonisation challenges for developing countries, particularly those in the Global South.

2. LATAMHAUS NETWORK

The LatamHaus Network (www.latamhaus.net) is an initiative joining international efforts to bring academics, industry and policymakers together to discuss issues related to the uptake of the Passivhaus standard in Latin America. This Network was born through several talks between the Latin American Passivhaus Institute (ILAPH) with the Authors. The planned objectives were set up as three milestones for the Network: 1) serve as a key player in developing capacity-building activities in Latin America, 2) bring together people that are interested in the Passivhaus to shape the agenda for its development in their countries and the rest of Latin America, and 3) produce evidence-based on the views of different stakeholders on different initiatives to support the Passivhaus development.

The Network, therefore, engaged with capacity building activities by offering scholarships to take the Passivhaus Designer Course for Latin America to academics, professionals and policy makers. Through this initiative, the Network seeks to plan several seeds of change in key stakeholders so that the Passivhaus principles can start to be embedded in the industry, academia and gradually into national policies. While it is difficult to appreciate the change in the short-term, some of the academics that received the training had already started to implement the Passivhaus design method into their teaching curricula, opening a broader view for net-zero building in their context.

The Network also engaged with local academics to develop research collaboration that looks at the Passivhaus's feasibility in specific climate regions in different countries. These research collaborations are ongoing, but, when finished, will add peer-reviewed cost-benefit analyses for the Passivhaus, not only in terms of energy but also CO_2 emissions and health. These collaborations had also highlighted the potential to include natural and bio-fibre construction materials in Passivhaus making use of the resources readily available in their doorstep.

Although impacted by the COVID-19 restrictions at the time of the delivery, the second milestone was shaped into three online workshops supported by a digital whiteboard for interactive activities between the participants (Figure 2). These workshops supported the discussion about 1) barriers and challenges that the Passivhaus has in Latin America, 2) Passivhaus and the Sustainable Development Goals (SDGs) in Latin America, and 3) how to develop resilient neighbourhoods. With these workshops, we sought insights on how we can support the development of the Passivhaus but also give some background. Therefore, the formats of the workshops were in three sections: lighting talks delivered by key actors for each of the themes and one academic, interactive activity in groups, and finally, a summary of the group discussions to collate and bring all together.

The critical lessons learned through these workshops are to develop initiatives that support the following:

- Developing public engagement activities.
- Cost-benefit analysis for the Passivhaus in all Latino America. Particularly environmental benefits (SDG 9), embodied energy (SDG 7), and health (SDG 3).
- Technical studies and engagement with local manufacturers.

Figure 2 Example of activities in the SDGs and Passivhaus workshop. Participants were asked to weigh the importance and effort needed to support the SDGs through the application of the Passivhaus. Source: Authors.

- Support national and local policymaking.

Finally, these lessons were used to inform the subsequent plans and modify the activities we had planned. Hence, the evidence from the different stakeholders and these lessons supported the delivery of the following two initiatives. These lessons were unavailable to support the action plan for the other activities.

3. ICE BOX CHALLENGE

The Ice Box Challenge is a citizen science engagement activity that involves building two boxes: one to local standard building practices and a second one to the Passivhaus Standard. The boxes are left outdoors with one ton of ice inside. After two weeks, the boxes are opened. The remaining ice is measured, demonstrating its effectiveness in keeping the heat out. By minimising the cooling/heating demand, on-site renewable energy production could suffice to run a building.

The Ice Box Challenge occurred between November 2^{nd} and 11^{th}, 2021, in the Plaza de Armas in Santiago de Chile (Figure 3 and 4). This event was also organised with the momentum of the Ice Box Challenge in Glasgow and the COP26 highlighting the Santiago-Glasgow COP26 route. The Ice Box Challenge had three key objectives: 1) to run an interactive 'living lab' experiment where Santiago's citizens could get involved; 2) to provide scientific evidence of the performance of two 'buildings' with the same use, density, shape and climatic conditions but with a different building envelop; and 3) serve as a lab for undergraduate students across the country so they can explore and understand better the standard in a tangible way.

The Ice Box Challenge has been a great tool not only to engage with the general public. It has proven invaluable to engage with local building materials producers and distributors, contractors and students to provide insights into the Passivhaus principles and construction methods explained through real-life experiences. An Ice Box Challenge was also delivered in Glasgow (July 23^{rd} – August 6^{th}, 2021). Glasgow's Ice Box Challenge provided the opportunity to engage internationally with students, professionals and academics in the UK to share their experiences delivering the Ice Box Challenge with their contra parts in Chile and start an international community to discuss shared interests.

Figure 3: Ice Box Challenge in Santiago de Chile. Source: Authors.

Figure 4: Passivhaus box with the ice inside at the beginning og the 10 days (before closing the box - 1000 kg of ice). Source: Authors.

Both buildings' indoor and outdoor temperatures and relative humidity were monitored and compared to provide rigorous evidence of the differences between both building standards. The Passivhaus remained close to 3.9°C - 5°C, remaining stable throughout the day throughout all the 10 days. The Chilean standard box ranged between 10°C – 19.2°C. After 10 days, both boxes were open and the remaining ice in them was measured. The Passivhaus box contained more than half of the ice with a total of 645 kg (Figure 5) and the box built to the local regulations (Figure 6) had 415 kg less than the Passivhaus box (230 kg). The opening of the box was timed with the Buildings day at COP 26 in Glasgow, where we presented live the results with the Latin American Passivhaus institute (ILAPH) in Chile.

Figure 5: Passivhaus box with the ice inside after 10 days (645 kg of ice). Source: Authors.

Figure 6: Local regulations box with the ice inside after 10 days (230 kg of ice). Source: Authors.

The key lessons learned from the Ice Box Challenge are the following:

- The Living Lab demonstrated how the general public could understand the Passivhaus concepts and apply them to day-to-day scenarios.
- It is essential that contractors and other people involved in the construction process understand the principles and why it is important to adhere to the specifications.
-
- Used as a tool for teaching, through lectures and their practical application, the students got a deeper understanding of the Passivhaus principles.

4. INTERNATIONAL WORKSHOP

The delivery of the net-zero future is not the responsibility of one country but needs to be a collective, global effort. Supported by the findings of the LatamHaus Network, an exploration of international and cross-country projects to deliver a net-zero future is a clear next step. With this activity, we seek to identify and engage with critical organisations, industrial partners and academics to build international collaborations.

To boost these interdisciplinary and intercontinental collaborations, we identified Passivhaus projects across Latin America, either built or under construction. The aim here is to map potential case studies. It has already enabled the authors to identify and engage with key industry actors, academics and national funding bodies. Further research will help shape national net-zero policies supported by world-leading studies that push the boundaries between the current building stock and the net-zero future in different countries.

The international workshop seeks support from industrial partners and academics from Argentina, Brazil, Chile, Colombia and Mexico. Additionally, we seek support from academics within Latin America, the UK and EU, as well as support from international funding bodies such as Latin American Research Councils (i.e. CONACyT, COECYT), UK Research and Innovation (UKRI) and the UK PACT, among other venues of funding to establish international collaborations.

Given that this activity is still to be delivered at the time of writing, there are no lessons learned or specific outcomes from this workshop. Nonetheless, we have had talks with the industrial partners and academics to develop a draft idea of how these collaborations may look. We hope to attract the required funding to develop different strategies that will support the Passivhaus development in Latin America.

The LatamHaus Network suggested several courses of action. For example, while several Passivhaus projects are under development, only residential buildings have been the focus of scientific scrutiny. Hence, there is a need to conduct a large-scale, cost-effective analysis of different Passivhaus case studies identified throughout Latin America[, such as office blocks…?]. Another course of action relates to the natural environment and its capacity to sequester CO2 emissions in Latin American countries. Therefore, looking at how Passivhaus buildings can be supported through natural building materials to reduce even further their CO_2 footprint.

5. DESIGN RESEARCH ROLE

Design research methods have allowed us to shape the net-zero agenda for our project. The use of research methods has been invaluable during the planning process to do the following:

- understand the current state of net-zero buildings in Latin America,
- respond through multidisciplinary approaches,
- shape the situations into something that everyone can understand it, and
- design outcomes and activities supported by the findings.

More importantly, design research allows us to better understand particular communities' needs and shape the research around that. In other words, we want to conduct research that crosses the traditional research boundaries with a bottom-top approach where the research question comes from the community. Hence, these research projects are informed by the activities of the LatamHaus Network.

Another crucial role of using design research methods to conduct and plan this kind of research project is that they provide the flexibility to incorporate both qualitative and quantitative research approaches and bend the traditional research boundaries to establish interdisciplinary research for all. Design research also enables academics to translate the research outcomes into tangible actions that can be applied and implemented at local, regional and national levels so that the research becomes an actor of change.

5. CONCLUSION

This paper presented a framework that can be exploited to introduce and start the discussion of the net-zero future in the built environment, considering social and academic aspects. The critical role of this framework developed through research design methods is summarised in three key points: 1) networking & capacity building, 2) engagement activities, and 3) research.

Networking & capacity building provides the basis for the research activities. The main task here is to build a network of people interested in working together and support them to develop the necessary skills to become actors of change within their reach.

Engagement activities provide the outreach for the research outcomes, but more importantly, open the science in a lay language that everyone can understand, helping so that they can be gradually absorbed in day-to-day life.

Research provides interdisciplinary project development and rigorous testing of ideas to be incorporated into the net-zero building industry.

Finally, the role of research design is to close the gap between academics and the general public, taking a bottom-top approach and translating the research outcomes into tangible actions for local communities.

ACKNOWLEDGEMENTS

This work has received funding from Research England through its E3 program. The authors also would like to thank all participants involved in the design and delivery of this framework. The following partners supported the delivery of the Ice Box Challenge: Municipalities of Santiago, Cochrane, Coyhaique; Asociacion de oficinas de arquitectos Chile, Centro Tecnologico para la Construccion, Instituto de la construccion, Green Building Council, Nuiform, Pro-clima, Arquiambiente, Braintech Science, Deceuninck, Rothoblaas, Lanarq, and Blokey.

REFERENCES

[1] A. Moreno-Rangel, E. Tsekleves, J. M. Vazquez, and T. Schmetterer, *The little book of Bio-Based Fibre Materials in Passivhaus*

Construction in Latin America, 1st ed. Lancaster University, 2021.

[2] INEGI, “Instituto Nacional de Estadistica y Geografia,” 2015. http://www.inegi.org.mx/ (accessed Feb. 05, 2015).

[3] J. Schnieders, W. Feist, and L. Rongen, "Passive Houses for different climate zones," *Energy Build.*, vol. 105, pp. 71–87, 2015, doi: 10.1016/j.enbuild.2015.07.032.

[4] PHI, "Passipedia: The Passive House Resourse," *Basics*, 2017. https://passipedia.org/basics (accessed May 03, 2021).

[5] A. Moreno-Rangel, “Passivhaus,” *Encyclopedia*, vol. 1, pp. 20–29, 2021, doi: 10.3390/encyclopedia1010005.

[6] V. Costanzo, J. E. Carrillo Gómez, G. Evola, and L. Marletta, "Suitability of Passivhaus Design for Housing Projects in Colombia," in *Sustainability in Energy and Buildings. Smart Innovation, Systems and Technologies*, vol. 163, J. Littlewood, R. J. Howlett, A. Capozzoli, and L. C. Jain, Eds. Singapore: Springer Singapore, 2020, pp. 97–107.

[7] A. Moreno-Rangel, T. Sharpe, G. McGill, and F. Musau, "Thermal comfort assessment of the first residential Passivhaus in Latin America," *J. Build. Eng.*, vol. 43, p. 103081, Nov. 2021, doi: 10.1016/j.jobe.2021.103081.

[8] E. Echeverria-Valiente, R. Garcia-Alvarado, F. Celis-D'Amico, and G. Saelzer-Fuica, "Integrated design experiences for energy-efficient housing in Chile," *Constr. Innov.*, vol. 19, no. 2, pp. 236–255, 2019, doi: 10.1108/CI-05-2017-0042.

[9] E. Vettorazzi, A. Figueiredo, F. Rebelo, R. Vicente, and E. Grala, "Energy & Buildings Optimization of the passive house concept for residential buildings in the South-Brazilian region," *Energy Build.*, vol. 240, p. 110871, 2021, doi: 10.1016/j.enbuild.2021.110871.

[10] GIZ, "NAMA facility - Implementation of the New Housing NAMA Mexico," 2014. http://www.nama-facility.org/projects/mexico.html (accessed May 20, 2009).

[11] W. Feist, "Technical Annex : Evaluation of social housing building types in Mexico: Study of energy efficiency, additional costs and CO2 mitigation as basis for the preparation of the "Supported NAMA for Sustainable Housing in Mexico - Mitigation Actions and Finance," Durban, 2012.

[12] C. Bravo-Orlandini, J. M. Gómez-Soberón, C. Valderrama-Ulloa, and F. Sanhueza-Durán, “Energy, economic, and environmental performance of a single-family house in chile built to passivhaus standard,” *Sustain.*, vol. 13, no. 3, pp. 1–15, 2021, doi: 10.3390/su13031199.

[13] J. Carrasco and G. Kokogiannakis, "Feasibility of PassivHaus standards and alternative passive design on climatic zones of Chile - Determination of energy requirements with dynamic simulation .," *Hábitat Sustentable*, vol. 2, no. 1, pp. 59–71, 2012.

[14] A. S. Cruz, R. S. de Carvalho, and E. G. da Cunha, “Passive house alternative proposal for the Brazilian Bioclimatic Zone 8,” *Int. J. Sustain. Dev. Plan.*, vol. 15, no. 6, pp. 827–833, 2020, doi: 10.18280/ijsdp.150605.

Factors that promote the offer of green financing for real estate projects of high energy efficiency housing

PAOLA PALOMINOS [1] [2] CARLOS MARMOLEJO [3]

[1] Pontificia Universidad Católica de Chile, Chile
[2] Universidad de las Américas, Chile
[3] Universidad Politécnica de Catalunya, España

ABSTRACT: The residential real estate market of Santiago Metropolitan Region encompasses 1,292 projects at march of 2021. Searching for projects that include sustainability certification or energy efficiency qualification becomes a great challenge through the real estate offer portals, which do not allow filtering sustainability variables as a segmentation attribute. The market share of highly energy-efficient homes is incipient, with only 12 projects in the metropolitan region, which can be accessed from the institutional websites of banks that offer mortgage financing agreements, in recognition of their contribution in environmental, social and governance variables (ESG). On the other hand, the real estate financing of housing projects, analyses variables in technical terms and economic results of the project and of the company involved in its development. Given this it can be inferred that the supply of financing appropriate to the reality of housing projects with high energy efficiency does not differ with respect to projects that do not consider energy efficiency as an attribute that points towards ESG principles. The search for those factors that promote green financing to produce highly efficient homes will be part of this research.

KEYWORDS: energy efficiency mortgage, Green Finance, energy efficient housing, sustainable real estate project

1. INTRODUCTION

The residential real estate market of the Santiago Metropolitan Region encompasses 1,292 new projects at the end of the first quarter of 2021, whose available supply totals 49,079 homes [1]. The search for projects that contemplate sustainability certification or energy efficiency certification becomes a challenge through real estate offer portals, which do not allow filtering sustainability variables as a segmentation attribute. On the other hand, through research, it has been possible to identify 12 projects in the same region that have either some type of certification or energy efficiency certification. This document studies the sources of financing used in real estate production and through the methodology of semi-structured interviews with agents participating in the financial market, the real estate sector and public institutions, it has been possible to identify a series of variables tending to increase the supply of green financing focused on the production of highly energy-efficient housing, which are related to the contribution that these projects generate towards the environmental, social and governance (ESG) variables that the institutions begin to monitor.

2. BACKGROUND AND RELATED LITERATURE

A background review has been proposed in 5 sections related to the investigation: Regulations and public-private agreements, available energy and sustainability certifications, real estate financing models, green finances and finally the relationship between the energy efficiency of housing and the risk of mortgage default.

2.1 Public policies and regulations aimed at climate change and green finance

The Paris Agreement approved in 2016 was ratified by 55 countries responsible for 55% of greenhouse gas emissions with the objective of refocusing the global response to climate change, sustainable development, the eradication of poverty with three central axes, keeping the increase in global average temperature below 2°C, increasing the ability to adapt to adverse effects of climate change and bring financial flows to a compatible level that is conducive to climate-resilient development with low greenhouse gas emissions[2].

The development of public policies related to this issue in Chile comes from the ratification of the Paris agreement in 2017, through the elaboration of the Green Agreement of Chile, which establishes commitments in five areas: i) Mitigation ii) Adaptation iii) Construction and Capacity Building iv) Technology Development and Transfer v) Financing [3]. This document points to the need to incorporate climate change risks into economic and financial decisions, identifying physical risks that can be transferred to the financial system through the impact of natural events on exposed economic sectors, and on the other hand, the Transition Risk inherent to the adjustment process towards a carbon neutral economy.

The Green Agreement additionally establishes the operation of a public-private Green Finance Table, which oversees managing risks and developing green financial policies and instruments that manage to detect and take advantage of market opportunities around climate change and the transition to a carbon neutral economy.

The form of green financing begins to be proposed through the definition of eligible green projects, which are related to renewable energies, energy efficiency, pollution prevention and control, sustainable management of natural resources, among others, including ecological buildings [4]

2.2 Certifications of energy efficiency and sustainability of homes in Chile

Law 21,305 on Energy Efficiency, enacted in Chile in February 2021, has the purpose of preparing the National Energy Efficiency Plan [5]. The plan will be renewed every five years, whose first goal is to reduce energy consumption by 10% by the year 2030. Along with this, it establishes that all homes, public buildings, commercial buildings and offices must have an Energy Rating (EPC) to obtain definitive reception by the authority [6].

The Ministry of Housing, together with the Ministry of Energy, have developed the Housing Energy Rating System, which is mandatory for all new buildings of the aforementioned types, establishes an energy label that presents 8 categories that depend on savings energy that the Housing can provide, the obligatory nature of the qualification process enters into force together with the drafting of the regulations of the law.

Additionally, the Ministries of Housing and Urban Planning, the Ministry of Energy and the Ministry of the Environment have developed the Sustainable Housing Certification (CVS [7]), which is currently a voluntary housing evaluation system which assesses aspects of its environmental, economic and social performance during the design and construction stages, which proposes three levels of certification.

At the same time, it is possible to find in Chile some Certifications of international origin such as LEED, EDGE and PASSIVHAUS, which are managed by the Chilean Corporation for Sustainable Construction and Development, Chile Green Building Council, who have been operating since 2010, all of these point to high standards. energy efficiency and sustainability.

The LEED certification is a multi-criteria certification system, which considers different aspects of sustainability and therefore considers the different potential impacts of a project during its useful life, also focusing on social and economic benefits and the efficient use of resources [8]. The EDGE certification (Excellence in Design for Greater Efficiencies, for its acronym in English), is an evaluation for new constructions that must meet a minimum saving of 20% in energy, 20% in water and 20% in energy incorporated in the materials in the building.

The Passivhaus certification, from Germany, has been available in Chile since 2010. It is a standard referring to houses with almost zero energy consumption based on an exhaustive procedure in the development of the project and its execution. To achieve this almost zero consumption, Passivhaus requires designing and building houses with a high degree of energy efficiency to achieve close to zero energy consumption.

2.3 Green Finance, Energy Efficient Housing and Green Mortgages

The European commission established the EU High-Level Expert Group on Sustainable Finance has delivered a series of recommendations aimed at how to direct the flow of capital towards sustainable investments. The process of preparing the recommendations has consisted of stages of analysis, which were submitted to public consultation (European citizens, non-financial sectors and public authorities), from the responses valuable information was obtained that allowed HLEG to develop a second part of analysis and preparation of new recommendations, which are in turn aimed at understanding that sustainable finances have a joint approach to the development of financial services that integrate ESG dimensions in all markets, practices, products and policy frameworks, which will imply reallocating investments on a large scale and close the sustainable development financing gap[9].

In relation to sustainable housing financing alternatives, it is first necessary to understand the aspects of financial alternatives, known as mortgage loans that can be of a fixed or variable interest rate, the study of consumers has determined that the greater the social vulnerability, they will opt for fixed-rate mortgages, therefore, making future expenses more predictable for the household manages to reduce the risks of a lack of liquidity and consequently the probability of default [10].

On the other hand, the energy efficiency of the home has progressed, homes with a higher level of energy efficiency are being built. Even remodelling projects include energy efficient renovations in both North America and Europe. The consumer has become aware and understands that energy efficiency is amortized over the useful life of the works, through lower heating and cooling costs. Despite these trends, the market has not reached its full potential [11]. Financing obstacles come from moderate and median-income buyers and homeowners. Investors involved in the financing have been reluctant to do so, in part because they lack reliable data on loan returns on which to base their decisions. Green or energy efficient mortgages (EEM) are those mortgage loans that link the mortgage interest rate with energy efficiency, in some way (Souto, 2019). The fundamental idea is to offer economic benefits to creditors, for the purchase or reform of a home EEMs are currently financed by three entities: Fannie Mae, Freddie Mac and the Federal Housing Administration (FHA), which are all entities promoted by the US Federal Government.

2.4 Energy efficiency in the Chilean housing real estate market

The scientific evidence related to the study of energy efficiency and its performance certifications (EPC) is very dissimilar between countries with developed economies and is opposed to developing economies. The behaviour of energy labelling in the real estate market of Santiago de Chile, whose analysis was carried out using the Kansey Engineering and Kano Model methodology to identify the home buyer and their perception of energy performance. It has detected that the energy rating negatively affects the willingness to purchase, with the most relevant attribute being the perception that housing is a good investment [12].

In developed countries, using the methodology based on the declared preferences of consumers, a study on the relationship between the relevance of energy efficiency in the choice of housing for rent and purchase in Barcelona, indicates that, if people are informed of both the ranking EPC and its environmental and economic repercussions, in terms that are easy to understand, energy turns out to be the most relevant attribute compared to other characteristics related to the quality and functionality of a home[13].

In the real estate market of Santiago de Chile, the attributes associated with energy ratings (which are linked to the score obtained) and knowledge of the certification scheme turn out to be inverse, that is, as the presence of the rating increases, the attractiveness of the home decreases, the energy rating of a home is perceived as a variable correlated with its price, which makes its purchase less attractive [12]. Other reasons are related to the perception of certification as an effective measure of the thermal efficiency performance of the home.

2.5 Real estate financing models in Chile

The cycle of the real estate process invites different types of actors from the financial sector to participate in the financing, the interest rate and the level of loan offered, reflect the perception of risk for each stage of the project life cycle [14]. This is separated into 2 phases, the first corresponding to the development that contemplates the acquisition of land, the design of the project and its specialties, the obtaining of permits, the construction and its municipal reception, the second phase corresponds to the operation at the moment in which income is obtained from the operation of the asset. The development phase is very intensive in financing and the associated risk is higher compared to the operation phase. The actors involved in real estate financing are varied, depending on the type of participation they establish, whether in the form of capital (acquisition of assets) or in debt (financial instruments and titles), they are made up of an industry of institutional investors in addition to the banks, as it shows in table 1.

Table 1: Real estate financing participants

Investor	AFP	Insurance Company	Investment funds	Banks
Financing type				
Actions	X			
Public Funds	X	X		
Direct investment		X	X	
Bonds	X	X		
Mortgages		X		X
Loans				
Leasing		X		X
Warehouse Land		X		X

About the financing available to buy a house through mortgages, the Chilean market has created a financial instrument called mortgage debt securities, which is also supported by the monetary correction due to inflationary adjustment.

2.6 Relationship between the energy efficiency of housing and the risk of mortgage default.

The studies that relate energy efficiency with the risk of mortgage default have been developed mainly in European countries and the United States, and are based on the statistical analysis of mortgage history of single-family homes used by their owner, the analysis considers a comparative study between homes with energy efficiency certification and those without certification, it was possible to verify that the risk of non-payment of mortgages associated with Energy Star certified homes is significantly lower than mortgages of homes without certification[15]. Subsequently, the energy rating was introduced into the analysis within the mortgage default risk score, verifying that factors such as wealth, unemployment and lack of liquidity are the variables with the highest correlation with the risk of default [16].

Recently, the study of housing mortgages with energy certification in the Netherlands shows that there is a negative correlation with respect to the risk of default, which has not only originated in energy efficiency technology, but also with the legislation

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

that establishes a standard [17] that links the labels with the behaviour of the mortgages, detecting significant relationships between a high rating and a low payment delinquency, using a logistic regression model. The study concludes that incorporating information regarding the energy rating of the home in the mortgage risk analysis model is beneficial for the credit provider, being able to grant larger amounts with controlled risk compared to providers that do not incorporate all the information.

3. METODOLOGY

The research is of a qualitative nature, designed to develop an in-depth review of opinions that have been collected through the technique called semi-structured in-depth interviews. The research design considered the selection of representatives of interest groups in the field of study, classifying them into groups of institutional or direct and indirect financial actors in the market. With these considerations, a search was made for normative and economic background, and specific literature and scientific articles that served as base material for the construction of conversation patterns related to the implementation of sustainable policies and finances that are oriented to the production of affordable housing. energy efficiency, from which the interviews were addressed.

3.1 Compilation and analysis of normative antecedents

The exhaustive search for regulatory and related information comes from various sources, beginning with public institutions: the Ministry of Finance, the Central Bank, the Commission for the Financial Market, the Ministry of the Environment, the Ministry of Energy, the Santiago Stock Exchange, and the Stock Exchange. Followed by publications made by advisors and recommendations: UNEP FI and the Principles of Responsible Banking together with the Principles of Responsible Investments. The IFC regarding environmental risk performance standards, The Principles for Green Bonds, The Equator Principles. Regarding the direct actors: Annual Reports, Integrated Reports, Strategic Development Plans of the actors consulted.

3.2 Definition of specific agent profiles for the study

The selection of specific profiles for the search for agents to study took into consideration, on the one hand, the contribution of public institutions in the generation of regulatory changes, regulations, public policies in sustainable finance that established goals and compliance related to the financial sector. On the other hand, the financing models of the real estate industry have been considered, considering the entire development cycle, namely, Investment, Project, Construction and Operation [12] The vision of the real estate developers themselves and of the appraisers who play a key role in the process of managing the mortgage loan is added as important additional profiles.

3.3 Application of the interviews.

Before conducting the interviews, a summary of conversation topics was prepared, which were sent to each agent as a conceptual framework for Development, the interviews were conducted electronically, with recording in some cases for later transcription.

Faced with the limitation of not getting representatives of the institutions to interview, such as the Central Bank and the Commission for the Financial Market, these actors were replaced by interviews with the specialized press or through conferences held with a specific focus. in sustainable finance for the economic development of Chile.

The agents interviewed are summarized in Table 2, the type of institution, the method used to analyse the information, those cases in which it was not possible to obtain a direct interview are indicated according to the source from which it was observed.

Table2: Agents studied and interviewed

Investor	Public Institution	Private Institution	Method
Treasury Ministry	X		Interview
Central Bank of Chile	X		Webinar
Commission for the Financial Market	X		Press Interview
Bank of the State	X		Interview
Commercial banks		X	Interview
Investment fund managers		X	Webinar
Pension fund administrators		X	Interview
Insurance companies		X	Interview
Real estate developers	X	X	Interview
Appraisers		X	Interview

3.4 Systematization of information collected interviews and conferences

To begin this process, it was necessary to carry out the transcription of interviews, review of notes, and selection of the thematic ideas addressed, with the purpose of investigating common and divergent factors that could give an idea of the central aspects that will allow progress towards the proposed objectives

4. FINDINGS

Since the establishment of the public-private green finance table, the actors involved are making progress in incorporating the risks of Climate Change in their decisions and have raised business opportunities related to ESG variables. Public institutions propose new regulations and standards that private institutions must incorporate, these regulations favour the development of new green financing, highlighting the products developed by Banco Estado as public banking, in the financing of Eco-efficient homes whose characteristic is the energy rating A, B or C, and the certifications available in the market, participates in the form of financing the construction of the project and also in the purchase of homes through mortgage loans. Likewise, on the part of private actors, Banco Santander has also developed green mortgage financing, aimed at projects with sustainability certification whose development has been aligned with the group's policies.

Within the arguments received by the agents interviewed, it was possible to find a line of convergent arguments and another line of divergent arguments. The converging arguments point to the transversal recognition of climate risks as a source of financial risk, and therefore the incorporation of ESG variables is important in the decision-making process, for this process to be successful in its implementation, it must necessarily be contained in the strategic planning of the organization, where the commitment of the board of directors is key in terms of providing attributions to ESG risk managers. The agents also agree that the lack of transparent, truthful and available information regarding compliance with ESG variables of investment alternatives can lead to confusion for investors who participate in secondary markets. The private banks pointed out that together with the implementation of the final rule on reporting ESG variables to the CMF, positive incentives should be generated, as opposed to disincentives in the form of taxes or mitigations, these incentives could be related to a better classification of risk of the institution that participates in ESG financing, as these are associated with greater resilience. At a deeper level of analysis regarding the financial institutions that are involved in the production of housing, currently only evaluating the technical and economic background of the project, the development company and its partners are open to incorporating ESG variables into said analysis, all once the Commission for the Financial Market makes the reporting of these variables mandatory, regarding which the regulations are under consultation. The financing of houses with energy efficiency, could comply with the ESG variables only if the Project in its entirety has Certification, in this sense the Energy Efficiency Law and the process of Energy Rating of Housing is a limitation that hinders the financing operation.

The line of divergent arguments can be seen among the financial institutions that have already developed green mortgages, of those that have not yet done so, the former recognize that these are projects that present better performance in terms of their economic return, since as they are ESG alternatives, they are investments that are less vulnerable and more resilient to risks. For their part, those institutions that have not yet developed ESG financial instruments, when faced with the decision to participate in the financing of a housing project with EPC, point out that it is not an easy approval process, because these projects present construction costs and sales prices higher than traditional housing projects located in the same environment according to market studies prepared by the same committee. This is also manifested in uncertainty regarding expected sales.

The aspects related to the financing of housing mortgage loans with EPC, these institutions only associate a better behaviour against non-payment due to the fact that they are housing projects aimed at high-income consumers, they do not associate it with savings in energy consumption produced by the energy efficiency and other sustainability facilities that the project incorporates. Faced with this issue, developers state that these projects are effectively aimed at high-income consumers, since they have the means to economically access sustainability equipment, however, this does not mean that they value sustainability as attributes over others such as location, design features and finishes and additional equipment offered by the market. This is consistent with the argument made by real estate appraisers, since they point out first that the certificates themselves have no effect on the willingness to pay, but rather that some architectural components that are evaluated in the certification, such as double-glazed windows and high energy performance enclosures (PVC window frames) and cellular concrete structures. Due to the above, the developers explain that the motivation to develop housing projects with EPC arises from the need to adopt differentiation strategies in the case of private housing. However, since these are subsidized housing projects with public resources, attributes of energy efficiency and sustainability are incorporated to obtain a higher score for the application of the project to be awarded the development funds.

5. CONCLUSION

In a transversal form, opinions have been collected from the interviews that demonstrate the fact that both the real estate market associated with housing projects with energy efficiency certification, as well as the offer of specific sustainable financing aimed at these real estate assets, is meagre.

The factors that can stimulate the supply of green financial instruments for housing production emerge from the converging arguments found and are mainly associated with the development of public policies, regulations and economic incentives. Public policies with a tendency to massively incorporate sustainability in construction, which could be integrated in a standardized way in the production of housing. Energy Efficiency Law in force with the different regulations, without a doubt they should strengthen the diffusion of Certification and Energy Rating of homes, in terms that are understood by the common citizen who is evaluating the purchase of a home. In relation to the regulations, the institutions refer mainly to the final publication and application of the general standard that integrates ESG variables in the annual reports of the institutions that issue securities on the stock exchange, their clients and suppliers. Regarding the economic incentives, two options were expressed, the most repetitive consists of the tax reduction of territorial tax or similar that would act as an incentive to the buyer, the second stimulates the financial sector, since they associate the incorporation of ESG variables with a better management of their risks, with which they hope to obtain a better risk classification in the market, which also has a positive impact and stimulates the promotion of home financing with EPC.

Advances in these public policies and regulations have not yet been developed with levels of detail that allow directly incentivizing the promotion of green financial products aimed at the production of highly energy-efficient homes, which, due to their composition, comply with ESG variables. The small size that this market currently has makes it difficult to create short- or long-term debt portfolios with a sufficiently attractive volume for investors looking for projects with ESG variables.

ACKNOWLEDGEMENTS

To María Fernanda Aguirre (GBC Chile); Cinthia Méndez and Alvaro Perez (Confuturo Insurance Company); Ricardo Catalán, V. Paz (B. State); Dagoberto Lopez (AFP Habitat); José Brito (Bank of Chile); Eduardo Deride (International Bank); Francisco Fuentes and Carmen Tapia (B. Santander); German Mayor, Alex Kunihiro, Marcela Fuentes, Carolina Sáez, José Valencia (Banco Itaú); Carlos Aguirre, Rolando Biere (ETSAB, Polytechnic University of Catalonia); Felipe Toledo (ASATCH); Stefan Renk, Paolo Brignardello; Sebastian Hube(Real estate developments); Daniel Serey (Toctoc.com); Nicholas Vergara (CPE).

REFERENCES

1. GfK Adimarck, 2021. Greater Santiago Real Estate Market Quarterly Study, 1st Quarter 2021.
2. Souto, R. e. (2019). Financing instruments for efficient building: Analysis of green bonds and mortgages. XIII CTV 2019 Proceedings: XIII International Conference on Virtual City and Territory: "Challenges and Paradigms of the contemporary city".Kittler, R., (1985).
3. Ministerio de Hacienda. (2019). Acuerdo Verde de Chile. Santiago, Chile.
4. The Green Bond Principles. (2018). Guide to the voluntary procedure for the issuance of Green Bonds.
International Daylight Monitoring Program, [Online], Available: http://idmp.entpe.fr/ [16 June 2008].
5. Ministerio de Energía . (2021). Ley 21.305 Sobre Eficiencia Energética.
6. Ministerio de Vivienda y Urbanismo. (2019). Manual de 6 Procedimientos: Calificación Energética de Viviendas en Chile. Santiago de Chile.
7. Ministerio de Vivienda y Urbanismo. (2020). Manual de aplicación de la Certificación de Vivienda Sustentable. Santiago de Chile.
8. Green Building Council Chile. (s.f.). Zona Certificaciones. https://www.chilegbc.cl/index.php?sec=proyectos-leed
9. EU High-Level Expert Group on Sustainable finance, 2018. Financing a sustainable European economy.
10. Hullgren & So¨derberg , 2013. The relationship between consumer characteristics and mortgage preferences A case study from Sweden. International Journal of Housing Markets and Analysis Vol 6.N°2, 209-230.
11. Kaza, N., Quercia, R. G., & Yue Tian, C.2014. Home energy efficiency and mortgage risks. Cityscape, 16(1), 279-298.
12. García, N. (2017). Capítulo 32: Financiamiento de activos Encinas, F., Marlolejo-Duarte, C., Aguirre-Nuñez, C., & Vergara-Perucich, F. (2020). When Residential Energy Labeling Becomes Irrelevant: Sustainability vs. Profitability in th
13. Marmolejo-Duarte, C., & Bravi, M. (2017). Does the Energy Label (EL) Matter in the Residential Market? A Stated Preference Analysis in Barcelona. Buildings, 7,53.
14. García, N. (2017). Capítulo 32: Financiamiento de activos inmobiliarios en Chile. En J. M. Simian, & V. Niklitschek, La industria inmobiliaria en Chile (págs. 679 - 691). Santiago, Chile: Pearson.
15. Kaza, N., Quercia, R. G., & Yue Tian, C. (2014). Home energy efficiency and mortgage risks. Cityscape, 16(1), 279-298.
16. Sanderford, A., & Overstreet, G. (2015). Energy-efficient homes and mortgage risk: crossing the chasm at last? Environ Syst Decis.
17. Billio, M., Costola, M., Pelizzon, L., & Riedel, M. (2021). Buildings' Energy Efficiency and the Probability. Journal of Real Estate Finance & Economics.

The cost of rehabilitating a historical building
Application of roof materials alternatives towards thermal comfort

BEATRIZ MOON[1], SARA GONÇALVES[1], SABRINA BARBOSA[1]

[1] Department of Architecture and Urbanism, Rio de Janeiro State University

ABSTRACT: In recent decades, the interest in evaluating the environmental performance of historic buildings has increased in Brazil. However, studies are still punctual. This study aims to thermally and economically evaluate the Casa do Colono Museum, localized in Petrópolis (Brazil), by applying different insulation materials on its envelope and installing a portable heater on its rooms. By using the DesignBuilder tool, simulations for the naturally ventilated model in its original state and 26 alternative cases were performed. As result, the original case presented expressive heat gains through the roof, causing discomfort by heat on 28% of the working hours on the upper floor. The insulation materials tested lowered the heat conditions, especially on the upper floor, while little improvements were observed in reducing cold conditions. In contrast, the use of the portable heater lessened the discomfort by cold on the ground floor but increased heat on the upper floor. The case with the best cost-thermal benefit was the 1 cm-EPS applied on the roof and 5cm-EPS installed in some walls of the ground floor, which would cost $356. This study highlights the importance in predicting the balance between cost and thermal performance when rehabilitating a heritage building.
KEYWORDS: Heritage, Economic, Thermal performance, Brazil, Computational Simulation

1. INTRODUCTION

In 2015, the United Nations (UN) created the Sustainable Development Goals to be met by 2030. Among the targets, it was recommended that nations strengthen their efforts to protect and safeguard the world's cultural and natural heritage [1]. Besides being a strategy that allows the preservation of the cultural aspects for future generations, protect heritage buildings may also reduce the environmental impacts from their demolition and construction of new buildings [2]. In addition to the importance of maintaining the cultural identity of a region, rehabilitating a building is also an opportunity to reduce energy consumption and CO_2 emissions necessary for its operation [3].

In Brazil, there are 1192 listed buildings by the National Institute for Historic and Artistic Heritage [4]. However, despite the numerous programs to encourage the safeguarding of national heritage over decades, governments strategies were often conflicting, weakening the preservation policies [5]. Although the country has recently presented regulations for the energy efficiency of new buildings [6], it still does not have regulations aimed at historic buildings.

Some national studies have dealt with the thermal performance of historical buildings considering different approaches. Some studies have analysed historical buildings in their current state and use, making environmental diagnosis [7,8], while others have compared their conditions before and after a set of proposed interventions, such as the insertion of shading devices [9], different types of glass [10] and insertion of insulation materials into walls [11] and roofs [12]. The work by Fernandes and Labaki [13], on the other hand, with a less conservative nature, considered the implementation of a solar chimney on the building facade. Moreover, there are studies that focused on the sustainability of the historic buildings. In particular, the work of Apolônio et al. [14] that proposed a retrofit according to the principles of sustainability. However, when rehabilitating a building, it is also important to look at beyond quantitative aspects, protecting its constructive and cultural aspects, which create identities and memories.

Unlike Europe, which concentrates most research on the thermal performance of historic buildings [15], in Brazil these studies are still punctual, although there is a vast collection of historic buildings in the country. One reason for that is the insufficient resource destinated to the preservation and maintenance of historic buildings. Additionally, economic analysis is frequently neglected, detaching academic research from practical design. Thus, this study aims to thermally and economically evaluate the application of different insulation materials on the envelope (roof and walls) of the Casa do Colono Museum, localized in Petrópolis, Brazil.

Petrópolis, also known as the Brazilian Imperial city, was founded by Dom Pedro II on March 16, 1843. The city was the site of the construction of the Imperial family's summer palace, with the aim of escaping from the heat and epidemics of Rio de

Janeiro. With the objective of populating the region, the immigration of Europeans, mainly Germans, was encouraged. From then, the immigrants started to build their houses and stabilizing in the region [16].

Listed by the CMTHCA - Municipal Council for Historic, Cultural and Artistic Listing –, the Casa do Colono Museum was built by a German immigrant in 1847. It is a unique construction that was built with vernacular techniques, and it is the only one in the city that shows how the first German emigrants lived in Brazil. Nowadays, furniture, household utensils, personal objects, paintings, and photographs are exposed to the visitants. The house is an icon of the city and a source of cultural and architectural knowledge. It had received 24.298 visitors in 2019, with an increase of 23.7% compared to the year before [17]; among them, 17.709 were students from 403 different schools.

2. METHODOLOGY

For this study, computational models of the Museum with the original construction and alternative materials were developed on the Energy Plus-based software tool Design Builder (Fig.1). Ten thermal zones (Fig.2), following the building rooms and the circulation area, were considered. Characteristics of the surrounding environment, such as vegetation, were not considered.

Figure 1:
Model and photo of the Casa do Colono Museum.

2.1. Petrópolis climate characterization

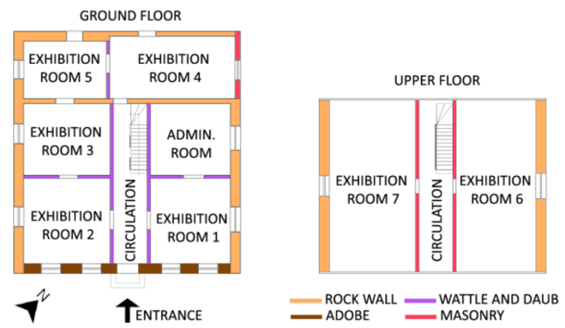
Weather data based on the test reference year (TRY) of Petrópolis was used. The city is classified as warm and temperate climate according to Köppen and Geiger, with the mean annual temperature and relative humidity of 13.6°C and 89.5%, respectively. The average monthly wind speed is 4m/s. The city is at 838 meters above sea level (latitude 22.3° S, longitude 43.1° W) in a mountain region.

In general, during cold seasons (from June to September), the air temperature levels are at the lowest, reaching on average 11°C, while during the summer, the average air temperature reaches 22°C. Precipitation and humidity levels are at its lowest in July and August (83% and 51mm on average, respectively). On the other hand, during the hot seasons, humidity reaches a peak of 95% and accumulated precipitation reaches 960mm.

2.2. Model description

The museum building has two floors, with a management room and five exhibition rooms on the ground floor and two more exhibition rooms on the upper floor. The construction was carried out from several construction techniques due to the adaptations made over the years. Thus, the building has the external walls made of adobe, rock and masonry and the internal walls of wood-to-pike and masonry. Regarding the floor materials, they are made of stone in the exhibition rooms 4 and 5, and timber floor in the other rooms. In addition, the foundations were made of raw stone and the roof is in fibber cement tiles. Figure 2 shows the internal layout and the different walls of the building.

Figure 2:
Internal layout and walls materials of the museum



For the openings, wooden doors were considered 100% open for the visitation time. However, the glass windows of the ground floor were 50% open and wooden windows on the second floor and in rooms 4 and 5 were set 100% open for 10 minutes every 1 hour during the visitation times. Table 1 shows the original building fabric materials characteristics and the internal heat gains considered.

Table 1:
Characterization of the building model.

Building envelope	Thickness (cm)	U (W/m².K)
External adobe wall	45	1,77
External rock wall	45/24	2,581/3,05
Internal rock wall	24	2,39
Internal wattle and daub wall	14	3,20
External masonry wall	24	2,44
Internal masonry wall	14	3,21
Rock floor	40	3,08
Timber floor	2	2,42
Fibrocement roof	0,8	6,73
Occupancy schedule	People (W/m²)	Equipment (W/m²)
8:30 a.m. to 4:30 p.m.	13,8	1,97
Door open schedule	Glass and wooden windows schedule	
8:30 a.m. to 4:30 p.m.	10 minutes every 1 hour	

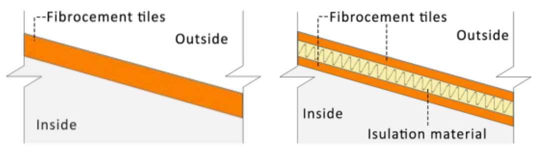
2.3. Modelling process and simulation analysis

The simulation of the original case was used as a benchmark reference for evaluating the influence of different materials and active heating systems on the building thermal performance. Thus, alternative cases using different thermal insulation materials and portable heater were modelled and simulated.

Firstly, different materials and thickness were applied on the ground and upper floors, as well as on the roof and on the external walls of the administration room and exhibition rooms 1, 2 and 3. For the analysis, the standard ASHARE-55 [18], which uses the adaptive approach to consider the indoor acceptable temperature as a function of the outdoor air temperature, was used.

For the whole roof of the building, six insulation materials were applied between the two existent layers of fibrocement tiles. The application considered the implementation of the material without compromising the visual aspect of the building. Figure 3 shows the original and the modified roofs.

Figure 3:
Schematic section of the original and the modified roofs.



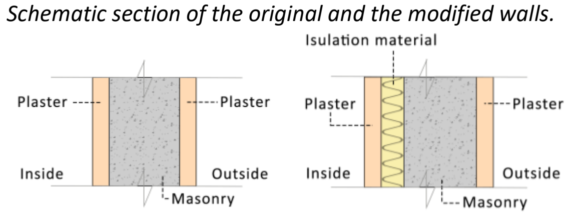
In addition, different thicknesses of insulation materials were considered. Table 2 characterizes the alternative materials evaluated. They were selected as they are the most commonly national used nowadays and are regulated by specific Brazilian technical standards. The thermal transmittance values of some materials were collected from the NBR 15220 [19].

Table 2:
Insulation materials characteristics for roof.

Material	Thickness (cm)	U (W/m².K)
Rock wool	1/3/5	2,660/0,975/0,791
Cork	1/3	2,827/1,327
Ceramic fibber	1/3/5	4,772/3,113/2,309
Expanded polystyrene (EPS)	1/3/5	2,477/1,107/0,712
Extruded polystyrene (XPS)	1/3	2,233/0,965
Polyurethane foam	1/3/5	1,958/0,816/0,515

Thenceforth, to limit the heat lost from the external walls, alternative models with insulation materials applied on those surfaces were also simulated. In those cases, expanded polystyrene - EPS (1cm) was set for the roof. Exhibition rooms 4 and 5 remained with the original materials. Three different insulation materials were considered: rock wool, expanded polystyrene (EPS) and polyurethane foam. They were applied between the masonry and the plaster on the inner side of the wall (Fig.4).

Figure 4:
Schematic section of the original and the modified walls.



Different thicknesses of such materials were considered. Table 3 characterizes the materials evaluated. In total, 25 cases were simulated and analysed for this passive approach.

Table 3:
Insulation material characteristics for walls.

Insulation Material	Wall	Thickness (cm)	U (W/m².K)
Rock wool	External rock	1/3/5	1,738/0,999/ 0,679
Rock wool	External adobe	1/3/5	1475/0,906/ 0,634
EPS	External rock	1/3/5	1,633/0,899/ 0,620
EPS	External adobe	1/3/5	1,339/0,823/ 0,583
Polyurethane foam	External rock	1/3/5	1,390/0,697/ 0,475
Polyurethane foam	External adobe	1/3/5	1,216/0,651/ 0,444

Regarding the active system, one case was simulated and analysed. A portable heater was installed in all rooms of the ground floor. This was not considered on the upper floor as the roof heats the rooms naturally. Table 4 shows the data set to simulate the portable heater.

Table 4:
Portable heater data.

Operating time	Fuel	Heating system type
8:30 a.m. to 4:30 p.m. (On 30min/Off 30min)	Electric	Radiant and convective

In order to examine the feasibility of the systems implemented, budgets assessments were carried out for the tested cases. Table 5 shows the prices (in dollar) of each insulation material and for the portable heater. For the last the cost the energy consumed is also shown. Cost regarding installation was not considered.

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

Table 5:
Cost of thermal insulators and portable heater.

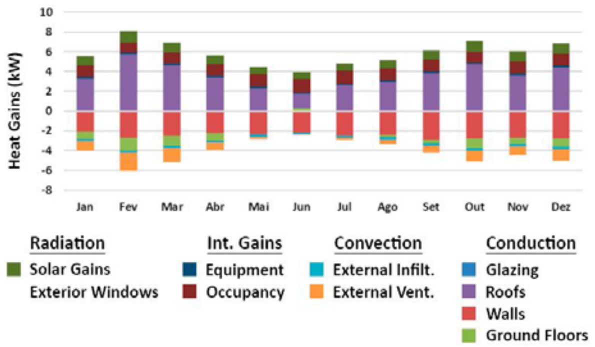
Material	Cost of 1m² ($)	
Rock wool	16.62	
Cork	12.84	
Ceramic fibber	28.62	
Expanded polystyrene (EPS)	2.09	
Extruded polystyrene (XPS)	3.46	
Polyurethane foam	31.89	
Equipment	**Equipment cost ($)**	**KW/h ($)**
Portable heater	3.676	0.17

3. RESULTS AND DISCUSSION

3.1 Thermal acceptance and heat gains of the original case

Results of the original case indicated different thermal acceptance levels on the building rooms. On the ground floor, 55% of the working hours was in thermal acceptability, i.e., 80% of people accept the thermal conditions in the museum during 55% of the working hours. On the other hand, in 44% of the time, people are in discomfort by cold and 2% by heat. Differently, on the upper floor, the thermal acceptability reached 43%, while 28% of time people was in discomfort by heat, and 30% by cold. Fig. 5 shows the expressive contribution of heat gains through the roof, which is the main cause of discomfort on the upper floor. Besides that, it is possible to notice that the discomfort by cold occurs as a consequence of the heat loses through the walls and external ventilation.

Figure 5:
Heat gains and losses of the Museum in its original state



3.2 Thermal acceptance of roof alternative cases

From the application of different thermal insulation materials on the roof, Table 6 shows the thermal acceptance of all cases tested. It is possible to notice that on the upper floor, the moments of discomfort by heat reduced and the comfortable moments increased with the application of the insulation materials. It is also clear that comfortable hours increase with thicker compositions.

On the other hand, on the ground floor, the hours of discomfort due to the cold conditions increases and the comfortable moments are reduced with the increase of the thickness of the thermal insulation materials applied. Thus, the use of insulation materials limits the heat coming from the roof towards the lower floor.

Table 6:
Thermal acceptance of roof alternative cases.

Material (roof)	Discomf. Cold	Comfort	Discomf. Heat
	ground / upper	ground / upper	ground / upper
Original case	44%/30%	55%/43%	2%/28%
Rock wool (1cm)	50% / 34%	50% / 51%	0% / 15%
Rock wool (3cm)	54% / 37%	46% / 59%	0% / 4%
Rock wool (5cm)	55% / 40%	45% / 59%	0% / 1%
Cork (1cm)	50% / 34%	50% / 52%	0% / 14%
Cork (3cm)	55% / 40%	45% / 58%	0% / 3%
Cer. fibber (1cm)	46% / 32%	54% / 44%	0% / 24%
Cer. fibber (3cm)	48% / 34%	51% / 49%	0% / 17%
Cer. fibber (5cm)	50% / 35%	50% / 52%	0% / 13%
EPS (1cm)	50% / 34%	50% / 52%	0% / 14%
EPS (3cm)	54% / 38%	46% / 59%	0% / 3%
EPS (5cm)	56% / 40%	44% / 59%	0% / 1%
XPS (1cm)	51% / 35%	49% / 53%	0% / 12%
XPS (3cm)	55% / 39%	45% / 60%	0% / 1%
Polyur. foam (1cm)	51% / 35%	49% / 55%	0% / 10%
Polyur. foam (3cm)	55% / 40%	45% / 59%	0% / 1%
Polyur. foam (5cm)	57% / 41%	43% / 58%	0% / 0%

It was also observed that the uncomfortable hours due to hot conditions on the upper floor present a considerable variation according to the material used, varying from 0 (polyurethane foam) to 24% (ceramic fibber). It was also noted that in all the alternative cases, the cold conditions on the upper floor increased, reaching up to 41% (5cm-polyurethane foam).

Considering the efforts to the reduce the heat moments on the upper floor, the ceramic fibre was the insulation material with less benefits to the model. While other materials reduced the moments of heat conditions by 18%, on average, the application of the ceramic fibre resulted in more similar values to the original case. It was also noted that some cases presented similar results, such as Rock wool (5cm), EPS (5cm), XPS (3cm); Polyur. foam (3cm). In those cases, there was a considerable reduction on the heat moments, although the moments of discomfort by cold increased in about 11%.

Comparing the cost of the materials and considering the similarity of the thermal acceptability of the cases presented, the EPS was considered the most appropriate material to the Museum roof. Its application would cost $270. It is also important to notice that the most expensive materials are not always the most suitable for a particular objective.

3.3 Thermal acceptance of wall alternative cases

In order to improve discomfortable conditions due to cold conditions on the ground floor, different thermal insulation materials on the walls were tested (Table 7). The comfortable moments on the ground floor increased in all cases. The improvements were, however, only from 1 to 5%, when comparing to the original case. Comparing the alternative cases, it was noticed that the case that used polyurethane foam (5cm) was the option with the highest improvement in comfortable conditions on the ground floor.

It was also noticed that the moments of discomfort due to heat conditions on the upper floor was reduced by 12% or 13% with the thermal insulation materials tested and the hours in discomfort moments due to heat conditions achieved 1% or stayed the same. Thus, by applying a layer of thermal insulation to the ground floor walls and to the roof resulted in a reduction of moments in displeasure by the cold on both floors, as well as a reduction in heat discomfort on the upper floor.

Table 7:
Thermal acceptance of wall alternative cases.

Material (wall)	Discomf. Cold	Comfort	Discomf. Heat
	ground / upper	ground / upper	ground / upper
Original case	44%/30%	55%/43%	2%/28%
Rock wool (1cm)	43% / 33%	56% / 51%	1% / 15%
Rock wool (3cm)	40% / 33%	58% / 51%	2% / 16%
Rock wool (5cm)	39% / 32%	59% / 51%	2% / 16%
(EPS) (1cm)	43% / 33%	56% / 51%	1% / 15%
(EPS) (3cm)	40% / 33%	58% / 51%	2% / 16%
(EPS) (5cm)	39% / 32%	59% / 51%	2% / 16%
Polyur. foam (1cm)	42% / 33%	57% / 51%	1% / 16%
Polyur. foam (3cm)	39% / 32%	59% / 51%	2% / 16%
Polyur. foam (5cm)	38% / 32%	60% / 51%	2% / 16%

In fact, the application of insulation materials caused a reduction on the uncomfortable moments by heat, especially on the upper floor, but little improvements were observed in reducing cold conditions.

Similar to the result of the roof simulations, the best option to improve the thermal comfort of the Museum was the polyurethane foam. However, considering the cost of the material and the little improvements in relation to the others, it is recommended that EPS is a viable option for the Museum. The application of such material would cost $356 to be applied to the building.

3.4 Thermal acceptance with portable heater

With the objective of reducing the hours of discomfort due to cold conditions on the ground floor, a portable electric heater was installed in all the exhibition rooms on the ground floor. From this case, the comfortable moments on the ground floor increased in 16% in relation to the original case. It is also important to notice that the discomfort by heat on the upper floor increased only in 1% compared to the original case.

Comparing the price of this system with the isolation materials tested the installation of the portable heater is more expensive. The equipment cost 3.676 dollars and the electricity bill would be around 17.457 dollars per year. Therefore, from the simulations it was possible to notice the difficulty of achieving thermal comfort for both floors with the same system.

Table 8:
Thermal acceptance with the portable heater.

Active system	Discomf. Cold	Comfort	Discomf. Heat
	ground / upper	ground / upper	ground / upper
Original case	44%/30%	55%/43%	2%/28%
Portable heater	27%/27%	71%/44%	2%/29%

The initial analysis of the conditions of the real building was important to identify the constraints of the building thermal performance, informing the heat gains and losses. The analysis of the of costs of the materials and equipment tested is also a beneficial resource to support the decisions to be made by designers.

4. CONCLUSION

This study aimed to thermally and economically evaluate the application of different insulation materials on the envelope (roof and walls) and the implantation of a portable heater of the heritage Casa do Colono Museum, an important construction for the history of Petrópolis, Brazil. In general, the main findings include:

- Fibre ceramic was the least suitable thermal insulation material to be applied as it presented similar results to the original case;
- Polyurethane foam had the best result among the cases tested, but is the most expensive material;
- EPS was the most suitable thermal insulation material for the building, considering the balance between thermal performance and cost;
- The application of thicker rock wool, EPS and polyurethane form into the walls

resulted in a slightly increase in cold discomfort and a gradual increase of the comfortable moments.

- The use of the portable heater resulted in a considerable improvement in hours of discomfort by cold, with similar discomfort by heat to the original case on the upper floor.
- The use of the portable heater may increase the comfortable conditions of the museum by 16%, but with a great expense.

Based on the findings above, it is indicated that EPS is applied to both roof and wall. The total expenses for the installation of the 5cm EPS thermal insulation on the roof would be $270 dollars and will result in a 10% improvement in hours of comfort on the upper floor; mitigating hours of discomfort. Furthermore, the application of 1cm-EPS on the roof and the 5cm-EPS on the ground floor walls would result in an increase in comfort by 5% on the ground floor and 8% on the upper floor. The total cost of this procedure would be $356 dollars.

As the historic building evaluated is listed, interventions that alter the appearance of the building's facades or its internal characteristics were not possible. Thus, this study demonstrates the difficulty in proposing interventions in a warm summer and cold winter climate, while maintaining the building original characteristics. It is important to note that the assumptions made, and the limitations related to the computational models are unlikely to capture the exact usage, occupancy profiles, climate and site conditions.

Lastly, the Casa do Colono Museum still has many possibilities to be explored to improve its thermal comfort. Active and passive systems such as underfloor heating and earth tube may also be useful to improve the thermal performance without altering the visual appearance of the building. Also, changing the window glass and the use of thermal paints are possibilities to improve the thermal sensation of the building users.

ACKNOWLEDGEMENTS

To the Research Support Foundation of the State of Rio de Janeiro (FAPERJ) for the scientific initiation scholarship granted during the period of writing this article, under public notice number 201.732/2021.

REFERENCES

1. United Nations. (2015). Millennium Develop. Goals Report.
2. Berg, M., Voordijk, H., Adriaanse, A. (2021). BIM uses for deconstruction: an activity-theoretical perspective on reorganising end-of-life practices. *Construction Management and Economics*, 39 (4), p. 323-339.
3. Munarim, U. and Ghisi, E. (2016). Environmental feasibility of heritage buildings rehabilitation. *Renewable and Sustainable Energy Reviews*. Inglaterra, 58: p. 235-249.
4. IPHAN. (2019). Lista dos bem tombados e processos em andamento (1938-2019).
5. Fridman, F., Araújo, A. P. S. d., & Daibert, A. B. D. (2019). Políticas públicas de preservação do patrimônio histórico no Brasil. Três estudos de caso (1973-2016). *Rev. Bras. Estud. Urbanos Reg.*, 21: p. 621-638.
6. ABNT - Brazilian Association of Technical Standards. NBR 15575. (2021). Thermal performance, Rio de Janeiro, 2021.
7. Gonçalves, J. C. S., Dolce, M., Mulfarth, R. C. K., Lima, E. G., Ferreira, A. (2018). Revealing the thermal environmental quality of the high-density residential tall building from the Brazilian bioclimatic modernism: The case-study of Copan Building. *Energy and Buildings,* 175: p. 17-29.
8. Knop, S. and Cunha, E. G. D. (2012). Evalution of the Thermal Performance of Historic Building with new use in the city of Pelotas. In *International Building Performance Simulation Association*. UK, September 10 - 11.
9. Moro, J., Correa, P. C. B., & Kruger, E. (2020). Avaliação da Eficiência Energética do Tribunal de Contas do Paraná, sediado em Curitiba. *Paranoá: Cadernos de Arquitetura e Urbanismo*, (28), p.1-22.
10. Japiassú, P. (2019). Método para avaliação de retrofit energético em edificações históricas brasileiras. Universidade de Brasília. Brasília.
11. Carvalho, A. R. d., Cunha, E. G. d. C., Krebs, L. F., Oliveira, A. L. C. d., & Silva, A. C. S. B. d. (2019). Estudo Piloto sobre aplicação da normativa ENERPHIT em um edifício histórico de Pelotas, RS. In *XV Encontro Nacional de Conforto Ambiental Construído*. João Pessoa, Brazil, September 18-21.
12. Werneck, D., Costa, J., Aguiar, J., Sousa, N., Lopes, A., Amorim, A. (2017). Studies on energy performance utilizing computer simulations towards a ZEB building: a case study in Chico Mendes Institute in Brasilia. In: *Plea 2017,* Edinburgh, Scotland, July 3-5.
13. Fernandes, L. O. and Labaki, L. C. (2016). Retrofit of educational facility through passive strategies in hot climate. In *9th Windson Conference: Making Confort Relevant. Windsor*, UK, April 7-10.
14. Apolônio, R. M., Omar, L. G., Jesus, M. H., Nogueira, M. C. J. A., Carvalho, B. C. (2010). Proposta de Retrofit para um edifício histórico seguindo os princípios de sustentabilidade. In *4º Congresso para o Planeamento Urbano, Regional, Integrado e Sustentável*. Portugal, October 06-08.
15. Martínez-Molina, A., Tort-Ausina, I., Cho, S., & Vivancos, J.-L. (2016). Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews*, 61: p. 70-85.
16. Neves, F. M. B. and Zenatta, E. M. (2016). Traços de Koeler: A origem de Petrópolis a partir de 1846. *Globalmídia Comunicação,* 1: p. 9-235.
17. Vieira, A. C. M. (2021). Annual report on the activities of the Casa do Colono Museum – Year 2020. Petrópolis, Brazil, April 19.
18. The American Society of Heating Refrigerating and Air-Conditioning Engineers. (2020). ASHRAE 55 – 2020 Thermal environmental conditions for human occupancy.
19. ABNT - Brazilian Association of Technical Standards. NBR 15220. (2003). Thermal performance of buildings Part 1: Definitions, symbols and units, Rio de Janeiro, 2021.

PLEA STGO 2022

WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE URBAN DEVELOPMENT

DAY 02
10:15 — 11:45

CHAIR
DENISE DUARTE

PAPERS
1672 / 1223 / 1457 / 1250 / 1621

17TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA 2022 SANTIAGO
Will Cities Survive?

Analysis of isolated shrubby-arborean species as a barrier to winds for urban thermal comfort

Methods to obtain the leaf area index

HELENA CRISTINA PADOVANI ZANLORENZI[1], LEONARDO MARQUES MONTEIRO[1]

[1]Faculdade de Arquitetura e Urbanismo da Universidade de São Paulo – FAUUSP, São Paulo, Brazil

ABSTRACT: Wind is a determining factor to obtain optimized thermal comfort conditions in open spaces. Analyzing the composition of shrub-tree species and their efficiency as a barrier to winds is important for urban thermal comfort, architectural landscaping and urban forestry. The present study is part of the author's doctoral research; empirical data about wind velocity attenuation was collected for 16 shrub-arborean species on the campus of the Technological Research Institute (IPT) at the University of São Paulo (USP) in São Paulo city, Brazil, and the results are being related to the Leaf Area Index (LAI) of species. There are different methods of obtaining the LAI; this research evaluated the best way to obtain this parameter for isolated arboreal elements as a wind barrier using two indirect (non-destructive) methods: using the Equipment LAI-2200C Plant Canopy Analyzer, and fisheye photos with digital camera with wide angle lens, which were applied to Gap Light Analyzer. Considering that the records of fisheye photos and LAI 2200C were taken in the same positions and conditions, it can be concluded that, for isolated plant elements, the use of fisheye photos is more appropriate, since these photos may have the useful area selected by the GLA program.
KEYWORDS: Outdoor comfort, Thermal comfort, Wind barriers, Vegetable barriers, Leaf area index

1. INTRODUCTION

Among urban microclimatic variables, wind is a determining factor to obtain optimized thermal comfort conditions in open spaces. Studies are being carried out on the composition of shrub-tree species and their efficiency as a barrier to winds, mostly for studies of urban thermal comfort, architectural landscaping and urban forestry. The relationships between the barrier's shelter capacity and its porosity are portrayed by [16] in an important global compilation of the studies carried out about plant barriers, also by [8-9]. Experiments with wind tunnel barriers, composing different heights and shapes was performed by [11], and [10] also varied in densities. These experiments were used as references and detailed in the bibliographic review of the author's master's thesis [17], where these factors are being related to the performance of the barriers, mostly porosity and its upwind position.

The present study is part of the author's doctoral research; empirical data on wind velocity attenuation was collected for 15 shrub-arborean species, and the results are being related to the Leaf Area Index (LAI) of species. LAI is the ratio of half of the total needle surface area per unit ground area [1-6-12-14-15]; it is a key vegetation structural characteristic that drives many vegetation functions and is used to describe plant canopies as a parameter in ecophysiological and biogeochemical models [3-5]. There are different methods of obtaining the LAI; the ways to obtain the LAI can be by direct destructive methods or by indirect non-destructive methods. The method defined by [14] comprises the direct destructive method, since to be obtained it involves the concept of harvesting all the leaves from the vegetation, measuring and counting them; or it can be based on the calculation of the average area of individual leaves collected and, from this data, estimate the LAI for the entire tree canopy.

To differentiate the magnitudes, it was proposed by [2] the effective LAI term (Le) for the LAI measured by the indirect methods, and the true LAI (L) which corresponds to the real LAI, obtained by the direct method. The aggregation factor (Ω) represents the non-random distribution of the canopy elements in the equation: $Le = \Omega \times L$ [2-15]. When the crown is crowded, the value of Ω is less than 1; for a more regular canopy distribution, Ω is greater than 1. The value equal to 1 considers the random distribution of the leaves, as initially assumed by the indirect methods model. As the value of Ω is generally unknown, it is more appropriate to have different denominations. Measurement by indirect methods requires calibration with the direct method.

According to [13], what defines the choice for the use of effective or true LAI is its application; the true LAI better represents the potential of the physiological activities of the vegetation, while the effective LAI better represents the radiation interception by the distribution of the leaves.

In the present study, it was considered that the effective LAI best represents the proposed objective, which is to evaluate the vegetation as a barrier in its geometric composition, and not exploring its physiological activities.

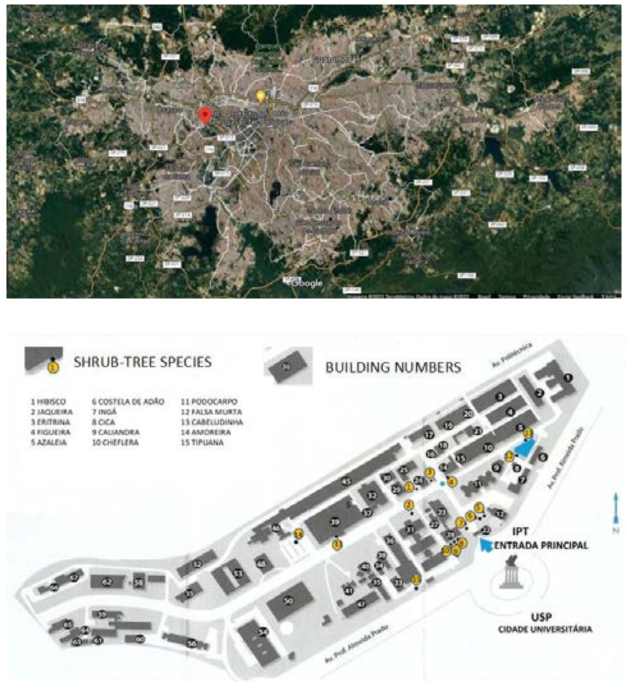
This research evaluated the best way to obtain this parameter for isolated arboreal elements as a wind barrier using two indirect (non-destructive) methods.

2. MATERIALS AND METHODS

2.1 Study area

In this empirical study, measurements were made on 15 shrub- trees species located on the campus of the Technological Research Institute (IPT) at the University of São Paulo (USP) in São Paulo city, Brazil (Fig. 1), which contains several plant species. The 15 species studied were chosen for the different compositions and densities of the crown composition, as well as the variety of available species.

Figure 1:
Location of the 16 studied species, in IPT, São Paulo city, Brazil.



2.2 Field data collection

The wind speed attenuation index measurements were made from 8:30 am to 4:30 pm, one day per species, between January 09 and January 30, 2020. Microclimatic variables were recorded by a Campbell Scientific Station composed of datalogger and solar collector for battery power, connected to two sets of equal equipments, one for each side of the plant barrier (thermohygrometer and sonic anemometer).

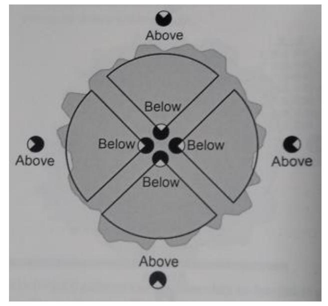
The LAI values were obtained simultaneously by two different indirect (non-destructive) methods:

- Equipment LAI-2200 Plant Canopy Analyzer (LI-COR);
- Fisheye photos with digital camera Canon T3i with wide angle lens Sigma 8mm, which was applied to Gap Light Analyzer (GLA) version 2.0.

2.2.1 Measurements with LAI 2200 (LI-COR)

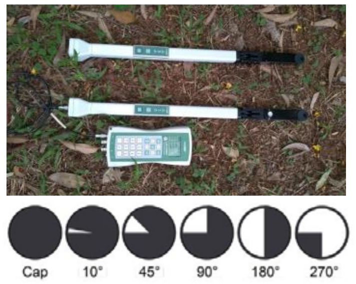
The LAI measurements were made at sunrise of January 09 and January 28, 2020. In each tree species, four measurements were taken, as referenced in the LAI 2200 Equipment Manual [4] for isolated elements (Fig.2).

Figure 2:
Illustration of a measurement in a tree with a 4 below readings 90º apart.



Using the LAI 2200C equipment, for each species, four measurements were taken outside the canopy and four measurements inside it, every 90º (Fig.2), with the protective cover opening 90º on the lens facing outwards (Fig. 3).

Figure 3:
The LAI 2200 Canopy Analyzer equipment before measurements, and the protective cover opening 90º among all options.



In LAI 2200 measurements carried out in 2020, it was decided to use only one rod, as was done with the previous version of the equipment (LAI-2000), and subsequent association of the data and calculation of the resulting LAI by the software available on the website from Li-Cor, the FV-2200. In the measurement of each species, the stem was initially placed in a remote position, in an open field close to the vegetation measured, and then measuring under the canopy. A cover with a 90º opening was used in both positions, as recommended in the equipment manual for isolated trees. With the stem positioned under the canopy, four measurements were taken per species, in a horizontal position, approximately every 90º in plan, at a certain distance from the body, with the opening facing the outside of the canopy. In arboreal plant elements with a canopy far from the ground, the stem was placed under the canopy for measurements; in shrubs whose body starts from the ground (as is the case of podocarpo and falsa murta species), or trees with very low crowns, the measuring rod was placed inside the crown at four different points (Fig.2). It is noted in the equipment manual that the reading in the remote position in the open field and the reading under the canopy must be exposed to the same view of the sky.

2.2.1 Measurements with Fisheye photos + Gap Light Analyzer (GLA)

The fisheye photos were taken in the same 90º quadrants described for LAI 2200. In total, twenty fisheye photos were taken. LAI was obtained by the method of hemispherical photos with a fisheye lens attached to the camera, associated with the Gap Light Analyzer (GLA) program. The photos were taken at the beginning of the day, without the presence of direct sun, throughout the month of January 2020, one of the measurements being taken together with the LAI 2200, taking four photos per measurement, one at every 90º.

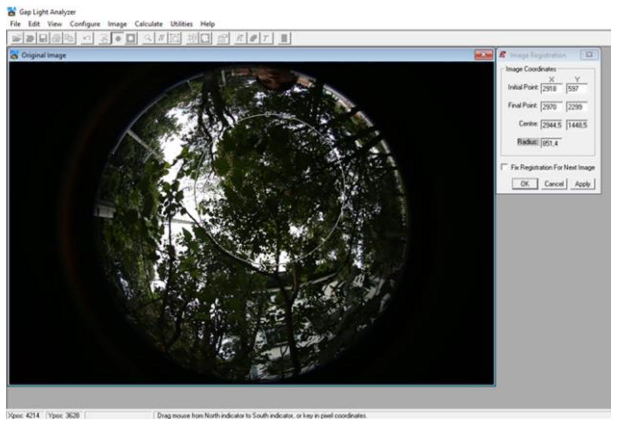
A Canon EOS 6D digital camera (high performance single-lens reflex) + 8mm F3.5 EX DG Circular Fisheye full frame lens, with 180º viewing angle, belonging to FAUUSP, was used for the photos.

According to [13], in the application they used to obtain the LAI from hemispherical photos (Can-Eye, with the same function as the GLA), the use of six to twenty photos was suggested. In the present research, twenty photos per species were collected, and the ten best ones were later selected to obtain the LAI.

The main criterion for choosing the ten best photos was to discard those that eventually resulted in a small distance between the lens and the leaves, which would change the reading of the sky fraction of the species.

The procedure used for each photo followed the indications in the GLA user manual [4]. The GLA program is free and very user-friendly. Initially, to access the desired photo, you must enable the 'other graphics' option on the 'type' tab. Opening one of the photos in the program, access 'configure' and 'register image'; the visual field to be considered is selected (excluding obstructions if necessary) according to Figure 4.

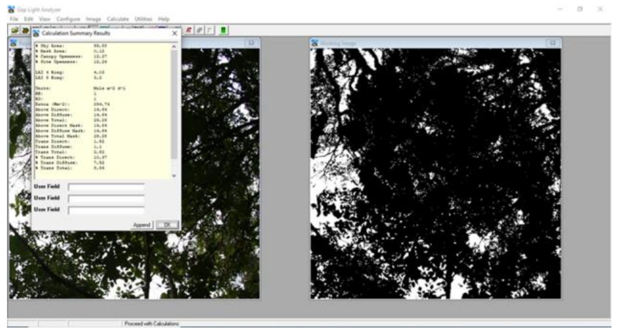
Figure 4:
Selection of the study area in the images by the GLA program.



Then, the program duplicates the photo within the chosen selection, and under the command 'image' and 'threshold' one of the images is converted to the binary form being a working image. The program's default pixel value is 128, which can be adjusted when the photo needs brightness adjustment. Finally, with the 'run calculate' command, several output data are obtained (Fig. 5), highlighting:

a) canopy opening percentage (% Canopy Openness)
b) LAI in ring 4 (LAI 4 ring) = effective leaf area index integrated over the zenith angles from 0 to 60º;
c) LAI in ring 5 (LAI 5 ring) = effective leaf area index integrated over the zenith angle from 0 to 75º.

Figure 5:
Output data from the GLA program.



The values resulting from ring five (5 ring) were used in this work, considering angles closer to those resulting from the LAI 2200, which also uses the reading of the five rings. For each species, the average of the values obtained in the ten photos was estimated to adopt the LAI value in this method.

3. RESULTS AND DISCUSSION

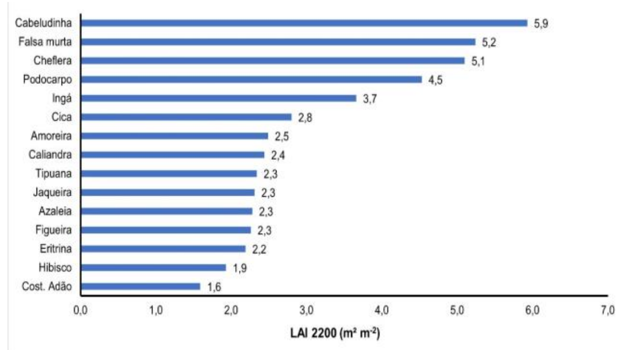
The results obtained from the measurements were evaluated and compiled.

The following results refer to the data collected by LAI 2200, in the form of a table (Table 1) and a graph (Fig. 6).

Table 1:
LAI resulting by species - Measurement with LAI 2200.

	SHRUB-TREE SPECIES	LAI (m^2m^{-2})
1	HIBISCO	1,93
2	JAQUEIRA	2,31
3	ERITRINA	2,19
4	FIGUEIRA	2,26
5	AZALEIA	2,28
6	COSTELA DE ADÃO	1,59
7	INGÁ	3,66
8	CICA	2,80
9	CALIANDRA	2,44
10	CHEFLERA	5,10
11	PODOCARPO	4,53
12	FALSA MURTA	5,24
13	CABELUDINHA	5,93
14	AMOREIRA	2,49
15	TIPUANA	2,34

Figure 6:
LAI resulting by species - Measurement with LAI 2200.

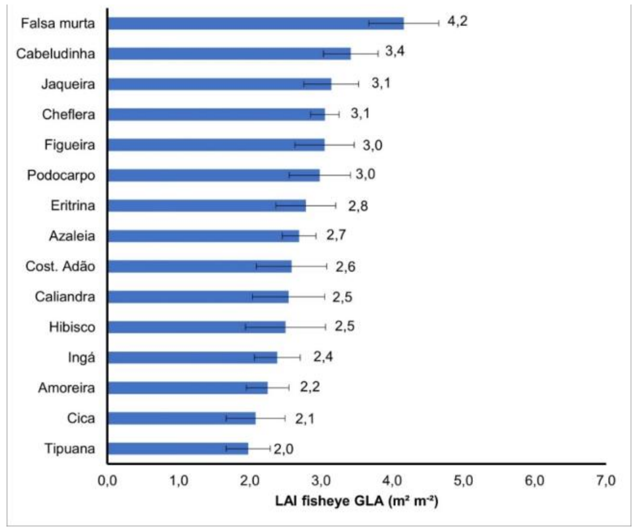


The following results refer to the data collected by Fisheye + GLA, in the form of a table (Table 2) and a graph (Fig. 7).

Table 2:
LAI resulting by species – Measurement with Fisheye + GLA.

	SHRUB-TREE SPECIES	LAI (m^2m^{-2})	CANOPY OPENNESS (%)
1	HIBISCO	2,50	12,97
2	JAQUEIRA	3,15	8,31
3	ERITRINA	2,79	12,06
4	FIGUEIRA	3,05	10,13
5	AZALEIA	2,69	10,06
6	COSTELA DE ADÃO	2,59	12,55
7	INGÁ	2,38	14,67
8	CICA	2,08	19,05
9	CALIANDRA	2,54	12,60
10	CHEFLERA	3,05	7,60
11	PODOCARPO	2,98	9,49
12	FALSA MURTA	4,16	3,05
13	CABELUDINHA	3,42	5,61
14	AMOREIRA	2,25	15,04
15	TIPUANA	1,98	17,80

Figure 7:
LAI resulting by species – Measurement with Fisheye + GLA.



A relevant issue in the use of hemispherical photos is that this method allows the elimination of elements external to the vegetation studied, such as buildings or other obstruction elements, by choosing the visual field to be considered in obtaining the binary photo that generates the value of the corresponding gap fraction; this resource is particularly important in the study of isolated trees inserted in the urban environment.

The relationship between the results obtained with the two indirect methods of LAI collection was analysed graphically according to the figures below, as well as a comparison between the LAI values and the percentage of canopy opening.

Figure 8:
The relationship between the results obtained with the two indirect methods.

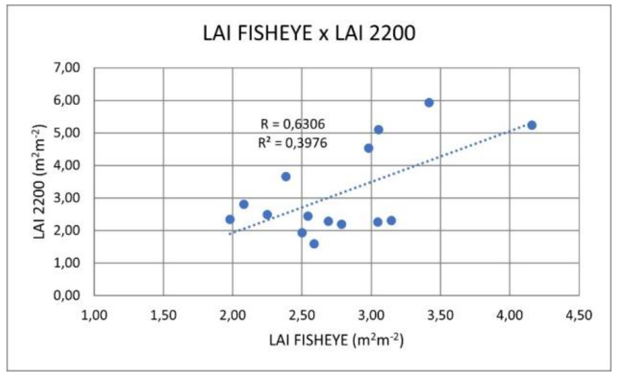


Figure 9:
A comparison between the LAI 2200 and the percentage of canopy openness.

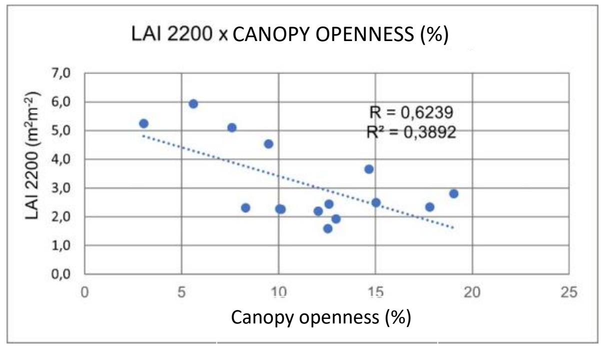
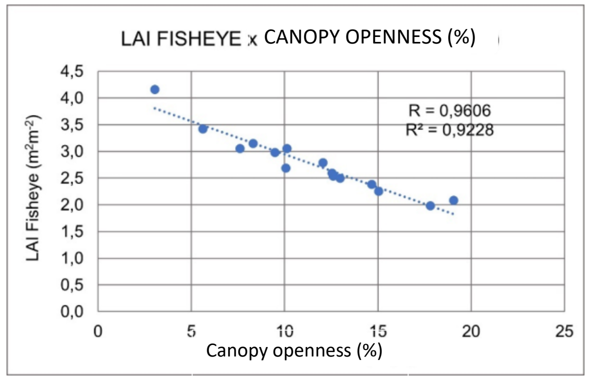


Figure 10:
A comparison between the LAI Fisheye + GLA and the percentage of canopy openness.



The relationship between the results obtained with the method of hemispherical photos showed a greater correlation with the percentages of canopy opening.

The original fisheye photos obtained from isolated plant species indicate unwanted presence of peripheral elements that interfered in the composition of the photo, such as buildings, other vegetation and eventually the machine operator, was registered.

4. CONCLUSION

Considering that the records of fisheye photos and LAI 2200C were taken in the same positions and conditions, it can be concluded that, for isolated plant elements, the use of fisheye photos is more appropriate, since these photos may have the useful area selected by the GLA program, excluding elements foreign to the vegetation canopy.

ACKNOWLEDGEMENTS

The authors thank the Faculty of Architecture and Urbanism, University of São Paulo (FAUUSP) and the the Luiz de Queiroz College of Agriculture, University of São Paulo (ESALQ USP) for the support and loan of measuring equipments. The authors are also grateful for the important support of the Institute for Technological Research (IPT) in allowing measurements on its campus, making this research feasible.

REFERENCES

1. Bréda, N. J. J., (2003). Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. *Journal of Experimental Botany* 54, No. 392, p. 2403-2417.
2. Chen, J. M.; Black, T. A.; Adams, R. S., (1991). Evaluation of hemispherical photography for determining plant area index and geometry of a forest stand. *Agricultural and Forest Meteorology* 56, p. 129-143.
3. Chen, J. M., Rich, P. M., Gower, T. S., Norman, J. M., & Plummer, S., (1997). Leaf area index of boreal forests: Theory, techniques and measurements. *Journal of Geophysical Research*, 102, 429–443.
4. Frazer, G.W., Canham, C.D., and Lertzman, K.P. (1999). Gap Light Analyzer (GLA): Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Copyright © 1999: *Simon Fraser University*, Burnaby, British Columbia, and the *Institute of Ecosystem Studies*, Millbrook, New York.
5. Jensen, R.R.; Hardin, P.J.;Bekker, M.; Farnes, D.S.; Lulla, V.; Hardin, A. (2009). Modeling urban leaf area index with AISA+ hyperspectral data. *Applied Geography* 29. p. 320–332.
6. Jonckheere, I.; Fleck, S.; Nackaerts, K.; Muys, B.; Coppin, P.; Weiss, M.; Baret, F., (2004). Review of methods for in situ leaf area index determination. Part I. Theories, sensors and hemispherical photography. *Agricultural and Forest Meteorology* 121, p. 19–35.
7. LAI-2200C Plant Canopy Analyzer Instruction Manual, Publication No. 984-14112. p. 6-17.
8. Lee,J-P.; Lee,E-J,; Lee,S-J. (2014). Shelter effect of a fir tree with different porosities. *Journal of Mechanical Science and Technology* 28 (2) 565-572.
9. Nord, M. (1991). Shelter effects of vegetation belts – Results of field measurements. *Boundary-Layer Meteorology* 54: 363-385.
10. Oke, T. R. (1987). *Boundary layer climates*. 2ed. Routledge and John Wiley & Son; London, New York.
11. Olgyay, V. (1963). *Design with climate – bioclimatic approach to architectural regionalism*. New Jersey: Princeton University Press.
12. Parker, G., (2020). Tamm review: Leaf Area Index (LAI) is both a determinant and a consequence of important processes in vegetation canopies. *Forest Ecology and Management* 477, 118496.
13. Shinzato, P.; Yoshida, D. F. O.; Duarte, D. H. S. (2015). O impacto da vegetação nos microclimas urbanos: Estimativa do índice de área foliar -IAF pelo método de fotos hemisféricas. *ENCAC ELACAC* - XIII Encontro Nacional e IX Encontro Latino-americano de Conforto no Ambiente Construído.
14. Watson, D.J., (1947). Comparative Physiological Studies on the Growth of Field Crops: I. Variation in Net Assimilation Rate and Leaf Area between Species and Varieties, and within and between Years. Published by: Oxford University Press. Annals of Botany, New Series, Vol. 11, No. 41, p. 41-76.
15. Weiss, M.; Baret, F.; Smith, G. J.; Jonckheere, I.; Coppin, P., (2004). Review of methods for in situ leaf area index (LAI) determination. Part II. Estimation of LAI, errors and sampling. *Agricultural and Forest Meteorology* 121, p. 37–53.
16. Wu,T.; Zhang,P.; Zhang,L.; Wang,J.;Yu,M.; Zhou, X.; Wang,G.G.(2018). Relationships between shelter effects and optical porosity: A meta-analysis for tree windbreaks. *Agricultural and Forest Meteorology* 259, 75–81.
17. Zanlorenzi, H.C.P. (2015). Áreas verdes e conforto térmico: o papel da vegetação no controle dos ventos. 129 p. Dissertação (Mestrado em Ciências) – *Escola Superior de Agricultura Luiz de Queiroz*, Piracicaba.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

PLEA SANTIAGO 2022
Will Cities Survive?

How hot is your city design?

Surface temperature portrait of São Paulo Metropolitan Region

LUCIANA SCHWANDNER FERREIRA[1] DENISE HELENA SILVA DUARTE[1]

[1] USP, Universidade de São Paulo, FAU, School of Architecture and Urbanism.

ABSTRACT: Urban form has strong direct implications on greenhouse gas emissions, urban thermal patterns, hydrological processes, dispersion of air pollutants, etc., consequently impacting the quality of life and the health of urban dwellers. The study of different urban forms and its impacts on urban microclimate is of great importance to inform urban designers, decision makers and the society to shape their choices towards a climate-sensitive approach. This paper investigates day and nighttime land surface temperature (LST) over different urban forms in São Paulo Metropolitan Region, Brazil, aiming to contribute with the study of subtropical urban forms in a megacity of more than 22 million inhabitants. Fifteen years of thermal data from Aqua-MODIS satellite were used, totalling 690 images for each variable. Results were explored both in metropolitan and pixel scale to highlight the differences of distinct urban arrangements. LST data, combined with other social and morphological aspects can help to deliver a cool design, both in human and thermal aspects, combining the high density we need with the great urban environment we want, especially in a scenario of climate change where extreme events of high temperatures are expected.
KEYWORDS: Urban Microclimate; Urban Planning; Local Climate Zones; Urban morphology.

1. INTRODUCTION

The effects of urban areas on microclimate have been scientifically observed for approximately 200 years in Europe. However, in tropical areas it is more recent, being Ernesto Jáuregui the pioneer with studies for Mexico DF in 1973 [1, 2].

Despite the long-term observations, urban climate knowledge has not been fully incorporated in urban planning, especially in tropical and subtropical areas, expected to face high rates of urbanization in the upcoming years [3, 4]. The reasons for this are not only technical, but also related to policy, organizational and market issues [5, 6, 7].

Urban form has strong direct implications on greenhouse gas emissions [8], urban thermal patterns [9, 2], hydrological processes [10], dispersion of air pollutants [2], etc., consequently impacting the quality of life and the health of urban dwellers. Thus, the study of different urban forms and its impacts on urban microclimate is of great importance to inform urban designers, decision makers and the society to shape their choices towards a climate-sensitive approach.

This paper investigates day and nighttime land surface temperature (LST) over different urban forms in São Paulo Metropolitan Region (SPMR), Brazil. It is the fourth largest metropolitan area in the world [11], formed by 39 municipalities with more than 22 million inhabitants [12]. It is located in the southeast Brazil, approximately 50km far from the coast, the altitude varies between 720m and 850m above sea level with a humid subtropical climate (Cfa), according to Köppen classification.

The aim of this research is to contribute with the study of subtropical urban forms by detailing daytime and nighttime thermal responses of different urban arrangements over a 15-year period.

2. METHODOLOGY

Remote sensing has been used in military and earth science since the beginning of the 20th century, however, its use for urban studies is more recent. The first Academic forums on the subject only began in 1995. Despite urban remote sensing being a well-developed area of remote sensing, its direct contribution to urban policy remains underexplored [13].

The use of remote sensing data in urban studies has several advantages: it allows the observation of large areas simultaneously at a low cost, offering an alternative to collecting data on the ground, which is usually expensive or even not possible for large study areas; it provides information on non-visible electromagnetic spectrum bands at different spatial resolutions and with global coverage; it enables the use of past data and the creation of time series, which offers a historical perspective of urban processes or attributes; the georeferenced data can be integrated with socioeconomic data in GIS environment.

The limitations of using remote sensing in urban studies are related to the peculiarities of image interpretation due to the heterogeneity and the tridimensional characteristics of the urban environment.

In this study daytime and nighttime LST of the Aqua-MODIS satellite were used. The MODIS were chosen due to the availability of the nighttime data and for its temporal resolution of 1 to 2 days. This temporal resolution overcome a common issue in surface urban studies: the bias produced by using few thermal images. Land surface temperature (LST) is a dynamic variable. Its study requires a large amount of satellite images to characterize its behavior [14]. The use of few thermal images can lead to errors in the analysis, if the days chosen for the study are not typical days of atmospheric stability. Therefore, Aqua MODIS daily images were suit for the purpose of this research.

Aqua-MODIS daytime images are acquired at 13h30 and nighttime images at 1h30, both at 1km resolution. The product MOD11A2 was used, which provides the 8-day average LST per pixel. All available data between September 2002 and September 2017 were used, totaling 690 images for each variable. Cloud contaminated pixels and those with errors equal or greater than 3K were excluded, as well as the main water bodies (seen in white in figure 1, 2 and 3). Water bodies were excluded from the thermal analysis due to the differences between water thermal capacity and the urban dry surfaces and the vegetated surfaces.

Mean images were computed for the rainy (spring and summer) season, which has the higher temperatures. Mean thermal amplitude was estimated by subtracting mean nighttime images from mean daytime images. The entire procedure was performed in the R software.

The mapping of urban morphology was performed according to the local climate zones (LCZ) concept, developed by Stewart and Oke [15] and LCZ classification is in accordance with the methodology of the World Urban Database and Access Portal Tools (WUDAPT) [16].

The LCZ are defined as regions with uniform coverage of soil, structure, materials, and human activities, occupying hundreds of meters or kilometers. Each LCZ has a characteristic air temperature regime that is more evident on dry surfaces, on clear nights with little wind, and on simple relief areas [14]. Despite the characterization of the LCZ being performed by contrasting the air temperature of each typology, the lack of a dense and reliable monitoring network led to the use of LST obtained by remote sensing as an alternative [17, 18].

Mean images are useful to inform the thermal pattern of an area with small or no changes in its urban occupation over the studied period. In this sense, LCZ maps were produced for 2002 and 2017, at 100m spatial resolution, to investigate changes in urban morphology throughout a change detection analysis.

This research used only free data and free software to allow its reproducibility. The LCZ maps are available for public use in free data repository [19, 20].

3. RESULTS AND DISCUSSION

Figures 1 to 3 present the LST results for the entire metropolitan region, with mean images of all rainy seasons. Urban occupation is given by the Local Climate Zone Classification of 2002 (figure 4) and 2017 (figure 5)

Figure 1:
Daytime mean LST of all rainy seasons from 2002 to 2017. São Paulo Metropolitan Region

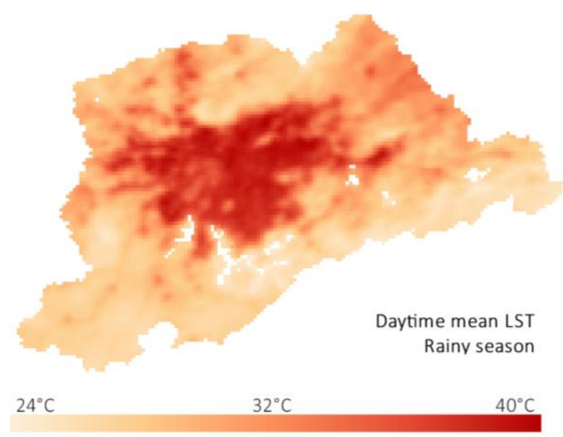


Figure 2:
Nighttime mean LST of all rainy seasons from 2002 to 2017. São Paulo Metropolitan Region.

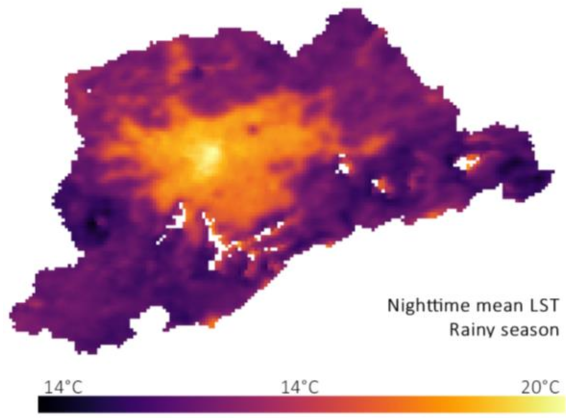


Figure 3:
Mean LST Amplitude of all rainy seasons from 2002 to 2017. São Paulo Metropolitan Region.

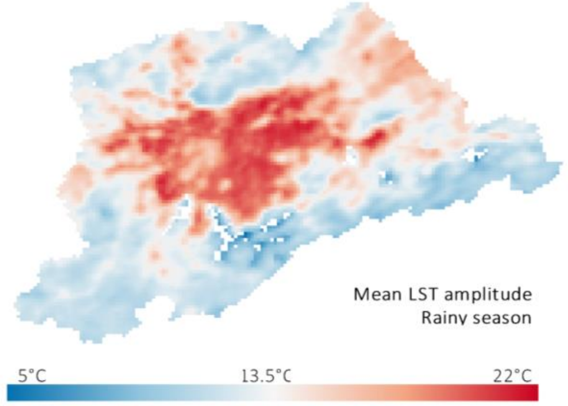


Figure 4:
Local Climate Zone Classification 2002. São Paulo Metropolitan Region

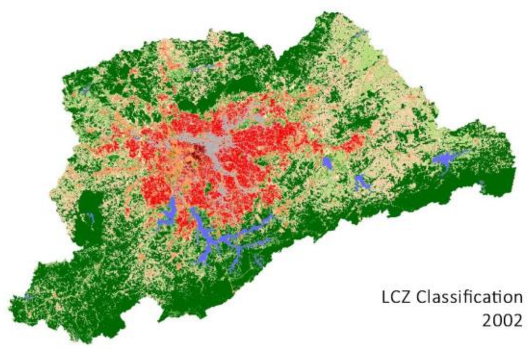
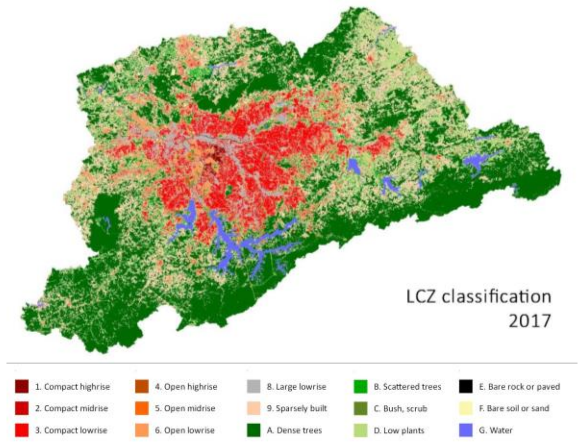


Figure 5:
Local Climate Zone Classification 2017. São Paulo Metropolitan Region



Urbanized areas presented higher daytime and nighttime surface temperatures compared to less urbanized regions; however, the urbanized area is not homogeneous, as explored in Figure 6. Regions (with 1 Km², corresponding to a MODIS pixel) with small or no changes in its urban occupation over the studied period were selected as examples according to the LCZ classification.

The compact LCZ morphologies presented the higher daytime LST, being the lowrise hotter than the highrise. Open highrise presented the lower daytime LST, 5°C lower than the compact lowrise in a 15-year mean image, meaning that in extreme events this difference can be higher.

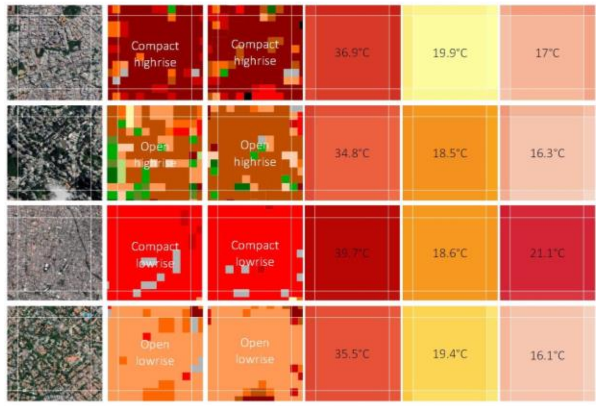
Open morphologies have more space between buildings and a greater vegetation cover. Highrise shadows are more effective in this situation as well as ventilation. Vegetation also contributes with latent heat exchange. The combination of these effects can explain the lower LST in daytime images in open arrangements. Also, the building shadows can explain the lower LST in compact highrise in comparison with compact lowrise.

The nighttime LST pattern is different from the daytime pattern, adding important information on the previous thermal studies of SPMR which analyzed only daytime data [21, 22]. The urban core, occupied by highrise compact building and other compact morphologies, is warmer than the open highrise arrangements and the lowrise typologies, a pattern compatible with the surface urban heat island. At nighttime, LST was higher in the compact highrise, where there are small spaces between buildings and large thermal mass. The thermal mass influences the heat accumulation and the sky view factor (SVF) influence the heat loss, as well as the vegetation cover.

Small SVF leads to a slower cooling in compact highrise, while higher SVF leads to a more rapid cooling in compact lowrise, which explains the higher LST amplitude in this morphology. On the other hand, vegetation biomass can slower heat loss, contributing to a slower cooling in open lowrise areas.

Figure 6:
Thermal patterns of different urban morphologies. Google Earth image, LCZ classification of 2002 and 2017, daytime and nighttime mean LST and mean LST amplitude of selected pixels.

Google Earth 2017	LCZ 2002	LCZ2017	Daytime LST	Nighttime LST	LST Amplitude



Figures 7 and 8 schematically represent the relationship between the urban form and the thermal dynamics both during the day and at night, showing the influence of the height of the buildings, the space between them and the presence of vegetation.

Figure 7:
Urban form and heat gain during the day.

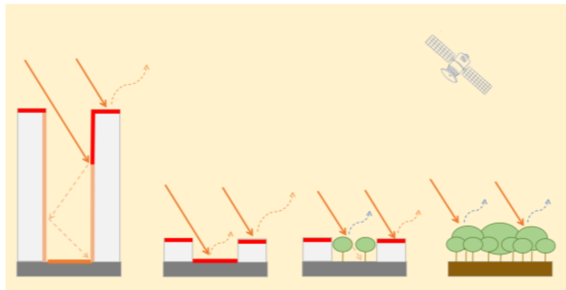
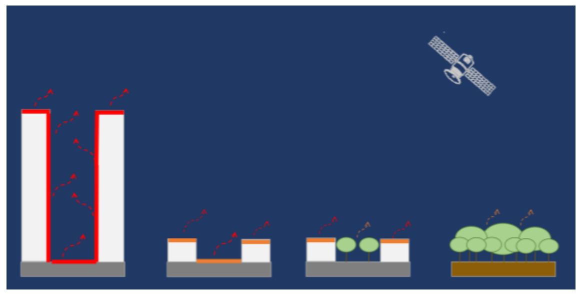


Figure 8:
Urban form and heat release during at night.



In addition to the thermal characteristics, it is important to highlight the urban design aspect of the LCZ typologies. Figure 9 shows street view examples from selected areas within regions showed in figure 6. In the São Paulo Metropolitan Region, open highrise and open lowrise morphologies are, in most of the cases, associated with high income neighborhoods, evidencing a social-climate associated issue. Additionally, street life in high income areas tends to be less intense, due to a security-driven urban design. The high walls of the gated communities many times occupy entire blocks, making streets even more insecure and less attractive to pedestrians.

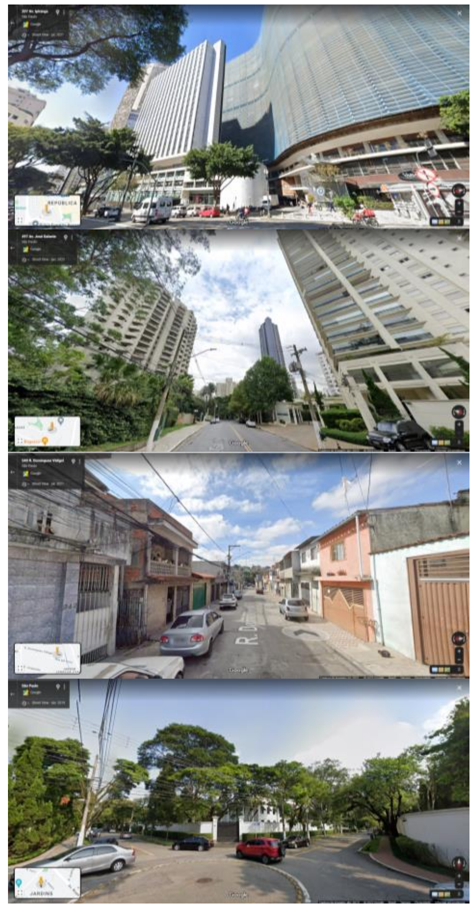
Figure 9:
Street view images of LCZ types.

Compact highrise

Open highrise

Compact lowrise

Open lowrise



4. CONCLUSION

The results indicate the role shadows, vegetation and SVF play in the heating and cooling patterns over different urban morphologies in São Paulo Metropolitan Region.

The thermal performance of existing urban arrangements can inform urban planners and decision maker towards a more climate sensitive design approach, indicating ideal building heights and spacing and the need for vegetation inside urban blocks and alongside the streets. Additionally, the combination of daytime and nighttime thermal data can give important tips about building performance for energy consumption.

Other aspects must also be considered, such as urban connections, public spaces access, social interactions etc. In São Paulo, the open highrise typology presented the best thermal performance from the pixel perspective, but from people perspective it is one of the most segregated areas in the city, with lots of gated communities and poor-quality public spaces.

Urban design is a complex task, and many factors must be considered to deliver a cool design, both in social and thermal aspects, combining the high density we need with the great urban environment we want, especially in a scenario of climate change where extreme events of high temperatures are expected.

ACKNOWLEDGEMENTS

This research was supported by the São Paulo Research Foundation FAPESP (#2015/17360-5 and #2016/02825-5) and the National Council for Scientific and Technological Development – CNPq (Grants 307042/2018-9 and 409774/2018-9).

REFERENCES

1. Mills, G., (2014). Urban climatology: History, status and prospects. *Urban Climate*, v. 10: p. 479–489.
2. Oke, T. R. et al., (2017). *Urban Climates*. Cambridge: Cambridge University Press.
3. Roth, M., (2007). Review of urban climate research in (sub)tropical regions. *International Journal of Climatology*, n. 27: p. 1859–1873.
4. United Nations (UN). Department of Economic and Social Affairs (DESA), Population Division (2019). *World Urbanization Prospects: The 2018 Revision* (ST/ESA/SER.A/420). New York: United Nations.
5. Eliasson, I., (2000). The use of climate knowledge in urban planning. Landscape and Urban Planning, n. 48: p. 31-44.
6. Erell, E., (2008). The application of urban climate research in the design of cities. *Advances in Building Energy Research*, v. 2, n. 1: p. 95–121.
7. Ferreira, L. S., (2019). *Vegetação, temperature de superfície e morfologia urbana: um retrato da região metropolitana de São Paulo* (Doctoral dissertation). USP, São Paulo, Brazil.
8. Prieur-Richard, A.-H., et al., (2018). *Extended Version: Global Research and Action Agenda on Cities and Climate Change Science*. pp. 1–23.
9. Middle, A. et al., (2014). Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones. *Landscape and Urban Planning*, n. 122: p. 16-28.
10. Zhe Z., et al. (2019). Understanding an urbanizing planet: Strategic directions for remote sensing. *Remote Sensing of Environment*, n. 228: p. 164-182.
11. United Nations (UN). Department of Economic and Social Affairs (DESA), Population Division (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations.
12. IBGE – Instituto Brasileiro de Geografia e Estatística. Diretoria de Pesquisas. Coordenação de População e Indicadores Sociais. (2021). Estimativas da População Residente no Brasil e Unidades da Federação com data de referência em 1º de julho de 2021. Available at: < https://www.ibge.gov.br/estatisticas/sociais/populacao/9103-estimativas-de-populacao.html?=&t=resultados>.
13. Wellman, T., et al. (2020). Remote sensing in urban planning: Contributions towards ecologically sound policies? *Landscape and Urban Plannin*, n. 204 (103921). https://doi.org/10.1016/j.landurbplan.2020.103921.
14. Sousa, Silvio Braz de; Ferreira, Laerte G. (2012). Análise da temperatura de superfície em ambientes urbanos: um estudo por meio de sensoriamento remoto no município de Goiânia, Goiás (2002-2011). Confins. Revista franco-brasileira de geografia, n. 15: 1–21. https://doi.org/10.4000/confins.7631
15. Stewart, I. D.; Oke, T. R., (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, v. 93, n. 12: p. 1879–1900.
16. Bechtel, B. et al., (2015). Mapping Local Climate Zones for a Worldwide Database of the Form and Function of Cities. *ISPRS International Journal of Geo-Information*, v. 4, n. 1: p. 199–219.
17. Cai, M. et al. (2018). Investigating the relationship between local climate zone and land surface temperature using an improved WUDAPT methodology - A case study of Yangtze River Delta, China. Urban Climate, v. 24: 485–502. https://doi.org/10.1016/j.uclim.2017.05.010
18. Geletič, J. et al. (2017). Statistical analyses of land surface temperature in local climate zones: Case study of Brno and Prague (Czech Republic). In: 2017 Joint Urban Remote Sensing Event (JURSE). Dubai (UAE). https://doi.org/10.1109/JURSE.2017.7924530
19. Ferreira, L. S., (2022). Local Climate Zone (LCZ) map of the São Paulo Metropolitan Region – 2002 [Data set]. Mendeley. https://doi.org/10.17632/VZW944WGHX.2
20. Ferreira, L. S., (2022). Local Climate Zone (LCZ) map of the São Paulo Metropolitan Region – 2017 [Data set]. Mendeley. https://doi.org/10.17632/3P743V3TFN.2
21. Lombrado, M. A. (1985). Ilha de Calor nas Metrópoles. O exemplo de São Paulo. São Paulo: Hucitec.
22. Fuckner, M. A.; Moraes, E. C.; Florenzano, T. G. (2009). Processamento de dados multiespectrais termais aplicados à análise espaço-temporal dos padrões de temperatura da superfície nas Regiões Metropolitanas de São Paulo e Rio de Janeiro. In: Anais XIV Simposio Brasileiro de Sensoriamento Remoto.

Urban Oasis for Adaptation to Climate Change

Analysis of Climate Adaptation Plans (CAP) around the world

Bruna Dallaverde de Sousa[1], Daniel Felipe Outa Yoshida[2] and Denise Helena Silva Duarte[3]

[1] University of São Paulo [2] University of São Paulo [3] University of São Paulo

ABSTRACT: Currently more than half of the world population lives in urban areas. In Latin America this figure is more than 80% and, in Brazil, around 84,4%. Worldwide this scenario is expected to increase in the next decades. In addition, climate change has a strong correlation with the increase of climatic extremes such as heat waves threatening people's health globally. Not only mitigation but also adaptation measures are urgent to make urban areas more resilient, energy efficient and healthier. Among adaptation measures are the provision of cooling places linked with public policies for urban design; greening, transport-oriented development and many other strategies embodying the strategic role of urban planning and design aiming for more resilience and health for urban communities. Another adaptation measure is greening which promotes ecosystem services reducing pollution, regulating climate and water management, promoting and protecting biodiversity and bringing well-being to people. This undergoing research aims to analyse Climate Adaptation Plans (CAP) around the world, bringing measures to mitigate heat stress approached by each CAP.
KEYWORDS: Climate change, Climate adaptation plans, Heat waves, Cooling Places.

1. INTRODUCTION

According to the United Nations Framework Convention on Climate Change (UNFCC), climate change is a phenomenon attributed directly and indirectly to human activity that modifies the global atmosphere composition that is beyond the natural climate variability which is already observed, creating changes in climatic pattern, rising global temperature average and extreme events attached to climate (IPCC, 2018).

Studies suggest that society will experience many impacts of climate change in the near future, over the next thirty years, and even more so in the second half of this century. Among these impacts, one that has significant implications for energy demand and the health of the population is the increase in the frequency and intensity of heat waves. Although there is no universally acceptable definition of heat waves (Perkins; Alexander, 2013; Robinson, 2001), these are understood as periods of unusual hot and dry/humid weather lasting at least two to three days and having a noticeable impact on human activities. Over the duration of heat waves, not only daytime temperatures reach high values, but also night time temperatures, and humidity changes beyond the long-term average. Heat waves are relative to a climate location; the same weather conditions may constitute a heat wave in one place but not another (Stefanon et al., 2012).

Extreme heat conditions are becoming more frequent, increasing risks to human health and health systems. The main impacts have been recorded in places where extreme heat occurs in context with population aging, urbanization, urban heat island, and inequalities in health care (Fajersztajn et al., 2016). According to Zhao et al. (2019), climate change will increase the number of deaths linked to heat waves between 2031 and 2080, and Brazil is among the most affected countries.

As for extreme temperature events, these overload the human body by damaging the cardiovascular and respiratory systems, especially for the most fragile people such as the elderly, pregnant women, children up to 4 years old, and obese people, according to the World Health Organization (WHO, 2018). Cities are not the cause of heat waves; however, they potentiate their effects. Because of the large concentration of asphalt, concrete, stone, and other inert materials, cities end up absorbing and retaining more heat than rural areas (Stone, 2012), and are therefore more vulnerable to heat waves.

As for the vulnerable population, in 2018 about 220 million people under 65 years of age were exposed to heat waves, a higher figure compared to the period from 1986 to 2005 (WMO, 2020). It is worth noting, according to Diniz et al. (2020), that the projections made for the near future (2030 - 2050) and distant future (2059 - 2099) show that excess mortality of the elderly related to heat waves will increase, being higher when urban adaptation actions are not applied, especially for cardiovascular diseases in women (up to 587 deaths per 100,000 inhabitants / year). In the Brazilian context, research indicates an increase in the frequency of heat waves over the years in different regions of the country with different climates. It is expected that by the end of the XXI with the increase in heat waves, the Northeast region, due to its location and social condition, will become the region most affected by intense heat (Geirinhas et al., 2017).

Importantly, urban areas have a dual role: besides housing much of the population, the present lifestyle is one of the main inducers of climate change, since cities are marked by excessive consumption, solid waste production, greenhouse gas emissions, intensive energy use, landscape fragmentation, soil sealing, predominance of inert and heat-absorbing materials, and other factors that intensify the effects of climate change. In this sense, the structuring of space, form of development and expansion of the urban fabric (Nobre, Young, 2011) added to the implementation of urban green infrastructure (Farrugia et al., 2013) are points to be considered. Urban green infrastructure can be interpreted as a hybrid of green spaces and built systems such as forests, wetlands, parks, green roofs and walls that together can contribute to ecosystem resilience and bring benefits to humans through ecosystem services (Naumann et al., 2011; European Environment Agency, 2012).

In view of the above, this work in progress has the general objective of systematizing the main national and subnational climate adaptation plans, looking mainly at the propositions for the creation of climate amenity spaces, called in this work as cooling places, and the propositions that rely on green infrastructure.

2. LITERATURE REVIEW

Many countries are concerned about the climate change scenario and cooperation agreements were established with the intention to limit the rise of global average temperatures, especially through the control of GEE gases emissions. The Intergovernmental Panel on Climate (IPCC) is one of the main world organizations dedicated to climate change, being responsible for the systematization of scientific knowledge of this theme and the comprehension about its causes and anthropic consequences (Hebbert; Jankovic, 2013).

In addition to vegetation, to adapt to climate change, there are initiatives in place in some cities for the creation of cooling places, which work as true oases in buildings and in the urban environment (Rosenthal, Kinney, Metzger, 2014).

In Brazil, the air-conditioned buildings, are, in general, of restricted public access, receiving mainly commercial use, in private spaces. Residential and public buildings, for the most part, are not air-conditioned (Duarte, 2015). Even if there were greater availability of buildings with air-conditioning, it is crucial to have action plans that include public buildings and spaces that do not depend mainly on this strategy, as a stimulus to decrease energy consumption and possible precaution in cases of power outage. It is important to note that one cannot rely on the use of air-conditioning in cases of extreme events, since there is also no guarantee that there will be enough energy to meet an increase in demand (Nunes, 2020)

Moreover, the use of air conditioning equipment will cause an increase in the heat energy emitted into the urban environment in such a way as to feed a vicious cycle. In Brazil, for several years now, thermoelectric power plants have been activated to complement the hydroelectric matrix, when the latter is not sufficient to meet the demand. Moreover, it is worth noting that natural ventilation is essential to minimize infection by microorganisms responsible for viral and bacterial diseases, since it enables the constant air exchange (Nunes, 2020). Thus, this cannot be an alternative thought of in isolation, since it is unsustainable due to the absence of continuos energy supply, the environmental consequences and the high cost of operation and maintenance (Duarte, 2015).

Urban green infrastructure has been pointed out as promising to reduce the adverse effects of climate change in urban areas, for example, balance the flow of water to alleviate flooding, promote thermal comfort through vegetation shading, provide support for people to copy the idea is to give opportunity to own food production (Krasny; Tidball, 2009; Cameron, 2012; Farrugia et al., 2013). Vegetation brings improvements in urban climate and contributes to decrease urban heating. The cooling effect is achieved through the processes of evapotranspiration, solar protection, increased longwave radiative flux and airflow control. At the same time, trees and other green components filter the air, mask noise in cities and prevent soil erosion, while contributing to the mental balance of city dwellers (Santamouris, 2001). In this sense, according to Santamouris et al. (2017), the potential for ambient temperature reduction brought on by the addition of trees or other green typologies depends greatly on the density and properties of the vegetation considered, the thermal characteristics of the city, and the prevailing climate conditions.

Urban trees have to deal with a number of additional stresses that are more fragile or that do not exist in forests. This is because city environmental conditions are generally more extreme, more dangerous, and can cause loss of vitality and increased mortality (Gillner et al., 2014). Among other factors, trees must deal with soil compaction, poor soil quality, and low soil volume; air and soil pollution, salt contamination, excessive heat, mechanical damage, vandalism, wind gusts, soil water changes, low nutrients, low water availability, and water stress (Brune, 2016).

As for the structuring of urban space, on the other hand, it is crucial to have the implementation of mitigating and adaptive measures through urban instruments, such as zoning, building codes, urban mobility planning, etc. (Tsuda, 2019). According to Humphreys et al. (2010), adaptation is understood as the combination of variables aimed at the resilience of the city to the point of balancing the intensity of climate change impacts and resulting in the generation of comfort, this being dependent on cultural and personal issues. In Architecture and Urbanism, adaptation deals mainly with the potential that urban spaces and buildings have for people to cope with new displacements in such a way as to mitigate the impacts generated by changes in climate and thus reduce vulnerability.

According to Giulio et al. (2016), there are a number of designations given to urban instruments aimed at mitigation and urban adaptation through climate change, and, in general, it is a set of strategies that cities should adopt to cope with climate change, reducing the negative impacts on the population, the economy, and the environment.

There are climate adaptation plans in force, mostly in developed countries, which advance in the understanding of the theme and in the implementation of practical measures to minimize the impacts. In Brazil, on the other hand, there has been little advancement in the development of adaptive premises, and most of actions are tied to mitigation (Duarte, 2019). But, at the scale of cities, only mitigation of heat can yield measurable improvements during the period of our own lives or the lives of our children (Stone, 2012). Despite this, Carvalho et al. (2020) highlight that, when analyzing the urban legislation of the State of São Paulo along with the master plans, the authors note that about 70% of municipalities do not institute a Municipal Climate Change Policy, emphasizing the need for discussion on climate policy and adaptive planning of cities.

3. METHODOLOGICAL PROCEDURES

The analysis of urban instruments aimed at mitigation guidelines and urban adaptation to climate change was carried out in order to systematize them according to the criteria outlined in the document Measuring Benefits of Urban Heat Adaptation published in March 2021 by the C40 Group of Major Cities for Climate Leadership (C40, 2021). The criteria were created based on the temperature reduction potential of the proposed actions and feasibility of implementation, as follows:

- Cool surface: found on sidewalks and roofs, these are those that reduce energy absorption and capture as a result of the reflective capacity of the elements;
- Green infrastructure:
  1. Urban parks: responsible for reducing the local urban temperature according to their size and canopy cover;
  2. Green corridors: correspond to connected green spaces in order to direct the wind and promote biodiversity;
  3. Vegetation, in general: corresponding to flowerbeds, bio-valets and green roofs.
- Urban form planning and design: according to the width of the streets, density, gauge, and materiality, it is possible to increase the albedo and consequently reduce the solar radiation stored on the urban surface.
- Heatwave response planning: corresponds to the policy of making the population aware of heat waves as well as action plans upon their occurrence in order to mitigate the effects generated by prolonged exposure to increased temperatures.
- Grey urban shading structures: corresponds to structures that provide shading, whose importance comes from the reduction of the amount of solar radiation captured and stored in the urban surface and, therefore, reduction of air and surface temperature.
- Urban Water features: due to their greater ability to absorb solar radiation, when compared to inert materials, and to evaporative cooling, water bodies can reduce the air temperature of the surrounding area and promote greater thermal comfort.
- Wind corridors: through convection and evaporation, wind corridors can generate temperature reduction.

In addition to these criteria, this analysis included the search for the so-called cooling places, conceptualized in this article as spaces of climate amenities distributed in a targeted manner throughout the city in order to assist the population during extreme heat.

It is worth noting the absence of conceptualization and specific literature on this topic, since the understanding about cooling places comes according to the local reality. For this article, we used the definition applied in Climate Adaptation Plans of developed countries such as the United States and Australia, in which the cooling places are mainly public or private air-conditioned buildings, able to receive the population, and where people are guided to go during extreme heat, besides some open spaces such as parks, public pools, squares with access to water, etc.

In total, 47 documents were analysed (Table 1), These documents follow the criteria: i) national plans, ii) subnational plans: preferably, administrative divisions corresponding to states and capitals; iii) documents available in official electronic portals; iv) cities mentioned in the consulted bibliographical references, so that there is a better understanding about the local conditions and possible similarities.

Out of 32 of these documents studied are from cities in the United States of America, 8 from European cities, 3 from Oceania, 2 from Asia, and 2 from Central America; circa 82% correspond to Climate Adaptation Plans, as defined by Obermaier and Rosa (2013), with delimitation of the guidelines aimed at the local reality. Already 8% fit the pattern of booklets that, according to the IAUC (2020), are documents with education character that address the basic concepts on the subject and are not restricted to the existing local demands.

4. RESULTS AND DISCUSSIONS

From the analysis of the above-mentioned plans, it was possible to understand the spatial distribution of the analysed plans (Figure 1), which are more present in developed countries, especially in the USA. It is noteworthy that the results obtained so far are part of the conclusions, as the research is ongoing.

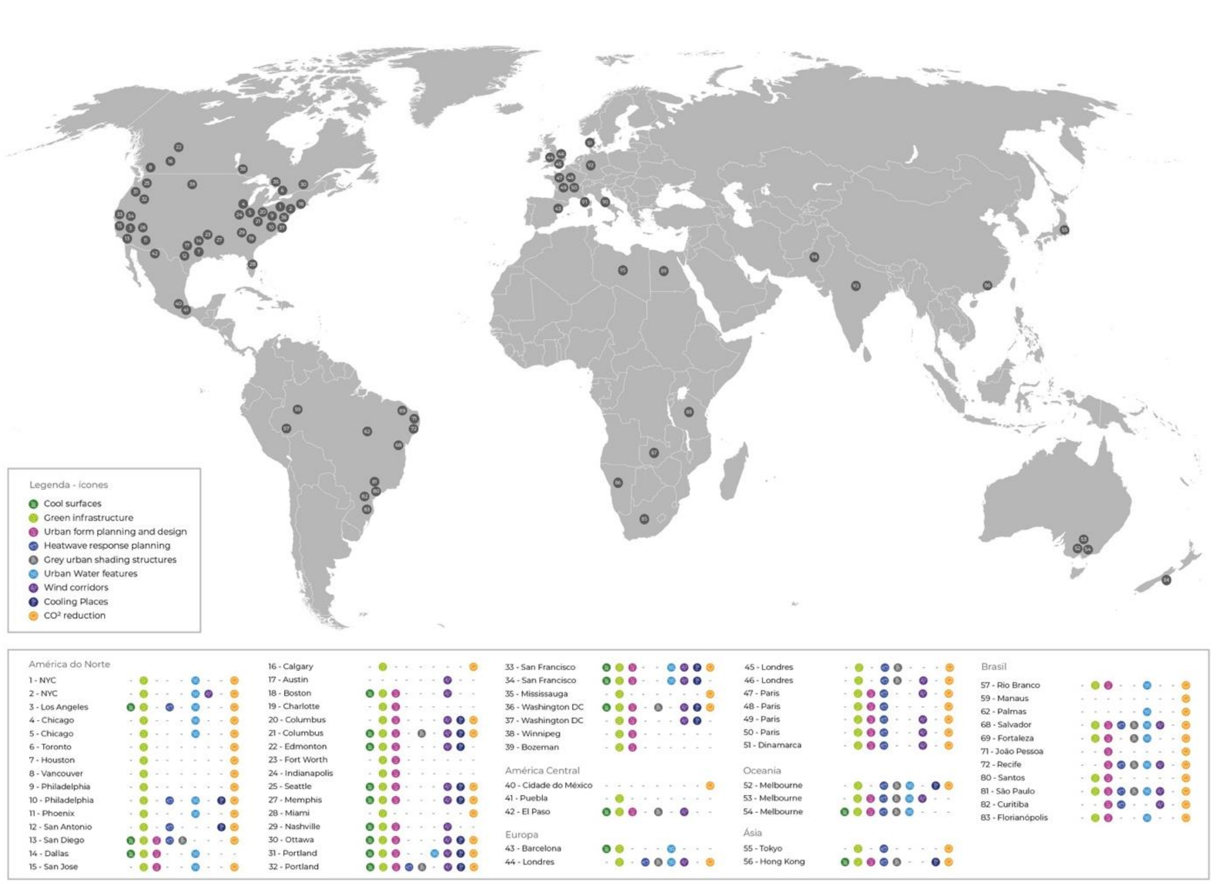


Figure 1: Spatialization of Climate Adaptation Plans (Authors, 2022)

In addition, it was possible to draw an overview of the main issues dealt with in the Climate Adaptation Plans and similar documents (Figure 2).

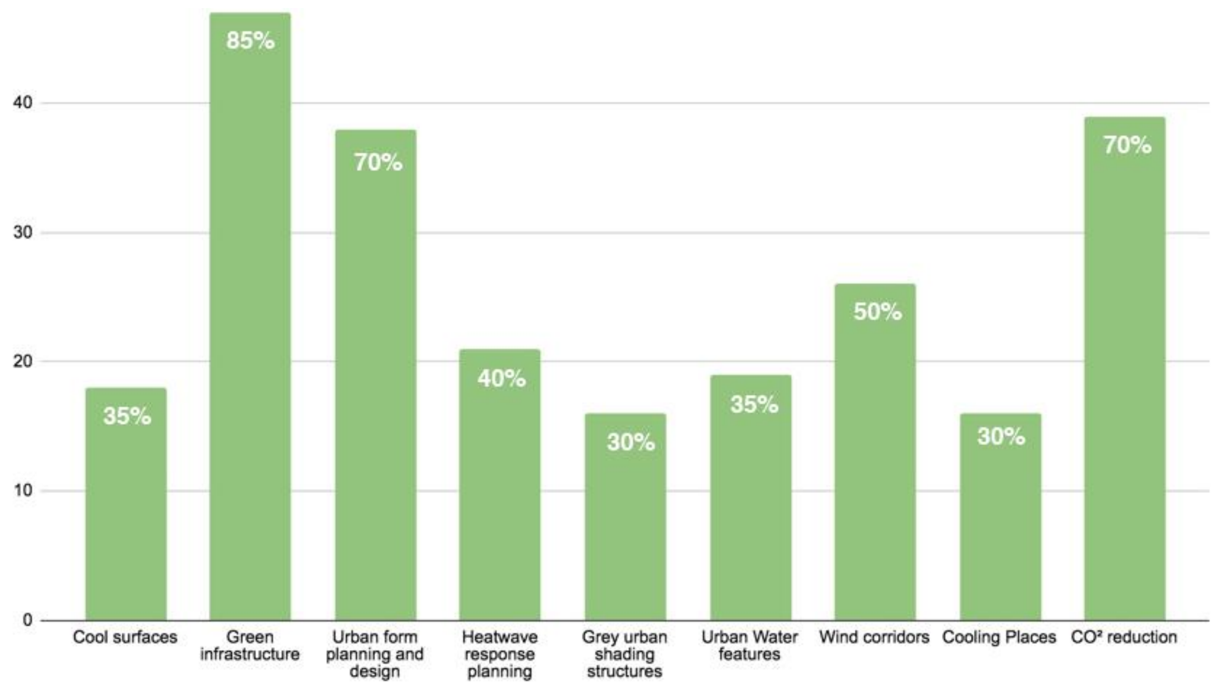


Figure 2: Analysis of climate adaptation plans according to mentioned criteria (Authors, 2022)

Among the actions mentioned by the C40, the mention of green infrastructure stands out (85%). Despite predominant, the level of detail given to this action fluctuates too much and three different approach patterns were found: i) only mention of the importance of the vegetation for alleviating thermal stress; ii) indication of guidelines for urban parks, urban vegetation and green corridors; iii) reference to green infrastructure plans based on the demand mentioned in the analysed documents.

For example: i) in the Strategic Focus Area Plan for the city of Charlotte, USA, the importance of planting trees as a strategy for maintaining community resources is highlighted, but guidelines for these plantations are not outlined; ii) in Guide to Urban Cooling Strategies referring to Australia, in addition to pointing out practical alternatives arising from green infrastructure, they show how vegetation can contribute to the reduction of thermal stress; iii) in Chicago Climate Action Plan, USA, other documents, such as the Urban Forest Agenda and the Chicago Trees Initiative, are mentioned.

The second most mentioned action refers to reducing the emission of greenhouse gases, such as CO_2. However, it is known that the concern with the urban environment should not be restricted to mitigation measures, but also address adaptive measures of cities in the face of climate change (Duarte, 2015).

It was considered important to highlight two other actions: heatwave response planning and cooling place, mentioned in only 40% and 30% of the analysed documents. There is a relationship between these actions, for example, in the case of the warning system triggered in cases of heat waves as part of the Excessive Heat Plan (Philadelphia Hot Weather - Health Watch Warning System - PWWS) project. In this program, municipal teams work together with the National Weather Service - NWS to determine the heat wave and the consequent alert when they are hit.

Thus, there is guidance for people to go to places determined as cooling places, which are located through an interactive map available on the internet, the Stay Cool Interactive Map. On this map there is an indication of places with milder microclimates for these become temporary refuges until there is recovery from the thermal stress caused by the constant above-average temperatures for prolonged periods. When analysing the existing climate adaptation plans, it can be noted that many of them recommend that people seek air-conditioned spaces as a way to recover from excessive and prolonged heat.

As for the actions related to urban planning and design strategies, 70% of the plans mention them, whose level of detail, as well as for green infrastructure, varies a lot. As an example, for this action, the Hong Kong's Climate Action Plan 2030+ is cited, which highlights the direct relationship between the reduction of air and surface temperature according to urban morphology and urban parameters, such as the minimum setback in urban lots and the shape of buildings.

5. CONCLUSIONS

Analysing the first results of this undergoing research, it is possible to observe that there is a recent need - in the last 10 years - for the development of climate adaptation plans, with most of the climate adaption documents found in developed countries. These plans aim to reduce the impacts generated by climate change and advance the understanding of the subject and the implementation of practical measures that minimize the expected impacts.

Despite this, part of the documents found can be classified as primers, as they approach the topic superficially and have an education rather than a performance or prescriptive nature. Most of these documents lack important details and may not be applicable to the reality.

It is noted the prevalence of green infrastructure, actions related to urban morphology and reduction of greenhouse gas emissions, the first two aspects being climate adaptation actions, while the last one is aimed at mitigating climate change. The actions related to cooling places, grey urban built-up structures and urban water features, it was observed that these are less frequent in the survey and it appears only in more recent plans, being first mentioned in 2015.

Due to the current demand and the need for measures aimed at climate adaptation, the urgency needs to readapt public spaces through the design of a network of cooling places distributed throughout the city. Cooling places must be designed in accordance to local reality and might be interesting to be associated with green infrastructure and better developed with urban morphology actions in order to alleviate the thermal stress generated by heat waves.

In the future, this research aims to include and analyse more climate adaption plans from other regions of the world to understand other adaptation scenarios. Furthermore, it is also expected to analyse and quantify the efficiency of the climate adaption measures, utilizing the high-definition computational model ENVI-met.

ACKNOWLEDGMENTS

Thanks to the Coordination for the Improvement of Higher Education Personnel - CAPES (88887.503185/2020-00), Sao Paulo Research Foundation - FAPESP (2020/01610-0), National Council for Scientific and Technological Development – CNPq (Research Productivity Grant 312592/2021-3 and 409774/2018-9 Universal).

REFERENCES

1.Brune, M., 2016. Urban trees under climate change. Potential impacts of dry spells and heat waves in three German regions in the 2050s. Report 24. Climate Service Center Germany, Hamburg.

2.Cameron, R. W. F.; Blanusa, T.; Taylor, J.; Salisbury, A.; Halstead, A. J.; Herincot, B.; Thompson, K., 2012. The Domestic Garden - Its Contribution to Urban Green Infrastructure. 2012 Urban Forestry & Urban Greening 11, 129– 137.

3.Carvalho, W.; Silva, A.; Bon, F.; Fernandes, R., 2020. Mudanças climáticas na metrópole paulista: uma análise de planos diretores e leis urbanísticas. Ambiente Construído, [S.L.], v. 20, n. 4, p. 143-156.

4.C40 Cities Climate Leadership Group, 2021. Heat Resilient Cities: Measuring benefits of urban heat adaptation. In: RAMBOLL FOUNDATION

5.Diniz, F., 2020. Ondas de calor e mortalidade de idosos: Projeções para o Brasil nos cenários das mudanças climáticas (USP 60+). São Paulo: Universidade de São Paulo - Instituto de Astronomia, Geofísica e Ciências Atmosféricas,

6.Duarte, D., 2015. O Impacto da Vegetação no Microclima em cidades adensadas e seu papel na adaptação aos fenômenos de Aquecimento Urbano: Contribuições a uma abordagem interdisciplinar. 2015. Tese (Livre-docência em Arquitetura e Urbanismo), Faculdade de Arquitetura e Urbanismo, Universidade de São Paulo, São Paulo.

7.European Environment Agency, 2012. (European Union) (org.). Climate change adaptation.

8.Fajersztajn, L.; Veras, M.; Saldiva, P., 2016. Como As Cidades Podem Favorecer ou Dificultar a Promoção da Saúde de seus Moradores? Estudos Avançados, São Paulo, v. 30, n. 86, p. 7-27.

9.Farrugia, S.; Malcolm, D.; Mccculloch, L., 2013. An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure, International Journal of Biodiversity Science, Ecosystem Services and Management v.9 p 136-145.

10.Geirinhas, J.; Trigo, R.; Libonati, R.; Coelho, C.; Palmeira, A., 2017. Climatic and synoptic characterization of heat waves in Brazil. INTERNATIONAL JOURNAL OF CLIMATOLOGY, [s. l.], n. 38, p. 1760 – 1776.

11.Gillner, S.; Bräuning, A.; Roloff, A., 2014. Dendrochronological analysis of urban trees: climatic response and impact of drought on frequently used tree species. Trees, [S.L.], v. 28, n. 4, p. 1079-1093.

12.Giulio, G.; Martins, A.; Lemos, M., 2016. Adaptação climática: fronteiras do conhecimento para pensar o contexto brasileiro. Estudos Avançados, [S.L.], v. 30, n. 88, p. 25-41.

13.Hebbert, M.; Jankovic, V., 2013. Cities and Climate Change: The Precedents and Why They Matter. Urban Studies, p.1332-1347.

14.Humphreys, M., Rijal, H., Nicol, J. Examining and developing the adaptive relation between climate and thermal comfort indoors. Proceedings [...] Adapting to Change: New Thinking on Comfort. Cumberland Lodge, Windsor, UK. London: Network for Comfort and Energy Use in Buildings; 9 a 11 de abril, 2010.

15.IAUC (Internacional Association for Urban Climate), 2020. From the IAUC President. Quarterly Newsletter of the IAUC. Issue n. 76.

16.IPCC (Intergovenmental Panel On Climate Change), 2018. Special Report - Global Warming of 1.5ºC. IPCC Working Group I Techinal Suport Unit.

17.Krasny, M., Tidball, K., 2009. Applying a Resilience Systems Framework to Urban Environmental Education, Environmental Education Research.

18.Naumann, S.; Anzaldua, G..; Gerdes, H.. et al, 2011. Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. 2011. Ecologic institute and Environmental Change Institute, p 29-40.

19.Nobre, C; Young, A. Vulnerabilidade das Megacidades Brasileiras Mudanças climáticas: Região metropolitana de São Paulo. Relatório Final. 2011.

20.Nunes, V. et al. COVID-19 e o cuidado de idosos: recomendações para instituições de longa permanência. Natal: EDUFRN, 2020.

21.Obermaier, M.; Rosa, L. Mudança climática e adaptação no Brasil: uma análise crítica. Estudos avançados, v. 27, n. 78, 2013.

22.Perkins, S. E.; Alexander, L. V. On the Measurement of Heat Waves. Journal of Climate, [S.L.], v. 26, n. 13, p. 4500-4517, 1 jul. 2013. American Meteorological Society.

23.Robinson, P. On the Definition of a Heat Wave. Journal of Applied Meteorology, [S.L.], v. 40, n. 4, p. 762-775, abr. 2001. American Meteorological Society.

24.Rosenthal, J., Kinney, P., Metzger, B. Intra-urban vulnerability to heatrelated mortality in New York City, 1997–2006. Health & Place, 30, 45–60, 2014.

25.Santamouris, M. Energy and Climate in the Urban Built Environment. London, James and James, 2001.

26.Santamouris, M.; Ding, L.; Fiorito, F.; Oldfield, P.; Osmond, Paul.; Paolini, R.; Prasad, D. Synnefa, A. Passive and active cooling for the outdoor built environment – Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. Solar Energy, n 154, p 14-33, 2017.

27.Stefanon, M.; D'andrea, F.; Drobinski, P. Heatwave classification over Europe and the Mediterranean region. Environmental Research Letters, [S.L.], v. 7, n. 1, p. 014023, 22 fev. 2012. IOP Publishing.

28.Stone Jr., B. The city and the coming climate. Climate Changes in the Places we live. New York: Cambridge, 2012.

29.Tsuda, F. Conforto, adequação climática e o papel dos códigos de edificações: os desafios de São Paulo frente ao estado da arte no Brasil e no mundo. 2019. Dissertação (Mestrado em Arquitetura e Urbanismo) – Faculdade de Arquitetura e Urbanismo, Universidade de São Paulo, São Paulo, 2019.

30.WMO - World Meteorological Organization. [online]. Earth experienced the warmest June on record. 2018.

31.Zhao, Q.; Li, S.; Coelho, M.; Saldiva, P.; Hu, K.; Huxley, R.; Abramson, M.; Guo, Y. The association between heatwaves and risk of hospitalization in Brazil: A nationwide time series study between 2000 and 2015. In: PLOS Medicine, 2019.

PLEA STGO 2022

WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

CityPlan Water Neutrality Framework for New Urban Developments

PEPE PUCHOL-SALORT[1], STANISLAVA BOSKOVIC[1], BARNABY DOBSON[1], MAARTEN VAN REEUWIJK[1], ANA MIJIC[1]

[1] Civil and Environmental Engineering Department, Imperial College London

ABSTRACT: New urban developments in capital cities will increase water demand and urban flood risk, while also decreasing water quality indicators in rivers and other watercourses. These effects will be exacerbated by the consequences of future climate change and the exponential increase in population growth. In this work, we present a novel systemic design framework for future urban planning called CityPlan-Water that looks at current and future water pressures at city scale and aims to achieve the concept of Water Neutrality (WN). This concept aims to first minimise impacts on urban water security and then offset any remaining stresses by retrofitting existing housing stock. CityPlan-Water integrates spatial data with an integrated urban water management model called CityWat, enabling urban design at a systems level and a systematic assessment of future scenarios. Results from CityPlan-Water in London suggest that it will be necessary to retrofit almost the same number of existing homes with Water Neutrality design options to completely offset the impacts of proposed new developments in the next ten years. In the end, CityPlan-Water aims to support urban planning through the use of data-driven analysis and to effectively design water neutral housing and sustainable urban development.

KEYWORDS: Water Neutrality, CityPlan-Water, urban water security, urban planning, systemic design

1. INTRODUCTION

Housing growth and the climate emergency are increasing the pressures in cities worldwide [1,2]. These pressures are adversely affecting the urban water cycle [3,4] and one of the biggest challenges for future planning is the impact of new housing development on water sustainability [5,6]. Understanding the impact of housing growth on land, water infrastructure and water quality will require integrated urban planning [7]. In the literature, there are several approaches to integrate urban planning with water management, which can address some of the aspects of the systems approach. Among them, a valuable methodological example for this integration is the Urban Planning Sustainability Framework (UPSUF) [8]. UPSUF is a novel systems-based framework that integrates design solutions, sustainability evaluation and the planning system process. UPSUF is based on the concept of blue green urban design, which integrates sustainable construction and urban form. Urban form is one of the key factors that influences sustainability and environmental performance in cities [7,9]; it captures buildings and land cover as well as amount of green and built space [10,11].

An emergent approach to urban water management is Water Neutrality (WN) [12]. WN does not imply to have zero water consumption only, but to be able to first minimise the impacts of the new development and then offset the remaining impacts within the existing urban system without increasing the current overall impact levels. We believe there is no clear evidence of the WN concept being applied at large scale and there is a lack of a digital and integrated method that accurately measures WN indicators combined with spatial configurations for urban planning. To maintain existing Urban Water Security (UWS) indicators and efficiently implement WN at the planning phase of a new urban development, a range of WN design options will be needed, either inside or outside the development area. These design options include, for example, Blue Green Infrastructure (BGI), efficient appliances, rainwater harvesting, water reuse systems and demand management social campaigns, amongst others.

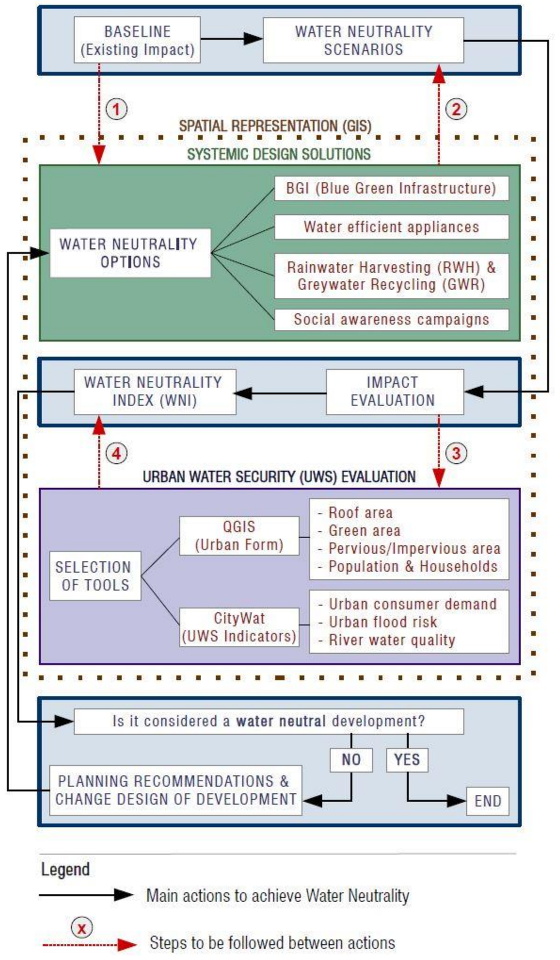
Systemic design is an emerging approach that has evolved in recent decades. It combines traditional design and systems thinking, taking a holistic and complete account of the urban form elements that constitute a complex system [13,14]. Following systemic design principles, all physical elements in a space (e.g., an urban development, borough, city, etc.) define a series of layers that, together, constitute the entire urban system. Therefore, systemic design sees the planning process as a whole and considers urban water infrastructure as one of the layers in the design of cities [15,16].

In this work, we present the novel concept of CityPlan conceived as an operational version of UPSUF. CityPlan aims to be applied to different areas of urban sustainability (i.e., water, air, biodiversity, urban microclimate, etc.). At the current stage of the work, CityPlan focuses on WN evaluation, therefore it is called CityPlan-Water. In there, the WN assessment is provided by the water management integrated model CityWat [17], which we combine with a spatial representation of the city of London, UK.

2. METHODOLOGY

The functionality of CityPlan-Water is based on UPSUF [8] and integrates three key components (Fig. 1), which includes representation of the CityPlan-Water process and operation (blue clusters in Fig. 1); the systemic design solutions (green cluster); and the Urban Water Security (UWS) evaluation (purple cluster). CityPlan-Water follows an iterative process that uses a defined target for Water Neutrality as a measure of the UWS through a spatial representation in GIS. The key purpose of CityPlan-Water is to evaluate WN at different scales, to influence planning decisions, and to guide stakeholders towards water neutral urban developments.

Figure 1:
Methodology diagram of the CityPlan-Water systemic design and evaluation framework.

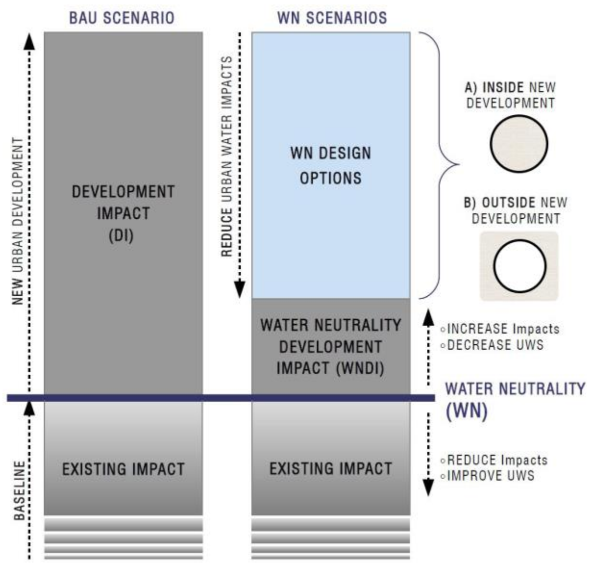


The results from CityPlan-Water will determine if a new urban development with proposed WN design options can be considered water neutral under a specific target. As with UPSUF [8], the iterative process provides a defined set of steps that takes the user from an initial baseline to new water neutral development scenarios, including the requirements of environment and regulatory bodies.

2.1 Water Neutrality systemic design concept

New developments increase the existing urban water impacts in cities and decrease UWS levels [18]. To define a new interpretation of the WN concept from a systemic design approach it is necessary to evaluate this increase under different urban design scenarios (Fig. 2). In our work, the Development Impact (DI) from new urban developments is calculated as an addition to the existing (pre-development) impacts (i.e., Baseline thereafter). To provide a comprehensive assessment of the WN concept, we consider two types of urban design scenarios: Business as Usual (BAU) scenario (left column in Fig. 2) and WN scenarios (right column in Fig. 2).

Figure 2:
Water Neutrality systemic design concept diagram.



Note: To fully achieve Water Neutrality (WN) is necessary to decrease the Urban Water Security (UWS) indicators as they were at the pre-development Baseline stage (existing impact).

The BAU scenario represents the project that is developed and built with traditional construction and design, primarily including hard and impervious surfaces and artificial materials [8]. Under the BAU option, no WN design options are implemented, and the DI is at its maximum level. To offset the impacts, WN scenarios are developed as design options that reduce the urban water impacts. These scenarios provide different levels of impact reduction, depending on the scale and size of the intervention. The WN options can be applied inside the development area (new buildings and land) or outside (existing infrastructure retrofit). We define the remaining impact of new developments on the urban water system of the city once WN options are implemented as a Water Neutrality Development Impact (WNDI). Hence, if WNDI is null, the proposed WN options are fully offsetting the impacts of the new urban development, and WN is fully achieved (threshold marked by the blue line in Fig. 2).

2.2 Water Neutrality Index

Based on the novel WN systemic design concept we introduce the Water Neutrality Index (WNI), which measures the relative difference between Development Impact (DI) in the BAU scenario and the Water Neutrality Development Impact (WNDI) in the WN scenarios:

WNI = (DI – WNDI / DI) x 100 (%) (1)

The WNI needs to be 100 to achieve full WN and to maintain UWS at the pre-development levels. In case the WNI is higher than 100, the existing UWS levels will be improved, creating an environment-positive urban development.

3. LONDON AS CITY CASE STUDY

London's population is projected to increase by 70,000 people per year, reaching 10.8 million citizens by 2041 [19]. This will require an average increase of 66,000 new homes per year, for at least twenty years, and around 50% of these homes being affordable if Londoners' needs are to be met.

London is divided into 32 boroughs, which are sub-divided for statistical purposes into smaller zones called Lower Layer Super Output Areas (LSOAs). London's urban pattern depicts a distorted grid radiating from the city centre to the city boundaries, changing in scale and density. Central areas follow traditional Georgian planning and are generally more compact with concentrated and large green spaces, while suburbs present a more sprawl distribution surrounded by metropolitan open land and a Green Belt [19].

Based on the new London Plan, the 10-year predicted target for net housing completion in the city will be 522,870 new homes by 2030 [19]. Currently, the city presents a strong potential for urban regeneration, as large areas are reliant on ageing infrastructure and will benefit from redevelopment and investment opportunities.

4. RESULTS

The WN systemic design as part of CityPlan-Water is developed at city scale at this stage and is based on the future predicted housing growth in London, where 522,870 new households are aimed to be built during the next 10 years [19]. As the CityWat model is lumped at city scale [17], we cannot specify spatially where these new households will be located. However, the results show the aggregated effect of the impact of new development and the scale of interventions needed for impact mitigation.

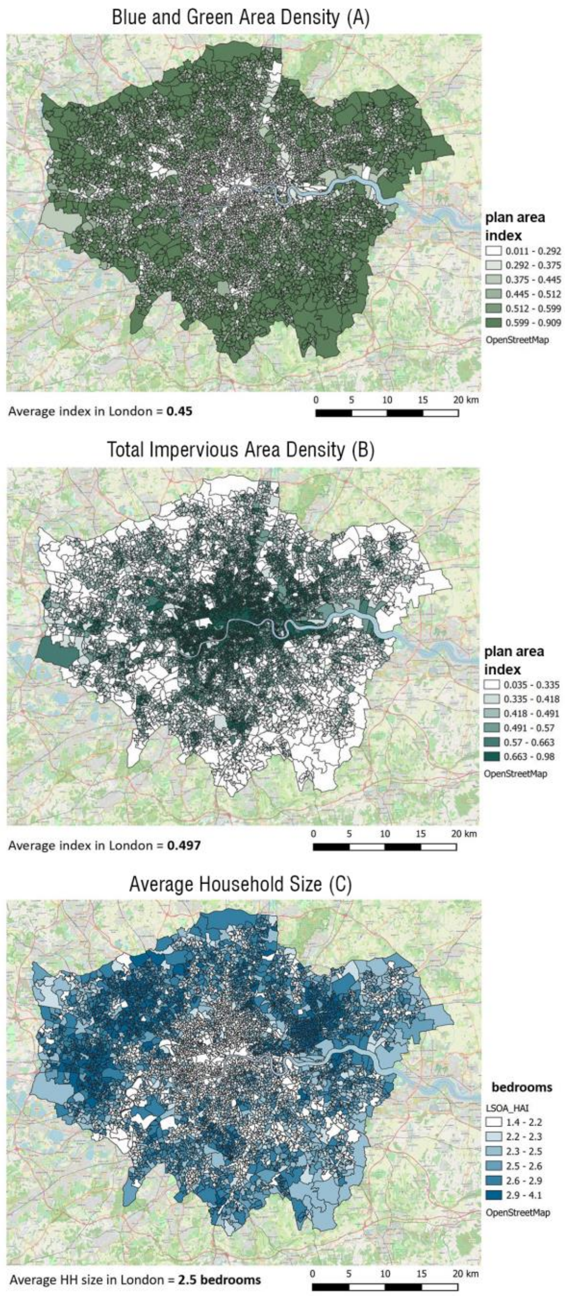
4.1 Analysis and visualisation of London's urban form properties

The area fraction equation [20] is used in this work to visualise London's urban form properties objectively. Density maps (Fig. 3) inform about the heterogeneity of each urban form in London and will help decision-makers to perceive which parts of the city are in more need of certain WN design options. Although in Fig. 3 we only show blue and green area density (A), total impervious area density (B), and average household size (C); we also considered roof area density, total pervious area density, and population density as key urban form properties for WN.

Hence, while roof area maximum value is 0.61 and minimum 0.01, with an average across London of 0.22; the blue and green area ranges from 0.011 to 0.909, with an average across London of 0.45 (Figure 3A). While the total impervious area percentage is around 37% of the city, the average plan area indexes of the pervious and impervious areas are almost equivalent (around 0.5 each). In addition, some LSOA units show a maximum of 0.98 of impervious area fraction, which reveals that there are London areas which are dramatically impervious, while others are very permeable, especially in the outskirts of the city. Finally, London's average population is 5,195 people per km2, although this can go up from 15,924 p/km2 to 92,722 p/km2 in the most densely populated LSOA zones. Regarding household size, the average in London is at 2.5 bedrooms per household although most of the central LSOA areas present between 1.4 and 2.2 bedroom per household, and houses in residential outskirts go up to 4.1 bedrooms in average per household (Figure 3C).

The urban form area fraction maps indicate that most of the building and impervious surfaces are concentrated in the central London, presenting major risks for flooding and the most significant challenges for urban WN. Although London is considered a green city, there are still some areas in the city centre that suffer from a lack of green space and a large percentage of impermeable surfaces. In parallel to this, a larger number of citizens are concentrated in the city centre, where also the average household size is smaller than in the city boundaries. This might produce highly localised water demand patterns and severe issues of wastewater production and sewage overflow. Although these localised issues cannot be captured with the CityWat model, they could be evaluated in more detail with semi-distributed water management models [21] or other finer resolution evaluation tools.

Figure 3:
Key London's Water Neutrality (WN) urban form properties represented in plan area fraction maps and divided by LSOA boundaries.



***Note:** Source: British Geological Survey landcover dataset and UK Census 2011.*

4.2 Water Neutrality scenarios and systemic design options

The scenario development process starts with the Baseline and the BAU simulations, which do not include any WN design option. The Baseline includes the impact from 3,266,170 existing households and a total population of 8,961,989 people (UK Census, 2011), while the 10-year housing projection for the London BAU scenario adds up to 3,789,040 homes and 9,800,000 people [19].

To introduce water efficiency, we consider installing appliances with an average of 35% water use reduction in all new 522,870 households (Scenario A). Next, we implement BGI solutions to the new building infrastructure. All new homes are equipped with 80% of green roof area in Scenario B. Finally, social awareness campaigns are assumed to affect the behaviour of all citizens living in new homes and reduce their demand by 4%, which defines Scenario C. The total number of citizens in new homes is calculated by the average number of people per household in London, estimated at 2.5 (UK Census, 2011) and multiplied by the number of new predicted homes [19]. This is different to the expected population growth of the city as some citizens are expected to be relocated from existing areas.

Rainwater harvesting design assumes a 400-litre tank installed in each new household. This volume is calculated by averaging the 1,000-litre tanks commonly used for individual households and considering a smaller capacity for flat buildings per household (Scenario D). To enhance the water reuse capacity, a Grey Water Reuse (GWR) system that assumes a 50% greywater recycle is installed in all new 522,870 new homes in Scenario E. Finally, Scenario F is set by aggregating all the WN design options from Scenarios A to E.

Once the options for new homes are defined, scenarios for retrofitting existing homes and urban infrastructure are developed by implementing the WN design options outside the development area. It is predicted with CityWat simulations that 432,500 existing homes is the minimum amount to fully offset the impacts in urban consumer demand. Hence, the Scenario G will implement efficient appliances of 35% consumer reduction in all these 432,500 existing homes. The first retrofit stage (Scenario J) will aggregate all the WN options in new homes (Scenario F) with the Scenario G. As Scenario J does not offset flooding risk or river quality, in Scenario H we install RWH systems of 400-litre tanks in all retrofit households. Next, the second retrofit stage (Scenario K) aggregates Scenario H with Scenario J.

The CityWat simulations also showed that 19 km^2 of impermeable land needs to be made permeable in the existing London's surface to completely offset the impacts in urban flood risk by new projected development. Hence, in Scenario I several solutions of BGI, all of them being permeable, are added to the city to reduce the total existing impervious area. In the end, all scenarios, both in new and existing retrofit solutions, are aggregated in the third and final retrofit stage (Scenario L), in which the impacts on the urban water system by new developments are aimed to be offset.

4.3 Urban Water Neutrality of London

After following the systemic design process and scenario development exercise explained above, the Urban Water Security (UWS) evaluation step is developed with the CityWat model. The simulations from the CityWat model provide raw values for each UWS indicator and each scenario. These raw values may be useful for water companies and environmental regulators such as the UK Environment Agency but might be hard to interpret by other stakeholders. Based on the raw values and following equation (1), we calculate the scores for the Water Neutrality Index (WNI) for each UWS indicators, which are much easier to be interpreted.

Table 1:
Water Neutrality Index scores based on the 10-year housing target in London.

WATER NEUTRALITY (WN) SCENARIOS	Urban Water Security (UWS) Indicators		
	Urban consumer demand (Consumer supplied, ML/day)	Urban flood risk (Excess stormwater runoff, ML/day)	River water quality (Phosphorus content, mg/l)
	Water Neutrality Index (WNI, %)		
WN DESIGN OPTIONS APPLIED TO NEW URBAN DEVELOPMENTS ONLY			
(A) Efficient appliances in new homes	35	4	25
(B) 80% green roofs in new homes	0	35	8
(C) Citizens concerned with water	5	1	3
(D) RWH in new homes	18	8	10
(E) GWR systems in new homes	14	2	8
(F) (A + B + C + D + E)	71	48	63
WN DESIGN OPTIONS APPLIED TO EXISTING BUILDINGS ONLY (RETROFIT)			
(G) Retrofit homes with efficient appliances	29	3	20
(H) Retrofit homes with RWH	16	7	9
(I) Add BGI to the existing London land	0	45	11
WN DESIGN OPTIONS APPLIED TO NEW URBAN DEVELOPMENTS AND EXISTING BUILDINGS (RETROFIT STAGES)			
(J) RETROFIT Stage 1 (F + G)	100	51	84
(K) RETROFIT Stage 2 (H + J)	105	57	88
(L) RETROFIT Stage 3 (I+K)	105	100	99

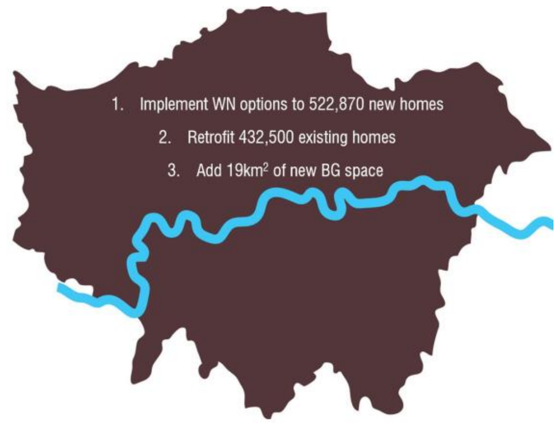
Note: It follows a colour code from red being WNI=0 (worst WN outcome) to green WNI=100 (WN fully achieved) and having grades of yellow and orange for intermediate values.

Table 1 demonstrates that urban consumer demand is not completely neutralised (WNI=100) until scenario J, which implies to fully implement all the WN design solutions inside development area and retrofit 432,500 existing homes with water efficient appliances outside the development. Urban flood risk is more difficult to be neutralised and does not achieve a score of WNI=100 until scenario L, which means to implement all the previous WN options and add 19 km^2 of BGI to the existing London's land. Finally, water quality achieves a maximum score of WNI=99 with scenario L too. Other intermediate scores for the WNI for each WN scenario are found in Table 1.

4. DISCUSSION

In this study, we first developed a WN concept for systemic design of new urban developments and then proposed a CityPlan-Water framework that includes the Water Neutrality Index as part of its evaluation cluster. From the results in Table 1, we observe that some WN design options are multi-functional and have a significant effect on all the UWS indicators (i.e., RWH systems), while others only affect one or two indicators (e.g., green roofs or Grey Water Reuse, GWR, systems). Based on the results obtained from the WNI in London, for the level of options implemented we note that it will be necessary to retrofit a considerable number of existing households outside the development area to achieve full WN at a city scale in London (Fig. 4).

Figure 4:
Lumped London map with the three key WN interventions to achieve a water neutral city.



These results of WN concept are based on the WNI value of 100, but this target could be scale-specific (e.g., water neutrality at a borough or wastewater zone level) or set at a different WN level (e.g., 80% water neutral developments). Although the value of water in London urban developments might be similar for being part of the same city, this might not always be the case and some trade-offs between the costs and the benefits of the WN solution per unit of water could emerge too. Finally, the selection of UWS indicators and target value for each indicator may vary depending on the urban context and the decision-makers involved. The targets for each Urban Water Security indicator might change depending on the urban area studied and its own properties (e.g., an area more prone to urban flooding could have a higher target for the urban flood risk indicator compared to consumer demand or river water quality in order to be considered 'water neutral').

5. CONCLUSION

The knowledge from this work and the application of the CityPlan-Water to the WN concept points to valuable potential to change how we design our cities to achieve urban water security. In this work, we presented the proof-of-concept of CityPlan-Water and the use of spatial data is taken from a high-resolution BGS dataset and divided by the LSOA boundaries, but next stages might include more publicly available datasets or different boundaries (i.e., London boroughs or wards). Large urban developments in London are scheduled for the next 20-30 years, which will create an important impact into the overall water system of the city and could be studied individually or in conjunction inside CityPlan-Water.

The framework has a strong potential for digitally enhanced decision making at different scales. Combining design and evaluation will guide different groups of stakeholders, some of those being housing developers, Local Planning Authorities or water companies, among others. In the end, the results from CityPlan-Water show a great potential of the framework to guide urban planners and policymakers from early stages of the planning process towards sustainability and urban resilience in cities' design.

ACKNOWLEDGEMENTS

This research is part of the CAMELLIA project (Community Water Management for a Liveable London), funded by the Natural Environment Research Council (NERC) under grant NE/S003495/1; and, part of the euPOLIS project, funded by the European Union's Horizon 2020 program H2020-EU.3.5.2., under grant agreement No. 869448. It would not have been possible without funding from the Engineering and Physical Sciences Research Council (EPSRC) Centre for Doctoral Training (CDT) in Sustainable Civil Engineering under grant EP/L016826/1.

REFERENCES

1. United Nations (2014). *World urbanization prospects: The 2014 revision, highlights.* Population division. United Nations.
2. Committee on Climate Change (2019). *UK Housing: Fit for the Future?* Public Report.
3. Rauch, W., et al. (2017). Modelling transitions in urban water systems. *Water Research* 126: 501-514.
4. Water UK (2019). *A framework for the production of Drainage and Wastewater Management Plans.* Public Report.
5. Brown, R. R., et al. (2009). Urban water management in cities: historical, current and future regimes. *Water Science and Technology* 59(5): 847-855.
6. Jones, J. A. A. (2014). *Water Sustainability: A Global Perspective.* London and New York, Routledge. 1st Edition.
7. Ford, A., et al. (2019). A multi-scale urban integrated assessment framework for climate change studies: A flooding application. *Computers, Environment and Urban Systems* 75: 229–243.
8. Puchol-Salort, P.; O'Keeffe, J.; Van Reeuwijk, M.; Mijic, A. (2021). An urban planning sustainability framework: Systems approach to blue green urban design. *Sustainable Cities and Society* 66: 102677.
9. Erell, E. P., Pearlmutter, D., and Williamson, T. (2015). *Urban microclimate: designing the spaces between buildings.* New York, Taylor & Francis. ISBN: 978-1-84407-467-9.
10. Jabareen, Y. R. (2006). Sustainable Urban Forms : Their Typologies, Models, and Concepts. *Journal of Planning Education and Research* 26(1): 38-52.
11. Boeing, G. (2018). Measuring the complexity of urban form and design. *URBAN DESIGN International* 23(4): 281-292.
12. Kemlo, A. and Lawson, R. (2009). Water Neutrality: An improved and expanded water resources management definition. Environment Agency Science report.
13. Battistoni, C., et al. (2019). A Systemic Design Method to Approach Future Complex Scenarios and Research Towards Sustainability: A Holistic Diagnosis Tool. *Sustainability* 11(16).
14. Bijl-Brouwer, M. V. D. and B. Malcolm (2020). Systemic Design Principles in Social Innovation: A Study of Expert Practices and Design Rationales. *She Ji: The Journal of Design, Economics, and Innovation* 6(3): 386-407.
15. Shin, S., et al. (2018). A Systematic Review of Quantitative Resilience Measures for Water Infrastructure Systems. *Water* 10(2): 164.
16. Moravej, M., et al. (2021). Site-scale Urban Water Mass Balance Assessment (SUWMBA) to quantify water performance of urban design-technology-environment configurations. *Water Research* 188: 116477.
17. Dobson, B. and Mijic, A. (2020). Protecting rivers by integrating supply-wastewater infrastructure planning and coordinating operational decisions. *Environmental* Research Letters 15: 114025
18. Jensen, O. and H. Wu (2018). Urban water security indicators: Development and pilot. *Environmental Science & Policy* 83: 33-45.
19. Greater London Authority (GLA), (2021). *The London Plan. The Spatial Development Strategy for Greater London.* Public Report.
20. Oke, T., et al. (2017). *Urban Climates.* Cambridge, Cambridge University Pres. ISBN: 9781107429536
21. Dobson, B., et al. (2021) Integrated Modelling to Support Analysis of COVID-19 Impacts on London's Water System and In-river Water Quality. *Front. Water* 3:641462.

Exploring the association between satellite indices and local climate zones in Brasília, Brazil

DANIELA WERNECK[1] MARTA ROMERO[1]

[1] Faculty of Architecture and Urbanism, University of Brasília, Brazil

ABSTRACT: This article presents a study that relates the spatial structure of the local climate zones (LCZ) classification with the land surface temperature (LST) and vegetation index in the tropical climatic context of Brasília. The methodological procedures encompass the application of the LCZ Generator tool to create the LCZ map, the Landsat 8 dataset to retrieve land surface temperature (LST), and enhanced vegetation index (EVI). Also, the spatial autocorrelation analysis using Moran´s I statistics was conducted. The result of the LCZ map illustrates that 12 of the 17 possible main LCZ classes were founded in the region of interest. The boxplot analysis indicates that built-up classes LCZ8 and LCZ3 are associated with the highest LST and the lowest EVI. The Moran´s I test reveals the presence of global and local associations for the LST and EVI indices. The study also shed light on the need for urban climate data at the local scale for Brasília to inform adaptation and mitigation strategies to overcome urban overheating.
KEYWORDS: Land Surface temperature, LCZ generator, LISA cluster, urban warming, urban greening.

1. INTRODUCTION

Cities modify the local climate creating the urban climate effect, but they are also impacted locally by global climate change [1]. The climate impacts are related to city metabolism, people's well-being, energy, health, and pollution. For instance, the urban heat island (UHI) phenomenon is intensified because of urban growth.

Voogt and Oke [2] state that UHI has been observed in the urban surfaces and the urban atmosphere. The surface heat islands (SUHI) mostly form in cities that are surrounded by moist soil or vegetation, cooled by the evaporation compared to the impervious urban surfaces. Therefore, it must be on the agenda of urbanists' and architects' work.

Only 61 years old, Brasília, the modern capital city of Brazil already experiences metropolitan problems due to the fast urban expansion. The changes in land use, cover, and their interactions with the urban climate require data production to describe the homogeneous urban patterns.

Based on this aspect, the main objective of this research is to relate the spatial structure of the local climatic zones classification (LCZs) with the land surface temperature and vegetation index in the climatic context of Brasília.

The LCZ consists of 17 main standard classes for characterizing urban landscapes, considering land cover, built types, and associated physical properties [3]. Detailed guidance about the classes and how to identify each one is given by Stewart & Oke [3] and in the global project WUDAPT – World Urban Database and Access Portal Tool (www.wudapt.org).

2. METHODS

The methods consist of four steps: first the identification of the study area. The second is the creation of the LCZ classification map. Next, we used Landsat 8 data to retrieve the enhanced vegetation index (EVI) and land surface temperature (LST). Finally, the spatial autocorrelation analysis between LST, EVI, and LCZs using Moran´s I statistics. The overview of the method is shown in the following sections.

2.1 Study area

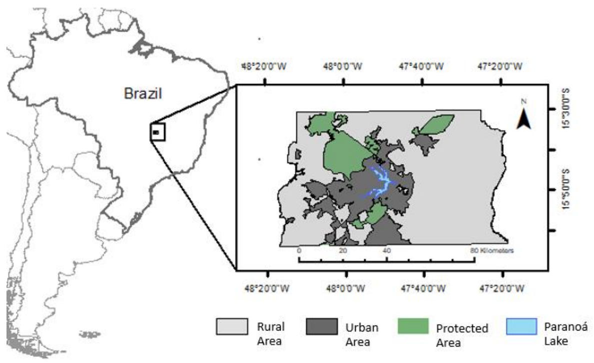
Brasília is located in the center-western region of Brazil, with coordinates 15° 47'S, 47° 56'W, and 1070 m above sea level (Fig. 1). According to Köppen and Geiger's classification, its climate is characterized as Aw (Tropical savanna). It presents two distinct seasons: (a) hot and humid season: rainy summer from October to April, and (b) hot and dry season: dry winter from May to September.

The average temperature ranges from 19.3°C during the rainy season to 23,1°C during the dry season, according to the last climate normal (1991-2020) recorded by the INMET - National Meteorological Institute [4]. The air relative humidity decreases in winter reaching an average level of 43.5%.

Figure 1:

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

Location of the Federal District of Brazil and its macro zones: urban, rural, and protected area.



Its Pilot Plan, designed by Lucio Costa, was inaugurated in 1960 and became a landmark for modern urban planning. It is a Unesco World Heritage site based on principles of the Athens Chart.

The urban conception of the Pilot Plan of Brasília translates four distinct scales based on the separation of functions: monumental, residential, gregarious, and bucolic. The monumental scale is represented by the East-West axis which concentrates the most important administrative activities, visual landmarks, and some of Oscar Niemeyer´s buildings producing a monumental landscape.

The residential scale, located in the north and south areas along the North-South axis, consists of blocks with residential buildings (maximum six floors and pilotis), local commerce, schools, and public green areas. The gregarious scale is located around the intersection of East-West and North-South axes and is configurated in sectors: financial, commercial, hotel, hospital, radio, and TV. The last, bucolic scale was guided by the incorporation of green spaces, an important morphological element in Lucio Costas´s design.

But today, the Pilot Plan is just one part of the Federal District, which is composed of 33 administrative regions that show contrasting landscapes, density, urban facilities, and infrastructure. The unplanned urbanization also contributed to an intense process of commuting, characterized by the daily movement of thousands of people to the economic and administrative center inside the Pilot Plan.

According to the last census [5], 96.5% of the population lives in urban areas that occupy 15.38% of the Federal District territory. Rapidly, the Federal District became the third-largest populated area in Brazil, with an estimated 3.015.268 inhabitants [5], behind São Paulo and Rio de Janeiro, which were founded in 1554 and 1565 respectively.

Urban green spaces

The city has been the target of environmental, cultural, historical, and socioeconomic concerns for the predictions of overpopulation, scarcity of water, energy demand, and urban warming. The District Climate Change Panel of the Environment Department of the Federal District Government (SEMA-DF) launched in November 2016 a technical document addressed to public policymakers.

The report described heat waves that alarmed residents when thermometers marked 40 °C in some parts of the city and precipitation disturbance. To sum up, changes in the climate observed over the past 50 years indicate an increase of 1.85°C in the mean minimum air temperature and an increase of 2.1°C at the mean maximum air temperature.

The temperature changes shed light on greening strategies for the urban area. Lucio Costa adopted large open and green spaces in his project and the vegetation was used to provide a smooth transition between the built and unbuilt spaces. In addition, they have the function of controlling the expansion of the Plano Piloto [6].

This character of the transition between built and unbuilt reinforced the role of the bucolic scale as an element that also contributes to the structure of the urban tissue and lends the city a park feeling [6]. Outside the Pilot Plan, the green areas do not have such functions and they can be an exception.

2.2 LCZ Classification

An adequate description of the study area´s urban form and function is necessary both for studies in urban climate and for the integration of climate information in urban planning [1]. Thus, the LCZs approach, which represents the local scale from the climate point of view, was chosen to describe the city form.

The first operation was the digitalization of the training areas (TAs) for the supervised classification platform called LCZ Generator [7], which maps the city into LCZs. TAs were carefully selected to be representative of the seasons of the year and obtained due to the characteristics of the LCZs system.

A total of 100 TAs were digitized across the urban, rural, and natural areas using Google Earth, and 11 of the 17 main classes were found in our region of interest.

Some of the urban zones were underrepresented: LCZ1 (compact high-rise), LCZ2 (compact midrise), LCZ7 (lightweight low-rise), and LCZ10 (Heavy industry). Even though they exist in the city, their TAs are smaller than the minimum size of 1 km² required by the classification. In this case, guided by the Verdonck et al. [8] findings, all underrepresented classes were removed from the TAs set.

The final Tas set, among geolocation and dates for satellite acquisitions, are the main inputs for the LCZ Generator (https://lcz-generator.rub.de). The output consists of the LCZ map and the accuracies results.

2.3 Satellite indices

The use of satellite thermal images is a technique of growing use by architects. Its use, combined with high spatial resolution images, can contribute to urban planning in terms of understanding the surface temperature variation, and its relationship with urban land uses. The availability of free images and the usage of open-source software make studies economically feasible in developing countries.

This step employs the Google Earth Engine to run an open-source script [9] to retrieve the mean LST and EVI indices for the year 2020. The Landsat8 images were masked for clouds covering up to 15% of the scene (Table 1). The observation time of each Landsat8 scene for Brasília was close to 13:00 UTC.

Table 1:
Landsat-8 images adopted in this work.

Image date	Cloud cover(%)	Image date	Cloud cover(%)
2020-04-27	2.3	2020-08-17	0.63
2020-05-29	0	2020-09-02	0.02
2020-06-14	0	2020-09-18	11.41
2020-06-30	4.33	2020-10-04	0.01
2020-07-16	0	2020-11-21	14.13
2020-08-01	7.44	-	-

Note: Path/row of all images: 221/071.

2.4 Global and local spatial autocorrelation

To explore the spatial autocorrelation between the two variables, the Moran´s I statistics were implemented in Geoda software (https://geodacenter.github.io). The global spatial autocorrelation is used to reject the hypothesis of spatial randomness [10].

The Local Indicator of Spatial Association (LISA) provides a relationship between the sum of the local statistics and consonant global statistics [10]. Thus, LISA describes the heterogeneity of spatial association across different locations defined by the LCZ polygons of the urban area.

The Moran statistic was computed using a spatial weight matrix that defines the spatial relationship among the LCZ polygons [10]. Statistical significance was based on 999 permutations.

As a result, the Moran´s I global coefficient, value ranges from -1 to 1. Positive values indicate spatial similarity, and negative values indicate spatial dissimilarity. The value 0 means the variable is randomly dispersed.

The local indicator generates a cluster map containing four clusters: high-high (H-H), low-high (L-H), low-low (L-L), and high-low (H-L). The H-H cluster indicates variables with high values surrounded by high values at LCZ neighboring polygons. The L-H cluster indicates variables with low values surrounded by high values, and likewise for the other clusters.

3. RESULTS

3.1 LCZ map

In this study, 11 of the 17 possible main LCZ classes were mapped in the region of interest (Fig. 2): LCZ 3 (compact low-rise), LCZ 4 (open high-rise), LCZ 5 (open midrise), LCZ 6 (open low-rise), LCZ 8 (large low-rise), LCZ 9 (sparsely built), LCZ A (dense trees), LCZ B (scattered trees), LCZ C (bush, scrub), LCZ D (low plants), and LCZ G (water).

The overall accuracy of the classification is 73% (Fig. 3). Some representative zones were very accurately classified, above 80% accuracy, such as LCZ 3, LCZ A, LCZ C and LCZ G. More metrics refer to the overall accuracy for the urban LCZ classes only (OAu), the overall accuracy of the built versus natural LCZ classes only (OAbu), and weighted accuracy (OAw). The assessment protocol is detailed in Demuzere et al. [7].

Figure 2:
LCZ map for the region of interest.

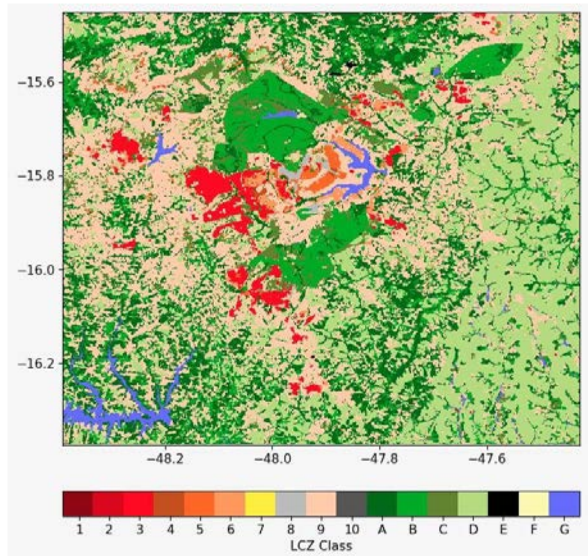
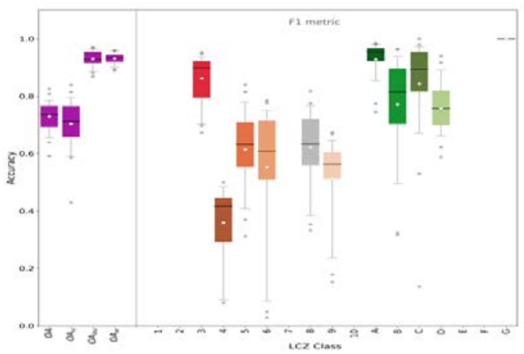


Figure 4:
Accuracy metrics.



Lower accuracy was obtained for LCZ 4 (open high-rise). This class appears at low frequency in the Federal District, thus it lacks a large number of training areas. Some studies relate to the limitation of detecting height variations [8, 11, 12].

A low accuracy value was also noted for LCZ 9 (sparsely built). The hypothesis remains on the fact that this class is dominated by natural land cover, such as scattered trees and low plants, which is confused with one of the natural LCZ types. The probability of this class behaving thermally as a natural land cover was pointed out by Demuzere et al. [11]. The confusion between urban classes due to the similarity of the spectral reflectance characteristics was noticed as a common issue in several studies [11, 12, 13, 14].

3.2 LST and EVI indices

Figure 4 and Figure 5 show the LST and EVI maps generated from Landsat8 images. The delimitation of the urban area of the Federal District was used to cut the raster files in order to focus the analyses on the intra-urban distribution of the spectral indices.

Figure 5:
Land surface temperature map of urban area.

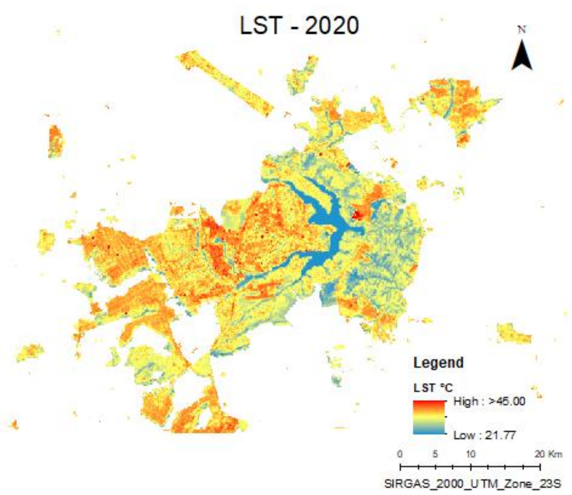
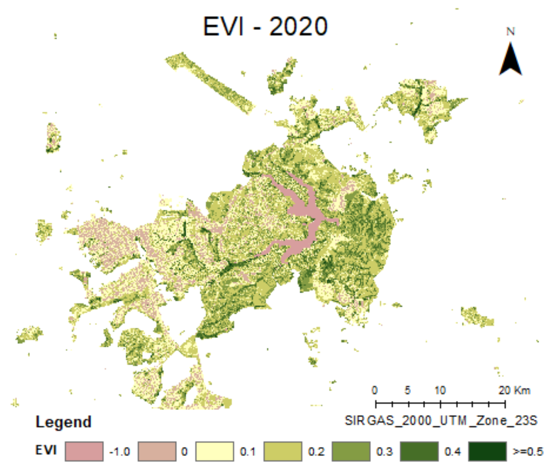


Figure 3:
EVI map of urban area.



The boxplots for LST and EVI values versus LCZ classes are shown in Figure 6 and Figure 7. The results indicate the hottest zones: LCZ 8 (large low-rise) and LCZ 3 (compact low-rise). The LCZ 17 (G – water) and LCZ 11 (A – dense trees) had the lowest LST, as expected.

The built-up classes that presented the highest EVI values also revealed the lowest LST: LCZ 5 (open mid-rise), LCZ 9 (sparsely built), and LCZ 6 (open low-rise).

Figure 6:
LST boxplots for each LCZ class.

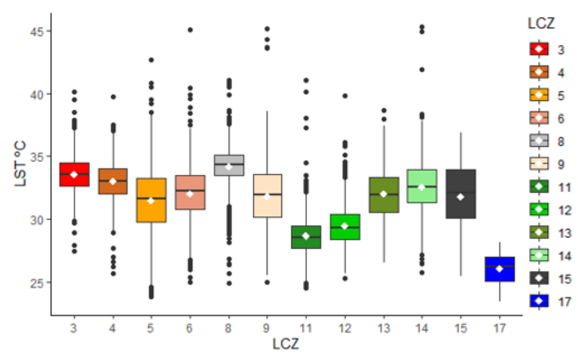
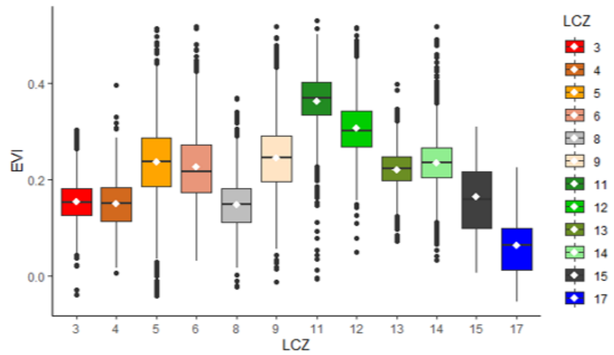


Figure 7:
EVI boxplots for each LCZ class.



The LCZ 5 is representative of the residential areas of Brasília´s Pilot Plan, designed according to the modernist view of Lucio Costa, highlighting density control, midrise buildings with pilotis, green belts, and restricted streets (Fig. 8). Among the LCZ 6 and LCZ 9, they are the predominant classes in wealthy neighborhoods.

The LCZ 3 is the predominant morphology of the consolidated periphery (Fig. 8). The LCZ 9 is also common in the periphery regarding areas in a consolidation process. In the future, some of them are expected to change the classification status toward LCZ 6 or LCZ 3 (Fig. 9).

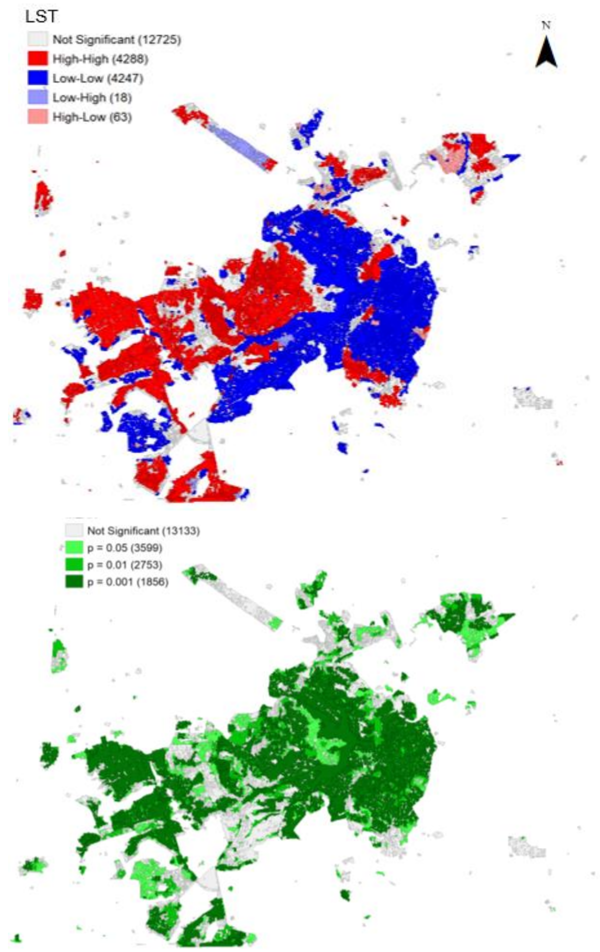
Figure 8:
Example of LCZ 3 (A) and LCZ 5 (B) located at Itapuã (A), and Plano Piloto – Asa Sul (B). Source: Google Street View, consulted online on the 14th of March 2022.

Figure 9:
Example of peripheral area (west) in a land cover/land use transformation process. Source: Google Street View, consulted online on the 14th of March 2022.

3.3 Spatial autocorrelation analysis

The Moran´s I test value of 0.78 reveals the presence of global association for the LST. The LISA map (Fig. 10) shows the clusters high-high and low-low suggesting LCZ with high LST surrounded by another LCZ with high LST. The reference to high and low is relative to the average of the neighbours, which is sensitive to the effect of outliers (e.g. the LCZ 17, an urban lake, could be pulling the overall average down).

Figure 10:
LISA cluster map and significance map – univariate analysis.



4. CONCLUSION

The need for urban climate data for the Federal District of Brazil is crucial to evaluate impacts on the thermal environment and to inform adaptation and mitigation strategies to overcome urban overheating. Hence, the LCZ map and satellite indices were used in an exploratory study of the global and local spatial autocorrelation.

The Moran´s I test reveals the presence of global and local associations for the LST values. The boxplots indicate that built-up classes with a high impervious surface such as LCZ 3 and LCZ 8 are associated with the highest LST. On the other side, the open arrangement with an abundance of pervious land cover and trees such as LCZ 5, LCZ 6, and LCZ 9 showed lower LSTs.

The knowledge of the spatial pattern of temperature hot spots and their associated land cover/built types is essential to map the trends of urban spread. This approach can be useful to urban planners to evaluate heat mitigation strategies such as planting trees, surface albedo, blue infrastructure, etc.

Future studies can focus the analyses on different seasons to enhance the results because of the variation of the vegetation due to the rain pattern. Further, air temperature data, including wind speed and mean radiant temperature would link the classification more directly to an indicator connected to human well-being for specific times of the day. The exposure to heat stress may be especially high in zones with a lack of vegetation.

Finally, the need for local warming information is considered crucial to localize vulnerable areas to develop a resilience plan, taking into account the particularities of each zone. Brasília contains several modernist buildings, public spaces, and unique urban planning at its core: the Pilot Plan. The presence of a highly valuable historical site reinforces the importance to improve the thermal environment of the city alongside the conservation of its modern heritage.

ACKNOWLEDGEMENTS

This study was financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. We also thank the Faculty of Architecture and Urbanism´s Postgraduate Program of the University of Brasília for the support.

REFERENCES

1. Hidalgo, J., Lemonsu, A., & Masson, V. (2019). Between progress and obstacles in urban climate interdisciplinary studies and knowledge transfer to society. Ann. NY. Acad. Sci., pp. 5-18.
2. Voogt, J. A.; Oke, T. R. (2003). Thermal remote sensing of urban climates. Remote Sensing of Environment, v. 86, n. 3, p. 370–384.
3. Stewart, I. and Oke, T. (2012). Local climate zones for urban temperature studies. American Meteorological Society, v.93, p. 1879-1900.
4. INMET – Intituto Nacional de Meteorologia. (2022). Normais Climatológicas – Distrito Federal. Available: https://clima.inmet.gov.br/GraficosClimatologicos/DF/83377
5. IBGE – Instituto Brasileiro de Geografia e Estatística. (2019). Available: www.ibge.gov.br
6. Governo do Distrito Federal. (2009). Plano Diretor de Ordenamento Territorial - PDOT. Documento Técnico.
7. Demuzere, M., Kittner, J. and Bechtel, B. (2021). LCZ Generator: A Web Application to Create Local Climate Zone Maps. Front. Environ. Sci. 9:637455.
8. Verdonck, Marie-leen, Demuzere, Matthias, Bechtel, Benjamin, Beck, Christoph, Brousse, Oscar, Droste, Arjan, Fenner, Daniel, Leconte, Francois, & Van Coillie, Frieke. (2019). The Human Influence Experiment (Part 2): Guidelines for Improved Mapping of Local Climate Zones Using a Supervised Classification. Urban Science, 3(1). https://doi.org/10.3390/urbansci3010027
9. Nill, L., Ullmann, T., Kneisel, C., Sobiech-Wolf, J. & Baumhauer, R. (2019). Assessing Spatiotemporal Variations of Landsat Land Surface Temperature and Multispectral Indices in the Arctic Mackenzie Delta Region between 1985 and 2018. Remote Sensing. 2019, 11, 2329.
10. Anselin, L. (2020). Local spatial autocorrelation. University of Chicago, Center for Spatial Data Science. https://geodacenter.github.io/workbook/6a_local_auto/lab6a.html#fn1
11. Demuzere, M., Mihara, T., Redivo, C. P., Feddema, J., & Setton, E. (2020). Multi-temporal LCZ maps for Canadian functional urban areas. https://doi.org/10.31219/osf.io/h5tm6
12. Vandamme, S., Demuzere, M., Verdonck, M., Zhang, Z., & Coillie, F. Van. (2019). Revealing Kunming's (China) Historical Urban Planning Policies Through Local Climate Zones. Remote Sensing, 11(14), 1731.
13. Prata-Shimomura, A., Ferreira, A. (2018). LCZ in metropolitan regions: surface temperature in urban and rural areas. Proceedings of 34th PLEA International Conference, Hong Kong, China: Smart and Healthy within the 2-degree limit. V. II, p. 796-801.
14. Ferreira, L. S.; Duarte, D. H. S. (2018). Land surface temperature, vegetation cover and urban morphology over different local climate zones in São Paulo Metropolitan Region. In: 10th International Conference on Urban Climate/14th Symposium on the Urban Environment.

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 02
10:15 — 11:45

CHAIR
JOANA GONCALVES

PAPERS
1606 / 1331 / 1322 / 1530

18TH PARALLEL SESSION / ONSITE

Wladimiro Acosta and the Helios System: 3 case studies

Comparative analysis and critical review

COLLO, FLORENCIA[1]

[1] Atmos Lab

ABSTRACT: Wladimiro Acosta was a pioneer in the use of meteorological science for architectural purposes. His Helios System, a methodology that he created in the 1930´s for designing with the sun in temperate warm climates, has proven to be grounded and sound. This paper reviews its application in three case studies across Argentina. The analysis is carried out through contemporary knowledge, solar and thermal simulations. Results prove that Acosta´s system works across different climates in the country and translates into sound thermal performances, even for contemporary standards.
KEYWORDS: Solar design, Helios System, Wladimiro Acosta, Argentinean modern architecture

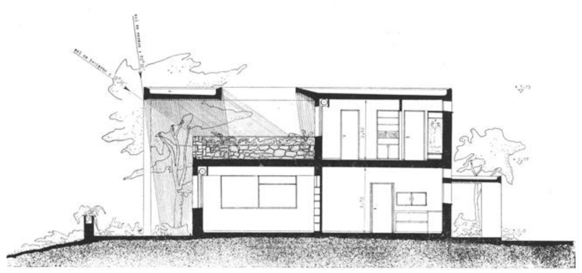
1. INTRODUCTION

Wladimiro Acosta was an absolute pioneer in the use of meteorological science for architectural purposes. Previous research carried out by the author (1) reviewed the validity of his Helios System, a methodology that he created in the 1930´s for designing with the sun in temperate warm climates. The research also pointed out his deep knowledge in the field that he gathered through climate, geographical, cultural and technical studies, as soon as he migrated to Argentina. His understanding about thermal comfort was accurate and he was probably the first architect to consider the science holistically from climate studies to building physics and how can design impact on physiological sensations:his theory compares with the contemporary approach to environmental design. This paper critically reviews the application of the Helios System into 3 case studies across Argentina. Conclusions are drawn from design features, solar, and thermal simulations. The work of Acosta is a key reference for Argentinean architects, as one of the first modern architects to practice in the country and with a strong line of thought rooted locally.

2. THE HELIOS SYSTEM

It is a design methodology for the temperate warm climate dominant in Argentina:the "starting point is the orientation of the building for which the decision is subject to solar access, breeze capture, and moisture regulation" and points out North as the most advantageous one, followed in order by NE, and East and West. The "shading slabs" are the most prominent feature: a "combination of large projecting slabs of 2m or more, elevated at a double height of 4,50 to 6m, and vertical protections N-S oriented" (Figure 1). As for the openings, Acosta explains how to adjust the size according to orientation for solar control, and how to consider shape and position to enhance daylight distribution and natural ventilation. He also suggests that all windows should have an operable upper part for winter ventilation purposes (Acosta, 1936).

Figure 1:
Section of a house with the Helios System



3. METHODOLOGY

The review of the designs is grounded on contemporary knowledge and simulation tools. Climate data was extracted from Meteonorom v8.0 (1980-2020), solar simulations were performed with Ladybug, and thermal simulations with EnergyPlus through Honeybee. A shading mask was performed on the shading systems to evaluate their effectiveness, sun hours were used to see how sunny outdoor spaces are, and solar radiation was calculated in summer and winter to study how much solar heat is regulated by Acosta. A version without the shading slab is calculated to evaluate how much heat it offsets in summer. Thermal simulations were used to understand conditions in free running mode as well as the heating load to compare with contemporary standards. All the houses have double brick walls with an air gap (U-value 2.7W/m^{2}K), single glazing (U-value5. 7W/m^{2}K) with night shutters (night U-value 1.87W/m^{2}K), and concrete slabs (U value 3.17W/m^{2}K). Infiltration was set as a "leaky building" for the EN standards, which translates approx. into 1ach. Free running zone operative temperatures were evaluated against the adaptive comfort zone based on EN 15251 (cat. II). For the heating load, the setpoint was 20ºC to match the EN norm.

4. CASE STUDIES: HOUSES AND CLIMATES

Case studies are summarised in Table 1 (Acosta and Gaite, 1976), together with climate data. The first one is the House in Ramos Mejía, in the outskirts of Buenos Aires, for the world-known photographers Grete Stern and Horacio Coppola. The second is the House in La Falda, Córdoba, emblem of the Helios System, as he presented the system to the public with this case study. The last one is the House in Bariloche, in the south of Argentina, for a couple with two kids. He designed several houses with this prototype, but only built this example. This house is not widely published.

4.1 The climates

The climate of Buenos Aires (latitude 34ºS) is characterised as Cfa in the Koppen-Geiger classification, temperate, with no dry seasons and hot summers. The outskirts are more continental than the zones next to the river with a higher diurnal variation, reaching at least 12ºC. Summers are hot, with an average high temperature of 31ºC and very high solar radiation, reaching 867 W/m^2. 47% of the time it is sunny, and the direct component is twice to three times the indirect one, which explains the importance of an effective shading system. The high diurnal variation calls for the use of thermal mass to stabilise temperatures. Winters are mild, with an average temperature of 10ºC in the coldest months. Mornings are cold (average of 4ºC), but days are sunny (around 45% of the time) and solar radiation is intense, reaching more than 400 W/m^2, which brings temperature to 16ºC on average in the afternoon.

The climate of La Falda is Cfb, temperate with no dry season and warm summers. The latitude is 31.5ºS, lower than Buenos Aires, but at 900m altitude, and in a much more continental area. The yearly average is slightly lower (17ºC for Buenos Aires, 15.8ºC for La Falda), but the diurnal range is higher, especially in winter. Summers reach an average high of 28.5ºC and are 42% sunny. In winter, it is common to wake up with 1ºC, but temperature reaches on average 16ºC in the afternoon, due to the higher solar radiation and proportion of sunny days (69%). This climate calls for special attention in capturing the winter sun.

The climate of Bariloche (latitude 41º, altitude 900m) is classified as Csb, temperate, with dry and warm summers. The annual average is 10.8ºC, which is very low. In summer, skies are sunny, with an average total radiation of 924 W/m^2 a day -more than in Buenos Aires and in La Falda. Temperatures in the morning are as low as 8-9ºC, but the afternoon reaches 23.6ºC on average. Winters are very cold, with a temperature average of 2ºC. During 1/3 of the days, temperature starts the day below 0ºC, and rises during the afternoon due to the high solar radiation. This can happen from early March to early November. Wind speeds are very high (average of 5.6m/s), which adds up to the cold.

4.2 The houses: comparative analysis

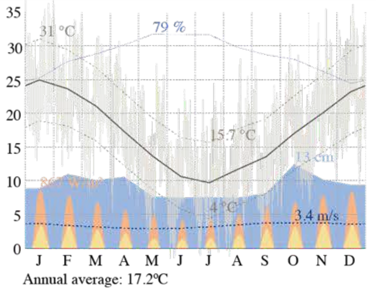
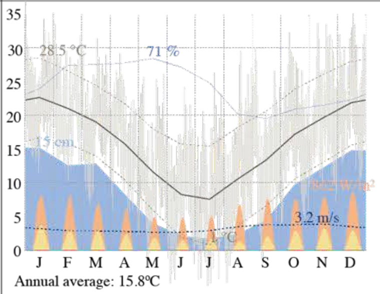
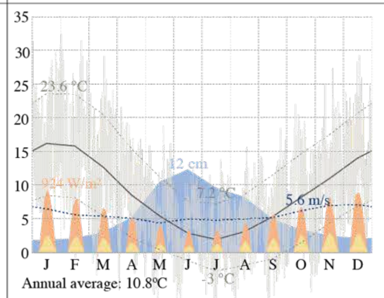
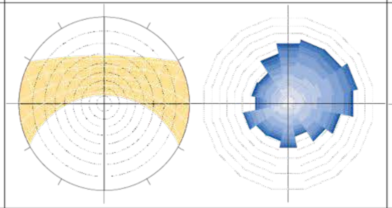
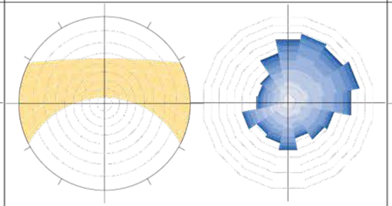
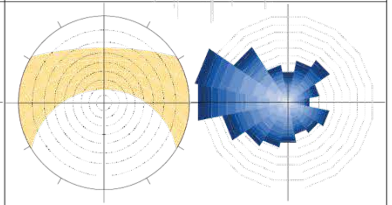
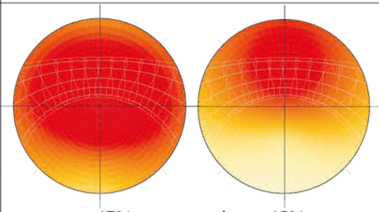
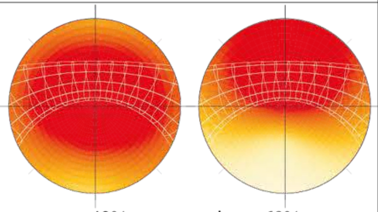
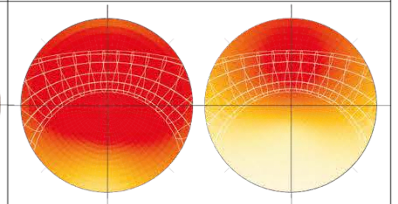
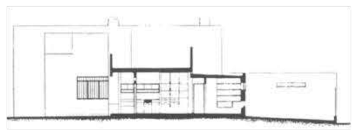
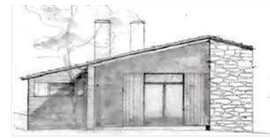
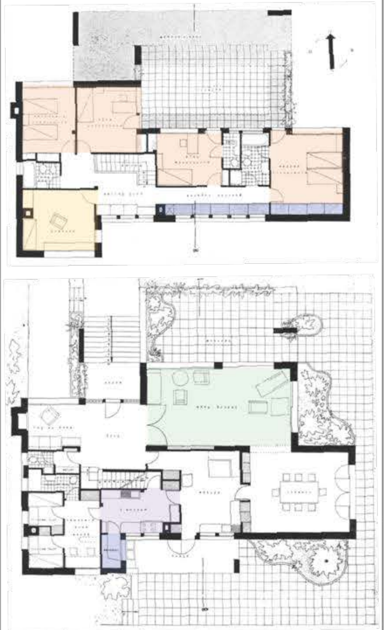
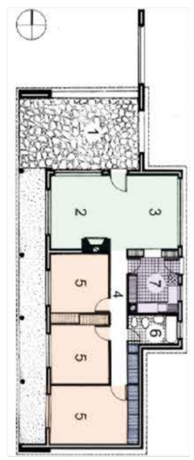
Acosta applied the principles of the Helios System in all his housing designs. The consistency with which he applies them is remarkable as none of the designs are similar in plan, but they all still follow the concepts. It is interesting to notice that the aesthetics of the houses is unique and distinguishable, an aesthetic where one can instantly recognize the challenges of the climates.

To deal with heat, in general, Acosta relies on the shading slab as horizontal solar protection, avoids openings on the west orientation where the sun is more intense, and creates cross ventilation through large openings at occupant height with mosquito nets. He designs different window types based on the specific position, orientation and use, whether sliding, pivoting, fixed or glass louvered. Shaded outdoor spaces below the shading slab can always be enjoyed during the hotter hours.

To deal with the cold, Acosta ensures big openings towards the north receiving full winter sun, and limits heat losses in all other orientations. Service functions and storage systems towards the south act as buffer spaces for the main rooms. All openings are equipped with an upper opening to ventilate above occupant height, and night shutters to further control heat losses. He also installs chimneys, concentrating night-time use in the warmer area. At the time insulation did not exist, so he used double layer brick walls with an air gap acting as insulation.

The house of Ramos Mejía was finished in 1939. It is inside the urban tissue, in a typical double plot of the city -17.5m wide- with a large garden. As most of the plots in Buenos Aires, it is rotated 45ºC from the cardinal points, with the front façade facing SW and the back one facing NE. The living-room, bedrooms, nursery, and kitchen are facing NE, and are protected by the system´s shading slab. The window-to-wall ratio reaches 30%. Towards the SW, Acosta positions the garage, storage, entrance, and the big photography atelier. He purposedly designed a very large window with U glass (to prevent from such a large heat loss) towards the

Table 1: Case studies and climates

	House in Ramos Mejía, Buenos Aires, lat 34º alt.0m	House in La Falda, Córdoba, lat 31.5º alt. 900m	House in Bariloche, Río Negro, lat 41º alt. 900m
Climate summary Monthly data — avg temp. — avg high/low — wind speed — humidity precipitations Daily solar radiation total diffuse			
Sun path & wind rose 0 2 4 6 8 10 m/s			
Calla dome and % of sunny days for summer and winter 0 70 140 210 280 350 kWh/m²	 summer: 47% sunny winter: 45% sunny	 summer: 42% sunny winter: 69% sunny	 summer: 58% sunny winter: 45% sunny
Helios system			
Section			
Plans main living areas work areas bedrooms kitchen buffer storage			

SW to get most of the year indirect light and incorporated other light sources from the NE and SE to add lighting variety (Acosta, 1946).

The house in La Falda was finished in 1940, and Acosta used it to present the Helios system to the wide public as he probably considered it its finest example (1943). The site was large and Acosta could choose the positioning and orientation of the house. The plan is relatively compact: living room, coin de feu and bedrooms are facing North, whereas circulation, kitchen and storage are facing South. He also positioned work areas towards the south -a studio and ironing zone- in order to have bright indirect light to perform the tasks. The window-to-wall ratio towards the north is large -34%, followed by the east one -26%- where he locates the dining room and a secondary bedroom. West and south window-to-wall are minimised -10 and 13% respectively-, as openings are only intended for minimum light purposes and cross ventilation. The Helios shading slab is intended for the large living room of the ground floor.

The house in Bariloche (1959) is the smallest one, as the climate calls for compacity and reduction of heat loss. It was located on a steep slope facing the beautiful Lake Mascardi towards the west, which prompted Acosta to rotate the house from the traditional North orientation. All main rooms are therefore facing west to get the low sun and the views: this deviation is possible due to the much colder climate. The living and dining room has openings towards the East, North and West. The kitchen and bathroom are orientated east, together with circulation and storage. This orientation has the steep slope, so the solar potential is reduced, especially in winter. The window-to-wall ratio towards the North and West reach 19%, whereas towards the east they are reduced to 11%, and no openings face south. In order to reduce the heat loss in this very cold climate, Acosta designed an inclined roof with a large air gap in between acting as insulation. Here, the Helios System is narrower and shorter, as the climate requires less protection.

5. SIMULATION ANALYSIS

5.1 Solar simulations

Results are shown in Table 2. The shading mask of La Falda proves that the system prevents the direct sun from reaching the glazed surfaces throughout the day for the 4 to 5 hottest months. During the rest of the year, the sun enters the living space throughout the day. During winter, the large windows in the north orientation receive high amounts of radiation (approx. 300 kWh/m^2) which translates into a significant amount of passive heat. East and West windows also receive a fair amount (180-190 kWh/m^2) to heat up the house. During summer, large north windows receive around 1/3 less radiation than in winter, which shows the success of the design. Without the Helios System, north windows would receive 50% more solar radiation in summer, which would add too much heat to an already hot atmosphere. The east and west orientation receive high amounts of radiation: in the east, the sun is welcome as it reaches the windows when temperatures are still 15-20ºC, whereas in the west, windows are minimal serving only service zones. This reduces significantly the heat added to the house. The garden receives the sun all year round, and the shading slab creates a shaded exterior area for summer.

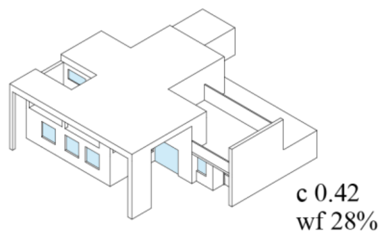
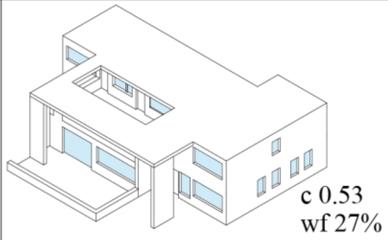
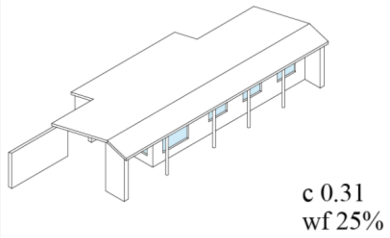
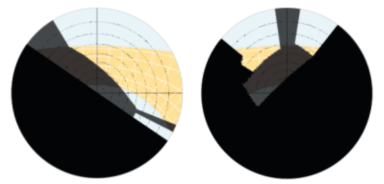
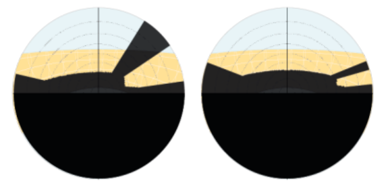
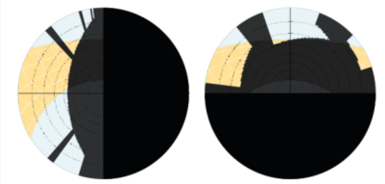
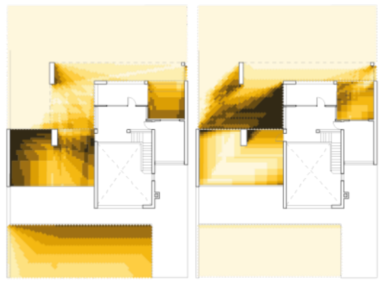
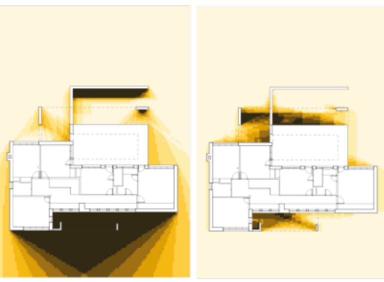
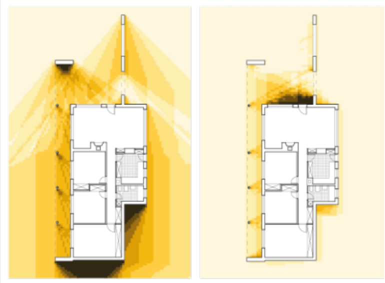
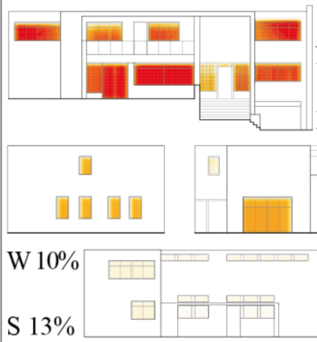
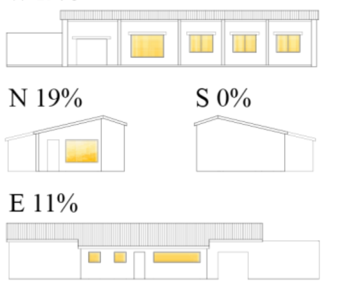
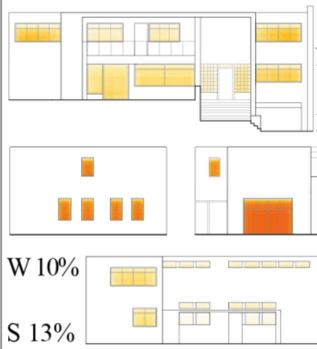
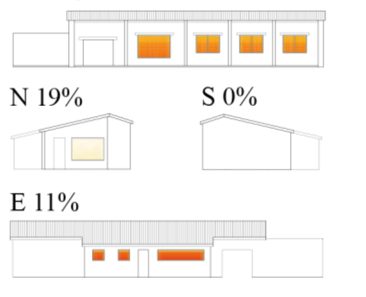
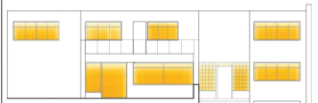
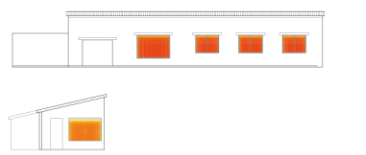
In Ramos Mejía, the slab protects the main NE windows from the intense and high midday sun. Windows receive radiation during the morning in summer, and up until 1-2pm in winter. The NW orientation is protected all year round (except some hours during winter) to avoid adding heat during the afternoon. Both orientations receive very similar amounts of radiation in summer and in winter (around 220 kWh/m^2), which proves the ability of Acosta to control the sun. Without the shading system, windows would receive 25% more radiation during summer. It is worth recalling that controlling the sun in the NE and NW is harder than due north due to the lower angles. The SW and NW orientations have very little windows, to prevent the heat of the afternoon, except for the atelier, for which the intentions were explained earlier. As in the case of La Falda, the garden is in full sun all year round, but the slab creates a protected shaded area during summer.

In the Bariloche case, the sun reaches the glazed surfaces all year round to add heat to the cold atmosphere. The shading slab protects the west windows only from the high midday summer sun and reduces the solar radiation on these surfaces from approx. 280 to 210 kWh/m^2, some 25%.

5.1 Thermal simulations

Results are shown in Table 3. The house in La Falda has a remarkable thermal performance. The main living room reaches 59% of the time in comfort: only at night it is not naturally in comfort and during some of the coldest winter days. During most of the winter, the space captures effectively the sun and raises its temperature naturally. During daytime, the house is some 5ºC warmer than outdoors, reaching comfort, and at night it is 15ºC warmer thank to the thermal inertia that keeps the heat. The heating load of the space and house is relatively high (50 kWh/m^2 for the living room and 75 kWh/m^2 for the full house). In reality, heating would only be required the days without sun during winter, which are not much. During summer, temperatures are in comfort throughout the day without overheating. At night and during the

Table 2: Solar analysis

	House in Ramos Mejía, Buenos Aires, lat 34° alt.0m	House in La Falda, Córdoba, lat 31.5° alt. 900m	House in Bariloche, Córdoba, lat 41° alt. 900m
General data - 3d view - Compacity - Window-to-floor ratio	 c 0.42 wf 28%	 c 0.53 wf 27%	 c 0.31 wf 25%
Overhang: - shading mask - orientation - height	 NE: 2.0m at 5.4m height NW: 2.0m at 5.4m height	 North: 2.2m at 5.4m height North: 2.2m at 5.4m height	 West: 1.5m at 3.6m height North: 1.5m at 3.6m height
Solar access: - sun hours on outdoor spaces on key days 0 2 4 6 8 hours a day	 21st of June 21st of December	 21st of June 21st of December	 21st of June 21st of December
Solar gains: - solar radiation falling on glazed surfaces - window-to-wall ratio by orientation Winter period 0 70 140 210 280 350 kWh/m²	 NE 30% NW 6% SW 31%	 N 34% E 26% W 10% S 13%	 W 19% N 19% S 0% E 11%
Summer period 0 70 140 210 280 350 kWh/m²	 NE 30% NW 6% SW 31%	 N 34% E 26% W 10% S 13%	 W 19% N 19% S 0% E 11%
Summer period House without Helios System 0 70 140 210 280 350 kWh/m²			

mornings, temperatures are around 20ºC (outdoors is around 15ºC) whereas in the afternoon it reaches some 28ºC, which is still in comfort. The inertia of the walls stabilises temperatures and keeps them below outdoors during the hottest hours.

The main space in the Ramos Mejía house is fairly protected as it is exposed only to the NE. It remains 46% of the time in comfort and is only cold during some winter days and nights. On average, temperature is naturally between 13 and 16ºC in winter, but during sunny days, it reaches the comfort band. This translates into a sound thermal performance, as the space only needs 20 kWh/m² of heating. Compared to the entire house (total of 83 kWh/m²), this space requires the least amount of heating (together with the bedrooms), which reveals Acosta´s strategic thinking. During summer, the house is also in comfort and protected by the shading slab. The main room only overheats during 1% of time, which is low for a climate that reaches an average high temperature of 31ºC in January. The thermal inertia of the walls and slabs and cross ventilation help to reduce temperatures and keeps them inside the comfort band. The space maintains the daily average at night (24ºC) and increases its temperature up to 28ºC during the day, which is up to 5ºC lower than outdoors during peak hours.

The house in Bariloche is cold across the year due to the general very low outdoor temperatures. Main rooms are in comfort for around 30% of the time spanning from early October to end of March. During summer, the house has temperatures between 20 and 26ºC, and is in comfort naturally. During winter, temperature inside swings from 6 to 12ºC naturally, which is 5 to 10ºC above outdoors. For a house without insulation and in a climate with such low temperatures, the performance is not bad. However, Acosta was well aware that this was not his best example which is why he kept the design far from the public eye: this house is only published in his complete works and has little information.

6. DISCUSSION

Solar simulations show that Acosta could accurately predict the sun´s position and its effect in all the latitudes and use it to design efficiently. The system proves to work properly in all the cases as solar radiation is minimised on glazed surfaces in summer but maximised during winter. Thermal simulations validate his methodology as sound performances are achieved in the main rooms of the house with no overheating.

7. CONCLUSION

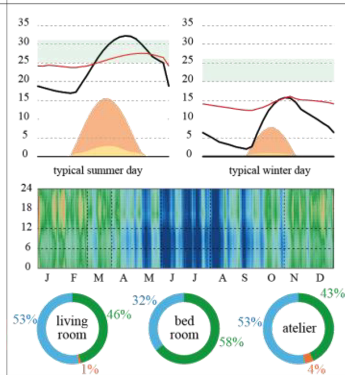
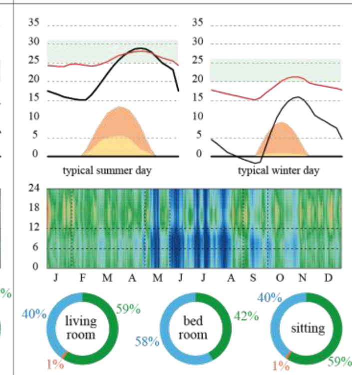
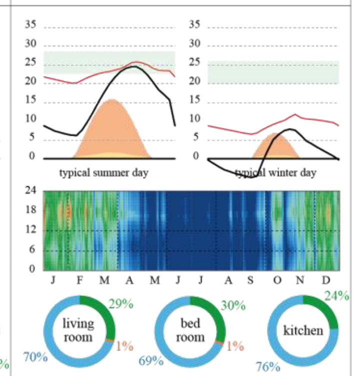
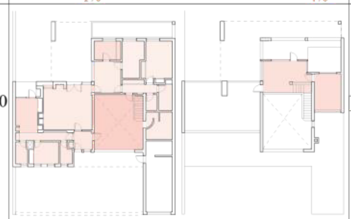
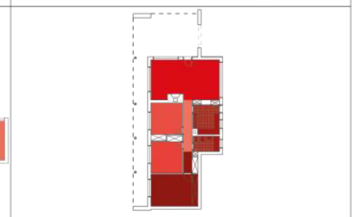
The principles of the Helios System were reviewed in a previous paper. Its application into case studies is consistent and proves to be effective for a sound thermal performance. Its simplicity and versatility allow adaptation to different contexts which suggests that it can still be implemented today in housing designs across the country.

ACKNOWLEDGEMENTS

The author would like to aknowledge Lawrence Monfort and Rafael Alonso Candau who made the termal simulations of this paper possible.

REFERENCES

1. Collo, 2017. Validation of Wladimiro Acosta´s Helios System, PLEA Proceedings, 2017 Edinburgh
2. Acosta, W., 1936. *Vivienda y Ciudad.* Buenos Aires: Ediciones Minihelios
3. Acosta, W., and A. Gaite, 1976. *Vivienda y Clima*. Buenos Aires: Ediciones Minihelios
4. Acosta, W., 1943. Vivienda tipo Helios en La Falda, Nuestra Arquitectura nº 168
5. Acosta, W., 1946. Casa Helios en Ramos Mejía, Nuestra Arquitectura nº 202

Thermal analysis	House in Ramos Mejía, Buenos Aires, lat 34° alt.0m	House in La Falda, Córdoba, lat 31.5° alt. 900m	House in Bariloche, Córdoba, lat 41° alt. 900m
Passive mode Typical days — exterior temp. — interior temp. confort band(EN) total radiation diffuse portion Comfort time (EN 15251) above EN in comfort below EN °C from target -8 -6 -4 -3 0 +3 +4 +6 +8			
Active mode Heating load 0 50 100 150 200 250 kWh/m²	 20 kWh/m² Living space 83 kWh/m² Total house	 50 kWh/m² Living space 75 kWh/m² Total house	 185 kWh/m² Living space 211 kWh/m² Total house

PLEA 2022 SANTIAGO
Will Cities Survive?

2000 meters above sea level

Climate adapted urban development strategies in the highlands of Oman

ALEXANDER KADER [1] NUSRAT KAMAL RITU [2]

[1] LXK Kader + Architekten
[2] Hasselt University

ABSTRACT: For hundreds of years in Oman, settlements were forged in harmony with the natural features and resources of each site including mountains, wadis, and favorable climatic conditions. However, accessibility of cheap energy in the late 20th century gave rise to an urban sprawl along the lowlands and coastal areas, leading to the abandonment of the environmentally friendly mountain regions. This paper revisits the climatic potential of the mountain regions and proposes a prototype city raised in the highlands with significantly minimized energy demands. Challenges of the past to sustain large-scale settlements in highlands due to insufficient water supplies are now proposed to be overcome using advanced technologies that utilize channeled water supply. With a compact urban density, climate adaptation strategies, an enhanced exterior comfort of urban spaces and the development of amenities in walkable distance for the new inhabitants would be pivotal in realizing the full potential of these settlements. As an exemplary site, the highlands of Al Jabal Al Akhdar mountain range of Oman, 2000 meters above sea level, are used to present proposals for climate-adapted developments. The results demonstrate how higher altitudes can uplift the quality of living to be more environmentally friendly, efficient and enjoyable.
KEYWORDS: Urban Ecology, Climate Adaptation, Bioclimatic Development, Energy Efficiency, Passive Design

1. CITIES OF TODAY – POSTPANDEMIC REVELATIONS

The world as we know it has changed forever. In recent months, the Covid-19 pandemic has brought forth a form of living that mankind had never foreseen. While there have been several differences of opinion on the execution of measures, the world today wonders if this new form of life is here to stay, and if so, what this means for our daily urban lives. Will people continue to flock to dense urban environments in hopes of better livelihoods? Will the meaning of "happy cities" change? What qualities of our existing cities would we wish to retain, and what qualities are we happy to let go of? Has the pandemic acclimated us to leading isolated lives in fear of our own health? Or has this period of isolation made us appreciate, more than ever before, the importance of communal living? Have the simple joys of a walking or biking in the neighborhood park and urban interactions found new meaning in our daily lives? Will we begin to live more consciously of our environments?

While the coronavirus pandemic is quite possibly the biggest transformation that we have been faced with, the past year has also brought to light the consequences of careless consumption of energy resources and pollution. From bushfires to hurricanes, floods, cyclones, and temperature extremes in the case of Oman, the message is clear: decades of the climate crisis have altered the course of our cities. Our job as planners remains to seek regenerative solutions to achieve cities that remain healthy and resilient in the face of global current crises.

2. LEARNING FROM YESTERDAY – THE CASE OF TRADITIONAL MOUNTAIN OASIS TOWNS IN OMAN

For hundreds of years in Oman, settlements were forged based on the availability of resources such as good soil, water, vegetation, and favorable climate conditions. These settlements existed in harmony with natural features available to each site including mountains and wadis [1]. However, following economic, political, and cultural developments in the 1970s, the accessibility of cheap energy gave rise to an urban sprawl along the lowlands and coastal areas, leading to the abandonment of the environmentally friendly mountain regions. Today with rising concerns of global warming coupled with depleting oil resources in the context of Oman, extreme temperatures in the lowlands and Batinah region along with unfeasible energy demands are inevitable.

However, by comparing the unsustainable development of today with the traditional Omani settlement structures, a lot can be learned about the application of passive energy-efficient design strategies for future settlement planning.

2.1 Exemplary Mountain oasis towns in Oman

To revisit strategies that allow for the planning and construction of new sustainable cities, it would be worthwhile to conduct a case study of the following traditional settlements in their urban layout, as well as their manner of construction:

Misfat Al Abriyeen, located in the province of Al Hamra, is a former agricultural centre built from clusters of low-rise mudbrick structures. Constructed from local materials like earth, stone and wood from date palms, the settlement sits atop a rocky ridge of around 150 m, with compact clusters of homes and the occasional souq and mosque structures positioned above the confluence of two *wadi* streams [2]. The entirety of the settlement was fashioned with thick mudbrick structures with openings placed strategically to enable cross ventilation. Furthermore, while the settlement most likely occurred due to the availability of water and agricultural land, the residents of the settlement sustained their livelihoods through the development of stepped terrace farming of local fruits and vegetable, irrigated by refined water channels called the falaj, thus utilizing the terrain available to them. Not only is the settlement an example for the application of site-specific passive design strategies, but it also sets forth an example of harnessing existing resources for settlements in the highlands to flourish autonomously.

Figure 1: The hajar mountain area and highlands (photo by authors)

The oasis village of Bilad Sayt, located in Wadi Bani Awf, like most other oases settlements in Oman began as a dense agglomeration of low-scale houses rising only up to two or three levels. The settlement also contains agricultural lands with gardens of palm trees, irrigated by the falaj system, which was, and continues to be today, the dormant water distribution system. The materials and organization of the village reflect the cultural and economic lifestyle of its inhabitants that are sustained primarily through trade and agriculture [3]. This, once again, is an example where traditional building materials, methods and planning approaches are implemented to the best of the inhabitants' abilities and expertise. Three factors primarily determined the layout of these traditional settlements: "ease of defense, topographical constraints, and climate" [4].

3. CITIES OF TOMORROW – REVISITING THE HIGHLANDS

While traditional Omani settlements built hundreds of years ago represent excellent models of climate-adaptive planning centered upon maximizing the potential of every site, the settlements of today fail to cater to the same principles. Today, Omani cities, specifically in the lowlands and coastal areas, suffer from extremely high temperatures that are further emphasized by inefficient planning, urban fringes, and a suburban dystopia. Where dense settlements, narrow streets and thick mudbrick structures once harmonized with lush palm vegetations to keep the harsh climate at bay, the sparsely built cities of today with little to no vegetation, sun protection measures or ground surface considerations rely heavily on energy-intensive air-conditioning. While this once might have seemed feasible due to abundant oil reserves and an economic boom, the rising climate concerns, and overall environmental awareness of today has made the necessity for an energy-efficient solution quite explicit. Therefore, the objective of this paper is to provide a strategy for prototype cities for the future development of Oman that explores and thrives in the climatic and energy potential of the mountain regions. This paper first presents the numerous benefits of living in the highlands. Through the research-by-design methodology, the paper then derives climate-adapted urban development strategies to facilitate highland living from 3 sets of design proposals for the selected case study site. In doing so, the paper presents ascertainable methods to be applied as urban design principles for a more sustainable future. As a solution for cities with extreme temperatures, new settlements could be raised at highlands where better climatic conditions with significantly minimized energy demands for air conditioning would pave the path for new urban planning policies in Oman. The challenge in the past to accommodate and sustain large-scale settlements in highlands due to insufficient water supplies could now be overcome using advanced technology and systems, including the storage and utilization of rainwater received frequently in these mountain regions. Urban qualities characterized by increased density, climate adaptation strategies, better exterior comfort of urban spaces along with the development of social and cultural functions to reduce commuting to other parts of the city would be pivotal in realizing the full potential of natural features of the mountain-

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

scape. Exemplary to these mountain regions, the Al Jabal Al Akhdar mountain range of Oman encompassing the Sayq Plateau is presented as a case study.

3.1 Location of Sayq Plateau

Figure 2: New proposed urban area in the highland of Sayq Plateau compared with Capital Area of Muscat (Source: by author and google earth)

Located 2000m above sea level, the Sayq plateau in the Jabal Al Akhdar mountain range of Oman avails cooler temperatures and more rainfall compared to the lowlands and desert plains. Due to a relative abundance of freshwater resources thanks to water channels directing groundwater as well as stored rainwater, the oasis settlements of Sayq Plateau continue to exist to this day, heavily dependent upon the productivity of their lush crop fields, orchards and other fruit gardens [5]. Exemplary of a culturally unique, agro-pastoral livelihood system coping with an otherwise fragile environment, the Sayq Plateau serves as an excellent example for highlands that are worth revisiting to build cities with higher sustainability and liveability standards [6, 7]. However, like several other oasis settlements of the region, the older, vernacular quotients of the city are increasingly being abandoned, with families and younger individuals moving to the suburban units due to lack of infrastructural planning or career prospects.

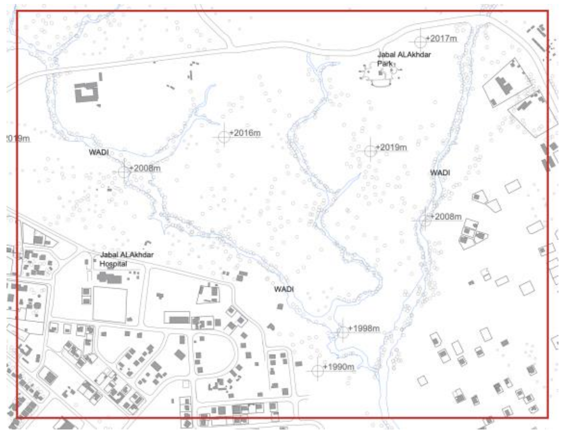


Figure 3: Site proposal at Sayq Plateau (Source: authors)

However, to combat rising energy demands and unsustainable planning practices on the rise today, this paper explores the possibility of setting forth an example of a well-sustained, nearly self-sufficient settlement in the highlands, achieved through adequate infrastructural planning complemented by site-specific urban design solutions that acknowledge and harness the climatic and energy potential of the region.

3.2 Climate comparison

The following diagrams present a comparison between the climate data of the Sayq Plateau with that of the capital area of Muscat.

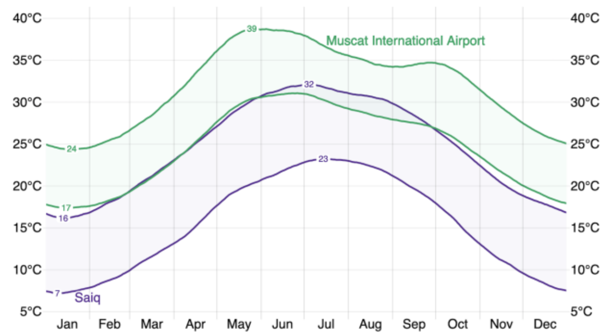


Figure 4: Comparison of average temperatures (high and low) of Sayq (purple color) and Muscat (green). Source: Weatherspark.com / Cedar Lake Ventures Inc.

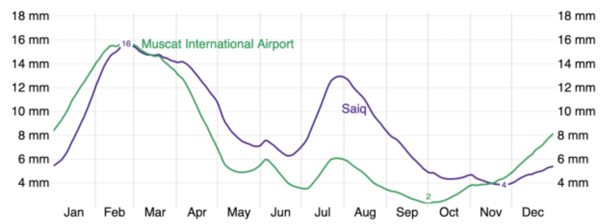


Figure 5: Comparison of average precipitation (high and low) of Sayq (purple color) and Muscat (green). Source: Weatherspark.com / Cedar Lake Ventures Inc.

As presented in the above charts, the Sayq Plateau receives far more precipitation all year round than Muscat, thus leading to better reliability on green plantations. The highlands also display significantly better temperatures all year round with a highest mean high temperature of 32 degrees Celsius during peak summer, as opposed to a mean high temperature of 39 degrees in Muscat during the same time period. In addition, the average air humidity at the Sayq Plateau is significantly lower than in Muscat. The lower air humidity also has an impact towards much more pleasant climatic conditions at the Sayq Plateau.

4. CASE STUDY PROJECTS FOR A NEW CLIMATE ADAPTED CITY IN THE HIGHLANDS OF OMAN

The following section presents a selection of three student thesis projects from the German University of Technology, developed under the supervision of the principal author of the paper. The millennia old symbiosis between nature and urbanity is explored by proposing how the future settlements of Oman could adapt to this new climate and land while perceiving the natural surroundings and responding to the environment. Thus, this contribution aims to propose settling in highlands such as Al Jabal Al Akhdar, availing near-Mediterranean climate as opposed to the extreme hot and arid climate in the low lying areas. It explores the possibility of drawing water from low lying areas that modern technology and advancements have now made feasible, thus making it viable for large scale settlements to prosper in these highlands. As demonstrated in the exemplary theses' masterplans below, it would be vital to integrate the distinctive features of Al Jabal Al Akhdar's landscape, flora and fauna as a staple of its economy and identity while introducing new lives, daily rituals and production materials without damaging or leaving a trace upon nature. In a city with a much more pleasant climatic potential further elevated by appropriate planning measures, our primarily indoor-driven lifestyle propelled by extreme weather conditions could be transformed into one that is healthier, outdoor-driven and revels in the comfort of moderate temperatures. Could we enjoy a cup of *kahwa* outdoors at noon like the French enjoy croissants for lunch in the streets? Could higher altitudes uplift our quality of living to be more environmentally friendly, efficient, and enjoyable?

Figure 6: Design proposal of urban development looping around a central wadi (Plan by Nusrat Kamal)

As shown in figure 6 this project proposes a primary "loop" around the wadi stream, bejeweled with dense, mixed-use structures consisting of schools, universities as well as offices, cultural establishments and basic services. A road network around the loop is proposed with minimum crossings over the untouched wadi, clearly assigning priorities to pedestrians and cyclists. Right at the heart of the loop sits a student city and an agricultural field, catering to the inhabitants residing in the plethora of dwellings available. The project recognizes the existing agricultural possibilities in parallel with the newly proposed mixed-use infrastructure as the "drivers" of the city and its social and economic structure, thus envisioning an educated, progressive society that understands, acknowledges, and truly taps into the potential of the site.

Figure 7: Bachelor thesis proposal – Development of varying densities for smooth transition into existing settlements (Plan by Abeer Al Hinai)

The case study project shown in figure 7 focuses upon densifying existing settlements and establishing well-connected newer developments. Drawing inspiration from the structure of traditional older Omani cities, vibrant city centers are proposed along the wadi junctions, in addition to smaller centers placed within the neighborhoods that cater to the residents' everyday needs. By determining soft mobility as a priority that is made possible due to moderate climatic conditions, the entire proposal centers upon the themes of proximity, multi-functional neighborhoods and varying density.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Figure 8: Bachelor thesis proposal – Development along a linear stream of cores / centres (Plan by Arwa Dayyani)

A system is also proposed whereby larger, denser structures are proposed closer to the wadi junctions and city centers, whereas smaller, low-lying building are proposed further away from the centers to allow for better transition into the existing settlements. Ultimately, a module-based approach is adapted to configure a range of building typologies, public spaces, urban green areas, and pedestrian walkways.

The project shown in figure 8 focuses on the establishment of a city centre with multiple cores formed in harmony with the site's terrain. It emphasizes upon development principles on the themes of Accessibility, Quality and Density. Further to improving inter and intra-city connections, the project also views the street to be as valuable as an open space and demands that they're designed and treated with the same attention. It also proposes a density for the site that is divided to smaller scale development comprising of varying building typologies depending upon the terrain on the site and the functions adjacent to each neighbourhood. Lastly, the proposal envisions multiple hotspots with different public programs to be implemented in a city, engaging various social groups, and hence designing a city that belongs to everybody.

5. HIGHLAND CITIES IN HOT ARID REGIONS – GENERAL ADVANTAGES

The following table draws from the various possibilities presented in the above student theses and presents a comparison between the existing cities in the lowlands and coastal areas of Muscat vs. the possible settlements in the highlands of the region.

Table 1: Comparison of existing conditions in the Capital Area of Muscat and the proposed settlements in the Highlands of Sayq Plateau

		Capital Area of Muscat (existing urban environment)	Highlands of Sayq Plateau (urban planning proposals)
Climate Related Points	Air **temperatures** and **humidity**	**Beyond human comfort zone** during large part of the year	**Within human comfort zone** most of the year
	Energy demand of buildings	**Very high** (for cooling)	**Low** (for cooling and heating)
	Urban **microclimate** of exterior space	Too **hot** during the six summer months	Comfortable most of the year due to higher altitudes and increased rainfall
	Air quality / dust	Heavy use of motor vehicles leading to air pollution, exhaust and fumes	Availability of lush green to combat any air pollution created due to motor vehicles
	Annual **precipitation**	Very low (approx. 100 mm annually), arid climate	low (approx. 316 mm annually)
	Local **agricultural** production potential	**Limited potential** due to high temperatures and lack of arable lands	Large expanses of plantations along with culture and site-specific agricultural fields. Potential to utilize local cultivars irrigated by the already refined falaj systems to further **expand agricultural production**
Urban Planning Related Points	Arrangement of buildings / **compactness**	Inefficient detached villas, large amount of **unused urban spaces**	**Compact** mixed-use neighborhoods with wide range of **dense** housing opportunities for various households such as courtyard houses, apartments, row houses, etc..
	Walkability	**Lack** of pedestrian oriented infrastructure and lack of proximity based planning	Inclusion of pedestrian **walkways** along with shading for pedestrians where required. Connection of pedestrian walkways to commercial, public or mixed-use functions to motivate walkability
	Mixed-use	Large areas of **mono-functional neighborhoods**, still with a clear trend towards suburban neighborhoods. Limited number of mixed-use neighborhoods that are not well-planned	**Mixed-use building models** with public services and educational facilities within close proximity to residences, encouraging a healthy mix of residents that are inclusive of all social spheres.
	Street layout	Large **unused spaces** between building plots and streets resultant from no direction relation between buildings and the streets.	Potential to implement an **integrated** street layout closely related to the arrangement of buildings and principles of compact settlements
	Mobility Management	Predominantly **unilateral mobility** consisting of individual traffic on the streets, leading to generating high amounts of emissions in the air.	Reduced dependency on private motorized vehicles and longer distances with a special emphasis on **soft mobility** facilitated by better climatic conditions. Provision of public transportation systems, leading to a more feasible consumption of energy
	Landscaping	Ornamental landscaping primarily along main streets. Landscaping requires constant maintenance due to higher temperatures and the use of water-intensive species of vegetation	Climate specific **green corridors** could be implemented for pleasant microclimate. **Local plants** would further provide a natural habitat for birds and other animals while filtering CO^2 and absorbing dust
	Use of materials	Primarily **reinforced concrete** skeleton constructions and hollow concrete blocks clad with plaster or imported finishes including marble, tiles, etc. Urban surfaces consist of hard, sealed surfaces that contribute to **urban heat islands**	Potential for use of **local materials** such as local stone pavements for pedestrian walkways and road surfaces. Unsealed surfaces would allow for more natural rainwater drainage. Use of readily available local natural stone, palm wood and palm fronds for building and urban furniture construction

6. CONCLUSION – TOWARDS MORE CLIMATE ADAPTED CITIES

The above case studies are presented as research by design base work for deriving argumentations and corresponding strategies to settle in high altitudes which are climatically more favorable than the hot and arid lowlands. As demonstrated by the case studies, the advantages can be threefold: ecologically, economically and socially. Ecologically due to the favorable climate as well as due to the climate adapted and energy saving planning strategies, e. g. by the denser building structures providing mutual shading and less solar exposure. Economically due to the increased energy efficiency, meaning less reliance on airconditioned cooling and less infrastructure to build. Socially, on one hand due to climatic factors such as the more pleasant microclimate and better thermal comfort at the interior spaces and also urban exterior areas, and on the other hand due to urban design factors such as shorter, more walkable distances for the inhabitants to reach all everyday functions.

While there is a need for further detailed studies, for example with quantification of densities, climate data and feasibility, it would be essential to begin such a debate towards sustainable planning. A new, informed community with detailed understanding of the specifics of the Omani culture, cultivars and climate would strengthen the existing network of settlements, setting a benchmark of energy efficient living for many other mountain settlements in the region as well as in other countries with comparable conditions.

REFERENCES

1. Buerkert, A., Dix, B.A., Al Rawahi, M.N., et al., (2021). "Agro-ecological landuse transformation in oasis systems of Al Jabal Al Akhdar, northern Oman", *Sci Rep 11, 7709*, [Online], Available: https://doi.org/10.1038/s41598-021-85515-9 [01 November 2021].

2. Bandyopadhyay, S., Quattrone, G., Goffriller, M., Al-Abri, H., Campolo, D., Georgiadou, K., Briguglio C., & Mershen, B., (2014). Documentation, Heritage Management and Tourism Development Plan: Al-Hamra, Misfat Al-Abriyin – Archiam, [Online], Available: https://www.archiam.co.uk/ do-cumentation-heritage-management-and-tourism-devel-op-ment-plan-al-hamra-misfat-al-abriyin/ [01 March 2022]. 3. Said, K., & Al Shueili, M., (n.d.). Towards a sustainable urban future in Oman: problem and process analysis (Muscat as a case study), [Online], Available: https://core. ac.uk/download/pdf/74366371.pdf [07 Octo-ber 2021].

4. Oborn, P. M., (1982). Ruwi, a New Town in the Sultanate of Oman: Its Development and its Architecture: a Dissertation Submitted for the Degree of Master of Architecture. Department of Architecture, Edinburgh College of Art/Heriot-Watt University, Edinburgh.

5. Gangler, A., (2003). "Oasis Settlement Structures / Oman." [Online], Available: http://sulamaintra.de/ docume-nts/publications/Gangler_2003.PDF [23 November 2021].

6. Luedeling, E., (2007). Sustainability of Mountain Oases in Oman: Effects of Agro-environmental Changes on Traditional Cropping Systems. Kassel: University Press.

7. Maher, N., Siebert, S., Luedeling, E., Buerkert, A., and Häser, J., (2004). "Settlement History of a Mountain Oasis in Northern Oman: Evidence from Land-Use and Archaeological Studies." In *Die Erde* 135: 81–106.

8. Buerkert, A., Luedeling, E., Dickhoefer, U., Lohrer, K., Mershen, B., Schaeper, W., Nagieb M., Schlecht, E., (2010). Prospects of mountain ecotourism in Oman: the example of As Sawjarah on Al Jabal al

Akhdar, *Journal of Ecotourism,* [Online], Available: DOI: 10.1080/14724040902 803404 [01 March 2022].
9. Ahmed, M., Victor, R., Jashoul, M., et al., (2016). Utili-zation of low quality water of mountain reservoirs: a case study from Al Jabal Al Akhdar, Oman. *J. Mt. Sci.* 13, 1423–1430, https://doi.org/10.1007/s11629-015-3748-7.
10. Weatherspark.com / Cedar Lake Ventures Inc., [Online], Available: https://weatherspark.com// [01 March 2022].

Lessons learnt from the Brazilian bioclimatic modernism

The case-study of the Sul American Bank building (1966)

RANNY L. X. N. MICHALSKI[1], ROBERTA C. K. MULFARTH[1], JOANA C. S. GONÇALVES[2], ALESSANDRA R. P. SHIMOMURA[1], BEATRIZ N. E SOUZA[1], GUILHERME R. M. CUNHA[1], SHEILA R. SARRA[1]

[1] Faculty of Architecture and Urbanism of the University of São Paulo, Department of Technology (FAUUSP, AUT, LABAUT), São Paulo, Brazil
[2] Architectural Association School of Architecture, London; Bartlett School of Architecture – UCL, London; School of Architecture and Cities, University of Westminster, London

ABSTRACT: In the face of climate emergency, learning from the environmental performance of bioclimatic precedents generates a technical knowledge useful to inform the future of buildings, following a growing market interest for better environmentally responsive initiatives in Latin America. In order to fill the lack of technical knowledge on the performance of existing examples from the Brazilian Bioclimatic Modernism, the research project that supports the content of this article brings real-life data as well as analytical results about the environmental performance of the office building originally design for the Sul American bank (1966), on Paulista Avenue, in São Paulo (latitude 24ºS) to be fully naturally ventilated and daylit. Outcomes from the analytical work showed that thermal comfort is possible for at least 60% of the time during the summer period, whilst good daylight was an asset before the obstruction caused by later tall neighbouring buildings that compromised it. Nevertheless, occupants' expectation regarding thermal and acoustic comfort led to the closure of the building to outdoors. This work is part of a wider research project about the environmental performance of buildings from the Brazilian Bioclimatic Modernism (1930-1964), from which other case-studies were presented in previous PLEA Conferences.
KEYWORDS: Office Building, Bioclimatic Design, Subtropical Climate, Environmental Conditions.

1. INTRODUCTION

Looking back to the glorious years of Brazilian modernism between 1930 and 1964, the country's architectural heritage was based on the understanding of key environmental principles, paying heed to solar orientation and the need for solar protection as well as to the benefits of daylight and natural ventilation [1]. Nevertheless, very little is known about the environmental performance of those buildings until now. In the 1970s, with the vast dissemination of the international style for commercial architecture in Latin American cities, the environmental qualities of the local bioclimatic office buildings were discarded to give place to the "glass tower" and the fully air-conditioned space. As a result of this change in the architectural culture, coupled with the boom of the commercial building sector, four decades later, space cooling in Brazilian office buildings accounted for approximately 47% of the total country's electricity consumption, followed by artificial lighting with 22% [2].

In the face of the climate emergency, learning from the environmental performance of bioclimatic precedents generates a practical technical knowledge, useful to inform the retrofit of existing buildings in general as well as the design of new ones, following a growing market interest for better environmentally responsive buildings in Latin America and the "rediscovery" of the possibilities for daylit and naturally ventilated office buildings in warm climates.

In order to fill the lack of technical knowledge on the performance of existing examples from the Brazilian Bioclimatic Modernism, the research project that supports the content of this article brings real-life data as well as analytical results about the environmental performance of the office building originally designed to be the HQ of the Sul American bank *(Banco Sul Americano)*, concluded in 1966, located on the Paulista Avenue, in São Paulo (latitude 24ºS), a major commercial and financial centre of the city (Fig.1). As other buildings from this time, this iconic piece of architecture was designed be naturally ventilated and daylit [1]. In this context, one of the main objectives of this environmental assessment was the impact of the emblematic movable external metallic shading devices on blocking solar gains and their effects on daylight. In parallel to that, there was the investigation about the viability of natural ventilation given the local urban acoustic conditions.

This work is part of a wider research project about the environmental performance of buildings from the

Brazilian Bioclimatic Modernism built in São Paulo, encompassing thermal, daylight and acoustic issues, from which other case-studies were presented in previous PLEA Conferences [3 - 5].

2. BRIEF DESCRIPTION OF RESEARCH METHODS

An evidence-based approach to the actual environmental performance of existing buildings from the Brazilian Bioclimatic Modernism was supported by a series of in-depth technical studies that encompassed a few specific measurements *in situ*, simplified calculations and informal interviews with the occupants regarding the acoustic environment, followed by a set of analytical work of advanced computer simulations to verify daylight and thermal conditions. For the assessment of the acoustic conditions, three single aspect rooms of different sizes were selected for the fieldwork, on the 20th floor (to where access was given to these studies). For the thermal and daylight analytical assessments, the 2nd and 14th floors were selected as representative of extreme exposures.

For the acoustics, sound pressure level, percentile levels, the equivalent modulation and the reverberation times were evaluated, following national standard's methodological procedures [6, 7] and the results were compared with established criteria [7, 8].

Thermodynamic and daylight simulations were carried out with the Ladybug Tools: environmental plug-ins for the Grasshopper digital modelling software.

The outcomes of the thermal assessment included cooling loads in the case of using air-conditioner, comfort hours during the summer period for the scenario of natural ventilation and weekly temperature profile for a typical warm week. The adaptive comfort model and the comfort zone by ASHRAE-55 [9] were adopted as the thermal performance criteria.

The daylight simulations followed the Climatic Based Computer Modelling Method (CBCM) [10], in which the range of Useful Daylight Illuminance levels (UDI) between 300 and 3.000 lux at the desk-height was adopted as the main performance criteria [11]. Daylight factors and illuminance levels were also verified. The analyses presented here look at cellular and open plan offices located at lower and higher floors. As briefly mentioned before, this technical environmental assessment aims to critically examine the effects of key architectural features of the case-study building, including its form and orientation as well as apertures and façade treatment, alongside the impact of the surroundings, upon the acoustic, thermal and daylighting conditions in internal spaces.

3. CLIMATIC CONTEXT

The city of São Paulo (Latitude 23.85° S; Longitude 46.64 ° W; Elevation 792 m) is in a region of humid subtropical climate (Cfa) [12], characterized by warm-humid summer days with predominantly partially cloudy sky, and mild and drier winter days with predominantly sunny sky. Predominant wind directions are Southeast and South during the summer and Northwest during the winter. Air temperatures are moderate for most of the year with an annual average of approximately 19 °C [13]. January is the hottest month, with an average minimum temperature of 19 °C and average maximum reaching 27 °C, whilst humidity levels vary between 31% to 100%. July is the coolest month, with average minimum of 17 °C and average maximum of 23 °C, whilst relative humidity varies between 26% to 100%.

Due to the subtropical conditions, the annual frequency of overcast sky is of approximately 60%. Diffuse radiation in São Paulo accounts for approximately 50% of total annual global radiation on the horizontal plan, therefore, having a significant impact on buildings' solar gains. To illustrate that, maximum global radiation on the horizontal plan in January (the hottest month of the year), for example, is 1.068 W/m^2, being 578 W/m^2 diffuse radiation.

From the climate diagnostic, it is possible to conclude that, in warm days, shading is fundamental for the thermal comfort in buildings as well as natural ventilation, which can also be beneficial during night-time, given the daily temperature variations, especially in the warmer period of the year. In cooler days, previous analytical work demonstrated that internal gains are sufficient to raise internal temperatures to comfort levels in office buildings in São Paulo. In other words, solar gains might be undesirable in office buildings, in this climate [14].

4. THE CASE-STUDY BUILDING

The iconic office building originally designed for the Sul American Bank by one of the key architectural practices of the Brazilian Modernist Architecture, Rino Levi Arquitetos Associados, was built in 1966, between Paulista Avenue and Frei Caneca Street, in São Paulo city (today occupied by Duratex S.A.) (Fig.1).

Figure 1: Banco Sul Americano (1966), Paulista Av. São Paulo.

The 15-storey slab-shape building, 15 meters deep by 45 meters long plan, sits on top of a horizontal base building, perpendicular to the busy avenue, which has been one of the main financial and commercial axes of the city since 1970s. As seen in other examples of the Brazilian Bioclimatic Modernism [3 - 5], the base building is projected over the public pavement, creating a cover from the rain and the sun typical of the local climate. The main façades, Northwest and Southeast oriented, are fully glazed with operable windows and external shading devices placed 1 meter from the façade, facilitating the opening of windows towards the outside, whereas the shorter façades are blind, including the one facing the Paulista Avenue (reducing exposure to urban noise). In addition to the articulation of the pure architectural forms, other remarkable architectural features from the international modernist movement identified in this building are the modularity of the concrete structure, the façade components and the terrace garden area on the base building (never landscaped as designed for, though). Being one of the main iconic modernist buildings in São Paulo, the original HQ of the Sul American Bank was listed in 2010.

The continuous lines of metallic external horizontal shading devices, 0.45 m wide and 1.5 metres long, are movable on the Northwest façade and fix on the Southeast. On the Northwest the shading devices are closer to each other, with 25 cm between each other, due to the longer exposure to solar radiation in critical times of the year, especially in the summer afternoons, whilst in the Southeast, the space between devices is 50 cm, in principle, opening more the views towards the outside (Fig.2).

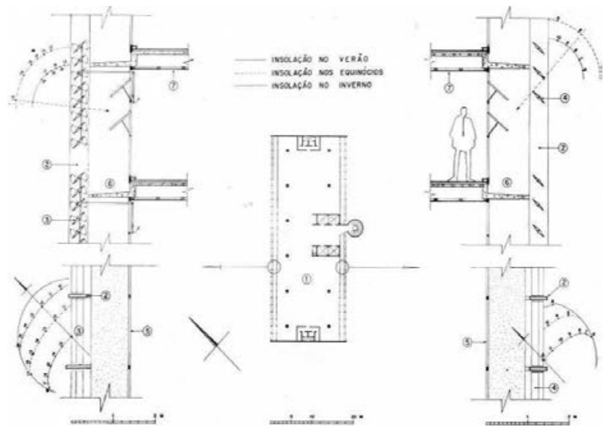


Figure 2: Schematic section showing the design of the different shading strategies according to the orientation.

The building's orientation offers a degree of protection against urban noise, whereas the narrow plan (15 meters wide) coupled with the shaded façades and operable windows were envisioned to maximize the potential for daylight and natural ventilation. The floor plan was planned to accommodate cellular and open plan offices (where cross ventilation should be possible, in theory). Despite the opening windows for natural ventilation, since 1990s several office spaces in the building have been operating with air-conditioning systems. Most recently, a full central air-conditioning system has been installed, to respond to occupants' current expectations of thermal and acoustic comfort as well as to increase the building's market value.

5. ENVIRONMENTAL PERFORMANCE

5.1. Acoustic conditions

The acoustic measurements in the office spaces were taken in the morning and afternoon of two sequential days (January 22nd and 23rd, 2020) with all windows closed (as recommended by the standards) (Fig. 3). In addition, outside measurements at 1 meter from the façade were also registered, by opening the windows. The later was done with the objective of register what would be the likely trend of the acoustic conditions inside, in the case of windows open.

Figure 3: Top - Floor plan with the indication of the case-study rooms and position of the points of measurement; Bottom – Views of 2 of the 3 rooms where measurements were taken.

The sound pressure levels measured in the three rooms show similar average values for the morning and afternoon periods, at around 55 dB (Fig.4). The external measurements showed much higher values during the entire period, at around 68 dB, which is a consequence of the urban activities (in particular the cars) at Paulista Avenue and Frei Caneca Street. The results of the external measurements call the attention to the need of acoustic insulation to protect the internal spaces from excessive urban noise. Nevertheless, even with the windows closed, the noise pressure levels and reverberation time found in all rooms were above the recommended ones [7, 8], pointing out to the need of reviewing the acoustic treatment of the internal spaces, regardless the impact of urban noise.

Nine-hours continuous measurements were carried out, from 9 am to 6 pm, in one point in room 1, occupied and with the air-conditioning system on, from which equivalent sound pressure levels were obtained as function of frequency for 1/1 octave and 1/3 octave bands, respectively (Fig.5). The result for the A-weighted equivalent continuous sound pressure level for the measurement period was 53,1 dB. From the results, it is possible to identify main noise contribution in low frequencies (from 63 to 200 Hz) typical from the air-conditioning system. The acoustic conditions in room 3 were verified at different times, with and without the occupation, but with the air-condition on. In all cases, established criteria were not achieved.

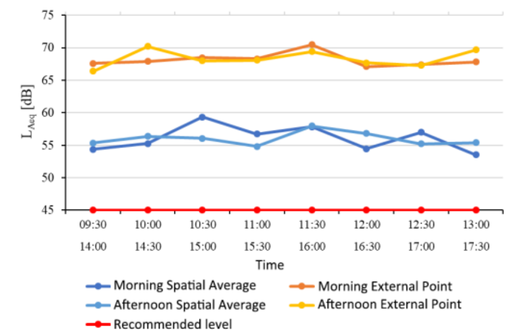


Figure 4: A-weighted equivalent continuous sound pressure level averaged in room 1 during the day.

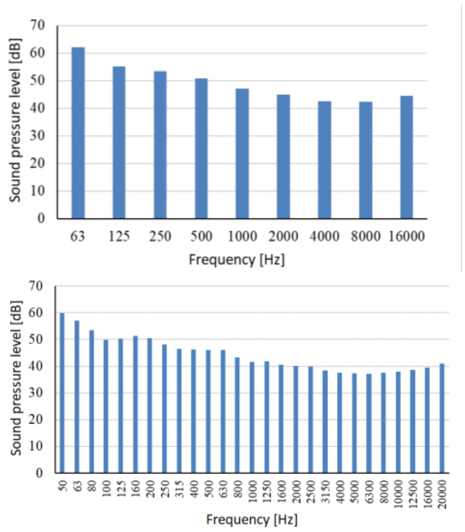


Figure 5: Top - Sound pressure level in 1/1 octave bands; Bottom - Sound pressure level in 1/3 octave bands.

5.2. Thermal response

To verify the building's thermal performance in its urban context, the thermodynamic modelling included the existing surrounding buildings, looking at the results for cellular offices in both oppositive orientations and for the open plan configuration, at the lower and higher floors. For the cooling loads, shown in Table 1, the setpoint of 24 ºC was assumed, following the common practice in most office buildings in São Paulo [4, 5]. The introduction of night-time ventilation showed the potential to reduce cooling loads between 13 and 20%, being the best-case scenarios were the SE cellular office and open offices on the 14th floor, followed by the cellular office in the 2nd floor facing SE.

The results for the assessment of the efficiency of natural ventilation in terms of hours in comfort during the summer period are shown in Table 2. In all cases, the frequency of hours in comfort surpasses 60%. In addition, a significant difference was observed between the ventilation schedules. In the SE office, on the 2nd floor - the best-case scenario - a figure of 84% for the 24-hour mode was found versus 74% when opening during occupational hours only (from 8 am to 8 pm). In general, the cellular offices performed better than the open plan offices, being the later on the 14th floor - one of the worst-case scenarios with 63% of hours in comfort. Despite the effect of cross ventilation in the second case, these results are likely to be related to the higher concentration of internal gains (10m² p/person in the cellular and 7 m² p/person in the open plan - as in real-life), and the bigger area to be ventilated in the second case, as the central corridor is not included in the scenario of cellular offices, coupled with the slightly bigger exposure to solar radiation (despite the shading devices). Comparing the two cellular offices, the SE ones have a better performance than the NW, with 74% of comfort hours versus 66% in the best case, being the conditions on the 2nd floor better than on the 14th. These differences can be explained by the less solar radiation onto the lower floor, coupled with the exposure to prevailing winds.

Table 1: Cooling loads at several office scenarios, including the reduction associated with night-time ventilation.

Offices		Cooling loads kW/m²	
		2F	14F
NW	AC	74.10	75.22
	AC + NT Vent	62.90	65.05
	Load reduction	15	14
SE	AC	63.15	68.57
	AC + NT Vent	52.23	54.77
	Load reduction	17	20
Open p.	AC	86.88	90.09
	AC + NT Vent	75.42	72.47
	Load reduction	13	20

Table 2: Percentage of hours in comfort during the summer. in the offices, for 2 natural ventilation schedules: 24-hours and occupation only (from 8 am to 8 pm).

Offices		2F %	14F %
NW	24 hr Nat Vent	73	71
	8 to 8 Nat Vent	66	62
SE	24 hr Nat Vent	84	76
	8 to 8 Nat Vent	74	69
Open p.	24 hr Nat Vent	69	73
	8 to 8 Nat Vent	64	63

The trend of Operative Temperatures in the cellular and open plan offices, on the 2nd and 14th floors, during three days of a typical summer week shows the maximum efficiency of natural ventilation, resulting in internal below the outside for most of the time. temperatures in the SE offices, on both floors and facing prevailing winds, where internal temperatures are very close for most of the time, with peak daily temperatures oscillating between 25 ºC and 28 ºC, in this period (Fig. 6). In the NW offices, the ventilation is slightly less efficient, reaching 29 ºC when outside is 27.5 ºC. In the open plan office, temperatures are higher, but still below the outside, with the exception of the overcast day, when all internal figures are higher than the outside, due to the impact of diffuse radiation, and internal peak is up to 5ºC more in the outside.

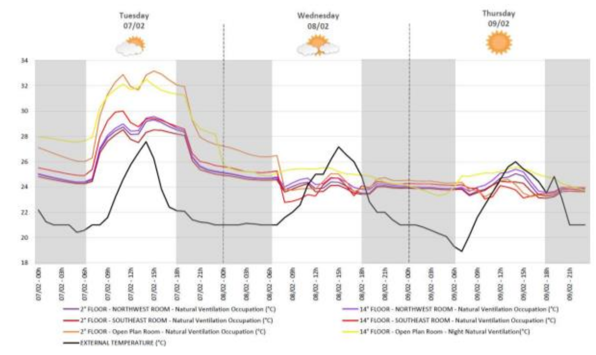


Figure 6: Profile of Operative Temperatures in the cellular and open offices, on the 2nd and 14th floors, with NV during occupation, for a 3-day period, in a typical summer week.

5.3. Daylight

For the daylight assessment, the simulated scenarios considered no tall surroundings (as at the time of the building's completion and to what the building was designed for) and the current scenario, with the obstruction of the existing buildings of the surroundings (Fig. 7 and Fig. 8). Results are shown here only for the open plan configuration, as the cellular office scenario blocks the daylight penetration in the central part of the plan. Figure 8 shows a significant increase of the overshadowing created by surroundings along the height of the case-study building, with an increase of 2 to 3 hours, in average, between the 3rd and the 13th floor in the solstices and equinoxes.

The simulation model considered the external shading devices fully open to maximize daylight access, meaning, at 90º to the façade. On the 2nd floor, the results for the scenario without the existing surroundings revealed that the entire plan could be occupied without the need of artificial light for at least 70% of the annual daylight hours (where lux levels between 300 and 3.000 were found), including the central zone, at 7.5 meters away from the façades. Between 1.5 and 3 meters from the façade (where the first row of workstations and cellular offices are located), UDI levels go up to 90% (Fig. 8). However, the obstruction created by the current urban surroundings, combined with the effect of the horizontal shading, reduced the UDI levels significantly across the plan. On the NW façade, whilst reasonably high UDI levels remain near the front (between 90 and 60%), values dropped from 60 to below 10% at the depth between 3 and 4.5 meters.

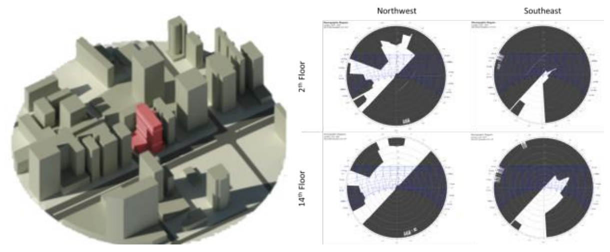


Figure 7: Left - digital model for the daylight simulations with the case-study building and its existing surroundings; Right - the shading masks at 2nd and 14th floors created by the surroundings.

Figure 8: Top and middle - UDI and DF simulations for the 2nd floor (NW-SE section) without the surroundings (best-case scenario), and with the surrounding buildings. Bottom – UDI and DF simulations for the 14th floor, with the surroundings.

On the SE orientation, the performance is worse, starting with UDI levels around 40% close to the façade and cascading to below 10% at 2 meters deep. On the 14th floor, the impact of the surroundings is slightly less, but still relevant, as daylight availability decreases from

90 to 50% within the first 4.5 meters depth at the NW façade. On the SE, UDI levels reach 50% at 2 metres, decreasing to below 10%, though, at 3 meters depth.

The correspondent Daylight Factors (DF) vary between 7 to 2% in most of the area in the best-case scenario of no external obstruction, showing an excellent daylight performance (assuming 2% as the minimum recommended [12]). DFs go down to below 2% already at 1.5 meters into the plan because of the impact of the obstruction on the 2nd floor, and at 3 meters on the 14th at the NE side and at 1 meter at SE. In general, lux levels are higher than 3.000 only at the first 1 meter on NW side, without the obstruction. Showing the efficiency of the shading devices in avoiding glare related to excessive lighting levels.

6. FINAL CONSIDERATIONS

The possibility of thermal comfort in the summer period for more than 60% of the occupied hours via passive means, in the current climate scenario of the city of São Paulo, shown by the analytical studies, raises questions about the need of air-conditioning from the perspective of the local thermal conditions, proving the success of the architectural bioclimatic strategies applied in the design of the Sul American Bank. In addition, the daylight assessment also showed how the external shading was efficient in controlling the daylight conditions in the original context, without the tall surrounding buildings. On the other hand, whilst until very recently some rooms could still operate using natural ventilation, despite the placement of localized air-conditioning devices, it is known that, to respond to occupants' expectations regarding thermal and acoustic comfort conditions, the building went through a major retrofit of its façades and cooling system, in the past years, which led to the introduction of a central air-conditioning system and permanent closure of all windows. The current scenario of urban noise and air pollution on site, partially captured in the acoustic measurements presented here, explains the closure of the building to the outside. However, it should be noted that even with the windows closed the internal acoustic conditions were an issue, to a certain extent, pointing out to the need of a deeper approach regarding the design strategies for acoustic comfort.

The impact of the urban growth was also verified in the daylight performance of the case-study building, where the obstruction created by neighbouring tall buildings, combined with the effect the external shading devices, proved to have a significant negative impact upon the daylighting conditions, reducing the depth of adequate levels to less than 1.5 meters.

Despite the challenges of the urban climate associated with noise and air pollution, the understanding of the opportunities for natural ventilation in office buildings acquired an extra level of importance in the context of the Covid-19 pandemic, especially considering the energy impact of improving fresh-air conditions by means of mechanical systems. For this reason, although the case-study presented here showed a successful environmental design, in principle, the establishment of sound urban planning with alternatives to mitigate urban noise and its impact at buildings, alongside with their thermal response in the scenario of climate change, is paramount to the future of buildings and cities.

ACKNOWLEDGEMENTS

Thanks to FAPESP, CNPq and USP for supporting the research work presented in this paper. Thanks to Itaú Bank S.A. for granting access to its premises.

REFERENCES

1. Gonçalves, J. C. S. (2016). A Clarion Call for a New Approach: Sustainability In: Brazil: Restructuring the Urban. AD. 1 ed. London: John Wiley & Sons, v. 86, p. 126-135.
2. Romero, M. A. (2001). Dynamic Evaluation by Computer Simulation using ESP-r in Office Buildings in São Paulo. In: *Proceedings of PLEA 2001*. Florianópolis, Brazil.
3. Gonçalves, J. C. S.; *et* al (2018). The Thermal Environment in the High-Density Tall Building from the Brazilian Bioclimatic Modernism. In: *Proceedings of PLEA 2018*. Hong Kong.
4. Mulfarth, R. C. K. *et* al (2021). The environmental response of office buildings from the Brazilian bioclimatic modernism in São Paulo. In: *Solar Energy*, 220, p. 617–634.
5. Mulfarth, R. C. K. *et* al (2020). The Potential of Passive Design for Offices in the City of São Paulo, fieldwork in the building of *Complexo Conjunto Nacional* (1963). In: *Proceedings of PLEA 2020*, La Coruna.
6. ABNT (2017). *ABNT NBR ISO 3382-3: Acústica – Medição de parâmetros de acústica de salas. Parte 3: Escritórios de planta livre*. Rio de Janeiro.
7. ABNT (2017). *ABNT* NBR 10152: Acústica – Níveis de pressão sonora em ambientes internos a edificações. Rio de Janeiro.
8. AS/NZS - Australian/New Zealand Standard (2016). *AS/NZS 2107: Acoustics. Recommended design sound levels and reverberation times for building interiors.* Sydney.
9. ASHRAE (2020). ANSI/ASHRAE Standard 55. Thermal environmental conditions for human occupancy.
10. Mardaljevic, I., *et* al (2012). Daylighting Metrics: Is there a relation between useful daylight illuminance and daylight glare probability? In: *First Building Simulation and Optimization Conference*. Loughborough, UK.
11. Nabil, A.; Mardaljevic, J. (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. Lighting Res. Technol. v. 37, n. 1, p. 41-59.
12. Vu-wien.ac.at. (2017). World Maps of Köppen-Geiger climate classification [online]. Available at: http://koeppen-geiger.vu-wien.ac.at/present.htm/14. LABEEE-UFSC (2005).
13. Arquivos climáticos. [Online]. Available at: http://www.labeee.ufsc.br/downloads/arquivos-climaticos/
14. Marcondes, M.; Yannas, S.; Bode, K. (2011). Façade's design solutions for office buildings with natural ventilation in São Paulo. In: *Proceedings of PLEA 2011*. Louvain-la-Neuve, Belgium.

PLEA 2022 SANTIAGO
Will Cities Survive?

Exploring the thermal quality of the Modernism legacy's architecture

Analytical studies of Acayaba's single-family houses in São Paulo

EDUARDO GASPARELO LIMA[1], JOANA CARLA SOARES GONÇALVES[2], RANNY LOUREIRO XAVIER NASCIMENTO MICHALSKI[1]

[1] Faculty of Architecture and Urbanism of the University of São Paulo (FAUUSP), São Paulo, Brazil
[2] Architectural Association School of Architecture (AA School), London, United Kingdom

ABSTRACT: When it comes to his buildings, Marcos de Azevedo Acayaba himself states that the concern with construction, production processes, and maintenance is decisive to the definition of the architectural key design features, along with the specific geography of the building site, following the principles of Bioclimatism. In that sense, this paper explores the thermal response and evaluates the performance of solutions and design strategies applied by the architect in three case studies in the city of São Paulo: Marlene Milan House (1972), Hélio Olga House (1987) and Vila Butantã Residential Complex (1998). The thermal quality of these houses has already been revealed at the 35th PLEA Conference by a work focused on results from field survey of environmental thermal variables. Here, the method is based on analytical studies carried out with the use of Ladybug Tools plug-ins. The adaptive comfort model for occupant-controlled naturally conditioned spaces established by ASHRAE-55 was adopted as the criteria to assess the results. The thermal quality of the three case-studies in the warmer period is unquestionable, with low percentages of hot-discomfort, while the cold period was left with room for improvement. *This result is directly related to the design strategies applied in the three residences.*
KEYWORDS: Marcos Acayaba, Thermal response, Analytical studies, Design strategies

1. INTRODUCTION

Marcos de Azevedo Acayaba graduated in 1969 from the Faculty of Architecture and Urbanism of the University of São Paulo. His architectural education was influenced by the need to contribute to technological development, coupled with the idea of integration between building, site, and climate. When it comes to his buildings, the architect himself states that the concern with construction, production processes, and maintenance is decisive to the definition of the architectural key design features, along with the specific geography of the building site [1], following the principles of Bioclimatism [2].

Thus, free from any style type, the building form in Acayaba's architecture results from rigorous analysis of specific local conditions, looking for the highest efficiency of the building techniques, environmental comfort, quality of space, and, as a consequence, architectural beauty, where, in the words of the architect, "*nothing is left and nothing is missing*" [1].

The work presented in this paper continues the technical investigation of the environmental quality of three single-family homes designed by Acayaba in the city of São Paulo, focusing on the buildings' thermal response – never previously quantitatively assessed –, from which the first phase of fieldwork was published at the 35th PLEA Conference [3], showing that, despite of the differences in the overall thermal response between the houses, the thermal quality in all cases is satisfactory in the summer, with a few hours when the internal temperature reaches or exceeds the external one. On the other hand, whilst focus was put in dealing with the summer conditions, the winter performance indicates room for improvement. The quality achieved in his architecture is related to the appropriate combination of multiple design strategies, on a case-by-case basis, moving away from the idea of the optimum or pre-determined solutions for the adequate environmental performance.

This paper discusses the results about the thermal response of scenarios that explore the potential of passive design strategies applied by the architect, which were studied by means of thermodynamic computer simulations. Those scenarios derived from observations and questions raised in the empirical studies.

2. CASE STUDIES

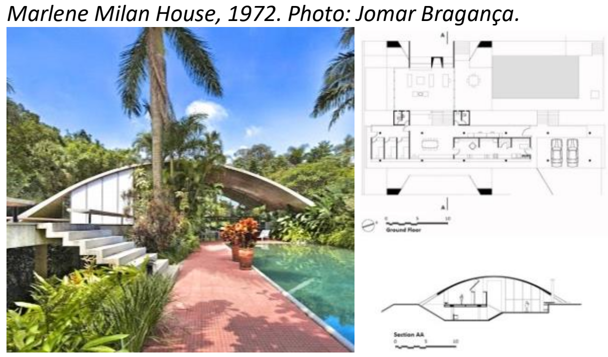
Three case-studies were selected considering different materials and construction techniques applied

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

in their architectural design, denoting a vast technological and constructive knowledge of the architect, which works the plasticity expression of his buildings based on the constructive techniques that best suit site demands, reinforcing the role of bioclimatic principles. The three houses are:

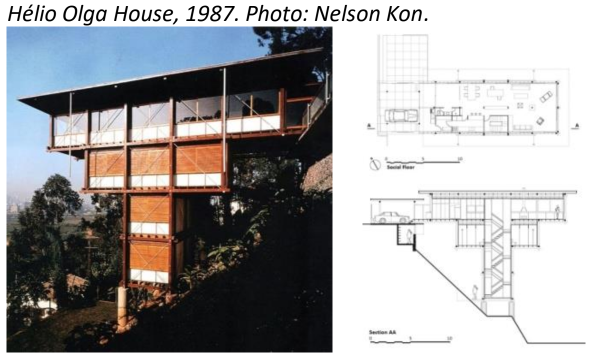
(I) Marlene Milan House (1972), in which Acayaba proposed a cast-in-place concrete arch, under which the uses were allocated and organized on three semi-levels integrated by the social areas (Fig. 1). This spatial integration, associated with the variable heights of the multiple areas, creates one single volume that facilitates convective air movements, as well as cross ventilation. The fluidity between internal and external areas is guaranteed by the high glazed panels (λ = 0.8 W/m°C), shadowed by the over-arching concrete roof (λ = 1.75 W/m°C). Adjustable lower openings in the glass panels were introduced, favouring the stack effect through higher openings. Perforated concrete blocks (λ = 0.91 W/m°C) with single glass coverage were also used in some external walls at lower levels, in order to maximize daylight and natural ventilation, and internal surfaces and partitions were made in *Cedro* wood (λ = 0.12 W/m°C). After residents reported high indoor temperatures during the first occupied summer, a layer of thermal insulation made of polyurethane was added to the external surface of the roof, which was painted in white to increase reflectivity of global radiation. The high vegetation density of the landscape design helped to lower temperatures, providing shading to the glass panels and to the roof. For the cold period, the most notable strategy is the provision of a fireplace, in a prominent spot in the living-room.

Figure 1:
Marlene Milan House, 1972. Photo: Jomar Bragança.



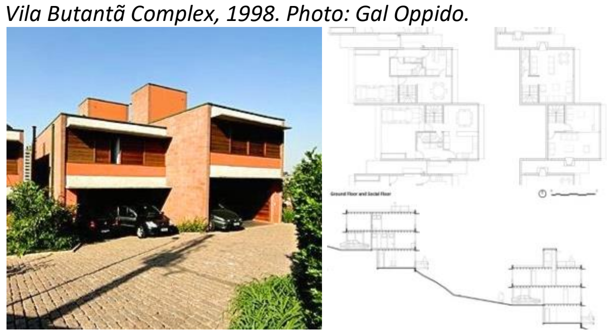
(II) Hélio Olga House (1987) is the result of the challenge to design on a steep site, in which Acayaba envisioned an independent structure, in *Angelim* wood (λ = 0.23 W/m°C), supported by only six points, preserving the site natural geographic characteristics (Fig. 2). A 3.30-meter modular cubic system was adopted, creating a residence of four floors whose main facade faces Northeast. For the subtropical climate of São Paulo, this is one of the best orientations for a long permanence place, maximizing solar access during winter and minimizing in the summer months. Light-weight building components were specified for walls and roof, in order to minimize the total structure weight, resulting in a light thermal mass building, highly coupled with outdoor temperature fluctuations. Maximum ventilation is the main strategy to control the rise of internal temperatures, playing a central role in the thermal performance of this residence. As mentioned, the wooden structure is exposed on all sides, including the floor area, where adjustable trickle vents were inserted as part of the inlets to increment air flows. To assist in the comfort conditions, internal translucent blinds were added by the occupants to block solar radiation through the windows in summer. In addition to that, the extended roof works as a shading device for the access floor and the trees' canopies have the same effect on the lowest floors (bedrooms). A fireplace in Hélio Olga House also occupies a central area in the social floor.

Figure 2:
Hélio Olga House, 1987. Photo: Nelson Kon.



(III) Vila Butantã Residential Complex (1998), that consists of a set of sixteen semi-detached single-family units designed in order to favor the communal leisure and adapt to the terrain slope (Fig. 3). The construction system is a structural masonry with pigmented concrete blocks (λ = 0.91 W/m°C), reinforced concrete slabs and wooden beams. This residential complex was designed with a considerable amount of opaque and heavy mass building components, ensuring considerable thermal inertia to its interior. Aside from the *brise-soleils* designed to block the solar radiation, in this specific case, the site planning arrangement of misaligned semi-detached residences facing East and West, resulted in shading benefits during the summer period. Following the same strategy as the other cases, the shading is associated with ventilation to achieve comfortable temperatures in the warm period. One more time, a fireplace for the social floor as a strategy for the cooler periods of the year was provided.

Figure 3:
Vila Butantã Complex, 1998. Photo: Gal Oppido.



3. METHOD AND ANALYSIS

In addition to the fieldwork presented by Lima *et al* [3], thermal dynamic computer simulations were performed to evaluate specific strategies and scenarios considering the climate of São Paulo (Latitude 23.85° S; Longitude 46.64° W; Altitude 792 meters above sea level), classified by the Köppen-Geiger Classification as humid subtropical with oceanic influence (Cfa) and characterized by warm-humid summer days with predominantly partially cloudy sky, cool and drier winter days with predominantly sunny sky, with prevailing wind directions being South, South-Southeast and Southeast during the year. Air temperatures are moderate for most of the year with an annual average temperature of 19.3 °C [4]. In typical warm days with clear sky, temperatures can reach figures above 30 °C in the beginning of the afternoon. On the other hand, under a cloudy sky, air temperatures in a warm day stay around 20 °C. In typical cooler days, air temperatures can go as high as 24 °C due to the solar radiation impact, whereas in a cooler cloudy day, air temperatures struggle to get above 15 °C.

The analytical work was carried out with the use of Ladybug Tools: environmental plug-ins for Grasshopper that connects to the EnergyPlus and OpenStudio engines to simulate. The different spaces of the buildings were digitally modeled in Rhino 3D software as individual thermal zone. In this paper, only the data obtained for living-room are presented. The adaptive comfort model and the comfort zone of 80% acceptability range for occupant-controlled naturally conditioned spaces established by ASHRAE55 [5] were adopted as the performance criteria.

A base case scenario (BC) was defined taking into account the residence occupied by a family of four. From that, occupancy, equipment, and lighting schedules were developed, as well as for opening windows and for shading devices, when available. In addition to the ventilation schedule, minimum and maximum outdoor temperatures setpoints were also defined between which the opening of windows is likely to occur. Alternative scenarios, specific to each house, were created based on the outcomes from the fieldwork which are better explained in the sequence.

4. ANALYTICAL STUDIES: RESULTS AND DISCUSSION

4.1. Marlene Milan House, 1972

The strategies applied in this house were mainly related to the roof, including shading, reflectivity provided by the white external surface, and thermal insulation. For that reason, the first scenario evaluated considers the BC without the shading provided by the surrounding vegetation (Scenario 1) and, in an accumulative way, the second scenario eliminates the thermal insulation of the roof (Scenario 2). The results can be seen in Fig. 4.

The BC Scenario indicates an annual comfort percentage of 53.41%, while the rest of the year presents only cold-discomfort. When evaluating the percentages per season, the comfort percentage in the summer is close to 80% and, in the winter, it reaches only 33.51%.

On the hottest days of the typical summer week, when outside temperatures can go as high as 32 °C, operative temperatures remain in the range between 24 and 26 °C (Days 4 and 5). On the other hand, on cold days, whose dawn temperatures go up to 12 °C (Day 3 of the typical winter week), operative temperatures get close to 16 °C, when the external air temperature peaks of the day before exceeds 25°C.

Analysing the typical summer week, it is noticeable that most of the temperatures are within the comfort zone. The exception is in the coldest dawn, when outdoor temperatures remain below 20 °C. The roof insulation associated with the shading caused by the vegetation may guarantee a good response to the high summer temperatures that commonly exceed 30 °C. However, its performance suffers a decrease in cold situations, such as in the early hours of summer days. This is corroborated by analysing the typical winter week, in which operative temperatures are within the comfort range only during some afternoons when external air temperatures already exceed the 20 °C in the early mornings.

When the vegetation is omitted, the comfort percentage rises to 59.22%, decreasing the cold-discomfort percentage. Nevertheless, no hot-discomfort is noticed. Seasonally, the comfort percentage is 85.69% in summer and 39.63% in winter, which corresponds to an increase of approximately 525 hours in comfort.

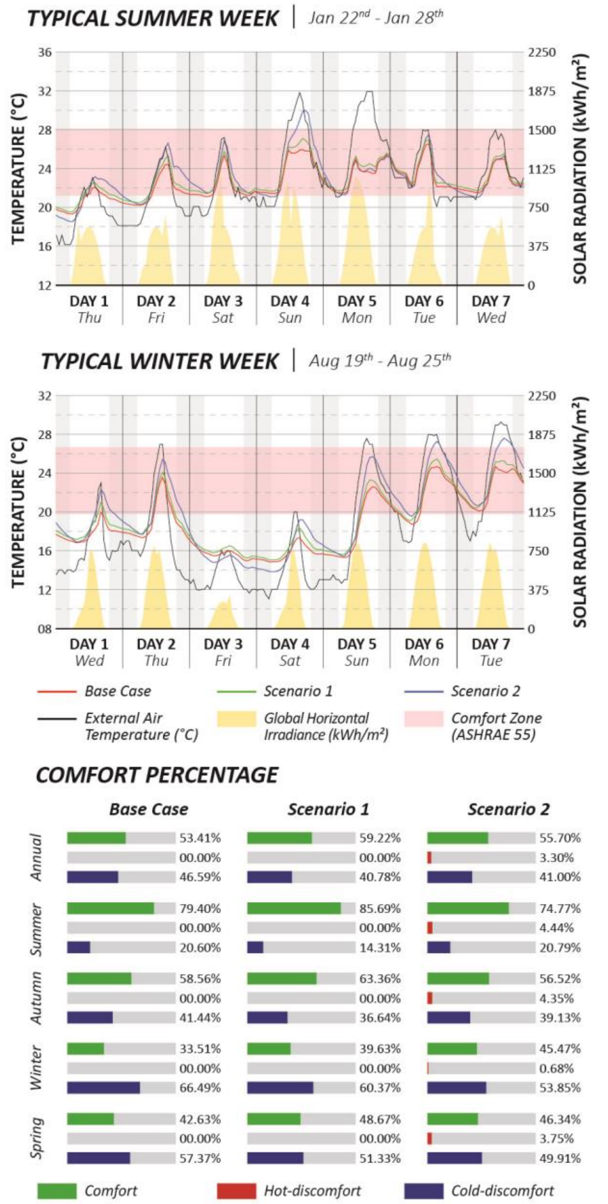
The radiation incident with the omission of the shading caused by the surrounding vegetation, associated with the roof insulation, is responsible for raising internal temperatures by up to 1.2 °C during daily periods and by up to 0.5 °C during dawns, causing some of these temperatures to get close or to reach the comfort zone.

The comfort percentage of Scenario 2 is 55.70% for the annual period, 74.77% for the summer, and 45.47% for the winter. Although the values are better compared

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

to the BC Scenario, it is necessary to point out that, without the thermal insulation, it is already possible to notice events of discomfort due to high temperatures during the year, including in the winter. Annually, the cold-discomfort is 41.00%, and the hot-discomfort is 3.30%. Hot-discomfort reaches 4.44% during the summer, and 0.68% during the winter.

Figure 4:
Simulated thermal response of Marlene Milan House, showing operative temperatures for the living-room compared against external temperatures and global horizontal irradiance for typical weeks of summer and winter, followed by the comfort percentage per year and per season.



Scenario 2 presents a great difference when compared to the others. The temperatures peaks during the summer reach 30 °C on the hottest days, exceeding the comfort range. During the dawns of cold days, operative temperatures get around 14 °C, about 1 °C lower compared to the BC Scenario. Still in relation to the typical winter week, days with milder temperatures, in which the temperatures values exceed 28 °C, produce internal peaks above 27 °C, which already exceeds the comfort range of the cold period.

4.2. Hélio Olga House, 1987

The strategies applied to this project were mainly related to natural ventilation and lightweight components, as well as solar access. In this case, different degrees of window aperture were evaluated, but, for this paper, only 100% (Scenario 1) and 5% (Scenario 2) of aperture were presented, since window apertures above 25% produced similar thermal responses. The results can be seen in Fig. 5.

For the BC Scenario, the windows apertures followed a pre-defined schedule and, therefore, the ventilation was not permanent. For the other scenarios, the windows were kept permanently open. In addition, tests showed that, due to the large number of windows and the dimensions of the apertures, values of 50% of window aperture or more lead to similar results.

The BC Scenario points out an annual comfort percentage of 53.81%, compared to a percentage of hot-discomfort equals to 4.83%, and cold-discomfort of 41.46%. Analysing the values during the summer season, the comfort percentage rises to 68.24%, the hot-discomfort reaches 5.14%, and the cold-discomfort reaches 26.62%. During winter, the comfort percentage is 47.55%, the hot-discomfort is 2.58% and the cold-discomfort is 49.86%.

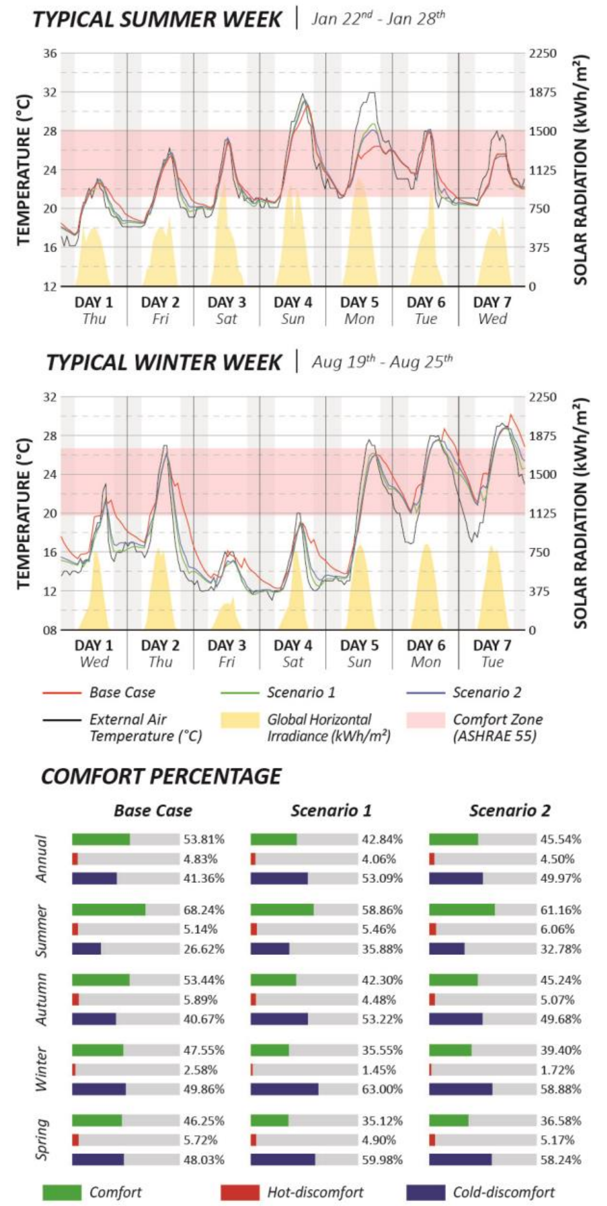
Scenario 1, with 100% of window aperture, presents an annual comfort percentage equivalent to 42.84%, while discomfort due to high temperatures reaches 4.06%, and 53.09% of discomfort due to lower temperatures. When the window aperture is reduced to 5%, the comfort percentage rises to 45.54%, the hot-discomfort also rises, reaching 4.50%, and the cold-discomfort drops to 49.97%. Seasonal comfort and discomfort percentages follow similar patterns to annual percentages and are detailed in Fig. 5.

On the hottest day of the typical summer week, the operative temperature of the BC Scenario exceeds 30 °C, about 1.7 °C lower compared to the external air temperature. For the other scenarios, the temperature peak reaches 31 °C, getting even closer to the outdoor temperature. The operative temperature peaks are even closer to the external ones on working days since the occupancy is higher and the internal gains are greater.

The results of the typical winter week for the BC Scenario, in which the windows are closed during the night and minimally open during the day, indicate that, even though it is a lightweight structure that heats up along with the elevation of the external air temperature, there is some internal heat load storage that causes the building to have a thermal delay during the cooling process.

The differences between the operative temperatures of Scenarios 1 and 2 are more noticeable during the early hours of the day, when there is no incidence of solar radiation. Thus, Scenario 1 presents lower temperatures as the heat losses are proportional to the size of the window aperture.

Figure 5:
Simulated thermal response of Hélio Olga House, showing operative temperatures for the living-room compared against external temperatures and global horizontal irradiance for typical weeks of summer and winter, followed by the comfort percentage per year and per season.



4.3. Vila Butantã Residential Complex, 1998

In this project, the main design drive was the adequacy of the semi-detached houses to the local topography, whilst for the building components, the material choice favoured thermal inertia, coupled with large openings to control ventilation and solar access, with movable external shading. As ventilation was evaluated in the previous case, two different forms of house implantation were studied: a detached house (Scenario 1) and a semi-detached house (Scenario 2), both with residences aligned. The results can be seen in Fig. 6.

The BC Scenario has an annual comfort percentage of 67.23%, while the percentages of hot-discomfort and cold-discomfort are 4.69% and 28.08%. Seasonally, the comfort percentage is 84.35% in the summer and 59.74% in the winter. Hot-discomfort reaches 4.77% and 2.45% during summer and winter seasons, respectively. Cold-discomfort during winter is considerably higher compared to summer (37,82% and 10,88%, respectively).

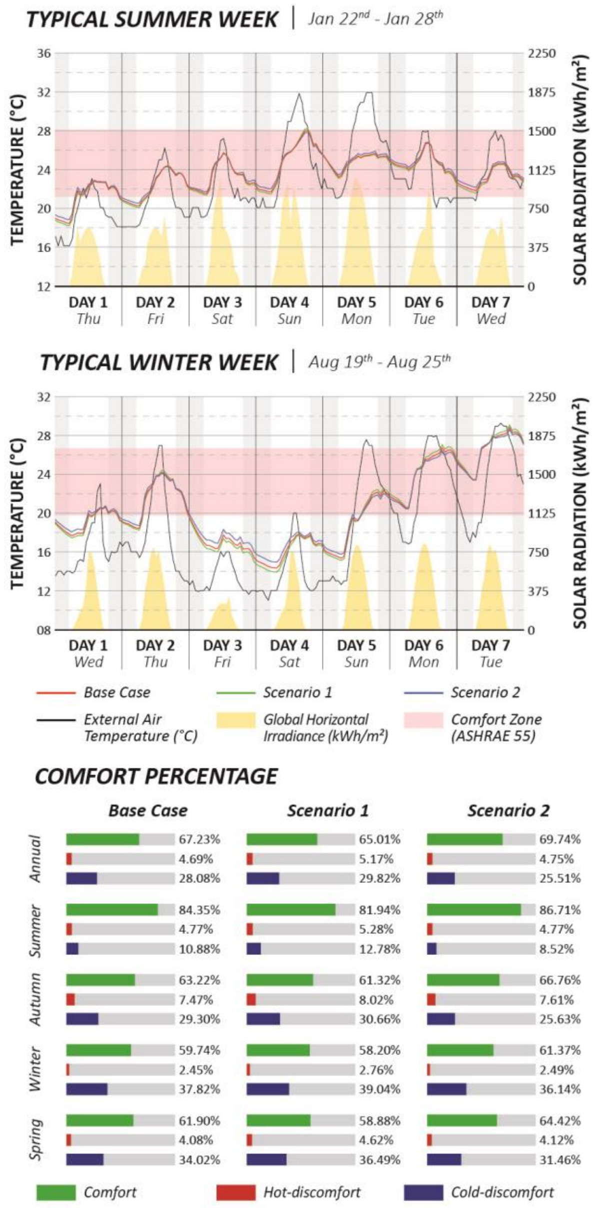
The detached residence (Scenario 1) presented greater discomfort for high and low temperatures (5.17% and 29.82%, respectively), resulting in a decrease in the percentage of comfort (65.01%). The same occurs with the pattern of seasonal results: during summer, the comfort percentage is 81.94%, the hot-discomfort is 5.28% and the cold one is 12.78%, while the comfort percentage reaches 58.20% during winter, the hot-discomfort is 2.76% and the cold one is 39.04%. This occurs due to the increase in the envelope exposure, favouring the indoor environment heating.

In the case of the aligned semi-detached homes (Scenario 2), the percentage of annual comfort rises 69.74%. Hot-discomfort (4.75%) is slightly higher compared to the BC Scenario, however it is lower compared to Scenario 1. Yet, the percentage of cold-discomfort is lower than the other two scenarios, registering 25.51%. Regarding the percentages related to summer, comfort is higher compared to the other scenarios and is equal to 86.71%. The hot-discomfort percentage is the same as in BC Scenario, while the cold-discomfort one is 8.52%. In winter, the percentage of comfort rises to 61.37%, cold-discomfort drops to 36.14% and the hot one is equivalent to 2.49%. Such variations are directly related to the increasing of solar access due to the two residences alignment.

The operative temperatures have very similar values in the three scenarios during the typical summer week, distancing more notably from each other during the early hours of the day. On warmer days, the operative temperatures can reach values of 28 °C, 4 °C below the external air temperature. However, there are few times when temperatures are not within the comfort zone, roughly occurring during milder dawns.

On cold winter days and with the windows minimally open, operative temperatures exceed 1.5 °C in relation to outdoor temperatures for the BC Scenario. For Scenario 1, the difference between the external and operative temperatures drops to 1 °C, while it is increased by approximately 2 °C in Scenario 2. Even with higher temperatures, none of the scenarios reaches the comfort zone on the coldest day.

Figure 6:
Simulated thermal response of Vila Butantã Residential Complex, showing operative temperatures for the living-room compared against external temperatures and global horizontal irradiance for typical weeks of summer and winter, followed by the comfort percentage per year and per season.



5. FINAL CONSIDERATIONS

The thermal quality in all of the three case-studies is satisfactory in the summer, with annual comfort percentages above 50%. Marlene Milan House and the Vila Butantã Residential Complex presented comfort rates above 80% during summer season. The lightweight components in Hélio Olga House, and the consequent low thermal inertia, led to lower comfort results in the warmer period, reaching 68.24%. Hot-discomfort in this specific house was also the highest one, with about 450 hours above the comfort zone. It is worth mentioning, however, that the predominant percentage of discomfort was due to low temperatures, during the early hours of summer days. Winter periods are more critical in the three residences, especially in the Milan and Olga Houses. Such scenarios could have better results if the fireplaces provided by the architect in the living-rooms, that weren't considered in the use and occupation schedules of simulations, were used. The presence of such element is not common to Brazilian culture, making remarkable the architect's understanding of São Paulo climate which, even with high temperatures during summer, demands spatial attention for cold periods. It is also worth noting that the adaptive comfort model is used in situations in which the occupant has a clothing insulation between 0.5 and 1.0 clo and the smallest increases in clothing could solve some scenarios of cold-discomfort. These results show, once more, that the correct understanding of the location conditions and the appropriate combination of multiple passive design strategies, on a case-by-case basis, are enough to guarantee the thermal quality in the architecture of residential buildings with bioclimatic features, reinforcing the results of fieldwork presented in the previous PLEA Conference [3].

ACKNOWLEDGEMENTS

Thanks to FAPESP (Process N° 2018/19902-8) for supporting this research project and to Marcos Acayaba for sharing his stories and knowledge.

REFERENCES

1. Filosofia de trabalho [Online], Available: http://marcosacayaba.arq.br/ [September 20th 2021].
2. Romero, M., (2012). Estratégias Bioclimáticas de Reabilitação Ambiental Adaptadas ao Projeto. Brasília: p. 3.
3. LIMA, E. G.; GONÇALVES, J.; MICHALSKI, R., (2020). Revealing the thermal quality of the modernism legacy's architecture: Marcos Acayaba's single-family houses in São Paulo. In: Proceedings of the 35th PLEA Conference, A Coruña, Spain.
4. Climate data. [Online], Available: http://climate.onebuilding.org [March 26th 2022].
5. AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR CONDITIONING (2017). ANSI/ASHRAE Standard 55-2013. Thermal environmental conditions for human occupancy.

WILL CITIES SURVIVE?

PLEA STGO 2022

November 22 - 25, 2022

ARCHITECTURE FOR HEALTH AND WELL-BEING

DAY 02
10:15 — 11:45

CHAIR
ISABEL RIVERA

PAPERS
1622 / 1515 / 1298 / 1642

19TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Engaging school facilities
A literature review

ALISON KWOK[1] MARK FRETZ[1] KEVIN VAN DEN WYMELENBERG[1] JOHN SEELY[2] MARIA C. CORONADO[1] JEAN LEE[2]

[1] University of Oregon – School of Architecture
[1] University of Oregon – Department of Special Education and Clinical Sciences

ABSTRACT: This paper encompasses a comprehensive literature review of existing literature to define key facility design elements of K–12 schools that impact student engagement and learning. The research was conducted in May–August 2021, summarizing existing peer-reviewed publications and reports that demonstrate the impacts of the built environment on students' performance. Approximately 500 international publications were discovered with direct relationships between learning and facilities, with relevance to key research topics, and were peer-reviewed. An annotated bibliography is developed with publication type, study type, sample size, study duration, and age or development stage. A white paper was developed in three categories: a) indoor environmental quality (thermal comfort, indoor air quality, lighting, view, acoustics); b) spatial environment (school maintenance and operation, school design, classroom organization); c) People/Community (social interaction, relationships, teaching/learning, belonging/safety/security, health and well-being). The white paper described the evidence in these three categories, analyzed their relationships, and presented key findings. A set of educational info sheets presented these findings in an accessible manner for the general public. The annotated bibliography, white paper, and educational info sheets produced from this project are of interest to legislature and state agencies for funding to renovate and construct new schools.

KEYWORDS: schools, literature review, indoor environmental quality, facilities, learning

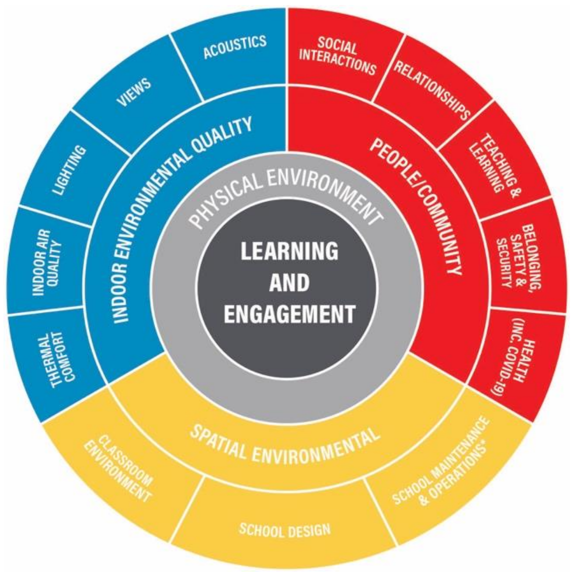
1. INTRODUCTION

As schools across the globe renovate or construct new facilities, there is a critical need to understand the key impacts of the built environment on children's learning, engagement, health and well-being. This study encompasses a comprehensive literature review of existing literature to define key facility design elements of K–12 schools that impact student engagement and learning. Research summarized existing peer-reviewed publications and reported the impacts of the built environment on student's performance and well-being. Approximately 500 international, peer-reviewed publications showed direct relationships between learning and facilities. An annotated bibliography, white paper, and a set of educational info sheets was disseminated in December 2021 through the NetZed Laboratory website at the University of Oregon.

2. LITERATURE REVIEW AND METHODOLOGY

The literature review initially drew upon more than 700 publications from architecture, science, and educational databases using a framework with learning and engagement at the center, enclosed by the physical environment and manifested by indoor environmental quality (IEQ), the spatial environment, and people/community (Fig. 1).

Figure 1:
Impacts on learning and engagement framework.



Publications included journal articles, dissertations, review, reports, case studies, field studies, books, and other literature reviews. The literature review further refined the selections to approximately 500 publications to form an annotated bibliography that includes: summary, publication type, study type, sample number, duration, and age or developmental stage.

This paper will describe selected (*) key findings in each of the three categories of the framework within subcategories: 1) IEQ: thermal comfort, indoor air quality*, lighting, views*, acoustics; 2) Physical: school maintenance and operation*, school design*, classroom organization; 3) People/Community: social interactions, relationships, teaching and learning, belonging/safety/security*, health and well-being.

3. FRAMEWORK OF FINDINGS

A selected number of key findings are described below in further detail under each category. A few are evidenced with references.

3.1 Indoor Environmental Quality (IEQ)

3.1.1 Indoor air quality (IAQ)

The existing literature agrees that IAQ has an effect on the health and performance of children in schools. Children encompass a vulnerable population when it comes to exposure to indoor pollutants as they may cause respiratory health symptoms and affect children with asthma (Chithra & Shiva Nagendra, 2018). Studies that used CO2 concentrations as a proxy to assess ventilation rates in schools consistently found that classrooms did not provide adequate ventilation rates to the students and did not comply with the existing standards, which creates the conditions for unhealthy indoor air quality (W. J. Fisk, 2017).

In addition, there is robust evidence that increased ventilation rates have a positive effect on student performance (Bakó-Biró et al., 2012; W. J. Fisk, 2017). These improvements have been assessed through test scores, specific tests on cognitive abilities or by measuring the speed at which students are able to finish certain tasks. Conversely, classrooms with lower ventilation rates have a negative effect on students' concentration and memory (Bakó-Biró et al., 2012; U. Haverinen-Shaughnessy et al., 2011; Nishihara et al., 2014).

Among the reviewed studies, only one directly related pollutants with student performance using longitudinal data. This study correlated air pollution data near schools from the EPA, with math and reading test scores using the Early Childhood Longitudinal Study (ECLS) from the National Center for Education Statistics. The study found suggestive evidence that poor IAQ in early childhood could affect school readiness, especially regarding pollen and ozone concentrations (Marcotte, 2017).

Further studies have looked at the relationship of IAQ with health, and its possible relationship with absenteeism. IAQ studies in schools have commonly used absenteeism as a proxy to assess student performance. Nonetheless, the relationship of absenteeism related to respiratory health effects and poor student performance, is not always consistent (U. Haverinen-Shaughnessy et al., 2012; Ulla Haverinen-Shaughnessy et al., 2015).

Additional environmental parameters are a promising area for the study of IAQ in schools. For example, among the reviewed studies, a few assessed the impact of reduced levels of relative humidity in the respiratory symptoms of children and teachers, others looked at its impacts on bacterial load, allergen, or influenza-A virus concentrations (Andualem et al., 2019; Angelon-Gaetz et al., 2016; William J Fisk et al., 2019; Reiman et al., 2018). These studies are directed towards relating IAQ with children's health, but how these environmental conditions influence student performance remains an open question.

In summation, the key findings of the review regarding IAQ are:

- Increased ventilation rates enhance student performance. Conversely, low ventilation rates hinder concentration and test performance.
- Pollutants and microbes in schools have been studied in relation to health but few studies have linked them directly with student performance.
- The relationship between IAQ, absenteeism, health, and performance need further study.

3.1.2 Views

A few studies have associated directly with student performance. For example, by comparing class scores in identical classrooms and classes with different view conditions, a study found significantly better final scores and class perceptions in undergraduate sections of a class with a view of an open grassy area, than those that overlooked a retaining wall (Benfield et al., 2015). Similarly, a year-long longitudinal study in elementary schools qualitatively describing window conditions found that good quality views were associated with better student learning in math and reading (Aumann et al., 2004).

Views of nature have been found to help direct attention and help students recover from stressful situations through physiological markers, attention span tests and self-reports. A randomized controlled experiment with high school students using three different window conditions (no window, good view, natural view), found that natural views helped students recover faster from stressful situations (Li & Sullivan, 2016). Therefore, the literature suggests that views, and particularly views of nature are beneficial for student wellbeing and performance.

The key findings of the review concerning views are:

- Views of nature decrease stress and increase student performance.
- A good view out of windows is significantly associated with better student learning.

3.2 Spatial Environment

3.2.1 School maintenance and operation

Building conditions have been associated with student performance, mediated by school climate. The reviewed research suggests that the way the school community perceives the building, as well as the social interactions the building allows for affect student performance (Maxwell, 2016).

Schools with most disrepair have been associated with high levels of absenteeism (Eitland, 2020) and lower academic performance (Berman et al., 2018; Chan, 1996) . Similarly, schools with low structural quality and high student mobility have been associated with lower student performance (Evans et al., 2010). In most studies, schools with more disrepair belong to communities of lower socioeconomic status (SES), minority or disadvantages students (Simons et al., 2010). Nonetheless, a few of them have controlled for SES and found that attendance was a mediator between building condition and academic performance (Durán-Narucki, 2008).

A few studies have compared green schools with traditional schools. The reviewed studies did not find any direct associations between energy efficient or LEED buildings and student performance. Nonetheless, one found a relationship between thermal and visual comfort with student performance (Apriesnig et al., 2020). This lack of association may be caused by the fact that certification towards energy efficient buildings may not always pursue health and performance goals (Eitland, 2020). Therefore, future studies could study schools that specifically pursue these objectives during their operation.

With the Covid-19 pandemic, the maintenance of ventilation systems became one of the most salient topics for school buildings. Nonetheless, before the pandemic, studies had looked into the maintenance and operation of ventilation systems in classrooms. The inclusion of mechanical means or sensors to regulate ventilation in classrooms is an alternative to provide adequate ventilation (W. J. Fisk, 2017). In addition, other parameters, such as relative humidity need control too. Extremely high levels may predispose the environment for the appearance of mould, and very low levels may cause respiratory, ocular or skin health effects (Wolkoff, 2018). Both situations were found in the reviewed literature, supporting the idea that schools need to maintain ventilation systems in schools and constantly monitor IEQ.

Some studies have calculated the cost of improving the ventilation systems of schools to provide ventilation rates that comply to the standard. Studies form the US and Europe argue that the cost of improving the ventilation rates doesn't compare in monetary value to the educational and societal benefits that this might produce (W. J. Fisk, 2017; Gehrt et al., 2019; Mendell et al., 2013). In fact, in a study from California, Fisk (2017) argued that doing this would constitute less than 0.1% of the public education spending in the US (W. J. Fisk, 2017).

As of February 2022, there is robust evidence supporting that ventilation and filtration play key in the prevention of the transmission of Covid-19. Multiple organizations have released documents with guidance on ways to improve ventilation and implement complementary measures to maintain healthy indoor environments. It is likely that with the Covid-19 pandemic, the health benefits, and related reduced medical costs of improving the ventilation systems in schools are even larger now.

The main findings on school maintenance and operations are:

- Ventilation investments are a cost-effective and long-lasting measure to prevent COVID-19 and can increase student performance.
- Building disrepair has been associated with student performance and absenteeism.
- Green schools haven't been directly associated with increased student performance, but their enhanced IEQ, relation to nature and energy efficiency are beneficial for students

3.2.2 School design

School and classroom size, as well as classroom density are among the key items for school design, and literature has investigated how they affect student well-being. The reviewed literature agrees that schools that provide opportunities to create small communities generates a greater sense of ownership (Hand, 2014). This is beneficial for students as it creates the possibility for developing relationships that are beneficial for learning, as well as more personalized instruction (Woolner et al., 2012). In a similar vein, a few studies have advocated for more flexible learning spaces. Flexibility may deemphasize the hierarchical nature of the classroom, and open possibilities of increased collaboration, teamwork and interaction with the school community. In addition, design flexibility provides opportunities for different classroom activities, such as group work and eating together (Deed & Lesko, 2015; Wu et al., 2020). Nonetheless, increased openness in the classroom can hinder the acoustics and control that teachers have over the classroom.

Specific to spatial design, studies found that different spaces in the school need to possess different environmental qualities. For example, classrooms need to provide adequate spaces for learning, while other areas of the school such as libraries, commons and atriums do not have such high requirements and benefit from providing spaces for socialization that improve engagement (Maxwell & French, 2016).

School grounds, outdoor spaces and green areas are very important for student health and positively impact learning. For example, a study found that tree cover and green spaces were predictors of student performance (Sivarajah et al., 2018). Similarly, outdoor learning has proven beneficial to increase attention and engagement in low performing students (Kuo et al., 2019).

A number of studies using self-reports have found that being in nature helped students' release stress and learn in a more satisfactory nature (Kuo et al., 2019). Indeed, the literature suggests that outdoor classrooms have valuable qualities for student learning, as they allow for play and the advancement of sensory and motor skills, as well as physical and cognitive development (Nel et al., 2017).

The key findings on school design from this review are:

- Schools' outdoor green space has a significant positive impact on health, learning and academic achievement.
- Schools should be flexible and accommodate for a variety of situations and activities social/private, noisy/quiet.

3.3 People and Community

3.3.1 Belonging, Safety, and Security:

The school building, school grounds and the neighborhood play a key role in the feelings of safety of students. Safety starts on the way to school, so areas that provide spaces to play, exercise and gather, can help neighbourhoods feel more like a community, and improve the sense of safety and belonging of children.

Similarly, building and grounds safety and security are important in case of natural disasters, terrorist attacks, internal violence, or other emergencies. In the reviewed literature, visible security measures, such as security cameras, were found to have mixed effects. Indoor cameras decreased students' feelings of safety, while outdoor cameras only generated a moderate sense of safety. In addition, cameras produced higher perceptions of safety in white students than black students, showing that these measures may not be perceived equally by all student communities (Lindstrom Johnson et al., 2018).

Other alternatives such as Crime Prevention Through Environmental Design (CPTED) have shown to generate better results as they can involve safety strategies through spatial design including access control, territoriality/maintenance, and natural surveillance. These strategies have been found to bring psychological comfort to the students and reduce their security concerns (Lamoreaux & Sulkowski, 2020).

Schools help students create social networks, which creates a sense of belonging. Belonging is important, as it impacts youth's cognitive functioning, academic outcomes, and multiple social emotional aspects. Overall, the literature shows that feelings of inclusion can have an impact in the well-being and life trajectory of students.

The key findings regarding belonging, safety and security are:

- Safety and security encompass the environmental and spatial visual cues from departure from the home, on the way to school and on school grounds and the physical building.
- Students who feel a sense of ownership and belonging to the school and community have social and academic success as well as long term trajectories of individual well-being and contributions to society.
- Familiarity with the physical layout and uses of school buildings encourages activity that contribute to the feeling of community and pride in the school, also yielding a sense of security during emergencies.

4. GAPS AND FUTURE RESEARCH

This literature review covered multiple ways in which the physical environment of school facilities affects learning and engagement. Regarding the selected key findings described in this paper, future directions of research include expanding the existing research developed on pollutants and microbes in schools and their associations with health and performance. In addition, research investigating school maintenance and its association with performance could be expanded to include calculations of COVID-19 prevention and its positive effects on student health and reduced absenteeism. Similarly, studies looking at green buildings focusing on health and wellness could investigate possible relationships with student performance, as the reviewed studies were not able to identify a relationship, given the unknown nature of the credits green schools pursued. Finally, studies expanding work on crime prevention through environmental design (CPTED) could validate the findings of existing studies.

The literature review showed that most studies investigated only one or two aspects of the built environment, given the difficulty, and overlapping effects of studying multiple parameters. Future research could investigate multiple issues at a time, to account for the multidimensional influences that occur in the learning process. In addition, the reviewed studies come from multiple disciplines, and therefore use a multiplicity of theoretical and research approaches, which do not allow for easy comparison. A consistency of measures and metrics regarding health, performance and their relations with the environmental parameters are needed. Finally, there is a need for interdisciplinary research, as studies are settled on their research niches, and they usually do not involve all the actors that interplay in the school environment.

5. CONCLUSIONS

Many of the key findings mentioned here are generalized. Yet to make comparisons, larger studies need to be made that contrast parameters across age groups, programs, sample sizes, seasons, socio-economic groups, and take into account cultural norms.

The deliverables of the project include the annotated bibliography, white paper report, and info sheets that were publicly disseminated in November 2021, and are currently available on the NetZED Laboratory website:

https://netzedlab.uoregon.edu/research/

ACKNOWLEDGEMENTS

The authors acknowledge funding and collaboration for this project from California School Facilities Research Institute. The authors deeply appreciate the database work student research assistants in the NetZED Laboratory at the University of Oregon: Stephen Feinberg, Alexandra Gottlin, Natalie Pfeiffer, Riley Greenheck, and Natasha Steeves.

REFERENCES

Andualem, Z., Gizaw, Z., Bogale, L., & Dagne, H. (2019). Indoor bacterial load and its correlation to physical indoor air quality parameters in public primary schools. Multidisciplinary Respiratory Medicine, 14(1), 1–7. https://doi.org/10.1186/s40248-018-0167-y

Angelon-Gaetz, K. A., Richardson, D. B., Marshall, S. W., & Hernandez, M. L. (2016). Exploration of the effects of classroom humidity levels on teachers' respiratory symptoms. International Archives of Occupational and Environmental Health, 89(5), 729–737. https://doi.org/10.1007/s00420-016-1111-0

Apriesnig, J. L., Manning, D. T., Suter, J. F., Magzamen, S., & Cross, J. E. (2020). Academic stars and Energy Stars, an assessment of student academic achievement and school building energy efficiency. Energy Policy, 147(January), 111859. https://doi.org/10.1016/j.enpol.2020.111859

Aumann, D., Heschong, L., Wright, R., & Peet, R. (2004). Windows and Classrooms: Student Performance and the Indoor Environment. HMG.

Bakó-Biró, Z., Clements-Croome, D. J., Kochhar, N., Awbi, H. B., & Williams, M. J. (2012). Ventilation rates in schools and pupils' performance. Building and Environment, 48(1), 215–223. https://doi.org/10.1016/j.buildenv.2011.08.018

Benfield, J. A., Rainbolt, G. N., Bell, P. A., & Donovan, G. H. (2015). Classrooms With Nature Views: Evidence of Differing Student Perceptions and Behaviors. Environment and Behavior, 47(2), 140–157. https://doi.org/10.1177/0013916513499583

Berman, J. D., McCormack, M. C., Koehler, K. A., Connolly, F., Clemons-Erby, D., Davis, M. F., Gummerson, C., Leaf, P. J., Jones, T. D., & Curriero, F. C. (2018). School environmental conditions and links to academic performance and absenteeism in urban, mid-Atlantic public schools. International Journal of Hygiene and Environmental Health, 221(5), 800–808. https://doi.org/10.1016/j.ijheh.2018.04.015

Chan, T. C. (1996). Environmental Impact on Student Learning. https://files.eric.ed.gov/fulltext/ED406722.pdf

Chithra, V. S., & Shiva Nagendra, S. M. (2018). A review of scientific evidence on indoor air of school building: Pollutants, sources, health effects and management. In Asian Journal of Atmospheric Environment (Vol. 12, Issue 2, pp. 87–108). Korean Society for Atmospheric Environment. https://doi.org/10.5572/ajae.2018.12.2.87

Deed, C., & Lesko, T. (2015). 'Unwalling' the classroom: teacher reaction and adaptation. Learning Environments Research, 18(2), 217–231. https://doi.org/10.1007/s10984-015-9181-6

Durán-Narucki, V. (2008). School building condition, school attendance, and academic achievement in New York City public schools: A mediation model. Journal of Environmental Psychology, 28(3), 278–286. https://doi.org/10.1016/j.jenvp.2008.02.008

Eitland, E. S. (2020). The Assessment of Building Interventions on Student Health. ProQuest Dissertations and Theses, 112.

https://search.proquest.com/dissertations-theses/assessment-building-interventions-on-student/docview/2459429706/se-2?accountid=41849

Evans, G. W., Yoo, M. J., & Sipple, J. (2010). The ecological context of student achievement: School building quality effects are exacerbated by high levels of student mobility. Journal of Environmental Psychology, 30(2), 239–244. https://doi.org/10.1016/j.jenvp.2010.01.001

Fisk, W. J. (2017). The ventilation problem in schools: literature review. Indoor Air, 27(6), 1039–1051. https://doi.org/10.1111/ina.12403

Fisk, William J, Chan, W. R., & Johnson, A. L. (2019). Does dampness and mold in schools affect health? Results of a meta-analysis. Indoor Air, 29(6), 895–902. https://doi.org/10.1111/ina.12588

Gehrt, D., Hafner, M., Hocking, L., Gkousis, E., Smith, P., & Pollard, J. (2019). Poor indoor climate, its impact on child health, and the wider societal costs. www.rand.org/giving/contribute

Hand, K. (2014). The Relationship Between the Physical Classroom Environment and the Academic Functioning of School Age Males and Females A doctoral project submitted to the faculty of the Shirley Mount Hufstedler School of E. February.

Haverinen-Shaughnessy, U., Moschandreas, D. J., & Shaughnessy, R. J. (2011). Association between substandard classroom ventilation rates and students' academic achievement. Indoor Air, 21(2), 121–131. https://doi.org/10.1111/j.1600-0668.2010.00686.x

Haverinen-Shaughnessy, U., Turunen, M., Metsämuuronen, J., Palonen, J., Putus, T., Kurnitski, J., & Shaughnessy, R. J. (2012). Sixth Grade Pupils ' Health and Performance and Indoor Environmental Quality in Finnish School Buildings. British Journal of Educational Research, 2(1), 42–58.

Haverinen-Shaughnessy, Ulla, Shaughnessy, R. J., Cole, E. C., Toyinbo, O., & Moschandreas, D. J. (2015). An assessment of indoor environmental quality in schools and its association with health and performance. Building and Environment, 93(P1), 35–40. https://doi.org/10.1016/j.buildenv.2015.03.006

Kuo, M., Barnes, M., & Jordan, C. (2019). Do experiences with nature promote learning? Converging evidence of a cause-and-effect relationship. Frontiers in Psychology, 10(FEB). https://doi.org/10.3389/fpsyg.2019.00305

Lamoreaux, D., & Sulkowski, M. L. (2020). An alternative to fortified schools: Using crime prevention through environmental design (CPTED) to balance student safety and psychological well-being. Psychology in the Schools, 57(1), 152–165. https://doi.org/10.1002/pits.22301

Li, D., & Sullivan, W. C. (2016). Impact of views to school landscapes on recovery from stress and mental fatigue. Landscape and Urban Planning, 148, 149–158. https://doi.org/10.1016/j.landurbplan.2015.12.015

Lindstrom Johnson, S., Bottiani, J., Waasdorp, T. E., & Bradshaw, C. P. (2018). Surveillance or Safekeeping? How School Security Officer and Camera Presence Influence Students' Perceptions of Safety, Equity, and Support. Journal of Adolescent Health, 63(6), 732–738. https://doi.org/10.1016/j.jadohealth.2018.06.008

Marcotte, D. E. (2017). Something in the air? Air quality and children's educational outcomes. Economics of Education Review, 56, 141–151. https://doi.org/10.1016/j.econedurev.2016.12.003

Maxwell, L. E. (2016). School building condition, social climate, student attendance and academic achievement: A mediation model. Journal of Environmental Psychology, 46, 206–216. https://doi.org/10.1016/j.jenvp.2016.04.009

Maxwell, L. E., & French, R. (2016). Elementary School Library Design: Student Perceptions of a Learning Commons. Children, Youth and Environments, 26(2), 61. https://doi.org/10.7721/chilyoutenvi.26.2.0061

Mendell, M. J., Eliseeva, E. A., Davies, M. M., Spears, M., Lobscheid, A., Fisk, W. J., & Apte, M. G. (2013). Association of classroom ventilation with reduced illness absence: A prospective study in California elementary schools. Indoor Air, 23(6), 515–528. https://doi.org/10.1111/ina.12042

Nel, A., Joubert, I., & Hartell, C. (2017). Teachers' perceptions on the design and use of an outdoor learning environment for sensory and motor stimulation. South African Journal of Childhood Education, 7(1), 11. https://doi.org/10.4102/sajce.v7i1.482

Nishihara, N., Wargocki, P., & Tanabe, S. ichi. (2014). Cerebral blood flow, fatigue, mental effort, and task performance in offices with two different pollution loads. Building and Environment, 71, 153–164. https://doi.org/10.1016/j.buildenv.2013.09.018

Reiman, J. M., Das, B., Sindberg, G. M., Urban, M. D., Hammerlund, M. E. M., Lee, H. B., Spring, K. M., Lyman-Gingerich, J., Generous, A. R., Koep, T. H., Ewing, K., Lilja, P., Enders, F. T., Ekker, S. C., Huskins, W. C., Fadel, H. J., & Pierret, C. (2018). Humidity as a non-pharmaceutical intervention for influenza A. PLoS ONE, 13(9). https://doi.org/10.1371/journal.pone.0204337

Simons, E., Hwang, S. A., Fitzgerald, E. F., Kielb, C., & Lin, S. (2010). The impact of school building conditions on student absenteeism in upstate New York. American Journal of Public Health, 100(9), 1679–1686. https://doi.org/10.2105/AJPH.2009.165324

Sivarajah, S., Smith, S. M., & Thomas, S. C. (2018). Tree cover and species composition effects on academic performance of primary school students. PLoS ONE, 13(2), 1–11. https://doi.org/10.1371/journal.pone.0193254

Wolkoff, P. (2018). Indoor air humidity, air quality, and health – An overview. In International Journal of Hygiene and Environmental Health (Vol. 221, Issue 3, pp. 376–390). Elsevier GmbH. https://doi.org/10.1016/j.ijheh.2018.01.015

Woolner, P., Clark, J., Laing, K., Thomas, U., & Tiplady, L. (2012). Changing Spaces: Preparing Students and Teachers for a New Learning Environment. Children, Youth and Environments, 22(1), 52. https://doi.org/10.7721/chilyoutenvi.22.1.0052

Wu, X., Oldfield, P., & Heath, T. (2020). Spatial openness and student activities in an atrium: A parametric evaluation of a social informal learning environment. Building and Environment, 182(February), 107141. https://doi.org/10.1016/j.buildenv.2020.107141

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

PLEA SANTIAGO 2022
Will Cities Survive?

Thermal performance in educational environments from the consideration of climate change in Medellín, Colombia

CAROLINA PATIÑO VÁSQUEZ[1] DAVID PALACIO ZAPATA[1]

[1] National University of Colombia, Faculty of Architecture, EMAT group.

ABSTRACT: Educational spaces should not consider climate as a factor that disturbs the development of activities and the quality of life of occupants. However, actions applied to reduce the high levels of discomfort, caused by an increase in interior temperature, lead to progressive infrastructural changes and overreliance on air conditioning installations. For this research, the current and future conditions of thermal comfort in the classrooms were evaluated, predicting climate change for the year 2050. The implemented methodology is based on computerized simulations from a predictive thermal comfort model, obtained from the modification of the city climate file, that afford the information to analyse the climate chance since three comparative viewpoints. The obtained results from the 4 classrooms studied show an approximate increase of 11,1% in discomfort for the year 2050, in which internal temperatures will be found for longer periods of time in temperature ranges between 25°C and 31°C, due partly to an increase in outdoors temperature, which results in an increase of approximately 3°C in a period of 30 years.
KEYWORDS: Climate Change - predictability - Thermal Comfort.

1. INTRODUCTION

Promote healthy environments, that guarantees a good quality of life and the full development of activities, has become in an impending necessity, especially in the educational sector [1]. However, in the "Universidad Nacional de Colombia, Sede Medellín", there has been a progressive increase in thermal discomfort by the users, partly due for an unsuitable relationship between activity – space, the increase in campus occupancy and a progressive impact of the climate change in the educational infrastructure [2]. Due to it, these circumstances have led to progressive infrastructural changes and air conditioning installations which help in reducing the thermal discomfort; nonetheless those actions that at first seems to be a solution, are insufficient in a medium and long term because they exclude things like: high energy-economic cost, the health consequences by the use of artificial cooling [3-4], and the city weather context.

Regarding climate change, that worsens the thermal indoor discomfort, a research [5] in Medellin city established that in a fifty years, the city would experience 0.8°C increase in the average temperature, 1.3°C in the minimum temperature, 0.5°C in the maxim temperature and a relative decrease in the humidity of 2.3%, Furthermore it is expected that in the decades of 2030-2040 and 2040-2050, there will be an increase of 0.5 °C in the hottest hours of the diurnal cycle and for the last decade mentioned, the amount of days that will exceed the threshold of 29 °C will be 150 [6].

Owing to this scenario, it is essential to quantify the thermal discomfort in the university [7] having into account the climate change, for this it is expected that the progressive increase in temperature due to climate change have a direct impact in the energy demand of the building and the user comfort, estimating that the educational spaces conditions will be more challenging due to the occupant high density and the sensibility of them to the heat [8]. Consistent to this, evaluate the incidence of climate change in educational spaces is the object of this investigation. This is the reason why the importance of this research lies in the fact that, based on data obtained in the simulations, it is possible to take, as an analysis methodology, from two time points (2020-2050), the ways how climate change can be analysed: evaluating the direct impact of the temperature in the infrastructure, the user's thermal comfort in relation with the comfort standard chosen and the relation between indoor and outdoor temperature of the building. [9]

2. METHODOLOGY

In the first stage, the methodological process focuses on the study of a representative building located on the university campus of the National University of Colombia in Medellin. The building mentioned before is the 24, where four classrooms located entirely on the fourth level were selected: Classrooms 402 and 411, with east west orientation, where theorical activities are carried out and Classrooms 406 and 418, with north south orientation, where theorical and practical activities are realized. (Practical and theoretical).

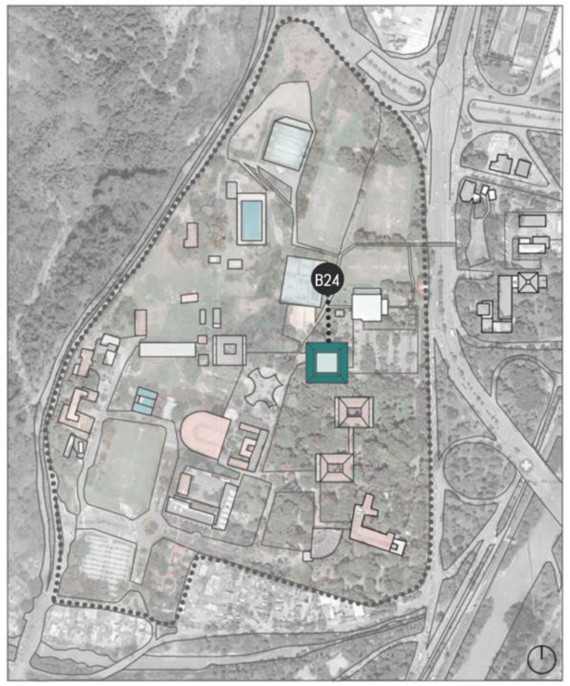


***Figure 1:** Location of the study building within the university campus.*

From the study case selection, parametric simulations were carried out in order to evaluate the thermal performance of 2019, which allowed to know the environmental situation on the classrooms during the mentioned year.

Afterwards, the weather file of the city is modified based on the morphing method [10] to 2050, using the CCWorldWeatherGen tool from the UK Met Office Hadley Center Coupled Model 3 HadCM3 with the aim of simulating the future thermal conditions, obtaining from this an approximation of a future comfort standard.

The pertinent results of thermal simulations were studied from three analysis variables: (1) using the adaptive comfort of 2019 and leaving the static comfort zone, (2) taking the adaptive comfort calculated with the outdoor temperature taking into account climate change and (3) leaving the comfort zone for study the relation between the inside and outside temperature.

2.1 Selection criteria

For the building selection in the university campus was important to choose a representative physical characteristic such as materiality and dimension. On the other hand, it was sought that the classrooms, as well as the classes, had the greatest variety of differentiating cases with the purpose of observing the behavior of particular present situations and the predictive study of the thermal comfort. The floor level was chosen based on the analysis of the floor that had the largest number of classrooms and scheduled classes.

Regarding to the choice of the classrooms, there was three global variables for the selection:

A. Orientation with respect to the cardinal points: a classroom was selected for each orientation (one classroom with south orientation, one north, west and east.
B. External conditions that affect the ventilation: obstruction or ease Trees, neighboring buildings and the level position of the chosen building.
C. The typologies of the classroom and specific necessities, for which two mixed classrooms and two theoretical classrooms were selected.

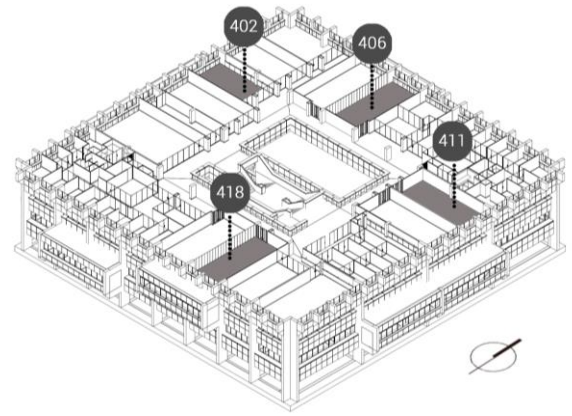


***Figure 2:** Selected classrooms in the building.*

2.2 Tools

For the parametric simulation of the spaces, the OpenStudio tool [11] was used through the Grasshopper software [12], which is an interface for graphical programming within Rhino 3D.

2.3 Metrics

The analysis of the results obtained by the parametric simulations were determined by the adaptive comfort model [13]. For the graphic understanding of this model, the adaptive comfort chart was used [14].

2.4 Simulation

A review of the annual hour by hour of thermal behavior for the year 2019 and 2050 and 2050 was used from the climatic archive of Medellín [15].

The classroom modelling was done independently as a thermal zone, the characteristics and implementations of the thermal simulated models are over served in the table (1) as in the figure (4).

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

SIMULATION PARAMETERS BY CLASSROOM			
CLASSROOM	ORIENTATION	TYPE OF CLASS	OCCUPANCY
Classroom 24 - 402	West - East	Theorical - 2W/m²	0.6ppl/m²
Classroom 24 - 406	North - South	Mixed - 6W/m²	0.62ppl/m²
Classroom 24 - 411	East - West	Theorical - 2W/m²	0.62ppl/m²
Classroom 24 - 418	South - North	Mixed - 6W/m²	0.4ppl/m²

SIMULATION PARAMETERS BY CLASSROOM		
	Surface	Description
OPAQUE SURFACES	Exterior walls	Solar absorptance : 0.7
		R value : 1.5W/m.K
		Rough
	Dividing walls	Adiabatics
	Ceiling	Layer 1.
		R value: 4.5W/m.K
		Layer 2.
		R value: 0.6W/m.K
		Layer 3.
		R value: 0.03W/m.K
	Mezzannine	Adiabatic
	Context	Neighboring classrooms
		Aleros (interior - exterior)
		Sun shades
TRANSLUCENT SURFACES	Facade window	U value: 5.8W/m²
		SHGC: 0.9
		Transmittance: 0.8

Table 1: *Parameters used in the space simulation.*

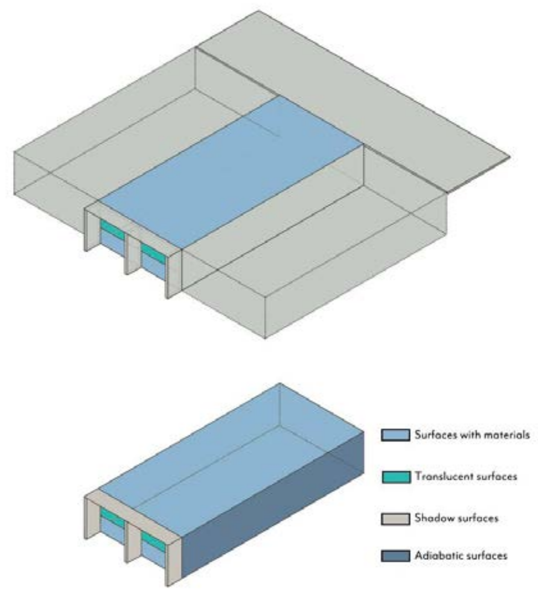


Figure 4: *Simulation parameters representation.*

2.5 Analysis criteria

1) Static comfort method: Analysis criterion that allows to see the general increase in temperature, as well as studying the deterioration range of each individual classroom. (Adaptation of infrastructure to climate change).

2) The adaptive comfort with climate change method: The comfort zone is recalculated taking into account the adaptive comfort zone for the present with the climate context of the city and taking the comfort zone for the future. Therefore, the dry bulb temperature for the year 2019 and 2050 (the entire range of annual hours) was taken from the climatic file and the formula for natural ventilation of ASHRAE 55 [13] was applied.

- To find the comfort temperature the equation 1 was used.

$$Tn = 17.8+(0.31*Tm)$$

Tn: Neutral temperature **Tm:** Average temperature

- Equations 2 and 3 were used to find the comfort temperature limits:

$$\textbf{Lim max}.\ Zc=Tn + 2.5°c$$

$$\textbf{Lim min}.\ Zc=Tn - 2.5°c$$

Zn = Comfort zone

3) Relation between interior and exterior method (RIE): This analysis criterion allows to see the relationship between the building and the exterior environment.

3. RESULTS

1) For this first criterion (Static Comfort Method), the individual behavior of each classroom is taken into account. The best performing classroom regarding the quantity of higher temperatures in both annual ranges, is the classroom 411 of theorical use, which has a total percentage of 33.7% of high temperatures in 2019, with an increase of 36,5% to 2050, and although it has the highest amount of variation in the total number of classrooms, it is still the classroom with the fewest number of hours by the year 2050, with 66,2% according to this comparison. On the other hand, the classroom with the worst results in respect to the number of high temperatures is the classroom 406 of mixed use, with a time of 44.8% of high temperatures in the present and 83,1% by 2050. According to the results, it is possible to consider that the type of activity inside the spaces directly influences, in this specific case, the thermal behavior.

Average Indoor temperature

Classroom	402	406	411	418
2019	24.5°C	24.6°C	24.6°C	24.5°C
2050	25.6°C	25.6°C	25.2°C	25.6°C

Average percent of hot hours

2019	44.8%	44.8%	33.7%	43.8%
2050	81.3%	83.1%	72.1%	81.8%
Variation	36.5%	38.3%	38.4%	37.5%

Table 2: *Average indoor temperature and general increase in discomfort, based on the static comfort method.*

2) The average percentage of thermal discomfort in the simulated classrooms for the year 2019 was 46,6% of the time; the differences between classrooms in regard to the least amount of time in discomfort and the longest amount had a difference of 11.1 % which equates to 796 hours. In 2050, the percentage of discomfort will be of 56% meaning that, in a period of 31 years, there will be a percentage increase in discomfort by approximately 10%.

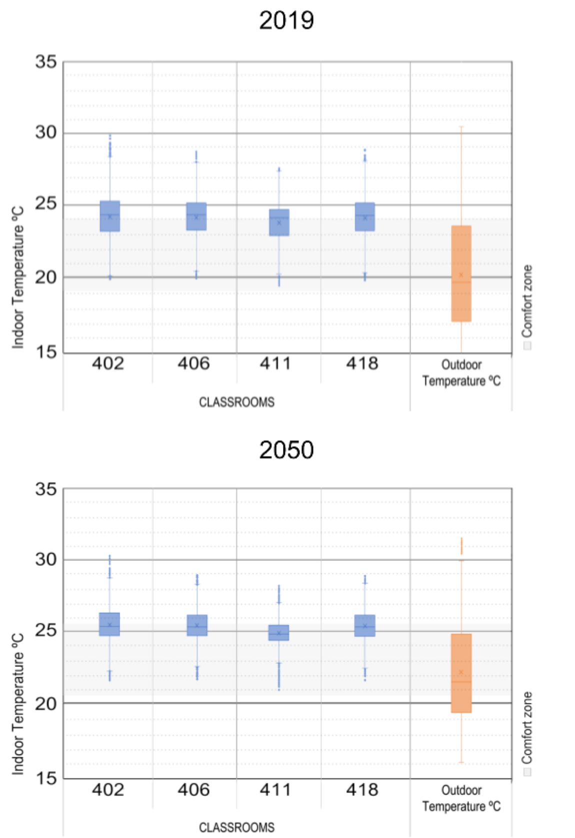
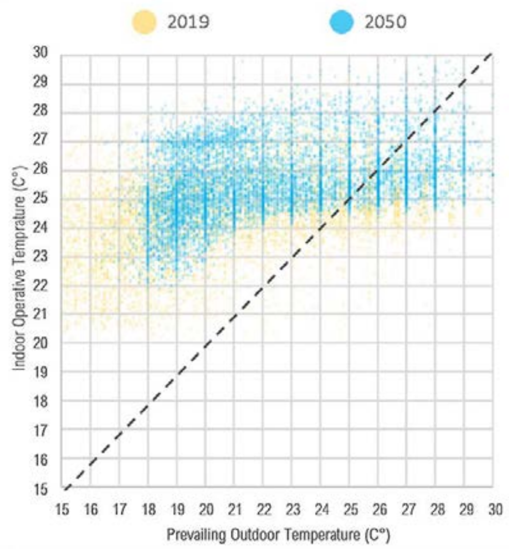


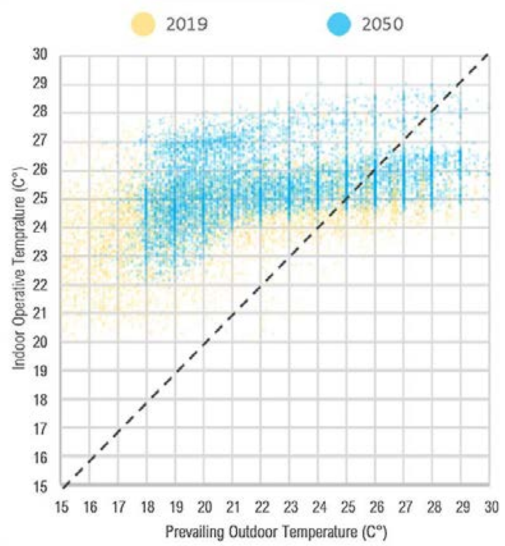
Figure 6: *Annual interior-exterior thermal results per classroom, based on taking the adaptive comfort into account climate change method.*

3) The obtained results show a generalized increase in the outside temperature by the year 2050 where the hourly temperatures exceed the resulting minimum thresholds for 2019 by 3°C, namely, in 2019, the registered minimums temperatures are in a range of 15°c to 18°C, for 2050, the minimum temperatures will be between 18°C and 21°C. Something similar happens on the interior temperatures, where there is an increase of 2°C in the minimum temperatures between the two study years: in for 2019 the average minimum temperature is 20°C, by 2050 it will be in 22°C. Despite this, there are no hours, in both indoor and outdoor temperatures that exceed the threshold of 30°C in both periods analyzed; what is identified is an increase of the quantity of hours that are between 26°C and 29°C by the year 2050. When comparing both temperatures, the one that both presents the highest amount of hours in high temperatures and gets closer to the threshold of 30°C is the exterior temperature, which shows an approximate difference of 1°C between the two highest temperatures in 2050. At the same time, it is demonstrated with this method that, generally, the best time periods where in the morning and in a small portion of hours during the night while, on the contrary, the worst hours are between noon and afternoon hours.

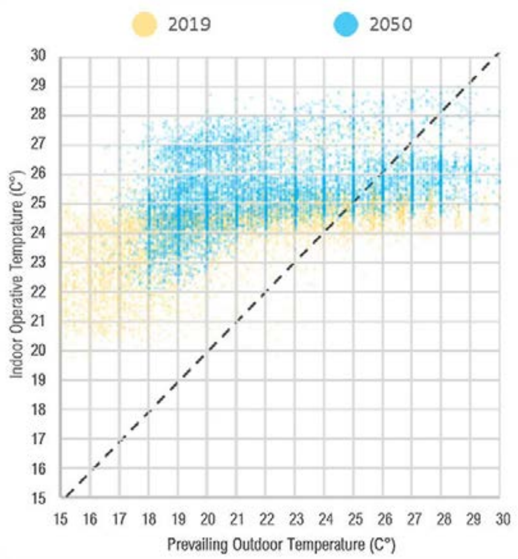
Classroom 402



Classroom 406



Classroom 411



Classroom 418

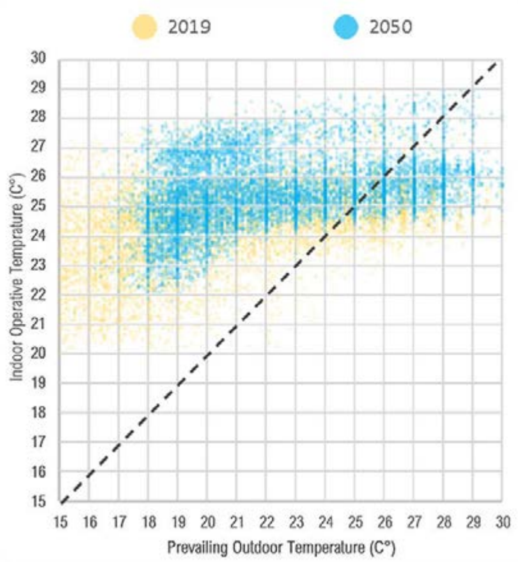


Figure 7: *Annual range 2019 and 2050, difference interior-exterior, classrooms 402, 406, 411 and 418. Based on Relation between interior and exterior method.*

4. DISCUSSIONS

(Belcher & Hacker, 2005) Use present meteorological data and transform it to portray the changes in degrees (day) caused by climate change. [11]. Their research on seasonal climates, showed that, in a period of analysis from 1989 to 2080 (91 years there will be an approximate increase of 6°C during summer, and an increase of 2 to 3°C during winter. Nevertheless, currently thermal analyzes are still being carried out with current climate files for future climate scenarios, which in reality are not current and sometimes come from historical sources that do not agree with present natural phenomena. This method can reach conclusive results, but sometimes can be inaccurate to the current and future situation.

In this same order of ideas, according to Medellin's climate action plan [4], it is predicted that between the decades of 2030-2040 and 2040-2050 the number of days that will exceed the threshold of 29 °C will be 150 days per year, however, our investigation did not find values above 29°C in our projection, even though the increase in exterior temperature is most prevalent in values that were originally in the range of 26°C to 28°C. This is due to the way an EPW file is built, which configures its data based on representative averages, removing extreme data points. In this sense, it is necessary to identify tools to carry out climate analyses focused on extremes, not on averages. However, the analysis based on the average manages to identify that there is a general increase in annual high temperatures; as well as the way (Restrepo – Betancur) [5] describes it, where Medellin will have an increase of 0.5 °C in the hottest hours of the diurnal cycle.

On the other hand, considering the three analysis criteria for climate change used in this pilot study, it is found that in the case of analysis criteria 1 (S.C.M.), there is a thermal worsening by 31% on average. With respect to criterion 2 (Ad.C.), there is an increase in discomfort by 10%; and criterion 3 (RIE) registers an increase by 90% of its worsening rate in a period of 31 years.

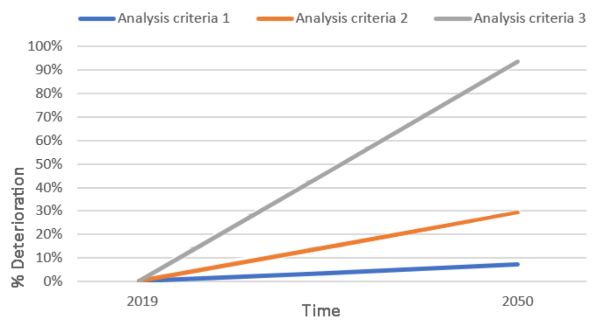


Figure 8: *Comparison of the percentage of worsening for the year 2050 of the three criteria analyzed.*

In the same lines, it is evident how in this case study, the analysis criteria 3 (RIE) is the most representative criterion. As shown in figure (9), on some occasions there is a difference of 5°C between interior and exterior temperature on an average day in the year 2050, which is an important difference considering that it is a tropical climate.

Classroom 418 – 2050

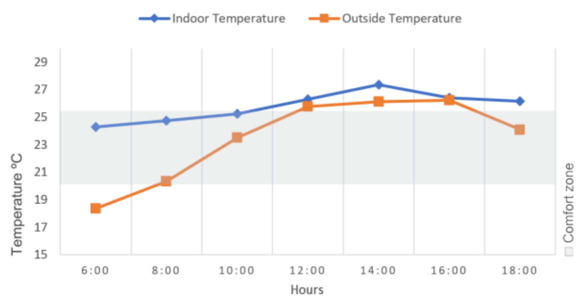


Figure 9: *Comparison of indoor and outdoor temperature classroom 418 in the year 2050.*

5. CONCLUSION

Being a pilot study of the physical conditions of the building and, in turn, of the university campus, it is possible to infer the deterioration tendency of the physical infrastructure is approximately 21.98% by the year 2050. In addition, the occupancy and thermal load by electronic devices were the most representative factor for thermal stress due to heat.

Regarding the current comfort conditions, the classrooms studied present an average discomfort rate of approximately 46.6% of the annual total and, by the year 2050, an increase in these conditions by 11,1%. Despite human adaptation to temperature change, said adaptation is not enough to maintain the same percentage of time within the comfort zone.

In relation to the relationship between outdoor and indoor temperature, the outdoor temperature presents a maximum increase of 3°C in a period of 31 years, in comparison, the indoor temperature reaches an increase of 5°C in its worst cases and an appreciable rise in the frequency of hours at high temperatures. In other words, while the difference between interior and exterior in 2019 was, in average, only 3°c, in the year 2050 it will be 4.3°c on average, this last metric being most affected by climate change in our case study.

As for the three methods of analysis, it is concluded that the results for each analysis criteria will be different for each case study, for which it is necessary to identify the representative situation most affected by the effects of climate change; In this way, measures can be applied in the medium and long term.

ACKNOWLEDGEMENTS

We gratefully for the National University of Colombia and the EMAT group from the faculty of architecture, Medellin. We are especially grateful to our professors Lucas Arango Diaz and Elizabeth Parra Correa, for guiding us in this process.

REFERENCES

[1] Corgnati, S. P., Filippi, M., & Viazzo, S. (2007). Perception of the thermal environment in high school and university classrooms: Subjective preferences and thermal comfort. *Building and Environment*, *42*(2), 951–959.

[2] Holmes, M. J., & Hacker, J. N. (2007). Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century. *Energy and Buildings*, *39*(7), 802–814. https://doi.org/10.1016/J.ENBUILD.2007.02.009

[3]Fong Silva, W., Alberto Severiche Sierra, C., & Marcela Fong Amarís, W. (2020. Sistemas de acondicionamiento de aire y ventilación como foco infeccioso de sars cov-2 en hospitales, clínicas e instituciones de salud. . Ipsa Scientia. *Revista Científica Multidisciplinaria*, *5*(1), 28–35. https://doi.org/10.25214/27114406.960

[4] Puteh, M., Ibrahim, M. H., Adnan, M., Che'Ahmad, C. N., & Noh, N. M. (2012). Thermal Comfort in Classroom: Constraints and Issues. *Procedia - Social and Behavioral Sciences*, *46*, 1834–1838. https://doi.org/10.1016/J.SBSPRO.2012.05.388

[5] Restrepo-Betancur, L. F., Peña-Serna, C., & Martínez-González, M. F. (2019). Climate change in the city of medellin – colombia, throughout fifty years (1960-2010). *DYNA (Colombia)*, *86*(209), 312–318. https://doi.org/10.15446/DYNA.V86N209.69531

[6] Alcaldía de Medellín. (2021). *Plan de Acción Climática 2020-2050*.

[7] Zhou, X., Lai, D., & Chen, Q. (2021). Evaluation of thermal sensation models for predicting thermal comfort in dynamic outdoor and indoor environments. *Energy and Buildings*, *238*, 110847. https://doi.org/10.1016/J.ENBUILD.2021.110847

[8] Akın Şahin, İşeri Orçun Koral, Akgül Çağla Meral, Erdoğan Bilge, & Dino İpek Gürsel. (2020). *(PDF) Climate Change Impact on Multi-Objective Optimization: A Case Study on Educational Buildings*. https://www.researchgate.net/publication/341902743_Climate_Change_Impact_on_Multi-Objective_Optimization_A_Case_Study_on_Educational_Buildings

[9] Dockery DW, J Schwartz, & J L Nguyen. (2013). The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity. https://www.researchgate.net/publication/2369473

[10] Belcher, S. E., Hacker, J. N., & Powell, D. S. (2005). Constructing design weather data for future climates. *Building Services Engineering Research and Technology*, *26*(1), 49–61. https://doi.org/10.1191/0143624405BT112OA

[11] *OpenStudio*. (n.d.). Retrieved September 17, 2021, from https://openstudio.net/

[12] *Grasshopper - algorithmic modelling for Rhino*. (n.d.). Retrieved September 14, 2021, from https://www.grasshopper3d.com/

[13] Standard 55 – Thermal Environmental Conditions for Human Occupancy, n.d.

[14] Mackey, C. (n.d.). *Adaptive_Comfort_Chart*. Retrieved September 17, 2021, from http://hydrashare.github.io/hydra/viewer?owner=chriswmackey&fork=hydra_2&id=Adaptive_Comfort_Chart&slide=1&scale=1&offset=0,0

[15] Chai, Q., Wang, H., Zhai, Y., & Yang, L. (2020). Using machine learning algorithms to predict occupants' thermal comfort in naturally ventilated residential buildings. *Energy and Buildings*, *217*, 109937. https://doi.org/10.1016/J.ENBUILD.2020.109937

[16] Cheng, Y., Niu, J., & Gao, N. (2012). Thermal comfort models: A review and numerical investigation. *Building and Environment*, *47*(1), 13–22. https://doi.org/10.1016/J.BUILDENV.2011.05.011

PLEA 2022 SANTIAGO
Will Cities Survive?

Overheating risk in naturally ventilated and conditioned elementary schools from the perspective of climate change

VERÔNICA MARTINS GNECCO[1] EMELI LALESCA APARECIDA DA GUARDA[2] MARTIN ÓRDENES MIZGIER[2] ROBERTO LAMBERTS[3]

[1] Università degli Studi di Perugia
[2] Federal University of Santa Catarina, Environmental Comfort Laboratory (LabCON)
[3] Federal University of Santa Catarina, Energy Efficiency in Buildings Laboratory (LabEEE)

ABSTRACT: The building resilience had become a significant question in the building energy efficiency field, considering the effects of climate change in their energy use. Passive strategies, such as natural ventilation, can improve indoor comfort conditions for occupants. However, with increasingly temperatures, the use of air conditioning becomes inevitable. This article aims to identify the overheating risk of naturally ventilated elementary school buildings in two Brazilian cities and measure the energy use when conditioning systems are added to guarantee indoor comfort conditions. The building was simulated for the current climate file plus four future climate scenarios. Three conditions were stablished: naturally ventilated, mix-mode air-conditioned and fully air-conditioned. For the naturally ventilated conditions, three criteria concerning overheating risk were analysed. The building failed in both cities, for the three criteria in all cases, demonstrating high overheating risk. The cooling energy use for the two air-conditioning conditions was very similar within each scenario, varying from 8.68 to 12.12 kWh/m².year in São Paulo and from 22.29 to 25.96 kWh/m².year in Manaus. The results showed that more legislative reaction and standardization of overheating risk in hot countries should be done, as well as investments to create more energy efficient buildings with lower need for active interventions.

KEYWORDS: Energy Simulation, Future Climate Profiles, Reference School Building, and Climate Neutrality.

1. INTRODUCTION

The mitigation of climate change is strong related to the energy use in buildings and natural ventilation can be a key strategy to overcome this question [1]. Considering the Brazilian climate, the natural ventilation strategy is recommended for most climate zones to reduce thermal discomfort caused by heat [2].

Schools, for example, are responsible for accommodate learning practices and play an impacting role in the community structure [3]. Thermal comfort conditions could affect students' academic performance [4] and even their school attendance [5], factor that is directly linked with ventilation rates [6]. This building typology will also face the impacts of climate change and should be specifically evaluated.

The Intergovernmental Panel on Climate Change (IPCC) publishes reports in order to investigate the impact of climate change on energy resources, human activities and extreme events, such as the last fully released, namely the Fifth Climate Change Assessment Report (AR5) [7]. Four scenarios of GHG emissions, air pollutant emission and land use are described: one stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.6 and RCP6.0) and one scenario considering high emissions (RCP8.5). The rising of air temperatures due to climate change can lead to overheating of indoor environments and have important effects in the human health [8].

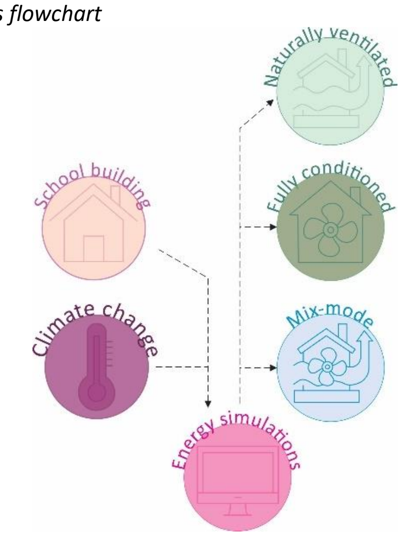
While studies concerning the overheating risk related to the warming climate are increasing, there is a lack of research in developing countries with hot climate, especially for educational buildings. The aim of this study is to investigate the impact of climate change in the natural ventilation strategy in Brazilian elementary school buildings, through an assessment of the overheating risk.

2. METHOD

The method of this article is divided in four steps (Figure 1): (1) climate files generation; (2) dynamic energy simulations; (3) overheating risk analysis and; (4) evaluation of energy use for cooling.

The elementary school building used for the study is the national archetype model for Brazil [9]. The two-storey rectangular building has nine classrooms and three administrative rooms and gross floor area of 1,566m². The Window-To-Wall Ratio is 60%. The front façade was oriented to the North orientation during the energy simulations. The construction system, the thermo-physical properties and building details are described in the study by Geraldi et al. [10]. No shading devices were used in the building.

Figure 1:
Method's flowchart



2.1 Climate files generation

The morphing method was used to generate the future climate files using the current files in SWERA version and EPW extension, through WeatherShift tool. The combination of 14 General Circulation Models (GMCs) establishes the tool development, as well as the use of Cumulative Distribution Functions (CDF) for each climate variable construction, through linear interpolation. The latter enables a better percentile distribution and decreases the uncertainties of the future climate pattern. The tool provides heating probabilities for the projections of 10% (less hot), 25%, 50% (intermediary), 75%, 90% e 95% (hotter).

In this paper, two climate change scenarios from the AR5 IPCC Report were morphed: RCP4.5 and RCP8.5, with two time-slices each, i.e., 2026-2045 (i.e., 2035) and 2056-2075 (i.e., 2065). In addition, current weather files in TMY format describe the baseline scenario. Two Brazilian cities representing different climate conditions of the country were chosen: São Paulo and Manaus, respectively Cfa and Am, in the Koppen-Geiger classification and 2A and 0A according to the ASHRAE 169 [11].

The investigation concerning the climate profile for the two cities, in the current and future climate files is showed in Figures 2 and 3. The annual average temperatures were 19.55°C in São Paulo and 26.8°C in Manaus. In both cities the average temperatures were within the minimum and maximum temperatures (Tmin/Tmax), with values lower than 34°C.

The average temperature (Tavg) during the current period and RCP8.5 – 2065 in Manaus was 26.8°C and 30.2°C, respectively. The increase between these periods for São Paulo was of +2.6°C (22.1°C).

Figure 2:
Climate profile in São Paulo of the current and future period

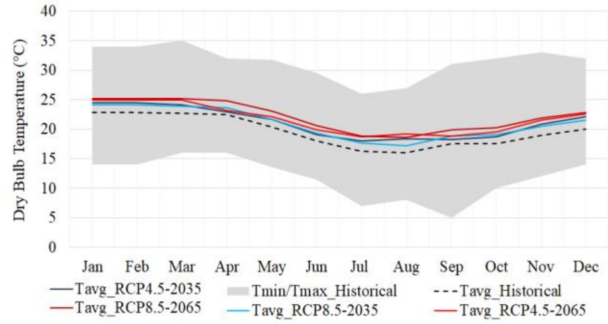
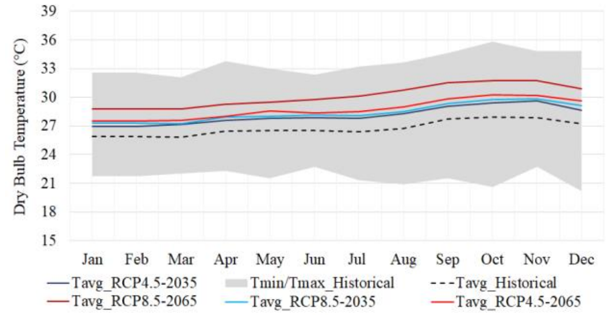


Figure 3:
Climate profile in Manaus of the current and future period



The investigation of overheating risk is crucial, considering the direct impact of the new climate conditions in the indoor environments and in the occupants' thermal acceptability.

2.2 Dynamic energy simulations

In order to access the climate data and energy use for the scenarios evaluated, energy simulations were performed. Three conditioned scenarios were considered for the classrooms: (1) only naturally ventilated, (2) Mix-Mode (MM), considering natural ventilation and cooling and, (3) only Fully Conditioned (FC) with close windows. Administrative rooms and transitional spaces were only naturally ventilated. The conditioned scenarios were considered for all occupied hours in classrooms during the year.

The simulation criteria, such as operation schedules and construction characteristics, follow the patterns found during energy audits in Brazilian elementary schools [10]. The occupied hours were set to 7:00–18:00 from 15th of January to 20th of December for administrative rooms and 7:00–12:00 and 13:00–18:00

for classrooms, with school year from 1st of February to 20th of December. A winter break from 1st to 30th of July was considered for both situations. Both (1) and (2) conditioned scenarios were made using Air Flow Networks in Energy Plus, the latter with Energy Management System tool, and 24°C as thermostat temperature. The FC scenario assumed that the HVAC system was active during the occupied hours in summer and spring, considering the cooling setpoint equal to 24°C. The operative temperature was adopted for the cooling use calculations, which considers the mean air temperature and the mean radiant temperature in its calculation. The Coefficient of Performance (COP) used was 3.6, following the most prevailing values in Brazilian elementary schools [10]. The simulations were performed in EnergyPlus and totalized 30 scenarios altogether.

2.3 Overheating risk analysis

The overheating risk was evaluated based on the criteria described by de Dear and Brager and presented in Standard 55 [12]. In this research only the air temperature was considered in calculations. The neutral temperature (T_n) is defined in Equation 1. Equation 2 described the maximum temperature admissible for acceptability of 80% of the occupants.

$$T_n = 17.8 + 0.31 \times T_{Emed} \quad (1)$$

$$T_{max} = T_n + 3.5 \quad (2)$$

where T_n – Neutral temperature (◦C);

T_{Emed} – Prevailing mean outdoor temperature (◦C);

T_{max} – Maximum acceptable temperature (◦C).

Three criteria were considered to evaluate the overheating risk, according the CIBSE TM52 [13]: (C1) hours of exceedance: the indoor temperature shall not exceed T_{max} more than 3% of the occupied hours; (C2) daily weighted exceedance: it defines a threshold for the duration of the daily overheating risk, i.e., the number of degree-hours that the indoor temperature exceeds the T_{max} by at least 1K, should be lower than or equal to six and; (C3) upper limit temperature: the indoor temperature shall not exceed 4°C more than the T_{max}.

The overheating risk was evaluated only in the classrooms, during the hot months for the Brazilian climates, from the 30th of September to 1st of May. The building was assumed unoccupied during the holidays, from 15th of November to 30th of January.

2.4 Evaluation of energy use for cooling

The increase of thermal load values in each future conditioned scenario, i.e., Mix-Mode (MM) and Fully Conditioned (FC), was compared to the current climate files. This analysis intends to evaluate the importance of the natural ventilation to the reduction of the thermal load, even if combined with artificial cooling.

3. RESULTS

3.1 Preliminary analysis: operative temperature fluctuation

First, to understand the indoor and outdoor temperature fluctuation, for conditioned and naturally ventilated scenarios, a preliminary analysis of the daily mean temperatures for each scenario was carried out. The daily temperature fluctuations showed operative temperatures (To) higher than the outdoor temperatures (Te) in all cases. Between the two conditioned cases (MM and FC) there were not significant differences of operative temperature values, considering that the thermostat was set in 24°C for both cases.

In São Paulo, the average difference for the conditioned scenarios between the external and operative temperature are 5°C and 4.1°C, for the current and RCP8.5 2065 climate files, respectively (Figure 4). Considering the Naturally Ventilated (NV) case, the average differences are higher, 8.9°C, 7.5°C, 7.2°C, 8.4°C and 7.8°C for the current, RCP4.5 2035, RCP4.5 2065, RCP8.5 2035 and TCP8.5 2065, respectively (Figure 5). Therefore, the demand for active and passive cooling strategies will constantly increase, due to the raise of mean outdoor temperatures and the regularly higher indoor temperatures.

Figure 4:
Daily average temperature of São Paulo – FC and MM

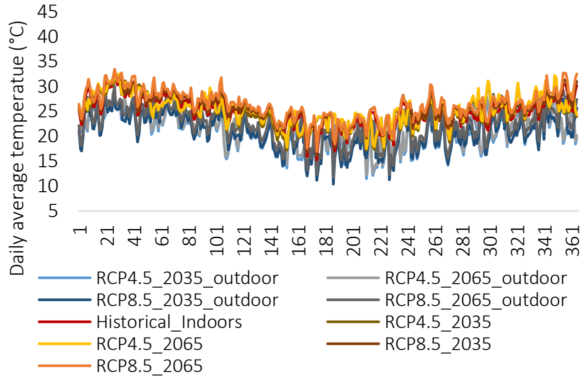
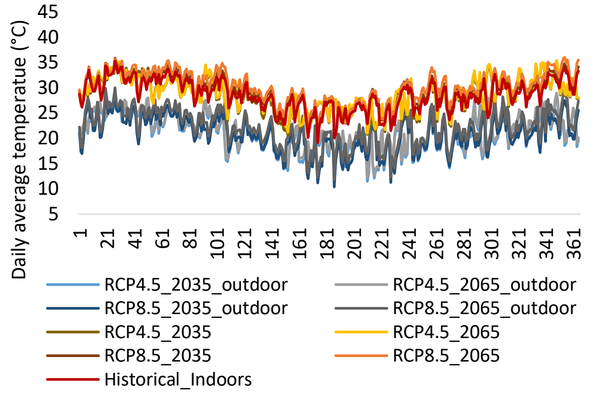


Figure 5:
Daily average temperature of São Paulo – VN



The profiles described in Figure 4 and 5 also showed that, even in the conditioned scenarios, where the temperature is set to reach the thermostat value, the indoor temperature fluctuates according to the outdoor temperature and the cooling system performance.

In Manaus, the same behaviour is observed in the three conditions: NV, MM and FC. The differences values in the conditioned scenario are slightly lower, 4.3°C and 2.3°C for the current period and RCP8.5 2065, respectively (Figure 6). In the NV scenarios, the temperatures differences are similar to São Paulo: 8.7°C, 8°C, 7.8°C, 7.9°C and 7.0°C in current, RCP4.5 2035, RCP4.5 2065, RCP8.5 2035 and TCP8.5 2065, respectively (Figure 7).

Figure 6:
Daily average temperature of Manaus – FC and MM

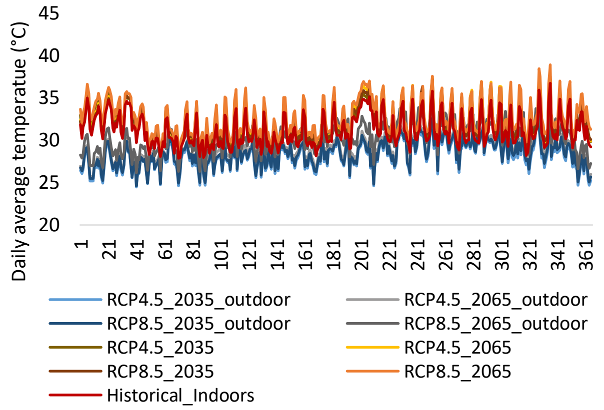
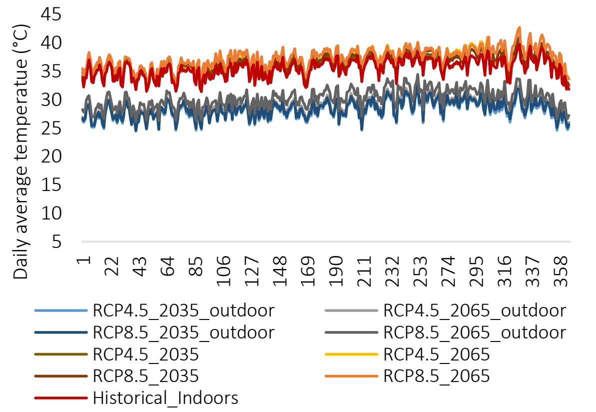


Figure 7:
Daily average temperature of Manaus – VN



There is a high overheating risk in both cities, mainly during the spring and summer months in São Paulo and during all year in Manaus. The three criteria described in 2.3 will be discussed in the next session.

3.2. Overheating risk analysis and cooling strategies in current and future scenarios

Table 1 shows the three criteria results for the two cities in the different emission scenarios. The data is given in percentage, number of days overcoming the threshold and number of hours overcoming the threshold for Criterion 1 (C1), 2 (C2) and 3 (C3), respectively. The three criteria fail in all cases, even with the shorter period of analysis (30th of September to 01st of May), indicating high overheating risk according to the stablished criteria.

Table 1:
Criteria 1 (C1), 2 (C2) and 3 (C3) results for overheating risk in naturally ventilated buildings, considering the three time-slices and two climate change scenarios.

São Paulo			
RCP 4.5	Current	2035	2065
Tmax	27.36	27.81	28.00
C1	16.67%	15.80%	15.82%
C2	95	81	80
C3	726	672	674
RCP 8.5	Current	2035	2065
Tmax	27.36	27.77	28.17
C1	16.67%	17.45%	18.07%
C2	95	105	117
C3	726	801	846
Manaus			
RCP 4.5	Current	2035	2065
Tmax	30.30	31.67	32.34
C1	21.04%	19.98%	18.90%
C2	184	150	127
C3	1035	925	847
RCP 8.5	Current	2035	2065
Tmax	30.30	33.73	35.43
C1	21.04%	15.01%	13.08%
C2	184	51	33

C3	1035	621	535

In general, the percentage of exceeded hours in C1 reduced in the future climate change scenarios due to the increase in the T_{max}, for both Manaus and São Paulo. This result might be explained by the adaptability of the occupant in constant higher temperatures. The exception is for the scenarios of RCP8.5 in São Paulo. This pattern is repeated for the other two Criteria in Manaus. However, considering the results for São Paulo the Criterion 2 presents a slightly rise from the current scenario to both RCPs 8.5, i.e., 2035 and 2065. In case of Criterion 3, the value increased in 2.77%, 9.36% and 5.32% from RCP 4.5 2035 to RCP 4.5 2065, from the current scenario to RCP 8.5 2035 and to RCP 8.5 2065, respectively.

The natural ventilation strategy might not be sufficiently effective to mitigate the effects of overheating in classrooms. The risk is present and could offer high levels of climatic stress to the occupants. A consequence is the increasing usage of air-conditioning systems to maintain the occupant's comfort conditions, which also elevates the energy use in buildings. Table 2 presents the energy use results per area unit (kWh/m².year) for Mix Mode (MM) and Fully Conditioned (FC) scenarios.

Table 2:
Cooling energy use for mix-mode (MM) and fully conditioned (FC) scenarios in kWh/m².year for Manaus and São Paulo, considering the three time-slices and two climate change scenarios.

São Paulo			
RCP 4.5	Current	2035	2065
MM	8.82	8.68	9.25
FC	9.58	9.55	10.11
RCP 8.5	Current	2035	2065
MM	8.82	10.26	11.46
FC	9.58	10.93	12.11
Manaus			
RCP 4.5	Current	2035	2065
MM	22.29	23.68	24.54
FC	22.30	23.68	24.55
RCP 8.5	Current	2035	2065
MM	22.29	24.13	24.95
FC	22.30	24.14	25.96

The results for cooling energy use are similar for the two scenarios, demonstrating that, during almost all occupied hours, operative temperatures are greater than the 24°C adopted as thermostat value. A special observation must be done for the obtained São Paulo values obtained for MM and FC in RCP 4.5 2035, 8.68 kWh/m².year and 9.55 kWh/m².year, respectively. Both are lower than the ones simulated for the current climate file, which can be explained by a limitation in the emission scenarios RCP4.5 and RCP8.5. Dodoo and Gustavsson [14] already noticed in previous studies the RCP4.5 scenario tendency of temperature increase up to 2060, decreasing and stabilizing by 2100.

For the other cases, the cooling energy use presented constant rise from the current climate file, with similar percentages between MM and FC operations. The biggest differences were 23.05% and 14.14% from the current climate file to the RCP 8.5 2065 for both São Paulo and Manaus, respectively in MM scenarios. The percentual difference in cooling energy use from the current climate file and each future climate scenario simulated are described in Table 3.

Table 3:
Percentual difference of the cooling energy use from the current climate file to the future climate files

Scenario	RCP 4.5		RCP 8.5	
	2035	2065	2035	2065
São Paulo				
MM	-1.65%	4.70%	14.06%	23.05%
FC	-0.32%	5.22%	12.32%	20.85%
Manaus				
MM	5.88%	9.20%	7.66%	14.14%
FC	5.83%	9.14%	7.60%	14.07%

Even if HVAC systems are not frequently installed in Brazilian school building's classrooms [15], this number tends to increase, following the pattern observed in the last years [16]. Consequently, with more conditioning equipment and higher temperatures, the energy use in schools is also raising, as showed in Table 3.

4. CONCLUSION

In this paper, the overheating risk was evaluated for elementary school buildings in Brazil, using three different criteria, based on the maximum temperature for each climate scenario. Also, the energy use for mix-mode and fully conditioned cases to maintain the established comfort conditions was obtained using the current and future climate files.

During all tested periods the three criteria failed, and the overheating risk intensifies for the future scenarios, which can provide high level of climate stress to classrooms' occupants. The maximum and minimum obtained values for C1 are 21.04% (current climate) and 13.08% (RCP8.5 2065) in Manaus and 18.07% (RCP8.5 2065) and 15.80% (RCP4.5 2035) for São Paulo.

The two conditioned scenarios had very similar values, which implicates that almost all occupied hours have higher temperatures than the established in the thermostat value. This condition can be suggested once the mix-mode system is only active with temperatures higher than the thermostat and the fully conditioned mode is active during all the occupied hours. The cooling energy use per unit of area was from 8.68 kWh/m².year (MM, RCP4.5 2035) to 12.12 kWh/m².year (FC, RCP8.5 2065) in São Paulo and from 22.29 kWh/m².year (MM, current climate file) to 25.96 kWh/m².year (FC, RCP8.5 2065) in Manaus.

Thus, only the natural ventilation strategy was not sufficient to mitigate the effects of climate change in both cities, increasing the need for active strategies in elementary schools. The use of other bioclimatic strategies should be indicated to reduce the overheating risk. Moreover, the impact of the overheating risk in the built environment still needs more attention in the legislation of Brazil: the NBR 15.575 [17] present some thermal performance indicators for buildings, ranked as minimum, intermediary, and advanced. This classification is obtained through the calculation of the percentual of occupied hours of the building within the established temperature comfort range, according to the local climate. This indicator may be the starting point to the inclusion of new overheating risk criteria in the Standards of Brazil and other countries characterized with hot climate, to guide engineers, and stakeholders to minimize its effects.

REFERENCES

1. K. Lomas and Y. Ji (2009) Resilience of naturally vent. Build. to climate change: advanced natural vent. And hospital wards. *Energy & Buildings*, 41, p. 629-653.
2. E. L. A. Guarda, et al. (2018). Efeitos do Aquecimento Global nas Estratégias de Projeto das Edificações por Meio de Cartas Bioclimáticas [In Portughese]., *Journal E&S*., 7.
3. European Commission. (2015). Implementing the Energy Performance of Buildings Directive (EPBD)
4. E. Kukrer and N. Eskin (2021) Effect of design and oper. Strategies on thermal comfort and productivity in a multipurpose school build., *Journal of Build. Eng*., 44.
5. J. Toftum et al. (2021). Develop. of a tool to predict the socio-econ. Consequences of better air quality and temperature control in classrooms, *Energy & Buildings*, 250.
6. J.Daisey,W.Angell,M.Apte(2003) Indoor air quality, vent. and health symp.: an analysis of existing inf. *Indoor Air*; 13, p.53-64.
7. IPCC (2014) IPCC Fifth Assessment Report.
8. C. Heracleous and A. Michael (2018). Assessment of overheating risk and the impact of natural vent. in educational build. of Southern Europe under current and future climatic conditions. *Energy*, 165, p. 1228-1239.
9. A. Veloso et al. (2021). *Relatório interno*: Convênio de cooperação técnico-financeira entre a Eletrobrás e o CBCS, destinado ao des. de benchmarks energ. no âmbito do PROCEL.
10. M. Geraldi et al., (2021). Evaluating the impact of the shape of school reference buildings on bottom-up energy benchmarking. *Journal of Building Engineering*, 45, p. 103142.
11. ASHRAE (2021). ASHRAE Standard 169: Climatic Data for Building Design Standards. 2021.
12. ASHRAE (2013). ASHRAE Standard 55: Thermal Envir. Conditions for Human Occupancy. 2013.
13. CIBSE (2013) TM52: The limits of thermal comfort: avoiding overheating in European Build.
14. A. Dodoo and L. Gustavsson (2016). Energy use and overheating risk of Swedish multi-storey residential buildings under different climate scenarios. *Energy*, 97, p. 534-548.
15. M.S.Geraldi and E. Ghisi (2020). Mapping the energy usage in Brazilian public schools. *Energy and Buildings*, 224, 110209.
16. M.S.Geraldi, M.V.Bavaresco, V.M.Gnecco, E.Ghisi and M.Fossati (2021) Impact of implementing air-conditioning systems on the school building stock in Brazil considering climate change effects: a bottom-up benchmarking. In: *Building Simulation*, 2021, Bruges. Proceedings…Bruges: IBPSA.
17. ABNT (2021). NBR 15575-1: Desempenho de Edificações. Rio de Janeiro. Brazil

PLEA SANTIAGO 2022
Will Cities Survive?

Acoustic design in open-plan learning environments

Dealing with sound intrusion for speech intelligibility

CONSTANZA IPINZA OLATTE [1,2] MAUREEN TREBILCOCK KELLY [1] MARIA BEATRIZ PIDERIT MORENO[1]

[1] Universidad del Bío-Bío
[2] Universidad de Santiago de Chile

ABSTRACT: Teaching methods and the conception of educational spaces have shifted, promoting new learning modalities and the designing flexible, adaptable and comfortable spaces. However, the new learning environments are challenging the indoor acoustic quality because of the noise caused by the variety of pedagogical activities. This article shows the acoustic simulation of a case study which has been designed to promote innovative pedagogical practices in Chile. The objective was to analyse the parameters of speech transmission index (STI) and speech distraction distance (r_d) during quiet and noisy learning activities. The analysis was carried out in two learning situations to assess how four noise scenarios affected student's intelligibility. The results showed that without activity noise, the STI complied with current acoustic standards. Nevertheless, when the background noise reached levels between 53-60 dB, the speech was distracting up to 4 meters, but the STI reached a fair intelligibility, but not acceptable, between students within a group at a maximum distance of 2 meters. In conclusion, current standards do not guarantee good speech intelligibility among students during group learning activities. In the future, incorporating new approaches to address a flexible acoustic design according to different pedagogical scenarios could improve student performance and well-being.

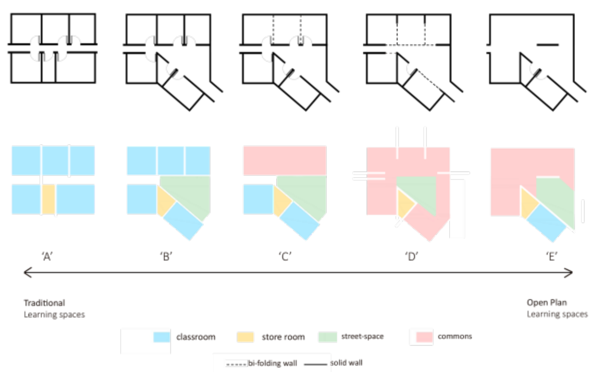
KEYWORDS: learning environment, open-plan school, noise, acoustics, speech intelligibility

1. INTRODUCTION

Since the beginning of the 21st century, teaching methods and the conception of educational spaces have shifted from a teacher-centred approach to a student-centred learning, promoting new learning modalities through the design of flexible, adaptable, and comfortable spaces (Barret et al., 2019; Nair et al., 2009; Nair, 2011; MINEDUC, 2020).

For example, Dovey and Fisher (2014), categorized the design of contemporary learning environments into five typologies depending on the degree of flexibility, an aspect which varies in a continuum between traditional enclosed classrooms and open-plan learning spaces (Fig. 1). According to these authors, these typologies can be better understood as assemblages, where teaching practices mix with adaptative space configuration.

Figure 1:
Degree of flexibility in learning spaces



Note: Representation of degree of flexibility in learning spaces based on the typologies of Dovey and Fisher [5], adapted by Cleveland et al [6], redrawn by the authors.

While pedagogical innovation in contemporary schools has fostered group, active and pedagogical practices, the new learning environments have removed some physical barriers of space, involving the students in a furniture dynamic use, and causing some complex problem with the acoustic wellbeing of the occupants (Robinson and Bellert, 2019; Shield et al., 2010).

Considering that conversation among students can be more important than the teacher's speech for creating a meaningful learning experience (Shield et al., 2015), current acoustic standards for school classrooms are not enough for the new learning environments, demanding the need to incorporate more flexible acoustic solutions for achieving an optimal speech intelligibility beyond the instruction activities.

While the research about the acoustic quality of flexible learning spaces is limited, most of the studies have shown more problems than solutions to answer the demands of the 21st century (Vijapur et al., 2021). Although a contemporary learning environment promotes collective and active practices with elements necessary to create a personalized experience, it can also promote intrusive noise, a lack of privacy, sound distraction (Kariippanon et al., 2018) and overstimulation, provoking stress in both teachers and students (Alterator and Deed, 2013). Thus, the excessive noise can trigger problems in terms of health (Geller et al, 2007), comfort (Bluyssen et al., 2018; Karjalainen et al., 2020) and performance (Klatte et al., 2013; Shield et al., 2003, 2006, 2008).

Classrooms should provide a suitable criterion to manage the indoor environmental noise, the Reverberation time (RT) and the Speech Transmission Index (STI) with the aim to provide a good communication between both teachers and students and students within a group. Nevertheless, there are a few countries with their own acoustic criteria for open-plan, semi open-plan or flexible learning spaces (BB93, 2015; BR15, 2015; DQLS, 2020).

Based on the information above, most standards recommend that the background SPL should be <35 dB(A), but this is only possible to be found in instructional teaching because noise levels between 58-77 dB(A) have been measured during group activities (Shield et al., 2015; Greenland and Shield, 2011; Sarantopoulos et al., 2014). For stipulations about RT, the factor mostly depends on the size of the room and the requirement of RT in classrooms should be between 0.4-0.6 seconds. Concerning STI according to standards its evaluation should be at least 0.6, which represents a "good" speech intelligibility evaluation (Table 1)

Table 1:
Relation between the STI value and speech intelligibility evaluation according to Barnett and Knight (1995)

STI	Speech intelligibility evaluation
0.00-0.30	Bad
0.30-0.45	Poor
0.45-0.60	Fair
0.60-0.75	Good
0.75-1.00	excellent

Nevertheless, the main acoustic issue in the new learning environments is the intrusive noise arising activities and comply with the criteria for speech intelligibility during activities to ensure easy communication and to maintain privacy withing individual teaching groups (IOA and ANC, 2015).

The uptake of the new learning environments, as the adaptation of the open plan schools, is increasing in Europe, Australia and New Zealand and recently emerging in the global south. This paper shows the acoustical simulation of a case study that consist of a new learning environment, which has been lately designed to promote innovative pedagogical practices in compliance with current acoustic standards in Chile (Fig. 2).

Figure 2:
Case study Future EduSpace in Chile

The goal of this study was to identify the acoustic environment in different furniture settings in the flexible learning space, by indicators of the STI and distraction distance (r_d) during group learning activities. To reach this target, as a first attempt, the acoustic performance in two learning scenarios (instructions and group work) with different levels of background noise level were simulated and the results between them were compared.

2. METHODOLOGY

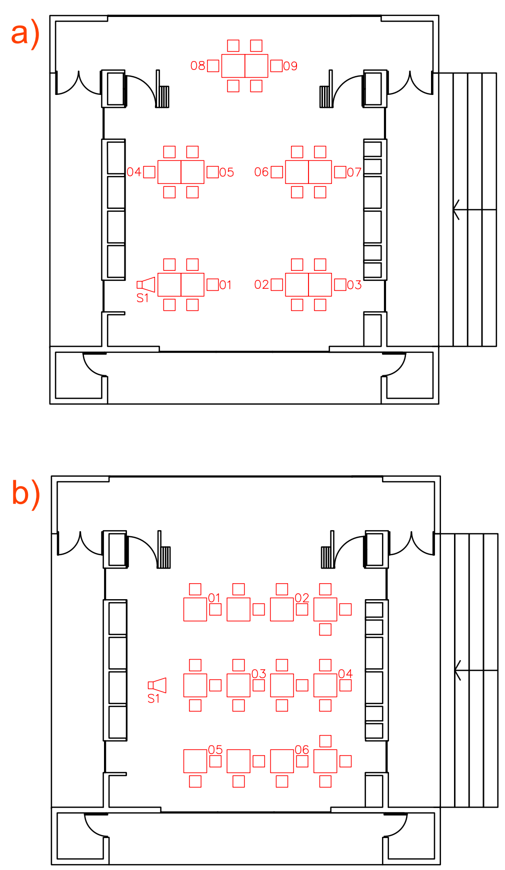
The analysis was carried out by an acoustical simulation in EASE software, using the AURA module composed of a hybrid Ray Tracing engine, which uses both a deterministic Image Model and Stochastic Ray Tracing methods.

2.1 Layout of learning space

The enclosed space has a capacity of 30 primary students (2.3 m^2 per students) and incorporates a folding partition increasing the area per student to 3 m^2 according to the learning process needs. This study contemplates the folding partition open because this space configuration represents the most unfavourable acoustic situation due to the volume increase in the classroom. Nevertheless, the RT of the open space is 0.5 seconds and complies with the current standards.

According to the group learning activity, the simulation was run in two learning configurations with different of background noise: group work organized in discussion sub-groups of 6 students and instructional teaching to evaluate and compare how the noise affects students' intelligibility (Fig. 3). In addition, from the STI results, the distraction ratios r_d were obtained from the source (in meters).

Figure 3:
Layouts of learning situations in the space



Note: Learning situations with source (S1) and receivers (01-11). a) sub-group work situation and b) instruction teaching situation.

2.2 Sources, receivers, and background noise

The computer model was run according to acoustic modelling of open plan spaces assumptions defining: first, source-receiver height, orientation, and vocal effort and second, calculation of overall noise level and the source directivity was modelled by means a representative three-dimensional directivity pattern for each octave band (IOA and ANC, 2015).

On the one hand, one source represented one student into a group and nine receivers both at a heigh of 1 m were implemented in the simulation of (a) sub-group work learning situation. On the other hand, in the (b) instruction teaching situation to quiet students, one source represented the teacher, located at a height of 1.65 m on the centerline of the room and six receivers at a heigh of 1 m. The speech spectra SPL (dB), positioned at 1 m in front of the speaker's lips, was set as an average of a raised voice effort of females and males (125-8kHz) as <51.0, 61.5, 65.6, 62.3, 56.8, 51.3, 42.6> (ANSI, 2010; Rindel, 2010).

To ensure a realistic prediction of STI, this study provides different noise levels based on the activity and the number of people speaking and generating background noise levels but excluded the speech source from which the STI was calculated (S1). Furthermore, this study assumed in the background noise that the acoustic insulation responds to current demands and the noise produced by equipment, e.g., dust and fume extract, computers, or projectors.

Table 2 shows the background noise assumptions used to calculate the STI values in both learning situations. The instruction teaching situation calculated the STI from the teacher's source in one background noise level (a) and the sub-group work situation calculated the STI from one student's source assuming three scenarios: noise discussion in all groups with four speakers without considering the source S1 (b), conversation in three groups without considering the source S1 (c), and general working of students in the space (d). The number of people speaking for the assumptions of the background noise, it answers to the operational speech sources in the space model and to the learning situations that involve the 30 students.

Table 2: *Background noise assumptions (dB) used to calculate the STI values.*

Type of background noise (dB)	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
(a) Instruction to quiet students	33.8	35.8	35.8	33.8	31.8	29.8	23.8
(b) Sub-group with 4 speakers*	55.0	66.0	71.0	68.0	60.0	53.0	44.0
(c) Sub-group with 2 speakers*	50.0	60.0	64.0	58.0	51.0	45.0	40.0
(d) General work	54.0	54.0	54.0	54.0	49.0	44.0	39.0

*Number of speakers in the room without considering source S1.

2.3 Prediction method

The simulation was run in EASE software, version 4.4 (AFMG, 2014), specifically in the Aura module, because it is composed by a hybrid ray tracing engine and allows mappings according to ISO 3382 and calculate the STI based on the IEC 60268-16 (International Electrotechnical Commission, 2020).

For the STI calculation, a high resolution of particles (rays), a long length of time (ms) and a default value for surfaces without scattering data of "40%-considerable structure" were selected. According to the user manual (Renkuz-Heinz, 2009), these parameters provide higher precision. Likewise, a simulated physical environment with 20°C and 50% of relative humidity was applied in each background noise scenario.

The acoustic distraction ratio r_d was identified from the STI results in every background noise scenario. The r_d, refers to the distance from the source speaker to a receiving point when the STI falls below 0.5.

3. RESULTS

The Fig. 4 and 6 shows the relation between speech intelligibility and distances r(m) from the source on the receivers. The top line r_d indicates the speech distraction distance when STI values fall below 0.5. In the Fig. 4, the results showed that when students were talking into the groups simultaneously with an environment noise higher than 60 dB (background noise assumptions b and c), the STI was less than 0.5. On the one hand, when the background noise was higher than 68dB (b), the STI was lower than 0.3, presented an evaluation of bad intelligibility between speakers and receivers into the groups. On the other hand, when the background noise level was equal or less than 60dB (c), it was possible to generate conversations among students into a group with a fair intelligibility at a maximum distance of 2 meters (Fig. 5).

Besides, when students were working in the space, without a continuous discussion (d General work), the distraction distance r_d, appeared into the ratio between 3-4 meters and it would be possible to maintain an occasional discussion in that area. The figure 5, shows a diagram of both background noise assumptions (c-d) with the areas of intelligibility into the group, indicating that it would be more convenient to organize groups of four or five students when the noise is higher than 60dB.

Figure 4:
STI in relation to distance r/m in sub-group work situation with three scenarios of background noise activities.

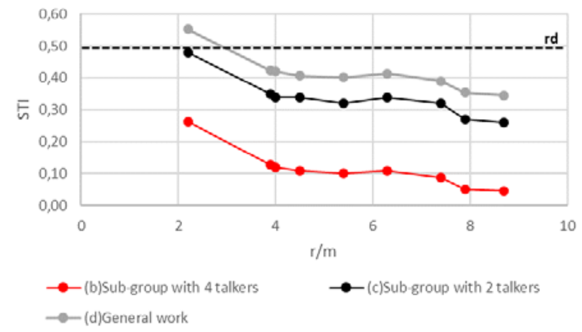
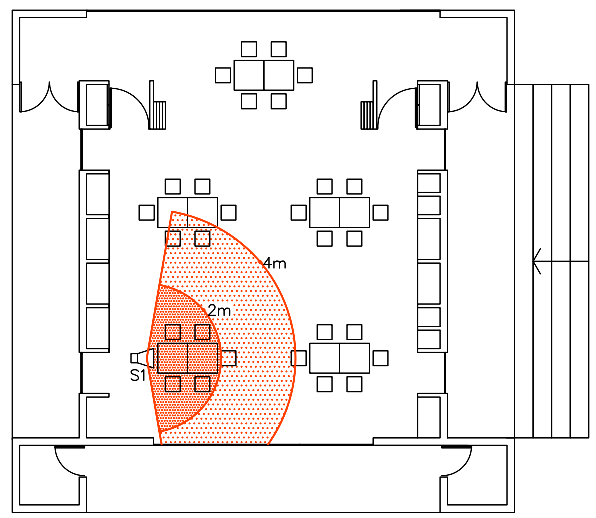
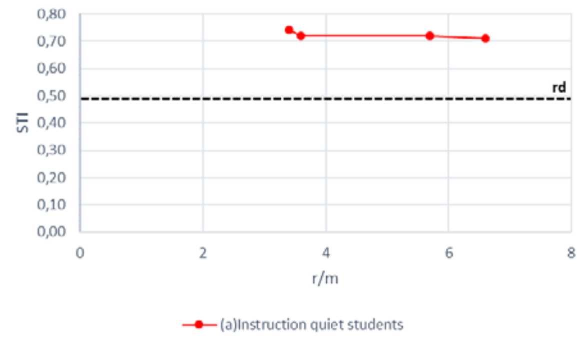


Figure 5:
Distance of STI fair in sub-group work situation with scenarios of background noise activities (c) and (d).



Finally, without noise from activities in the instruction learning situation to quiet students (a), the STI in all measurement points was higher than 0.7, and the space complied the intelligibility standards at least 6.7 m of distance (Fig. 6). Comparing these results with the Fig. 4, it is noted that even if a space had an adequate reverberation time, when the noise increased, the distance between receivers and source had a greater impact on the speech intelligibility of students into the groups and in the other groups of discussion.

Figure 6:
STI in relation to distance r/m in instruction teaching situation to quiet students.



4. DISCUSSION

The main acoustics issues in flexible learning spaces are the management of noise from different groups of people speaking independently. As a result, all these factors significantly increase the background noise level, decreasing speech intelligibility (Kariippanon et al., 2018). For good speech intelligibility, the STI should be between 0.6 and 1.0, which gives an STI rating of either 'good' or 'excellent' and the reverberation time should be less than 0.6 seconds.

This study evaluated STI conditions in four activity noise scenarios: (a) instruction to quiet students (35 dB); (b) sub-group with 4 speakers (68 dB); (c) sub-group with 2 speakers (60 dB); and (d) general work (53 dB). The acoustic conditioning requirements are different, because teacher instruction should convey the speech to whole class in a quiet environment and group or general work need to protect speech intelligibility within learning group during noisy activities, reducing, at the same time, intrusive noise from other groups.

In this case, based on the simulation of the background noise assumption (a) instruction to quiet students, the STI results obtained a good speech evaluation above 0.7. However, for primary students who are developing their speaking and listening skills, previous studies have recommended reaching an STI equal to or higher than 0.75 (Mealings, 2016).

On the other hand, recent studies argued that conversational intrusive noise has more detrimental effects on message comprehension than other types of background noise (Puglisi et al., 2021) and it has been reported inside classrooms that the noise generated by students is the most annoying noise for them (Bluyssen et al., 2018). In the background noise assumptions (b, c, and d) with noise levels above 53 dB, the impact of the distance on the student's intelligibility was significant between 2-4 meters in two noise assumptions (c and d). Previous research recommended located students into 3 meters of distance for critical listening activities (Greenland and Shield, 2011).

Although the limitation of this study was the application of a computer simulation in one space to test and compare the differences between two possibilities of furniture distribution and learning approach. This study, also showed how in a same space, the furniture distribution, and the background noise as a result of a learning activities, challenge the wellbeing of students through the comprehension of speech, demonstrating that the current acoustic design standards are not enough for mitigate the noise distraction between the groups of students. Further research about spatialized learning practices, the degree of flexibility of environments, and acoustic quality are required.

5. CONCLUSION

Nowadays, the new learning modalities require flexible spaces in noisy environments that affects teachers and students' performances and challenge the acoustic design standards. Although, several authors have offered practical solutions from four general strategies to reduce noise distraction categorized as: Learning management mediated by an organizational support, layout of the space, movable furniture and absorption solutions on ceilings and walls (Oseland, 2018).

In conclusion, current standards do not allow to ensure good speech intelligibility between students during group learning activities with noise levels above 53 dB. In the future, it is recommended to test and define acoustics control and design strategies, based on the understanding of the acoustics environment within new learning environments, and as result, improve the speech intelligibility in order to reduce the noise distraction generated by conversation during the group learning activities.

ACKNOWLEDGEMENTS

This work was funded by the National Agency for Research and Development (ANID) / Scholarship program /DOCTORADO NACIONAL 2020-70220191. The authors would like to thank the Future Edu Space Project, financed by the Innovation Fund for Competitiveness (FIC-R), Code BIP 40011072-0 Generation of Technological Capacities for the Construction of State-of-the-Art and Sustainable School Educational Spaces from the Biobío Region, for the information provided in this study.

REFERENCES

1. AFMG. (2014). *EASE Version 4.4*.
2. Alterator, S. & Deed, C. (2013). Teacher adaptation to open learning spaces. *Issues in Educational Research*, 23(3): p. 315-330.
3. ANSI (2010). ANSI S12.60. *Acoustical performance criteria, design requirements, and guidelines for schools*. American National Standards Institute.
4. Barnett, P. W. and Knight, R.D. (1995). "The Common Intelligibility Scale", *Proc. I.O.A*. Vol 17, part 7.
5. Barrett, P., Treves, A., Tigran S., Ambasz D. and Ustinova, M. (2019). *The impact of school infrastructure on learning: A synthesis of the evidence.* http://dx.doi.org/10.1596/978-1-4648-1378-8
6. BR15 (2015). Bygningsreglement 2015. Trafik-, Bygge- og Boligstyrelsens nyhedsmail. Danmark.
7. Bluyssen, P. M., Zhang, D., Kurvers, S., Overtoom, M., & Ortiz-Sanchez, M. (2018). Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings. *Building and Environment*, 138: p.106–123. https://doi.org/10.1016/j.buildenv.2018.04.032
8. Cleveland, B., Soccio, P. & Love, P. (2016). Learning Environment Evaluation and the Development of School Facility Design Guidelines. In *Annual Meeting of the Australian Association for Research in Education*. Melbourne, Australia, Nov 27-Dec 1.
9. Department for Education and Skills (2015). *Building Bulletin 93 Acoustic Design of Schools BB93*. The Stationary Office.
10. Dovey, K. & Fisher, K. (2014). Designing for adaptation: The school as socio-spatial assemblage. *The Journal of Architecture*, 19(1): p. 43–63. https://doi.org/ 10.1080/13602365.2014.882376
11. DQLS (2020). *Designing Quality Learning Spaces – Acoustics*. New Zealand Ministry of Education.
12. Geller, R., Rubin I., Nodvin, J., Teague, W. & Frumkin, H. (2007). Safe and Healthy School Environments. *Pediatric Clinics of North America*, 54(2): p.351-373. https://doi.org/10.1016/j.pcl.2007.01.005.
13. Greenland, E. and Shield, B. (2011). A survey of acoustic conditions in semi-open plan classrooms in the United Kingdom. *The Journal of the Acoustical Society of America*, 130(3): p.1399–1410.
14. International Electrotechnical Commission (2020). *IEC 60268-16: Sound system equipment-Part 16: Objective rating of speech intelligibility by speech transmission index*.
15. IOA & ANC (2015). *Acoustics of Schools: a design guide*. Institute of Acoustics and the Association of Noise Consultants.
16. Kariippanon, K., Cliff, D., Lancaster, S., Okely, A. & Parrish. A. (2018). Perceived interplay between flexible learning spaces and teaching, learning and student wellbeing. *Learning Environments Research,* 21(3): p. 301–320. https://doi.org/10.1007/s10984-017-9254-9
17. Karjalainen, S., Brännström, J., Christensson, J., Sahlén, B. & Lyberg-Åhlander, V. (2020). A Pilot Study on the Relationship between Primary-School Teachers' Well-Being and the Acoustics of their Classrooms. *International Journal of Environmental Research and Public Health*, 17(6): p.2083. https://doi.org/10.3390/ijerph17062083
18. Klatte, M., Bergström, K. & Lachmann, T. (2013). Does noise affect learning? A short review of noise effects on cognitive performance. *Frontiers in Psychology*, 4: p. 578. https://doi.org/10.3389/fpsyg.2013.00578
19. Mealings, K. (2016). Classroom acoustic conditions: Understanding what is suitable through a review of national and international standards, recommendations, and live classroom measurements. In *2nd Australasian Acoustical Societies Conference, ACOUSTICS 2016*. Brisbane, Australia, Nov 9-11.
20. MINEDUC (2020). *Guía de Criterios de Diseño para Proyectos de Ampliación, Reposición y Construcción Nueva de Espacios Educativos de Calidad*. Ministerio de Educación.de Chile
21. Nair, P., Fielding, R. and Lackney, J.A. (2009). *The Language of School Design: design patterns for 21st century schools*. Education Design Architects.
22. Nair, P. (2011). *The Classroom Is Obsolete: It's Time for Something New*. Education Week.
23. Oseland, N. (2018) *Open Plan Classrooms, Noise & Teacher Personality*. Workplace Unlimited.
24. Puglisi, E., Warzybok, A., Astolfi, A. & Kollmeier, B. (2021). Effect of reverberation and noise type on speech intelligibility in real complex acoustic scenarios. *Building and Environment*, 204. https://doi.org/10.1016/j.buildenv.2021.108137
25. Renkuz-Heinz. (2009). *EASE Version 4.3 User's Guide & Tutorial*. Available: https://www.afmg.eu/en/ease-4-tutorial.
26. Rindel, J. H. (2010). Verbal communication and noise in eating establishments. *Applied Acoustics*, 71(12): p.1156–1161. https://doi.org/10.1016/j.apacoust.2010.07.005
27. Robinson, A. and Bellert, A. (2019). Co-teaching in (refurbished) flexible learning spaces: Promoting quality acoustics for learning and collaboration. In *Sound Decisions: Moving Forward with Acoustics*. Australia, Victoria, Nov 10-13.
28. Sarantopoulos, G., Lykoudis, S., & Kassomenos, P. (2014). Noise levels in primary schools of medium sized city in Greece. *The Science of the Total Environment*, p. 482–483, 493–500.
29. Shield, B., Conetta, R., Dockrell, J., Connolly, D., Cox, T., & Mydlarz, C. (2015). A survey of acoustic conditions and noise levels in secondary school classrooms in England. *The Journal of the Acoustical Society of America*, 137(1): p. 177–188.
30. Shield, B. and Dockrell, J. (2003). The Effects of Noise on Children at School: A Review. *Journal Building Acoustics*, 10(2): p. 97-116. https://doi.org/10.1260/135101003768965960.
31. Shield, B. and Dockrell, J. (2006). Acoustical barriers in classrooms: the impact of noise on performance in the classroom. British Educational Research Journal, 32(3): p.509-525. https://doi.org/10.1080/01411920600635494
32. Shield, B. and Dockrell, J. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. *The Journal of the Acoustical Society of America*, 123(1): p.133–144.
33. Shield, B., Greenland, E. & Dockrell, J. (2010). Noise in open plan classrooms in primary schools: a review. *Noise & Health*, 12 (49): p. 225-34.
34. Vijapur, D., Candido, C., Göcer, Ö. & Wyver, S. (2021). A Ten-Year Review of Primary School Flexible Learning Environments: Interior Design and IEQ Performance. Buildings, 11(5): 183. https://doi.org/10.3390/buildings11050183

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 02
10:15 — 11:45

CHAIR
ULRIKE PASSE

PAPERS
1671 / 1371 / 1396 / 1268

20TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Strategies for a 2050-ready project in an urban environment

Thus, avoiding social inequalities

MARTIN MURRAY[1], SHANE COLCLOUGH[1], PHILIP GRIFFITHS[1]

[1] Department of Computing, Engineering, and the Built Environment, Ulster University, Shore Road, Jordanstown, Belfast, Co Antrim, BT37 0QB
Corresponding author: Murray-M46@ulster.ac.uk

ABSTRACT: The research is related to a mixed-use, low-rise, energy-plus construction project proposed within the back lands of a large town in the Republic of Ireland. The overall premise of the project and the research is to investigate the potential for such developments to optimise energy use, support local microgrids and promote in society, a culture of understanding, attuned to the resource limits within which we need to operate. The project therefore reflects a central theme of the PLEA 2022 conference which is to question how our cities and towns might thrive, were we to recreate the way we inhabit and use them. The project is specific to the temperate climate of Northern Europe which reflects moderate heating demand in winter with potential overheating in summer subject to design considerations of ventilation and orientation of glazed facades. It has been found that PV optimisation combined with the maximum self-use on site of such renewable electricity, combined with batteries and heat pumps, form the basis of an optimum strategy for such inner town sites.
KEYWORDS: Mixed -use, Community Energy, Urban regeneration, PH, nZEB

1. INTRODUCTION

We replace approximately 1% of our buildings per annum across Europe. By 2050 therefore, 70% of our building stock will still consist of buildings which currently exist. Various strategies have been set in place to address the energy shortcomings of these buildings and render them fit for the carbon zero society envisaged then. This paper and the background research concerns itself with the strategies necessary to define the other 30% of buildings to be constructed now, and which need to reflect an optimum strategy toward 2050. The subtext of the paper therefore is that by careful selection of the energy strategies for this 30% of new buildings we might avoid greater social inequality across urban environments. Specifically, the paper is concerned with the context of Irish towns and villages.

Towns and cities can gather regions together, lend phenomenological meaning to the lives of their citizens and reflect the identity of a nation. The etymology of 'city' derives from the Latin root 'civitas', which means 'citizenship'. The expression 'citizen' itself is an Anglo-French word dating from the 14th century, (fem. citeseine), meaning an inhabitant of a city or town. Being a citizen within Europe is therefore linked inextricably also with urban living. Ireland, by way of contrast to mainland Europe, has lacked the more traditional pattern of European urban city living, and it is mainly smaller towns and villages, which constitute our urban centres. Part of this reflects Ireland's unique position within Europe, for having experienced 800 years of continual colonisation, prior to achieving independence in 1922.

Throughout much of the 19th and 20th centuries Ireland remained culturally and economically a deeply rural society with isolated homesteads grouped in clusters around local towns. The notable growth of the Irish economy since the 1980's has paralleled a sustained movement toward living in urban areas, usually in the form of suburban sprawl across both residential and commercial development. The main street has suffered as a result, socially, economically, and physically.

Indeed, it has remained an open question as to whether the facades and monuments of our towns and cities are those of a colonial power or are they authentically Irish? [1]. In the 20th century the independence afforded by the motor car allowed the emergence of a 'bungalow-bliss' society which combined a feeling of modernity with the freedom of rural living. Our towns and villages have been left to lie fallow. The cultural and energy relevance of this now is inherent to the challenge of making these very same towns and villages attractive places for low carbon living. An energy rich urban environment can help to address social inequality, conversely a lack of access to modern and affordable energy can contribute to chronic and persistent poverty. The case study is offered as a potential methodology to alleviate social inequality.

2. A STRATEGY TO NOWHERE

70% is a dominant figure in Irish residential statistics. 70% of the Irish population are now considered to be urban dwellers. Of our occupied dwellings, the semi-detached typology, (28%) and the larger detached single-family home, (42%) together constitute 70% of our residential stock, and 70% of that stock was built prior to 2000.

It is no surprise therefore that residential heating represents 61% of the energy demand for our building stock, and so to significantly reduce this energy profile, and reduce carbon emissions, one million of our 1.7 million occupied houses, (200,000 additional units are unoccupied), will need retrofitting. The Government has set a strategy of tackling 500,000 houses by 2030, which represents the renovation of 170 houses per day, every day, for the next eight years, while at the same time continuing to fulfil the normal construction needs of any moderately functional economy.

2.1 Heat pumps and power grid solution

The overriding methodology settled upon by statutory regulations, to reduce GHG emissions, is to reduce energy demand through better construction standards, and provide the energy needed from zero carbon sources, predominantly the electrical power grid. Ireland is fortunate in being located within the maritime temperate climate of Northern Europe requiring only moderate winter heating and suffers little by way of summer overheating. However, this may well change in the years ahead, as the summer of 2022 has indicated, no region is immune to climate devastation.

It is estimated that the power grid will need to expand by somewhere between 28% to 43% by 2030, to meet heating, transport, and data centre requirements. With policy targets of 900,000 electric cars on the road and 600,000 domestic heat pumps installed, the potential catastrophe of a power system failure is a reality.

Transitions are always difficult, and as the electrical power system transitions toward zero emissions, carbon gas will become a critical and expensive transition fuel. The latter part of 2021 witnessed gas price increases, in the wholesale market of 250% and this, before Russia's 2022 invasion of Ukraine. In Ireland one of the main energy providers in the marketplace has advised that as of March 2022, gas bills will increase by 39% while electricity, which in unitary terms is four times more expensive already, will increase by 27%. In such circumstances the poor will suffer.

2.2 Fuel Poverty

Across Europe 16% of the overall population suffered from 'fuel poverty' even before the start of the European war. (Fuel poverty being a term commonly understood to reflect a household which needs to use more than 10% of its disposable income to maintain a reasonable comfort level within the home). In Ireland fuel poverty is believed to affect almost 26% of the population, with significant numbers of these households living in urban environments. Such fuel poverty represents the sharp end of social inequalities, and this paper is engaged with understanding how by adequately addressing new 2050-ready urban development we may address social equality and establish a strategy for prioritising our retrofit programmes.

To prepare our buildings for a zero-carbon future, two main strategies of energy reduction are envisaged. New buildings are required to be constructed to a nearly zero energy building (nZEB) standard, while the renovation of existing buildings must also meet nZEB standards where 25% of their enclosing fabric is to be replaced, (the latter requirement being framed within a catch-all phrase of 'affordability'). Overall retrofitting of our existing residential buildings is intended to achieve a minimum building energy rating (BER) of B2, which has been identified as being cost-optimal; optimality being a driving force, despite our government declaring a climate emergency.

2.3 The shortfall of cost optimality

The cost optimality principle is defined as the *'the energy performance level which leads to the lowest cost during the estimated economic lifecycle'* [2]. The difficulty of this definition is that the '*economic lifecycle*' is open to significant fluctuations depending on discount rates, the economic period considered, and the cost centres considered. Effectively, what is cost optimal can really be an expression of a political or economic viewpoint. The effect of this is either to constitute a shortened viewpoint and curtail ambition by overvaluing the present costs of sustainability, or accept that there is an intergenerational responsibility, which demands the adaptation of a longer-term perspective.

The priorities expressed by these two economic viewpoints constitute either an economic view that is traditionally neo-classical, and which frames a sustainable future as one that can only be achieved through economic growth within a competitive marketplace; or a second viewpoint which effectively jettisons economic growth as a measure of societal success and focuses on equity, eradicating poverty, encouraging resource conservation, and accepting ecological limits and a circularity of economy.

Because the fundamental difference between the two viewpoints is one of temporal perspective then this is also reflected in their attitude to future values and the interpretation of those in the present, all effectively achieved through 'discounting'. This a theme also referenced by Krznaric in his recent book, *The Good Ancestor* [3] which warns against overvaluing present actions or events or services He quotes Frank Ramsey, generally regarded as the father of discounting, who commented in 1928 that the discounting of the welfare of future generations was *'ethically indefensible and arises merely from the weakness of the imagination'*. Perhaps a more pragmatic viewpoint is that of Newell & Paterson, (1998) who noted that *'it is generally only those environmental initiatives that do not threaten the interests and routines of industrial capitalism that succeed'*. [4]

What is clear is that from an economic perspective, the one which favours cost optimality alone will only ever identify the best lowest cost initiatives. By way of contrast, a Life Cycle Analysis (LCA) which provides a weighted framework approach incorporating life cycle environmental and cost indicators will assess the impact of building production, construction type and materials, operational use and end-of-life implications, across all of the building's life span [5]. This creates the opportunity to create environmental solutions that mean something in the longer perspective. The case study project goes one step further with a view to creating 'an energy somewhere'.

3. A STRATEGY TO SOMEWHERE

How then to proceed? When we reach beyond the restrictions of cost optimality it becomes possible to create a richer three-dimensional view of where we want to be from a sustainable point of view. In *'Blueprint for a Sustainable Economy'* [6], the value of the environment in its broadest sense, is the primary concern. This requires us to expand our considerations across an extended timescale taking a view of equity across generations similar to, the tradition of 'Seventh-Generational Thinking' [7].

Figure 1*: Design view of development, (south facing).*

Such considerations would naturally extent also toward our built heritage and the need to take care of our cities, towns and villages which are themselves a cultural and social asset and given our carbon budgets effectively a non-renewable resource of embodied carbon. It is in this context that the strategies for the case study project are set. The added benefit of the case study project is its setting within an urban environment, facilitating an easy form of low carbon living and allowing people to be able to walk and cycle predominantly, and when necessary, share a car to get around. The project therefore reflects a central theme of the PLEA 2022 conference which is to question and formulate how our urban environments might thrive toward 2050.

4. A 2050-READY PROJECT

The project underlying the research consists of a mixed-use, low-rise development of three campus-style buildings (492m^2), located on a 600m^2 back-lands urban site, located within an Irish town.

The overall premise of the project and the research is to investigate the potential for such developments to optimise local energy use, support local microgrids and promote in society, a culture of understanding, attuned to the resource limits within which we need to operate. The research also aims to answer one specific question which is to assess whether the current nZEB energy standard as practiced in Ireland is an adequate methodology for addressing the urgent need to reduce our GHG emissions, meet our 2050 requirements and in parallel protect against social inequalities.

Figure 2: *Ground floor plan of development.*

The validity of the question and the context for its consideration lies within the myriad of emerging climate challenges such as impending time constraints, resources allocation, social inequalities, fuel poverty and the overriding issue of the future electrical capacity of our power grid.

None of these issues can be addressed adequately on their own, but together they constitute the compelling challenge of this generation.

4.1 PH or nZEB

The project is designed to PH standards of energy conservation. In Ireland the nZEB standard, which is also the regulatory standard, is primarily an asset rating methodology and lacks the cohesiveness of the PHPP design software which is also flexible across different residential and commercial uses.

By way of contrast, the nearly Zero Energy Building (nZEB) strategy in Ireland which controls energy use and carbon emissions related to buildings, categorises buildings as either dwellings or non-dwellings and uses two different proprietary softwares to predict their energy use. These are the 'Domestic Energy Assessment Procedure' (DEAP) and the 'Non-Domestic Energy Assessment Procedure' (NEAP). These softwares are not intended to act as design tools, but rather are intended to act as compliance portals to ensure basic energy and carbon emissions reduction and therefore also as a statistically dependable asset rating for the national building stock [8]. In an urban environment where 2050-ready buildings would benefit, from a flexibility of either commercial or residential occupation, this strategy may not be optimal, nor conducive to ease of policy implementation nor future use flexibility.

This paper is therefore concerned with investigating the energy challenges, benefits, and implications, that might flow from the creation of an urban energy rating which combines aspects of both DEAP and NEAP in a format that supports a flexibility of subsequent use and reuse. The validity of the approach derives from the common typology of inner town and village buildings, which historically have been two to three stories in height incorporating a mixture of uses and social interactions. As the challenge of economically renewing and decarbonising our towns and villages becomes more acute, energy policy will need to recognise the inherent flexible characteristics and scale of these urban buildings, and the innate need for urban life to be able to modify and alter them, as our social and societal needs require.

Currently the DEAP predictive software for residential use and NEAP, the predictive software for commercial use, occupy very different but parallel energy assessment spheres. Linking these to create an energy profile for small multi-use buildings (250m2 or less), seems beneficial if we are to create urban buildings with real use and design flexibility. Such research is particularly needed to rebalance the cost optimality orientation of the current nZEB standard software, which reflects only limited occupancy and heating periods within dwellings, supports moderate levels of fabric performance only, incorporates incomplete energy use profiles, (no plug loads), inadequate indoor air quality (IAQ) assessment, poor site climate data, and therefore also reflects no real assessment of future overheating potentialities.

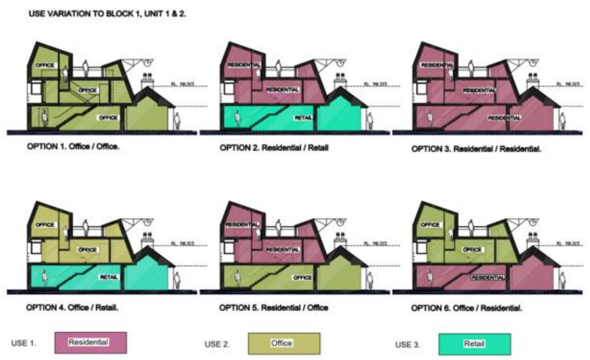
4.2 Designed for a future flexibility of use

In the case study, all buildings exhibit a flexibility of use through their sectional designs. (Fig 4). The west building (Block 1), (consisting of units 1 and 2), exhibits use flexibility through its sectional design, allowing any one of six different use configurations across its lifetime. The energy implications of achieving and measuring this 'long life, loose fit, low energy' flexibility is one significant aspect of the research ongoing. The case study is intended both as a research model but also as a commercially viable development which can structure a financial way forward, identify the direct benefits of improved performance, calibrate the support costs, and establish the financial supports that such developments may require in the short term, either as green finance, loans, or grants.

4.3 Fabric first and airtightness.

The project is designed to passive house (PH) standards of fabric which reflects the first strategy for all new 2050-ready construction projects. Hand in hand with exemplary u-values must be increased air tightness. which becomes significant as the u-values of low energy buildings are improved and thermal bridges eliminated. The nZEB standard lacks this concern for air tightness and therefore by necessity has to rely on Part F (Ventilation) of the Building Regulations to ensure compliance with same. Unlike the PH standard, it reflects no connection to a standard which has been considered from the beginnings as a design based unified whole.

Figure 3: *Sectional design (block 1) to allow six different options for building use, across residential office and retail use.*



4.4 Decarbonised heat

The successful implementation of energy transition strategies is an enormous challenge from both a householder perspective and a societal perspective. Preliminary research metrics from the case study would suggest that fabric is the first energy when it comes to new constructions. Thiers & Peuportier (2012) examined the environmental life cycle impact of retrofitting passive house and multi-family social housing building to net-zero source energy building using 12 environmental indicators [9]. The authors discovered that no heating system solution was the optimum choice for each of the 12 environmental indicators evaluated, but that fabric performance was benficial across eight of them. The way forward therefore is one of a holistic approach with inbuilt potentiality for optimisation. Given recent events, Covid, Russia, the Ukraine, it is clear that in a period of rising energy costs 'passive' solutions trump 'active' solutions every time. Heat pumps are only as efficient as the space they are heating.

4.5 Optimum PV

In the past the environmental impact of the Irish electricity grid was found to play a significant role in determining the hierarchy of retrofit packages when examined as to cost optimality and pay back. The recent events referenced have changed all of this. A significant portion of the case study currently in hand is to understand the role of PV within the overall energy system. The concept of system is critical as there are many variables which can affect the cost-optimal results including: discount rates energy prices, insulation thicknesses, building orientation, and intended building lifespan. these are the new system limits.

4.6 Life cycle costing analysis

These are also the terms and metrics of life cycle costing analysis, and they give a clearer view as to the real cost optimality of new constructions. Buildings and construction in the EU accounts for 50% of all extracted materials, 30% of water consumption and 33% of generated waste [10].

Figure 4: *View of development from north-east.*

Because of the importance of selecting appropriate sustainable materials, the use of Life Cycle Assessment (LCA) in building design is now critical. France, the Netherlands, and Finland have all committed to LCA becoming mandatory in building design. Germany and Austria have introduced semi-mandatory requirements for building LCA.

LCA is also closely aligned with emerging EU issues of Environmental, Social and Governance (ESG), which are beginning to form a significant context within which construction investment decisions are made, based on future implications for energy efficiency, worker safety, and administrative independence. In such a way an improved nZEB standard, in line with PH protocols, could become an intentionally influential standard

5. PROJECT CONCLUSION

Geographical locations are climatically unique and therefore the energy strategies for particular countries are unique. As the literature makes clear the rolling out of nZEB as an EU standard has reflected this need to overcome significant climate disparity across member states, north and south.

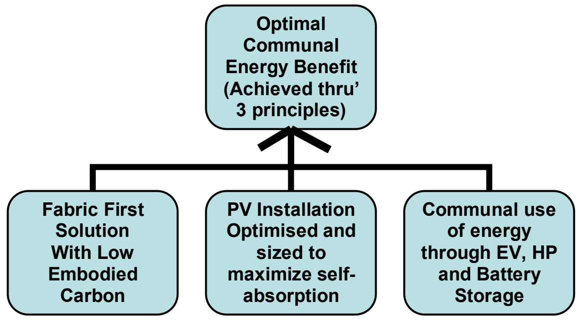
However, what is common to all countries, is the need for renewable energy generation, and the necessary political will to bring forward policies to support local generation. It is inevitable that the climate emergency will bring fundamental change to the way we do business, however in resisting such change and by aligning with market values, the nZEB implementation in Ireland has become a victim of the prevailing economic and political culture that legislates downward, and allows the marketplace to verify the validity of policy direction and determine the breath of its vision.

This is regrettable and it is in this respect that the nZEB legislation in Ireland is in 2021, questionable as to its fitness for purpose. It establishes no more than an asset value for buildings and creates a technological 'solution' for low energy buildings derived from what the market can sustain. However, as the literature review indicates the resulting energy use of nZEB buildings has proven difficult to predict, data has been misleading and buildings represent potentially a greater misuse of resources, beyond any acceptable notion of optimality. It thus creates an ideal scenario for widening inequalities as resources are loss and finances eroded. It is clear from the literature review also, that a market driven economy by its nature can only define a problem by the parameters of its own value system. In the context of an 'emergency', a market response focused on access to energy, cost, technology, and a lack of perceived value in community and manual labour will inevitably fail to respond cogently.

5.1 The need to go beyond nZEB

That there is an urgent need to proceed beyond current nZEB cost optimality metrics and limiting energy boundaries to a more socially equitable solution is emphasised by the emerging metrics of the case study the hall marks of which are encapsulated in the Figure 5 below:

Figure 5: *Formatting optimal low-energy building(s) to support the realisation of communal energy.*



The case study sits within these aspirations of balance, just as it sits also within the limitations of the nZEB strategy as currently formulated and legislated for. However, the case study data indicates that a broader leadership nZEB standard would create a greater equality and optimality of energy use between supplier and user. In one sense this relationship between supplier and user is already happening through the roll out of smart metering which allows real time engagement between the energy user and the local supply grids.

However, what PH delivers is a predictable energy performance which allows PV to be sized optimally. This is important in the context of the case study since allowing multiple potential uses (domestic and non-domestic), across the buildings requires also a well performing and predictable fabric. In table 1 below utilising benchmark nZEB metrics creates significant deviations in energy use where different building uses are intended. This can severely limit the commercial flexibility of the development project.

Table 1: *A comparison of the predictive energy use across all units reflecting a two potential end uses. The monthly energy use can vary by over 500% depending of end uses.*

Table 3: Primary energy profile per unit across different uses – nZEB Profiles (Benchmark energy use estimates only)

Use	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Totals
	(105m2)	(79m2)	(110m2)	(42m2)	(78m2)	(78m2)	(492m2)
Residential (BER:A2 50kWh/m2/yr)	5,250	3,950	5,500 €880.00	2,100	3,900	3,900	24,600
Retail (338 kWh/m2/yr)	35,490	26,702 €4,272.32	37,180 €5,948.80	14,196	26,364	26,364	166,296 (€26,607.36)
Annual PV[2] (kWh/yr)	1,121	3,363	5,980	zero	4,111	4,111	18,686
Highlighted units	Grey colour indicates the probable optimal usage in regard to rental income and mixed use which equates to 66,936 kWh/yr (5,578 per month).						

It is recommended that all research studies should have a burning question, one that remains kindled when the winds of despair blow. The burning question of this study is why are we building to construction standards with such relatively poor fabric performance, and limited by cost optimality strictures, when the capability exists within the industry to do more, and a climate change emergency has been pronounced worldwide? Addressing this question is absolutely necessary if we are to avoid built-in social inequalities within our 2050 aspirations and if our urban communities are to survive and prosper.

By addressing whether this changed relationship is conducive to aligning energy and social policy, the project also reflects a central theme of the PLEA 2022 conference, which is to question whether energy-equality and social-equality can be aligned in a world of diminishing resources, commercial imbalances, and technological driven solutions.

ACKNOWLEDGEMENTS

This paper is supportive of ongoing Ph D research at the University of Ulster. I am grateful to the University for their academic sponsorship and to my supervisors, Dr. Shane Colclough, and Prof. Philip Griffiths, for their ongoing support.

REFERENCES

1. Mulvin, V., *Approximate Formality - Morphology of Irish Towns.* Gandon Press, 2020 ISBN:9780951536490.
2. Buildings Performance Institute Europe (BPIE), (2013), Implementing the cost-optimal methodology in EU countries, lessons learned from three case studies, *ISBN: 9789491143083.*
3. Krznaric, R., (2020), The Good Ancestor: A radical prescription for long term thinking. *Ebury Publishing.*
4.Newell, P., Paterson M., (1998) A climate for business: Global warming, the state and capital.
Review of International Political Economy 5(4):679-703 DOI:10.1080/096922998347426
5. Sturgis & RICS, (2017), Whole life carbon assessment for the built environment.
6. Blueprint for a Sustainable Economy. By D. W. PEARCE and E. B. BARBIER London: Earthscan, 2000, 273 pp. L12.95 ISBN 1 85383 515 3.
7. David Suzuki Foundation (Canadian charitable number: BN127756716RR0001) *(US charitable number: 94-3204049)*
8. Implementation of the Energy Efficiency Directive *(2012/27/EU), EPRS Review 579.327, April 2016.*
9. Thiers, S., Peuportier, B, Energy and environmental assessment of two high energy performance residential buildings, *Build. Environ. 51 (2012) 276–284. https://doi.org/10.1016/j.buildenv.2011.11.018.*
10. EURIMA, Life Cycle Assessment of Buildings- A Future-proofed Solution in the Digitalised World of Tomorrow, *European Insulation Manufacturers Association, 2017.*
11. Clarke, L., Sahin-Dikmen, M., (2020).
Unions and the green transition in construction in Europe: Contrasting visions. European Journal of Industrial Relations.
https://doi.org/10.117/0959680120951705

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

PLEA SANTIAGO 2022
Will Cities Survive?

Effect of neighbourhood density on energy consumption

A comparative study of two inner-urban neighbourhoods in Des Moines

SEDIGHEH GHIASI[1], ULRIKE PASSE[1], YUYU ZHOU[1]

[1]Iowa State University, Ames, USA

ABSTRACT: Unprecedented efforts to cut greenhouse gas (GHG) emissions show an urgent need to avoid the detrimental impact of climatic change, such as urban overheating. While different sources account for sizable GHG emissions, US residential building energy consumption accounts for about 50% of CO2 emissions. Therefore, residential buildings provide a significant potential to reduce energy use and thus emissions. Many neighbourhood characteristics, such as residents' income level, the average age of residents, education, etc., influence energy use. This study focused on the effect of neighbourhood density on energy consumption by comparing two existing neighbourhoods with different densities in Des Moines, Iowa, USA. Using the urban modelling interface (UMI), annual heating and cooling energy use were estimated for the two neighbourhoods using two metrics including Energy Use Intensity (EUI), and population density. The results showed in air-conditioned buildings, considering trees, annual cooling and heating loads in the high-density neighbourhood will be 26.93% and 48.49% lower than the low-density neighbourhood. The sensitivity analysis results also indicated trees around buildings and air conditioning systems influence building energy consumption. The findings of this study implied increasing housing density in urban neighbourhoods can open more land for urban green spaces, which could mitigate urban overheating.
KEYWORDS: Urban Density, Neighbourhood, Energy Consumption, UMI, Residential

1. INTRODUCTION

During recent decades, cities throughout the world have aimed to decrease energy consumption. Yet, according to the Energy Information Administration (EIA), global energy consumption in buildings will grow an average of 1.3% per year from 2018 to 2050 (Hojjati, 2019). The primary consequence of increasing energy consumption is soaring greenhouse gas (GHG) emissions, a major cause of the changing climate, contributing to exacerbating negative consequences, such as urban overheating. A report published by the Organization for Economic Co-operation and Development (OECD) indicates that GHG emissions will increase 50% by 2050, if the current global policies on mitigating climate change remain unchanged (OECD, 2010). Therefore, policymakers need to know urgently what changes to the current policies will be the most effective. Deliberate intervention by policymakers requires an understanding of how to best update policies to effectively mitigate GHG emissions and develop cities to be more resilient to upcoming climate change. One way to inform policymakers is to investigate the major sources of GHG emissions. While different sources account for sizable portions of GHG emissions, residential buildings within the U.S account for about 50% of the CO2 emissions (Knowles, 2008).

Reducing energy consumption in this sector will significantly mitigate GHG emissions. This opportunity has prompted this study into the effect of neighbourhood density on energy consumption to develop a customized guidance for local policymakers regarding neighbourhood design. Many studies have explored the relationship between energy consumption and density on both a global and an urban scale.

One study that specifically investigated energy consumption on a global scale is Güneralp et al. (2017). They used top-down and bottom-up approaches and scenarios to investigate the relationship between future urban densities and energy use under different urbanization scenarios. They found that while increased urban density can effectively decrease energy consumption, the amount of decrease varies in terms of geographical location on a global scale.

In a similar study, Mostafavi et al. (2021) focused on the effect of urban density on energy consumption in the USA. They also confirmed that the importance of urban density differs for metropolitan cities in the USA. Their study was based on US Geological Survey's National Land Cover Dataset (U.S. Geological Survey, 2018) and the US Census. They explored a correlation between urban density and energy use intensity (EUI) using frequentist and Bayesian statistics.

Yet, while the role of urban density on energy consumption is undeniable, only a limited number of publications are concerned with the complex interaction of urban density and microclimate created by the building stock in a neighbourhood. Ma et.al (2022), Mauree et al. (2019) showed microclimates created through the interaction of urban landscape features, such as buildings or the existence of trees, can influence urban energy consumption. This was another motivation to include a localized weather data instead of a typical meteorological year (TMY) weather data for the whole city to obtain more realistic results. The current study fills this gap by including interaction among buildings and microclimate conditions for clusters of buildings. To accomplish this, the current study used the urban modelling interface (UMI) (Urban Modelling Interface | MIT Sustainable Design Lab, n.d.), which can consider high-resolution localized climate conditions (Reinhart et al., 2013). Mindali et al. (2004) argued that a true understanding of energy consumption requires investigations at various types of density (e.g., inner area density, employment density). Therefore, it is important to provide a clear definition for density and scale of study. Density can be defined in a variety of categories including indoor density, parcel density, residential neighbourhood density, citywide density (Angel et al., 2020). Based on a definition from Eldridge (1984) on the scale of a neighbourhood, density can be defined as equation 1:

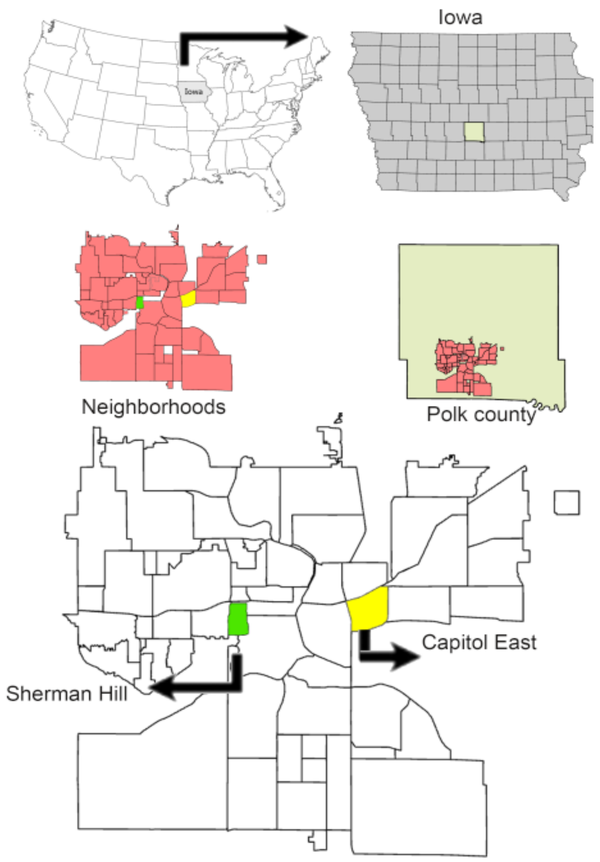
$$\text{People per residential neighborhood area} = \frac{\text{total population}}{\text{residential neighborhood area}} \quad (1)$$

Unfortunately, no standard exists what to include as residential land and what to exclude in defining the total area of the neighbourhood. This means researchers should specify their criteria for excluding or including non-residential parts of neighbourhoods in density analysis. (Forsyth, 2003).

1.1 Study area

This study is a part of a larger study that focuses on developing an innovative approach for the integration of social and biophysical models for urban and urban-adjacent food-energy-water (F-E-W) systems. Therefore, the study areas were selected to complement the main research project to assess the effect of land-use change patterns on energy consumption. The neighbourhoods investigated and compared in this study are two neighbourhoods located in Des Moines, IA, USA. (Figure 1). The first neighbourhood is Capitol East, where the majority housing type is single-family. The reason for selecting this neighbourhood is a tendency from residents and city planners to revitalize housing in this area. Housing in Capitol East is older and in great need for improvements since most of the buildings in this neighbourhood were built around the early 1900s (City of Des Moines GIS Data City of Des Moines GIS Data, n.d.), (Alcivar et al., 2014).

Figure 1:
Location of the two study areas. source: author



In this study, only residential buildings were included.

Table ***1:***
Comparison of density in two study areas

Neighborhood	Total population	Total gross area	Density
Sherman Hill	6533	4218m2	1.54
Capitol East	754	2149m2	0.35

As this study aims to assess the effect of neighbourhood density on energy consumption, we used a second neighbourhood to compare two neighbourhoods with different densities but similar overall area sizes. The second neighbourhood was Sherman Hill, which is four miles further west from the Capitol East. The reason to select the second neighbourhood for comparison is their similar areas and their different densities. In Sherman Hill 82 percent of buildings have more than one unit (Neighbourhood 10-Year Plan – Sherman Hill, 2017). The different building types in the second neighbourhood indicate it to be denser compared to the first neighbourhood. Because of limitations in data availability, we focused on a group of buildings in each neighbourhood. Table 1 compares the density of the two areas based on Equation 1. Table 1 indicates that Sherman Hill is four times denser than Capitol East. Table 2 compares two groups of buildings selected in the two neighbourhoods. As shown in Table 2, for the same number of buildings, buildings in Sherman Hill are taller. The total gross area shows the total area of the sum of all areas on all floors of a building. As the total gross area of buildings in Sherman Hill is larger than Capitol East, Sherman Hill accommodates more residents in the same number of buildings compared to Capitol East.

Table 2:
Comparison of two groups of buildings in each neighborhood

Neighborhood	Total gross area	Mean height	Number of buildings
Sherman Hill	$32513 m^2$	23.7 feet	86
Capitol East	$9334 m^2$	15 feet	90

1.2 Data collection

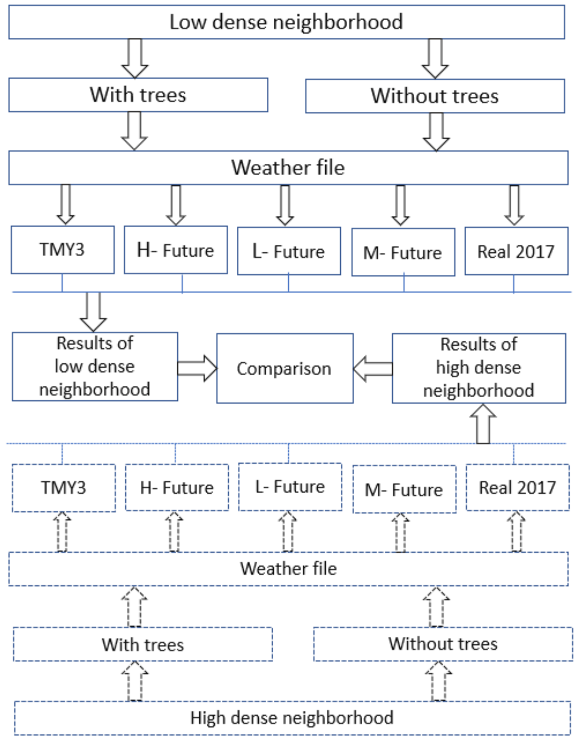
This study uses four main datasets. The first dataset includes building information such as building footprint, height, heating- ventilation- air conditioning (HVAC) system, and buildings' material acquired from the Des Moines Assessor office. The second dataset is a full tree inventory (e.g., shape and size of their canopies, trunk height, species, height, location). The third dataset includes five weather data: typical meteorological year (TMY3), measured weather data for 2017, future weather data with high, low, and medium GHG emissions impact. The fourth dataset is the 2009 Residential Energy Consumption Survey (RECS) from the U.S. Energy Information Administration (EIA) (Residential Energy Consumption Survey (RECS) - Energy Information Administration, 2016) is a representative sample of housing units and acts as a reference to assess the reasonability of energy consumption estimation for the study areas.

2. METHODOLOGY

2.1 Methodological framework

As described before, this study is a subsection of a larger research project. The process of developing the 3D model is described in the previous publication (Hashemi et al., 2018). The main platform for running simulations is Urban Modelling Interface 3.0 (umi), which can efficiently accommodate a large volume of buildings in simulations. This study follows a sensitivity analysis to provide a systematic approach to identify how variation in input parameters such as weather data, buildings material, air conditioning system, trees, and most importantly, neighbourhood density affects the output of the energy consumption estimation model. Figure 2 shows the methodological framework developed for this study. First, in the Capitol East neighbourhood, buildings were sorted into two main groups: buildings with air conditioning systems (AC) and naturally ventilated buildings (NV).

Figure 2:
Methodological framework developed for this study



Based on the data received from the Assessor office (County Assessor - Polk County Iowa, n.d.), NV buildings were constructed with eight material assemblies, and AC buildings were built with six material assembly types. Therefore, eight scenarios based on constructional materials were defined for NV buildings, and six scenarios were defined for AC buildings. To assess the most energy efficient material assembly type, we assumed all buildings have one of the materials defined in the scenarios for AC and NV buildings for each simulation. Comparing the results of all scenarios, the most energy efficient material were selected and assigned to all the buildings as a fixed parameter. The next step was to assess the effect of density on energy consumption under five different scenarios in terms of the weather files noted in the previous section. To investigate the importance of trees, we presented the results with and without consideration of trees. This study considered the effect of population, height, and building type. Therefore, the results are presented based on two metrics: square meter and population density.

2.2 Validation:

The 2009 RECS dataset from the West North Central Census Division was used to evaluate the model Based on RECS dataset. Based on RECS survey, annual gas consumption for space heating in Iowa (EUI) is 56.78 kWh, and annual heating load based on the simulation results in Capitol East is 80.14 kWh/m^2, and Sherman Hill is 41.28 kWh/m^2. The comparison of results of this study with the RECS dataset confirms the results of this study are in a reasonable range.

3. RESULTS

As discussed in the methodology section, the first step of the sensitivity analysis was to determine the most energy-efficient material for facade, partitions, roof, and ground for all buildings. Table 3 shows the most energy efficient material assemblies for the buildings based on umi inputs. By assigning these materials to all the buildings in both study areas, we can consider buildings' material as a fixed parameter. Sensitivity analysis helps to find the controlling role of each parameter towards the final results. Table 4 shows effectiveness level of different material assembly on annual energy consumption per meter square.

Table 3:
Assessment of the most energy efficient material assembly based on UMI results

Material	Thickness
Facade	
Hardwood_680kgm3	0.013
Oriental_Strand_brd_OSB	0.013
Hardwood_680kgm3	0.013
Polystyrene_extryded_30kgm3	0.05
Fibreglass_batts_15kgm3	0.065
Gypsum_Plaster_brd	0.013
Partition	
Gypsum_Plaster_brd	0.012
Plywood_wood_pamels	0.012
Fiber glass_battle_15kgm3	0.05
Gypsum_plaster_brd	0.012
Softwood_496kgm3	0.025
Roof	
Asphalt Shingle	0.02
Plywood_wood_panels	0.02
Fiberglass_batts_15kgm3	0.15
Softwood_496 kgm3	0.04
Gypsum_plaster_brd	0.013
Ground	
concrete_reinforced-2400kgm3	0.8
Gypsum_plaster_brd	0.013

***Table 4*:**
Comparison of standard deviation (STD) and mean of heating/cooling (kwh/m2) consumption for different materials to identify their level of importance in Capitol East based on umi results.

weather file	AC/NV	Heating-Cooling	STD	Mean
TMY3	NV	Heating	143.73	3232
	AC	Heating	129.05	3323
		Cooling	18.82	773
H- future	NV	Heating	224.79	2748
	AC	Heating	79.94	2684
		Cooling	15.92	1284
L- future	NV	Heating	84.50	2889
	AC	Heating	165.12	2722
		Cooling	112.87	1185
M- future	NV	Heating	74.77	2711
	AC	Heating	88.82	2711
		Cooling	40.21	1260
Real 2017	NV	Heating	129.20	3079
	AC	Heating	123.65	3086
		Cooling	13.80	713

Table 5 shows the percentage of difference in energy consumption in the high-dense neighbourhood compared to the low-dense neighbourhood in two metrics. In table 5 and 6 the following abbreviations were used. 1: without trees, 2: with trees, W1: TMY 3, W2: high impact GHG emissions (H- Future), W3: low impact GHG emissions (L-Future), W4: medium impact GHG emissions (M- Future), W5: Real 1027, H; Heating, C: Cooling.

Table 5:
Comparison of percentage of difference in annual heating and cooling load in Sherman Hill in compare with Capitol East, Metric: kWh/m2

			W1	W2	W3	W4	W5
1	NV	H	49.90	52.99	53.01	53.56	51.32
	AC	H	50.30	53.33	52.66	51.76	52.25
		C	26.81	28.60	27.22	29.09	26.65
2	NV	H	47.14	48.22	50.62	51.14	51.37
	AC	H	48.49	50.60	48.82	51.94	50.68
		C	26.93	29.45	37.48	30.52	29.77

Table 6:
Comparison of percentage of difference in annual heating and cooling load in Sherman Hill in compare with Capitol East, Metric: kWh/capita

			W1	W2	W3	W4	W5
1	NV	H	53.75	56.60	56.62	57.13	55.06
	AC	H	54.11	56.91	56.29	55.47	55.92
		C	32.43	34.08	32.81	34.53	32.29
2	NV	H	51.20	52.20	54.41	54.90	55.11
	AC	H	52.44	54.40	52.75	55.63	54.47
		C	32.54	34.87	42.28	35.86	35.1

Table 7:
Comparing the effect of different weather files on annual heating and cooling load in two study areas without considering trees. In table 7 the following abbreviations were used. 1: Capitol East, 2: Sherman Hill, W2: H- Future, W3: L-Future, W4: M- Future

			W2	W3	W4	W5
1	NV	H	-19.32	-13.25	-17.76	-7.89
	AC	H	-19.45	-12.03	-19.50	-6.63
		C	59.90	42.47	57.81	-9.91
2	NV	H	-24.30	-18.64	-23.78	-10.49
	AC	H	-24.37	-16.21	-21.87	-10.30
		C	57.07	34.39	51.97	-9.34

4. DISCUSSION

The result of this study is presented using two metrics: per person (total energy consumption of neighbourhood divided by population of the study area), per meter square (total energy consumption of neighbourhood divided by gross area of the neighbourhood).
Two neighbourhood models were developed in umi to conduct a simulation-based sensitivity analysis using weather files and materials as additional variables, to assess the effect of density on energy performance in the selected neighbourhoods. Simulations were performed using the five weather files: typical meteorological year (TMY3), measured weather data for 2017, future weather data with high- low and medium emissions impact. Noticeably lower energy consumption was confirmed in the umi model for annual cooling and heating energy use in the high-dense neighbourhood for all scenarios.

Table 4 shows the calculated mean and standard deviation for a variety of material assemblies present in the neighbourhoods for all the scenarios. As standard deviation is not further from mean, changing materials have no significant role in the overall trend for annual heating and cooling load. Therefore, the existing materials have no significant impact on the energy performance of both neighbourhoods.

Sherman Hill is four times denser than Capitol East, as described in the introduction. We expected less energy consumption for the high dense neighbourhood based on the literature review. Detailed results will be discussed separate for air-conditioned buildings and naturally ventilated building in the next section.

4.1 Air-conditioned buildings

Heating loads in air-conditioned buildings in the high-dense neighbourhood, under all five weather files on average were 55.74 percent lower than the low-dense neighbourhood (per person). Cooling load in the high-dense neighbourhood were on average 32.23 percent lower than the low-dense neighbourhood. Including the effects of trees, heating and cooling load will on average be 53.94 and 36.14 percent lower. Considering trees as a parameter shows the importance of trees in minimizing the effect of the urban heat island.

4.2 Naturally ventilated buildings

Similarly, for naturally ventilated buildings, the heating load is lower on average by 55.83 percent on for all scenarios. Including the effects of trees will result in 53.56 percent less energy consumption.

4.3 Effect of different weather files on energy consumption

Table 7 compares results of simulations for TMY3 weather file with the other weather files including measured weather data for 2017, future weather data with high- low and medium emissions impact. The results show considering the future effects of greenhouse emissions will lower down heating load and level up the cooling load. Results confirmed importance of considering the effect of urban heat island (UHI) on energy consumption. In a related study conducted by author (Ghiasi et al., in press) a similar result for effect of UHI on energy consumption could be observed. It worth to mention that for both metrics the effect of different weather files were the same.

As we discussed, single family houses show more energy consumption in comparison with multifamily houses. The other additional parameters which were added to this analysis showed how other parameters affect energy use which can be used as a guideline for urban designers to lower down the effect of GHG emissions.

5.CONCLUSION

This paper followed a comparative sensitivity analysis to evaluate the impacts of neighbourhood density on building energy performance under five different weather data files. We analysed energy use for 86 buildings in two neighbourhoods which differed in terms of number of units in each building. The results were presented in two metrics: per capita, and per meter square. The percentage of difference for the two metrics was the same. Although more residents inhabit high-density neighbourhood, energy use for heating and cooling is lower for all metrics used. Our results suggested that to cope with upcoming climate change; one of the potential solutions for lowering GHG emissions could be to design denser neighbourhoods. While this can currently only be recommended for this location, future studies should also include a variety of climates to assess the impact different climates have energy use for neighbourhoods with varying densities.

REFERENCES

1. Alcivar, J., Blumstein, A. L., Dostart, K. E., Drahos, J. W., Levinson, L. R., Whitson, J., & Rongerude, J. M. (2014). Capitol East neighborhood charter plan update. https://dr.lib.iastate.edu/handle/20.500.12876/63027
2. Angel, S., Lamson-Hall, P., & Blanco, Z. G. (2021). Anatomy of density: measurable factors that constitute urban density. Buildings and Cities, 2(1), 264–282. https://doi.org/10.5334/bc.91
3. County Assessor - Polk County Iowa. (n.d.). Www.polkcountyiowa.gov. https://www.polkcountyiowa.gov/county-assessor/
4. Eldridge, N. (1984). Population density: the choice of gross or net residential area. Urban Policy and Research, 2(1), 23–26. https://doi.org/10.1080/08111148408522642
5. Forsyth, A. (2003). Measuring density: working definitions for residential density and building intensity. Design brief, 9(1), 2-8. http://annforsyth.net/wp-content/uploads/2018/05/db9.pdf
6. Ghiasi, S., Y. Zhou, U. Passe, and J. Thompson. (in press). "A Sensitivity Analysis to Investigate Urban Heat Island Impact on Building Energy Consumption." In International Building Simulation (IBPSA) Conference, Bruege, Belgium. 2021.
7. Güneralp, B., Zhou, Y., Ürge-Vorsatz, D., Gupta, M., Yu, S., Patel, P. L., Fragkias, M., Li, X., & Seto, K. C. (2017). Global scenarios of urban density and its impacts on building energy use through 2050. Proceedings of the National Academy of Sciences, 114(34), 8945–8950. https://doi.org/10.1073/pnas.1606035114
8. Hashemi, F., Marmur, B., Passe, U., & Thompson, J. (2018, June). Developing a workflow to integrate tree inventory data into urban energy models. In Proceedings of the Symposium on Simulation for Architecture and Urban Design (p. 34). Delft, The Netherlands: Society for Computer Simulation International. https://dr.lib.iastate.edu/handle/20.500.12876/56106
9. Hojjati, B. (2019, October 21). Global energy consumption driven by more electricity in residential, commercial buildings. U.S. Energy Information Administration (EIA). https://www.eia.gov/todayinenergy/detail.php?id=41753
10. Knowles, H. S. (2008, June). Realizing residential building greenhouse gas emissions reductions: The case for a Web-based geospatial building performance and social marketing tool. In Proceedings of the 17th Annual International Emission Inventory Conference: Inventory Evolution-Portal to Improved Air Quality, Portland, Oregon (pp. 2-5).
11. Ma, R., Wang, T., Wang, Y., & Chen, J. (2022). Tuning urban microclimate: A morpho-patch approach for multi-scale building group energy simulation. Sustainable Cities and Society, 76, 103516. https://doi.org/10.1016/j.scs.2021.103516
12. Mauree, D., Naboni, E., Coccolo, S., Perera, A., Nik, V. M., & Scartezzini, J. (2019). A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities. Renewable and Sustainable Energy Reviews, 112, 733-746. https://doi.org/10.1016/j.rser.2019.06.005
13. Mindali, O., Raveh, A., & Salomon, I. (2004). Urban density and energy consumption: A new look at old statistics. Transportation Research Part A: Policy and Practice, 38(2), 143-162. https://doi.org/10.1016/j.tra.2003.10.004
14. Mostafavi, N., Heris, M., Gándara, F., & Hoque, S. (2021). The relationship between urban density and building energy consumption. Buildings, 11(10), 455. https://doi.org/10.3390/buildings11100455
15. National Land Cover Database | U.S. Geological Survey. (2018, September 11). Www.usgs.gov; Earth Resources Observation and Science (EROS) Center. https://www.usgs.gov/centers/eros/science/national-land-cover-database
16. Neighborhood 10-Year Plan – Sherman Hill. (2017, July 24).https://www.shermanhilldsm.org/documents/10-year-plan/
17. OECD. (2010). OECD Environmental Outlook to 2050: The Consequences of Inaction - Key Facts and Figures - OECD. Oecd.org.
18. Reinhart, C., Dogan, T., Jakubiec, J. A., Rakha, T., & Sang, A. (2013, August). Umi-an urban simulation environment for building energy use, daylighting and walkability. In 13th Conference of International Building Performance Simulation Association, Chambery, France (Vol. 1, pp. 476-483).
19. Residential Energy Consumption Survey (RECS) - Energy Information Administration. (2016). Eia.gov. https://www.eia.gov/consumption/residential/
20. Urban Modeling Interface | MIT Sustainable Design Lab. (n.d.). Web.mit.edu. Retrieved March 27, 2022, from https://web.mit.edu/sustainabledesignlab/projects/umi/index.html

PLEA SANTIAGO 2022
Will Cities Survive?

Multi-level microclimate analyses of Mediterranean grouped individual holiday housing in hot summer conditions

MARJAN SANSEN [1] ANDRES MARTINEZ [1] PHILIPPE DEVILLERS [1]

[1] LIFAM, Ecole Nationale Supérieure d'Architecture de Montpellier, Montpellier, France

ABSTRACT: How will cities survive? Worldwide, climate change has a rising impact on summer temperatures. This study contributes to the search of how to design future neighborhoods adapted to summer heat in peri-urban areas, as an alternative to individual housing. It researches the link between urban morphology and microclimate of Mediterranean grouped individual holiday housing in hot summer conditions. In order to do so, it combines architectural and engineering methods and analyses. The first ones consider multi-level typo-morphological analyses through re-drawing, the second ones consider multi-level on-site measures, bridging street spaces, intermediate outdoor courtyard spaces and indoor spaces. A first level of analysis links the street and the intermediate outdoor courtyard spaces, but no clear connection was observed. A second level of analysis links the intermediate outdoor and indoor spaces. The case study is holiday housing on the French Mediterranean coast, built in the '60s. Several of those '60s developments are considered precursors of bioclimatic architecture. The multi-level analyses allow to detect, quantify and under-build passive design strategies for hot summer conditions: courtyards can function as thermal buffers, but only when covered or when combined with wind accessibility and vegetation; partially buried walls' tempering effect leads to quasi-constant temperatures.

KEYWORDS: temperate Mediterranean climate, courtyard, grouped individual holiday housing, passive design strategies

1. INTRODUCTION

Climate change has a rising impact on temperatures worldwide. On the one hand, a phenomenon of Mediterranean sprawl is notified in France, towards the North and inlands: the "*Mediterraneanization*" of the French climate (DRIAS, 2020). On the other hand, the Mediterranean basin turns out to be a hot-spot of global warming, and even more so during summer months (Cramer et al., 2018). Predictions mention more and longer heat waves for the coming decades (Moussa et al., 2020). Hence the interest in studying summer conditions in Mediterranean areas.

This study researches the link between urban morphology and microclimate in Mediterranean grouped individual holiday housing in hot summer conditions. In order to do so, it combines architectural and engineering methods and analyses.

Kropf (Kropf, 2014) elaborated a framework for typo-morphological analyses. This method covers different scale-levels, going from urban tissue (neighbourhood), to streets and plots, to buildings and materials. The framework also shows the "*network of voids*", linking voids on different scales: street spaces, intermediate outdoor areas between buildings and streets (courtyards), and indoor rooms. These three voids, and their link to urban microclimate, are the focus of this research.

There's a link between urban morphology, urban microclimate and energy use (Adolphe, 2001; Taleghani et al., 2015). In literature, different methods are deployed to study this link. Mostly used are software simulations (Ratti et al., 2003), but others use morphologic and geometric indicators and equations (Adolphe, 2001) or on-site measures (Zakhour, 2015). Many of these studies focus on what is known as "urban canyons", or a symmetrical section of a certain length in city centres. However, Ali-Toudert studies irregularities in the urban canyon, or the effect of asymmetry, galleries, overhanging facades and vegetation on thermal comfort (through simulations) (Ali-Toudert & Mayer, 2007). This article also tackles irregularities in the urban canyon, in the shape of intermediate courtyards between the street and the building, (through on-site measures).

On street level, impacting parameters on comfort are openness to the sky, urban porosity and wind, orientation, building envelope, green and water (Ali-Toudert, 2007). On courtyard level, the question is raised whether those intermediate courtyards have a thermal buffer effect, like traditional courtyards or covered courtyards in the centre of the building (Diz-Mellado et al., 2021), and how they affect indoor comfort?

The hypothesis is that there are locations in the morphologies that are more or less cool and comfortable, and that these differences have an impact on the courtyard spaces and the interior spaces of the house.

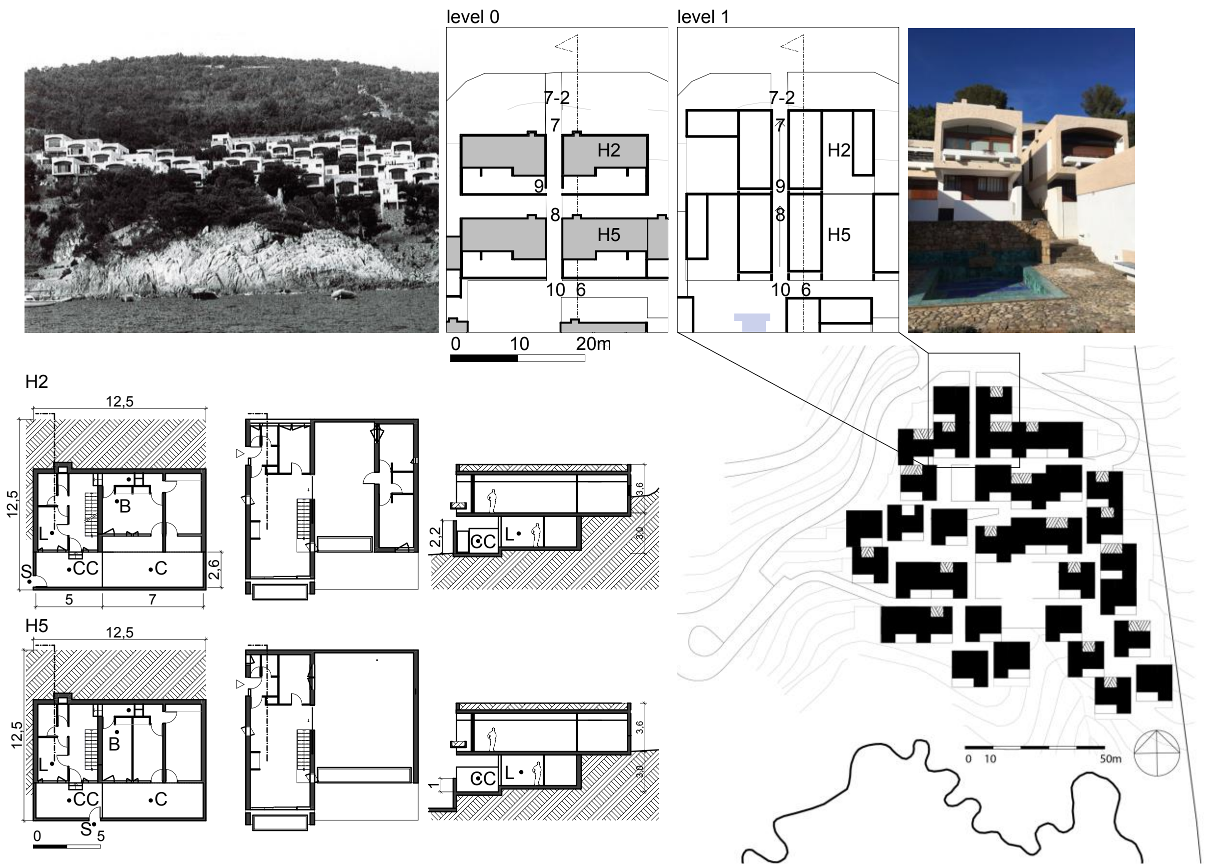
Former research demonstrated that this holiday housings is a fundamentally different morphology than a traditional urban downtown morphology (Sansen et al., 2021). The buildings only have a ground or first floor and are often separated from the street by a courtyard. In addition, the buildings are less compact than in a city center and there is more vegetation. So there are several passive design strategies typical to these neighborhoods that contribute to coolness: uphill building, tree vegetation, courtyards, covered courtyards, partially underground spaces (Sansen, 2021). On-site measures allow to quantify and under-build those passive design strategies in summer conditions.

2. CASE STUDY PRESENTATION

The case study is called the Merlier. It's grouped individual holiday housing in Ramatuelle, France (43° 11' 44''N 6° 39' 56''E), and was built in the '60 by the Atelier de Montrouge (Fig.1). It was developed especially for hot summer conditions, and several of those '60s holiday developments are considered precursors of bioclimatic architecture (Bartoli, 2020). The Village is located 30 m from the Mediterranean Sea at an altitude from 19 to 50 m (on a 23% slope).

Within the Köppen-Geiger classification, the village has a Csa climate: temperate Mediterranean with hot dry summers and mild humid winters. Table 1 gives an idea of typical mid-season and summer conditions, with data from the nearby Météo-France weather station in Cap Camarat. During summer months, mean temperatures around 24°C are current, although they reached 37,3°C in 2021. The main wind directions are NE and SW. Almost half of the time (51,6%) wind speed is less than 1,4m/s, and only 5% of the time, wind speed is higher than 4,4 m/s. Within the context of global heating, temperature rise in the case study village could reach 2,4 °C in 2100. This simulation is based on the moderate RCP 4,5 scenario of the last IPCC report (IPCC, 2021) and the data of the DRIAS portal

Figure 1:
Re-drawing of the case-study the Merlier in Ramatuelle, France



Note: Street level: Numbers 6 to 10: six strategic spots for on-site measures in the street.
House level: Outdoor sensors are in the street (S), the courtyard (C) and the covered courtyard (CC). Indoor sensors are in the adjoining spaces: laundry (L), bedroom (B); and in the hallway (H). Source of the upper left photo: (Blain, 2008, p.149)

Table 1:
Historical and mean mid-season/summer temperatures

Météo-France weather station in Cap Camarat					
T (°C)	MAY	JUN	JUL	AUG	SEP
Max hist.	32	34,9	36,9	37,3	33,4
Min hist.	4,8	9	13	11,8	9
Mean	17,3	20,9	24,1	24,4	21,2

3. METHODS
3.1 Re-drawing

The case-study was re-drawn using Archicad software, based on cadaster plans, original architects' plans and aerial pictures (Fig.1). On-site fieldwork completed this information.

3.2 Multi-level on-site measures

The on-site measures were organized on three levels: first a thermal walk in the morphology, looking for cool spots in order to narrow down the research area; then street measures in order to characterize the street's microclimate; and finally, house measures in the courtyards and indoor in order to study the courtyard microclimate and the indoor connection. Compared to typical mean temperatures (Table1), the days of the in-situ measures were warmer and rather windy (Table2).

The technical equipment consists of a measuring unit connected to three digital temperature and humidity sensors, and to an anemometer (Table3).

Table 2:
Météo-France's values during on-site measures

Météo-France	Tmax (°C)	Tmin (°C)	Tmean (°C)	Wind mean (m/s)
Morphology 07/07/2020	31,2	21,5	26,3	4,0
Street 08/07/2020	29,4	22,8	25,6	3,9
H2-Day1	25,8	21,6	22,9	5,8
H2-Day2	24,8	21,3	22,6	6,0
H2-Day3	27,8	21,0	23,9	4,7
H5-Day4	27,0	20,6	23,4	5,2
18-23/06/21				

Table 3:
Technical information of the measuring equipment

Sensor	Variable	Accuracy	Range	Resolution
Almemo D6	Dry bulb	± 0,3 K	-20 to 80 °C	0,01 K
	Temp RH	±1.8 %HR	0-100%	0,1 %hr
FVA 615-2	Wind	±0,5 m/s	0,5-50 m/s	0,1 m/s
HD403TS DeltaOHM	Air Speed	±0,2 m/s	0,1-5 m/s	-

For the street level measures, the lot is mounted on a geometer's tripod with a wooden wedge, which allows to fix the sensors at different heights. At the courtyard and house level, the technical equipment is doubled, and a hot wire sensor is added to detect indoor air movement (natural nocturnal ventilation).

On morphology level, a first analysis of morphologic and geometric indicators gave indications of areas with a strong potential of being cool in summertime (Sansen et al., 2021). Added to this, a thermal walk, wandering and exploring with a sensor at 1m (mean value of 30 seconds), allowed to detect, verify and confirm the neighborhood's "cool spots". Based on this information, a "cool street" was selected. The height of 1m above ground nears the human-biometeorologically significant height, or "*the average height of a standing person's centre of gravity in Europe*" (=1,1m) (Matzarakis et al., 1999).

On street level, a thermal profile was made in the "cool street", one day in summertime. Martin-Vide (Martin-Vide et al., 2003) makes itinerant thermal profiles, but on an urban scale and while moving by car. This approach is adapted to the scale of the village, doing semi-itinerant measures by foot: temperature, humidity and mean air speed are monitored every 5 minutes, on three different heights (h = 0,45m; 1m and 1,65m) and on six strategic spots (Fig.1). Those are selected concerning different street sections (H/W) and orientations, tree vegetation, topography and connection to courtyards. Results in this article only discuss the values of the sensor at 1m, since additional information of the other sensors is not relevant for this part of the research.

Finally, two houses were selected on the "cool street" (H2 and H5 in Fig.1). H2 is uphill, H5 downhill, and both of them have a partially underground ground floor. Both of them also have a courtyard (C) (H/W = 0,85 and 0,31) and a covered courtyard (CC) on the South side, in a lateral way and not in the center of the house. The courtyard of H2 is surrounded by walls. The courtyard of H5 is closed off by a parapet of 1m and vegetation. In addition, it is suspended with regards to the street. This kind of suspended courtyard in front of the house, characterized by a parapet and vegetation is common in surrounding traditional villages, like Gassin and Ramatuelle. On-site measures of temperature, humidity and mean air speed were taken simultaneously outdoors and indoors during four days, monitoring values every 15 minutes, at 1m above ground. The first three days monitored H2, the last day H5. The outdoor sensors are in the street, the courtyard and the covered courtyard; the indoor sensors are in the adjoining spaces (laundry and bedroom) and in the hallway, which is disconnected from the outdoor spaces and has an underground wall in the back (Fig.1).

Outdoor and indoor comfort are evaluated through Givoni's diagram. Although the diagram is essentially used for indoor comfort, it is considered precise enough and practical for architectural use (Fernandez & Lavigne, 2009), meaning it is a visually clear way to evaluate and compare the on-site measures.

In addition, the thermal gap (TG) between the outdoor temperature and the courtyard's microclimate is analyzed. TG is defined as the temperature difference between the maximum outdoor temperature (MOT) and the courtyard temperature (CT) (Diz-Mellado et al., 2021). MOT is monitored in the NS street for H2; EW street for H5.

3. RESULTS

On morphology level, the thermal walk detected cool spots. The coolest spots are in the shadow of a tree (7-2), a bush (next to 10), a building, a narrow street or a covered courtyard (next to 9). Within the same street, only a couple of steps away, temperature differences rise up to 8°C (between sunny 10 and a green and shady bush nearby 10). There's a difference of 2,1°C between the covered courtyard next to 9 and 9 in the shaded NS street. The selected "cool street" is oriented NS. It's a narrow street made of stairs, leading from a square downhill to a green area uphill. The street is surrounded by houses with one or two levels.

On street level, the results show a microclimate with impressive temperature differences, under the influence of S and SW winds, since early SE winds almost don't enter the street (Fig.2). Spot 7-2 stays under Météo-France's temperatures all day. It's an uphill spot, on the fringe of the village, touching the green area, like spot 7. They both are very windy (0,4 to 1,8 m/s). Spot 10 on the contrary, stays far above Météo-France temperatures all day. All measures in the EW street on the bottom of the hill (6 and 10), are not very accessible to wind (0 to 0,5 m/s). Sun heats up EW streets for a longer time than NS streets. Uphill 9 is between 0,6°C and 7,5 °C cooler than downhill 6. Uphill and green 7-2 is between 0,1 and 6,9 °C cooler than downhill 6.

All measures of uphill spots touching the green area (7, 7-2), are entirely within Givoni's comfort zone corresponding to the wind speed (Fig.3). All measures in the EW street on the bottom of the hill (6, 10), are out of Givoni's comfort zone. Spots 8 and 9 are partly in Givoni's comfort zone.

Figure 2:
Thermal profile of the cool street. Black arrows: Météo-France's wind direction. Black suns: sensor in the sun

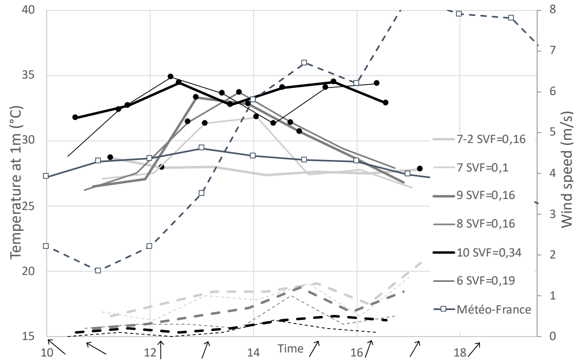


Figure 3:
Givoni's comfort diagram with the cool street measures

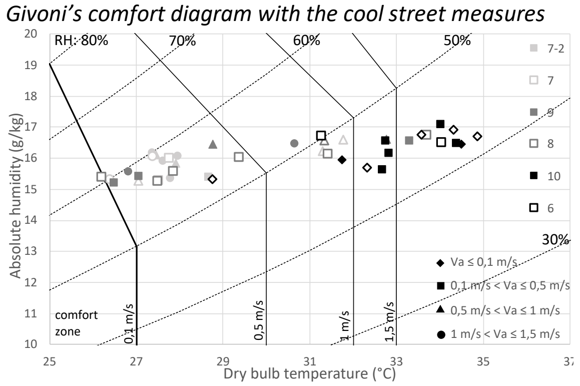


Table 4:
TG: the temperature difference between MOT and CT

	TG (°C)	Day1	Day 2	Day3	Day4
H2	Courtyard	1	-0,4	0,5	
	Covered	6,6	1,3	6,5	
H5	Courtyard				3,6
	Covered				6,7

On courtyard level, H2's courtyard measures are warmer than the NS street most of the time (up to 8°C!), even though they're slightly cooler than the MOT on days 1 and 3 (Table4). This means the courtyard functions like a hot spot, compared to the street, and certainly not like a cool spot. On the contrary, H5's TG between the courtyard and the EW street temperature is 3,6°C (Table4). Overall, it's cooler in the courtyard than in the street (Fig.4) indicating that it functions as a thermal buffer. Different from H2's courtyard, H5's has a 1m parapet and a suspended position, making it accessible to wind. Vegetation protects it from solar radiation. These lateral courtyards depend on their suspended position, vegetation and accessibility to wind to have a thermal buffer effect.

The TG between the CCs and the outdoor temperature is higher and goes up to 6,7 °C (Table4 and Fig.4), since they're protected from the sun most of the time. It is interesting to notice that the CC's temperature is lower than Météo-France's data during the day, and higher at night (Fig.4). The TG is 1,2 °C, meaning the CC has a cooling effect. At night, heat that was stored in the concrete construction during the day is released and blocked under the cantilever, so the CC cools less down than the street and Météo-France's measuring station.

Givoni's comfort diagram (Fig.5) confirms a majority of courtyard measures outside of the comfort zone; and a majority of CC measures within the comfort zone. Discomfort is caused by high humidity. Both houses' ground floors are partially buried in the slope, explaining the high humidity. H5's more comfortable and less humid than H2.

Concerning the indoor measures (Fig.6 and 7), the laundry (adjoining the CC) is warmer than the other rooms, during the day and at night, because it has two exterior walls in contact with the outdoor environment. The hallway stands out because its temperatures are quasi-constant, between 22 and 24°C. Thanks to the underground wall in the back and the tempering effect of earth, there's almost no outdoor influence.

4. DISCUSSION & CONCLUSION

Finally, when looking at the network of voids (Table5) and the link between street space and courtyard space, no clear connection is observed. The comfortable top-of-the-slope situation didn't create comfort in H2's courtyard. The uncomfortable situation downhill on the EW street, didn't create a discomfort in H5's courtyard. On the contrary. Uncomfortably high EW street temperatures make H5's humidity drop and comfort increase.

The link between the outdoor courtyard and indoor space is observable though. H5's indoor spaces are more comfortable, thanks to a well ventilated and more shaded courtyard (maximum temperature 30,4°C), that functions as a buffer zone between the street and the house. H2's indoor space is less comfortable and very humid. Its courtyard is less ventilated and temperatures rise up to 36,6°C.

Table 5:
Comfort overview: the network of voids

Comfort (%)					
Street		House Outdoor		House Indoor	
		H2			
7-2	100				
7	100			H	2,4
9	71,4	C	2,2	B	7,6
		CC	17,2	L	10,7
8	57	H5			
				H	46,5
10	0	C	22,9	B	45,8
6	0	CC	54,5	L	36,8

Figure 4:
Outdoor measure results of day 4 in H5
Arrows: TG between MOT and CT; between MOT and CCT; between maximum Météo-France temperature and CCT

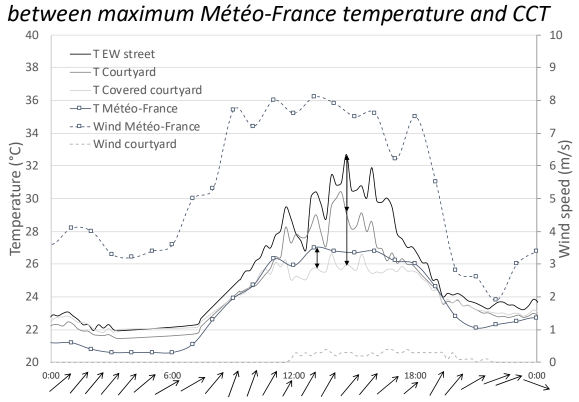


Figure 5:
Givoni's comfort diagram with the outdoor measures of H5

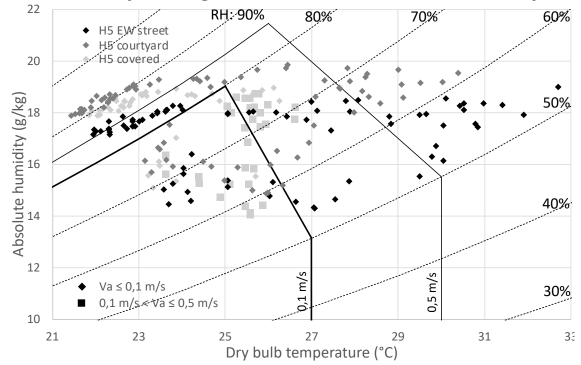


Figure 6:
Indoor measure results of day 4 in H5

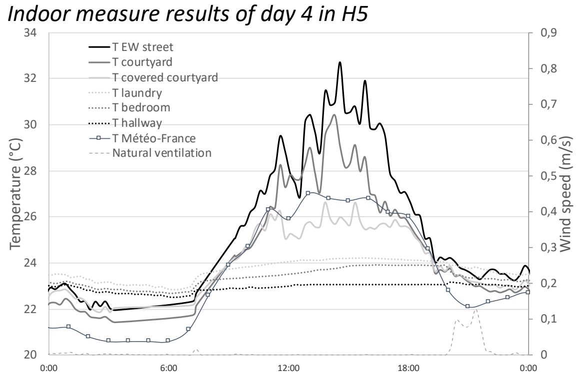
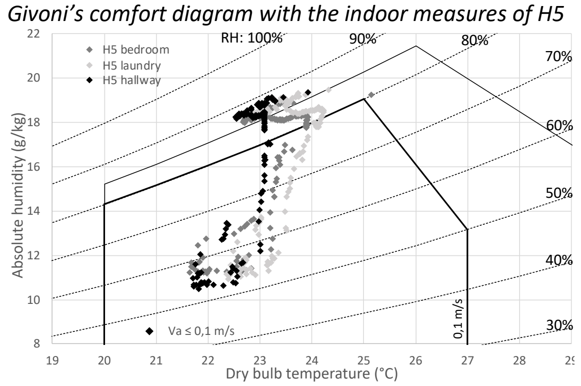


Figure 7:
Givoni's comfort diagram with the indoor measures of H5



H5's TG of 3,6 °C is comparable to the TG found in a courtyard study in Cordoba, Spain (between 2,5 and 8,4°C) (Diz-Mellado et al., 2021). Although Cordoba also has a Mediterranean climate, the study was conducted in more extreme summer conditions (maximum outdoor temperature of 37°C, compared to 27,8°C in this research). The studied courtyards are located in the center of the building, and they are less elongated (H/W = 0,81 and 0,87; compared to H/W = 0,85 and 0,31 in this study). They are less accessible to the sun. This research accentuates the importance of wind accessibility in temperate Mediterranean climate, in lateral courtyards. They sure knew what they were doing in nearby traditional villages, where planted suspended courtyards are thriving, and courtyards between the street and the building are rare. It also confirms the positive effect of covered courtyards in outdoor comfort (TG between 1,3 and 6,6 for H2, 6,7 °C for H5), compared to Diz-Mellado's values (up to 15,4°C) for a courtyard covered with textile (Diz-Mellado et al., 2021).

So going back to the initial question "how will cities survive?", this research claims that courtyards can function as thermal buffers in temperate Mediterranean climate, but only when covered, or when combined with wind accessibility and vegetation. In addition, courtyard microclimate is not the only passive design strategy affecting indoor comfort here. The partially buried walls in the slope and the tempering effect of earth lead to quasi-constant temperatures and contribute much more. Although humidity becomes an issue when houses are partially embedded or buried, the cooling potential is huge.

ACKNOWLEDGEMENTS

The authors wish to acknowledge FEDER – Région Occitanie's funding for OEHM – Optimisation Energétique de l'Habitat Méditerranéen.

REFERENCES

1. Adolphe, L. (2001). A Simplified Model of Urban Morphology: Application to an Analysis of the Environmental Performance of Cities. *Environment and Planning B: Planning and Design*, *28*(2), 183–200.
2. Ali-Toudert, F. (2007). Sustainability and Human Comfort at urban level: Evaluation and Design Guidelins. *Proceedings of the International Conference on Sustainable Buildings*, *Part 2*, 702–709.
3. Ali-Toudert, F., & Mayer, H. (2007). Effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons. *Solar Energy*, *81*(6), 742–754.
4. Bartoli, P. (2020). *Habiter les vacances*. Marseille : Editions Imbernon.
5. Blain, C. (2008). *L'Atelier de Montrouge—La modernité à l'oeuvre (1958-1981)*. Paris : Actes Sud / Cité de l'architecture & du patrimoine.
6. Cramer, W., Guiot, J. et al. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, *8*(11), 972–980.
7. Diz-Mellado, E., López-Cabeza, V. P., Rivera-Gómez, C., Galán-Marín, C., Rojas-Fernández, J., & Nikolopoulou, M. (2021). Extending the adaptive thermal comfort models for courtyards. *Building and Environment*, *203*, 108094.
8. DRIAS. (2020). *Les nouvelles projections climatiques de référence DRIAS 2020 pour la métropole* (p. 98).
9. Fernandez, P., & Lavigne, P. (2009). *Concevoir des bâtiments bioclimatiques*. Paris: Éditions le Moniteur.
10. IPCC (2021). *Climate Change 2021—The Physical Science Basis*.
11. Kropf, K. (2014). Ambiguity in the definition of built form. *Urban Morphology*, *18(1)*, 41–57.
12. Martin-Vide, J., García, M. C., & Esteban, P. (2003, January). *Spatial differences in the urban heat island of the Pre and the Post-olympic Barcelona (Spain)*. 5th International Conference on Urban Climate, Lodz.
13. Matzarakis, A., Mayer, H., & Iziomon, M. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology*, *43*, 76–84.
14. Moussa, R., Najem, W., Bocquillon, C., & Allam, A. (2020). Specific climate classification for Mediterranean hydrology and future evolution under Med-CORDEX regional climate model scenarios. *Hydrology and Earth System Sciences*, *24*(9), 4503–4521.
15. Ratti,C., Raydan,D., & Steemers,K.(2003). Building form and environmental performance: Archetypes, analysis and an arid climate. *Energy and Buildings*, *35*(1), 49–59.
16. Sansen (2021). L'intuition conceptuelle à la base d'une approche climatique. *Pré-Actes-6èmes RDNAP*, 189–201.
17. Sansen, M., Martínez, A., & Devillers, P. (2021). Mediterranean Morphologies in Hot Summer Conditions: Learning From France's "Glorious Thirty" Holiday Housing: *Journal of Contemporary Urban Affairs*, *5*(1), 19–34.
18. Taleghani, M., Kleerekoper, L., Tenpierik, M., & van den Dobbelsteen, A. (2015). Outdoor thermal comfort within five different urban forms in the Netherlands. *Building and Environment*, *83*, 65–78.
19. Zakhour, S. (2015). The impact of urban geometry on outdoor thermal comfort conditions in hot-arid region. *Journal of Civil Engineering and Architecture Research*, *2*, 862–875.

Learning sustainable design from modern Egyptian architecture

How the Pre-HVAC residential buildings of Sayed Karim embody contemporary sustainability principles

MAHMOUD ELKADY [1] SHERIF GOUBRAN [1]

[1] Department of Architecture, School of Sciences of Engineering (SSE), American University in Cairo

ABSTRACT: HVAC proliferation has had a lasting effect on architecture, forcing buildings to comply with the infrastructural and newly acquired physiological requirements. This paper sheds light on the sustainable and ecological design inspirations that pre-HVAC modernism can offer. The study critiques the exclusion of Global South modernist architecture from the sustainability movement– often overlooking their concern for passive means of ventilation for the sake of reductionist and orientalist understandings of vernacular examples. It does so by investigating Egyptian modernist architecture and theories. Through a structured thematic analysis of Egyptian Modernist Sayed Karim's (1911-2005) work, the paper proposes a more integrated, holistic, and critical understanding of the many meanings of "sustainable architecture." This research portrays this by examining evidence of sustainable design principles in the architect's work, emphasizing passive environmental control strategies. In addition to the critical sustainability lessons extracted from the modern Egyptian residential buildings, the qualitative analysis of archival documents highlights that social and economic dimensions of sustainable development are key themes that guided the architect's design thinking. The analysis presented opens a new venue for how today's sustainable architecture movement can benefit from Global South modernism, taking passive ventilation strategies as precedent.
KEYWORDS: Modernism, Passive, Ventilation, Sustainability, Sayed Karim

1. INTRODUCTION

In the sustainability discourse, modernist architecture is often blamed for the generation and perpetuation of irresponsible practices that negatively contribute to the environment. Vandevyere and Heynen argue that "the […] discourse should be conceived as a […] revised version of the paradigm of modernism" altogether, instead of pitting them against each other [1]. They recommend that modernism should not be conflated with technocratic paradigms and that sustainability should avoid searching for a "singular optimal technological pathway" [2]. Despite ongoing efforts by academics and practitioners to deconstruct current notions of sustainability, sustainability is yet to integrate the rich contributions of modernism.

A point of contention in the history of modernism is the proliferation of heating, ventilation, and air conditioning (HVAC). HVAC proliferation has had a lasting effect on architecture, forcing buildings to comply with the infrastructural and newly acquired physiological requirements. This paper sheds new light on the sustainable and ecological design inspirations that pre-HVAC modernism can offer. It does so by investigating Egyptian modernist architecture and theories. The study critiques the exclusion of Global South modernist architecture from the sustainability movement– often overlooking their concern for passive means of ventilation for the sake of reductionist and orientalist understandings of vernacular examples. Through a structured thematic analysis of Egyptian Modernist Sayed Karim's (1911-2005) key works, the paper proposes an integrated, holistic, and critical understanding of the many meanings of "sustainable architecture" that can benefit our academic discourse and current design practices. Passive environmental control strategies and socio-economic considerations of the end-users are explored and explained to build on the existing literature that calls for incorporating international modernism with sustainable theories.

2. BACKGROUND AND THEORETICAL APPROACH

The integral role of sustainability in architectural academe, practice, and research is a testament to its close connection to history, natural science, culture, politics, and capital [2-4]. It is natural to expect that sustainability will continue to play a pivotal role, especially with the imperative risks of the Anthropocene. In order to advance sustainable architecture, Owen and Dovey propose to position "both sustainability and architecture as social practice" [4]. This would represent the natural transition expected from the sustainability discourse, as the scope of practice and theory gradually increased as the transition from "green" to "eco-" to "sustainable" took place [5]. Guy and Framer contest the positivist assumptions underpinning sustainable architecture practice and research and urge adopting a social constructivist perspective instead. Jarzombek even explains that the concept of sustainable architecture itself has a lot to learn, as it has not yet successfully replaced the socio-political parameters it counters [2, 6]. Despite the emergence of modernism before the establishment of modern sustainable design theory, sustainability, both ideals share foundational ethos.

Modernism and sustainability are not mutually exclusive but are highly compatible in different respects. When technology and sustainability are brought up, we consider the vernacular a nobler precedent than modernism [7]. Harlow et al. showcased how the sustainability discourse history is intertwined with utopian themes, almost congruent with utopian themes of modernist architects and thinkers [8]. As such, modernism can be inferred to be intrinsically sustainable and intellectually concerned with the betterment of human lives through the built environment, including environmental and ecological scopes understood today through sustainability. Therefore, it is anachronistic to disregard modernist architecture in the current sustainability discourse for failing to adhere to contemporary practices and objectives.

Modernism can be construed as the enabler of mechanical ventilation. However, Barber explains in Modern Architecture and Climate [9] that HVAC successfully hijacked the modernist movement since its commercial inception in the 1930s. Barber's book exhibits the sensitive design consideration of Le Corbusier and other architects to environmental control by examining the detailed drawings of their buildings. Through the work of Olgyay and the marketing of HVAC, occupational expectations and building requirements changed to accommodate the newly founded necessity of air conditioning. Air conditioning, not modernism, relieved architects from the constraints of passive ventilation requirements and allowed for thinner building shells and skins [10].

To reconsider modernism's place in sustainability, it is advisable to reassess the reductionist and romantic notions that embody vernacular architecture. Lara suggests that modernism can be made vernacular, explaining through his study of modernist Brazilian architecture that modernism should not be conceived as the opposite of the vernacular, but both are instead in a dialectical relationship [11]. Such emerging scholarship on vernacular architecture deconstructs the boundaries and strict connotations attached to modernism when considering the sustainability discourse, especially after reconsidering how HVAC came to take hold of our building practices. It is, therefore, necessary to work towards "Sustainable Modernism" through the adoption of modernism's legacy and "accepting that there is continuity between the desire to be modern and the imperative to be sustainable" [12].

Published literature rarely studied or reflected pre-HVAC modernist buildings of Egypt from an ecological lens. Specifically, and to the best of the authors' knowledge, no previous research has studied how modernist Egyptian buildings and architects have addressed contemporary sustainability concerns: the environmental, social, economic, and cultural dimensions.

3. METHODOLOGY

The selected paradigm of the research is shared with Vandevyvere & Heynen, which is the epistemological stance on a modern architecture that presumes the environmental, ecological, social, and technical stances of modernism as part and parcel of sustainability [1]. A combined research strategy was used to describe, explore, and explain pre-HVAC Egyptian modernist architecture, to develop current theoretical arguments pertaining to modernism's place in sustainability. The first research strategy entailed an interpretive-historical analysis of the modernist architecture precedents studied to evaluate the relevance of its design decisions to sustainability in a qualitative manner and to identify a standardized design theme to be explored across the formative building components identified. Inspired by Lara's work on Brazilian modernism, the second research step is a formal analysis of the design objectives and tools employed in the formative examples identified.

For this research, the work of Egyptian architect Sayed Kareem was selected since it falls within the pre-HVAC category proposed by Ashour [13]. Sayed Karim produced many architectural works, but he was also an influential figure in the architectural field. He voiced his opinions and concerns over the city's future in his magazine (Al'Imara), his book Ishtirakyat Al Villa, and numerous newspaper articles. The selected works mostly fall before the proliferation of HVAC in Egypt, and where drawings, writing and architectural texts are available for analysis.

Sayed Karim's archive, which is housed at the American University in Cairo's (AUC) Library, was used to collect data. The documents used for the analysis included the drawings for the selected buildings and Karim's writings. Additionally, architecture journals and magazines were used to trace the social production of space in time. These provide an essential source for this contextual dimension, showcased by El-Ashmouni's examination of Alam Al Benaa [14]. Relevant issues of Al'Imara magazine, which showcased and analyzed Karim's works, were used as a secondary source.

In order to assess Karim's sustainable design principles, the criteria of selection were confined to residential buildings designed between 1945 and 1960, well beyond the emergence of HVAC as a viable climatic control solution for residential architecture in Egypt. Therefore, the following buildings were selected for analysis: El Maadi Building (circa 1945); Al Goheni Building, Heliopolis (1948); Zamalek Tower (1953); and Housing Model 10, Nasr City (1959).

Figure 1:
El Maadi building, AUC RAC.

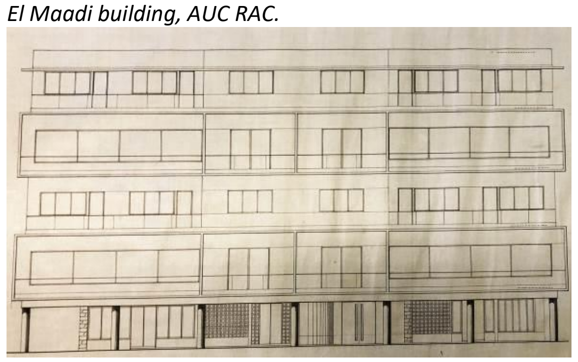


Figure 2:
El Goheni building, Al'Imara Magazine.

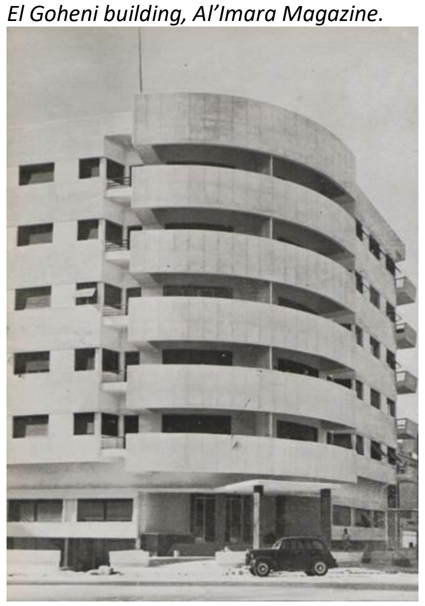


Figure 3:
Zamalek tower, Al'Imara Magazine.

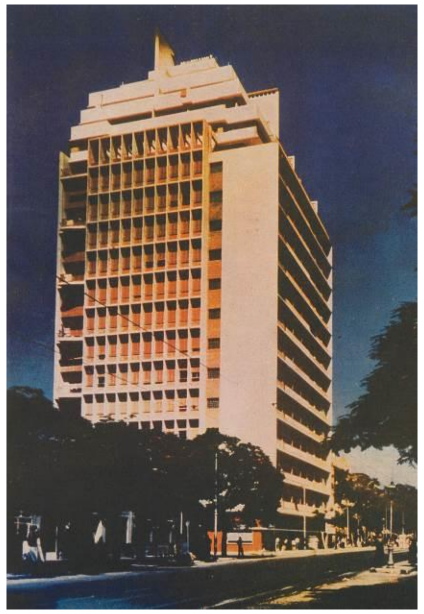
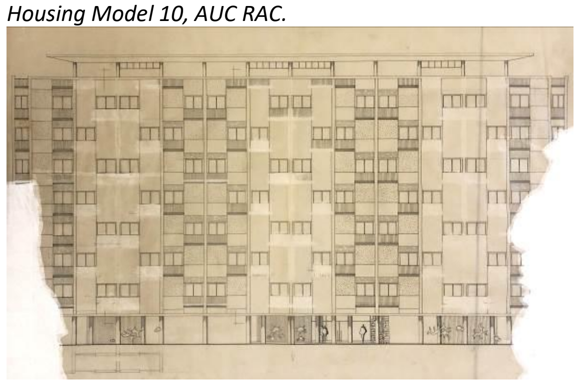


Figure 4:
Housing Model 10, AUC RAC.



3.1 Data Analysis

The investigation involved critically assessing the drawings of the buildings while exploring Karim's writings in Al'Imara magazine. The data was derived from the architect's archives and secondary sources. Based on the historical interpretation of Karim's archival material, solar shading and natural ventilation were identified as the most prominent design concerns considered in his writings (and, by extension, his designs). Given the research's premise that HVAC diluted environmental and sustainability concerns in modern architecture, natural ventilation was chosen to be the theme for the formal analysis of the four buildings.

The formal analysis of the design drawings and sketches investigated the manifestation of natural ventilation concerns in the architectural and experiential designs of the buildings. Similar to Lara's analysis of local Brazilian modernist examples, several iterations of graphical analyses and exercises were conducted, with the primary objective of identifying and explaining the ventilation techniques employed. It is important to note that the intent was not to identify design patterns but to explore the nuances of Karim's ventilation strategies employed in the selected buildings.

In exploring passive ventilation strategies, the initial analysis highlighted the importance of cross ventilation in the four buildings. As such, the detailed formal analysis focuses on identifying and describing passive ventilation design in the typical floor plan. The North and prevailing wind directions were identified for each building before cross-ventilation paths were studied based on the inlet-outlet pressure difference.

4. FINDINGS AND IMPLICATIONS

The formal analysis conducted on the four buildings showcased a variety of design approaches to cross ventilation. While the analysis of each building reveals a different degree of concern for ensuring adequate cross ventilation for all units, it is clear that massing and fenestration were made use of in all selected buildings to include an inlet and an outlet—even in spaces that do not enjoy more than one orientation.

It is difficult to identify a specific design pattern across the four buildings regarding ventilation (and more generally towards environmental control). Instead, each design is a unique response to the specific site restrictions, programmatic needs, and the dynamic socio-political forces of the period. The buildings revealed different design priorities given to functional, environmental, socio-cultural, and aesthetic motivations. A case in point is the difference between Al Goheni building and Zamalek tower, where the former showcases careful attention to create cross-ventilation in six out of eight non-wet rooms and spaces, even at the cost of larger areas. On the other hand, Zamalek Tower, designed to be a monumental example of modern living for Cairo's elite, gave more importance to maximizing utility and views than ensuring cross ventilation. Zamalek tower's floor plan reveals several unaddressed opportunities for creating cross ventilation (such as creating a staggered form or adding fenestration to walls inclined at angles larger than 90 degrees) highlighting the aesthetic and socio-economic concerns of the design. The tower's powerful and solid eastern façade is a primary reason for limiting cross ventilation to only five out of the floor plan's thirteen non-wet rooms.

Figure 5:
El Goheni building's cross-ventilation analysis.

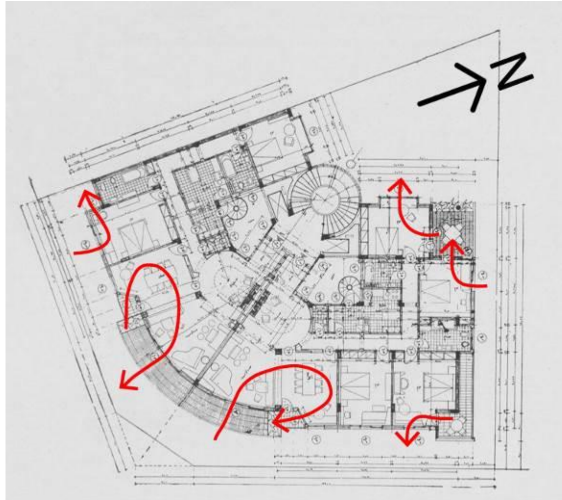
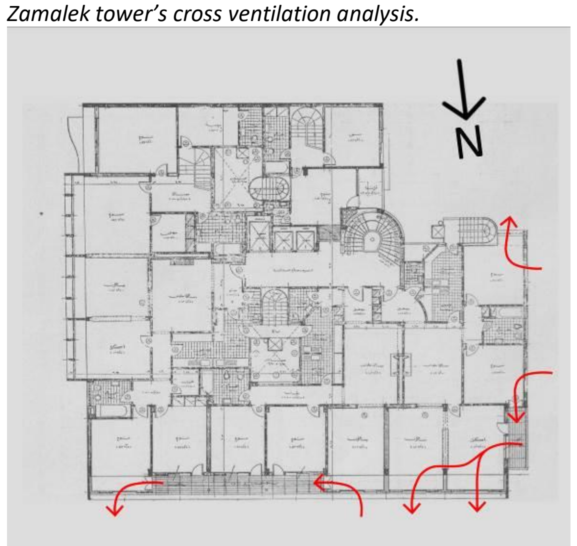
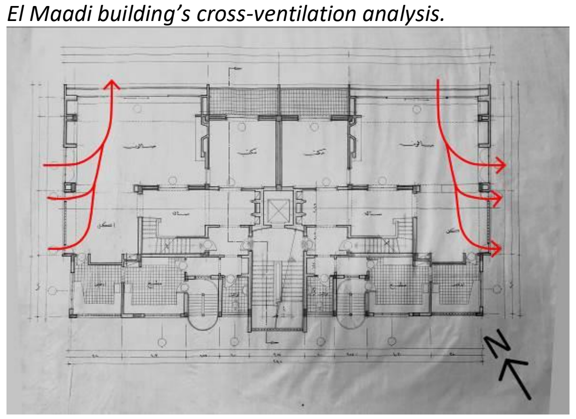


Figure 6:
Zamalek tower's cross ventilation analysis.



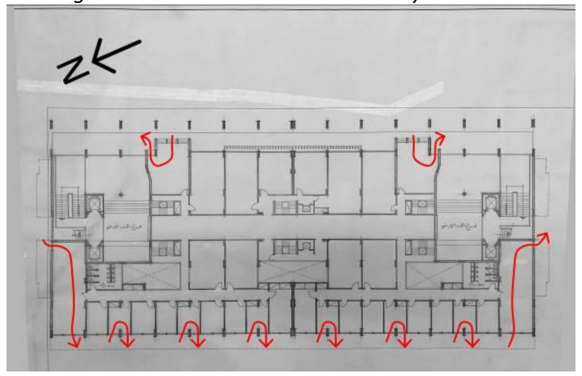
For El Maadi building, a much more straightforward design approach was adopted. Characterized by an open floor plan, the duplex apartments' lower floors have large living spaces that stretch across two orientations. Since the top floor plans and sections are missing from the floor plan, it is difficult to predict if cross ventilation was designed for the bedrooms.

Figure 7:
El Maadi building's cross-ventilation analysis.



Housing Model 10, the latest building out of the four, is an excellent example of Karim's socialist ideals for post-revolution Egypt. The floor plan available at the AUC archive, shown in figure 8, is a draft of the building's "forgotten floor," a signature trademark of Karim's mixed-use housing [15]. The forgotten floor houses office buildings on the first floor, while the rest of the buildings are dedicated to apartments. Many of the extruding columns create wings that would lead to a pressure difference, therefore greatly enhancing stack effect, either by design or by accident.

Figure 8:
Housing Model 10's cross-ventilation analysis.



Given the striking differences in cross ventilation strategies explored through the formal analysis, it is evident that natural ventilation was one of Sayed Karim's many sustainable design concerns. The analysis of ventilation design elements and configurations indicates that natural ventilation was a necessary element, even if not present in all rooms, in pre-HVAC residential architecture. The variety of design approaches described exemplifying how natural ventilation was integrated with other design concerns, sometimes taking precedent and other times curtailed for more pressing design intentions.

5. DISCUSSION

The results lead to an understanding of modernist architecture that is aligned with Vandevyvere & Heynen's stance on the parallels between modernism and contemporary sustainable development values [1]. The formal analysis, along with Karim's writings, shed light on Egyptian modernism's thoughtful integration of sustainability, indicating that there is indeed a philosophical common ground between modernism and sustainability [16].

Studying passive environmental control methods can help us recognize that sustainability is an academic construct, one that can be limiting and anachronistic [6, 16]. Sustainable design and research can benefit tremendously from studying modernist designs and theory. Instead of being its "absolute counterpoint" [1], Egyptian modernist architecture, and other Global South (and North) examples, can supplement sustainable architecture, specifically in climates similar to Egypt's hot and dry desert conditions [16].

6. CONCLUSIONS

Natural ventilation in Egyptian modernism is just one example of the intricate ways sustainability was practiced by Global South architects. Rather than being an active design motivation, natural ventilation was a defacto necessity, a design requirement that bled into the design's social, economic, functional, and aesthetic concerns. Although natural ventilation was not a primary concern in the design of the selected buildings, the takeaway is that it was always incorporated, with additional room for enhancement had Karim sought it as a primary objective.

Instead of retrofitting sustainable practices—as is the case with contemporary architecture when it refers to vernacular architecture for inspiration—modernist architecture can remind us of the importance of weaving passive climatic control strategies into our designs.

ACKNOWLEDGMENTS

We would like to thank and acknowledge the support provided from the American University in Cairo, through the Undergraduate Research Program and other research funding that made it possible to complete this work. The authors would also like to acknowledge the technical assistance of Balsam Saleh and Muhammad Feteha from the Rare Books and Special Collections at the AUC Library, as well as the guidance provided by Dr. Momen El-Husseiny during the dissertation thesis academic course, which helped in the development of this research.

REFERENCES

1. Vandevyvere, H., & Heynen, H. (2014). Sustainable development, architecture and modernism: Aspects of an ongoing controversy. Arts, 3(4), 350–366. https://doi.org/10.3390/arts3040350
2. Ibid.
3. Jarzombek, M. (1999). Molecules, money and design: The question of sustainability's role in architectural academe. Thresholds, 18, 32–38. https://doi.org/10.1162/thld_a_00500
4. Owen, C., & Dovey, K. (2008). Fields of sustainable architecture. The Journal of Architecture, 13(1), 9–21. https://doi.org/10.1080/13602360701865373
5. Madge, P. (1997). Ecological design: A new critique. Design Issues, 13(2), 44. https://doi.org/10.2307/1511730
6. Guy, S., & Farmer, G. (2001). Reinterpreting sustainable architecture: The place of technology. Journal of Architectural Education, 54(3), 140–148. https://doi.org/10.1162/10464880152632451
7. Vellinga, M. (2013). The noble vernacular. The Journal of Architecture, 18(4), 570–590. https://doi.org/10.1080/13602365.2013.819813
8. Harlow, J., Golub, A., & Allenby, B. (2011). A review of utopian themes in sustainable development discourse. Sustainable Development, 21(4), 270–280. https://doi.org/10.1002/sd.522
9. Barber, D. (2020). Modern architecture and climate: Design before air conditioning. Princeton University Press.
10. Arnold, D. (1999). The evolution of modern office buildings and air conditioning. ASHRAE Journal, 41(6), 40.
11. Lara, F. L. (2009). Modernism made vernacular: The Brazilian case. Journal of Architectural Education, 63(1), 41–50. https://doi.org/10.1111/j.1531-314x.2009.01027.x
12. Vandevyvere, H., & Heynen, H. (2014). Sustainable development, architecture and modernism, 350–366.
13. Ashour, S. (2017). Pioneer Egyptian architects during the Liberal Era (1919-1952). Sharikat Art Sbūt lil-Daʻāyah wa-al-Iʻlān.
14. El-Ashmouni, M. (2013). The rationale of architectural discourses in post-independence Egypt: A contrapuntal reading of 'Alam al-Bena'a (1980-2000). University of Adelaide.
15. Elshahed, M., & Volait, M. (2020). Cairo since 1900: An architectural guide. The American University in Cairo Press.
16. Kady, M. M. El, & Goubran, S. (2022). The Sustainability of Egyptian Modern Architecture. International Conference on Sustainability: Developments and Innovations (ICSDI).

PLEA STGO 2022

November 22 - 25, 2022

ANALYSIS AND METHODS

DAY 02
12:00 — 13:30

CHAIR
MASSIMO PALME

PAPERS
1320 / 1257 / 1161 / 1277 / 1177 / 1335

21TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022

Will Cities Survive?

A First Look at Italian Cloisters Resilience to a Changing Climate

The case of San Sepolcro in Parma (IT)

ELEFTHERIA TOULOUPAKI [1] BARBARA GHERRI[2] EMANUELE NABONI[2]

[1] Department of Civil Engineering, Aristotle University of Thessaloniki
[2] Department of Engineering and Architecture, University of Parma

ABSTRACT: Urban environments have been facing increasing average temperatures and more frequent heat waves due to climate change. This represents an even greater challenge for historical cities, courtyards, and cloisters, where restrictions due to conservation call for calibrated thermal resiliency strategies based on thorough assessment. In this study, the resilience of the San Sepolcro cloister (a form of enclosed courtyard used in monasterial architecture) in Parma is assessed in response to future climatic conditions. Using the software ENVI-met, a microclimatic model is created, and microclimate is simulated for the present (2020) and a future scenario (2080) for the hottest day of summer, to investigate overheating mechanisms in the context of a historical urban district. Finally, results are analysed and possible strategies to address overheating in the future, in the building and urban scale, are sketched.

KEYWORDS: Climate change, Thermal resilience, Courtyard, Cloister, Microclimate

1. INTRODUCTION

With more than half of the world population living in cities [1] and climate change intensifying during the last decades, the need to address increasing average temperatures and frequent heatwaves in urban environments is more relevant than ever. The challenge is greater for historical cities, where architectural mitigation and adaptation measures need to be foreseen in accordance with conservation regulations.

Climate change is currently impacting cultural heritage globally. Despite enhancements in the understanding of the relationship between climate and buildings during the last decades, there are still knowledge gaps hampering the adaptation of historical typologies, such as the courtyard and cloister, in the microclimatic variation of future climates with no literature discussing the specific matter at the time of writing. The proposed research aims at identifying how cloisters (typical courtyards with a history of more than 5000 years) are responding to the harsh effects of climate change in the dense urban fabric of Parma.

This computational study, based on the ENVI-met software tool, attempts to make a first step towards understanding the thermal resilience of a representative cloister, today and in future climatic conditions. According to [2], a space is thermally resilient if it is able to achieve locally desirable thermal levels despite the overarching event of climate change. The desirable thermal levels would be those that are comfortable to people and that are positively allowing the ecosystem to evolve. Such thermal thresholds cannot be defined universally, but rather they should be studied locally [2]. On such bases this study is intended to act as the beginning of further speculations on possible architectural strategies leading to resilience.

2. BACKGROUND

Parma is a city located in the region Emilia-Romania, Italy. The dense urban fabric of the city is made of historical buildings framing several courtyards and patios. A recurring typology is the “cloister”, an open courtyard that connects spaces through a surrounding, covered, walkway/arcade. The diffusion of cloister buildings in the historical urban fabric is very relevant: the city of Parma is dotted with 24 cloisters (Fig. 1), associated with as many monastery or convent buildings. The cloister of San Sepolcro, here assessed, was built in the Renaissance period and its original form is almost entirely preserved.

Understanding a cloister’s thermal behaviour, now and in the future, is the first step towards the implementation of architectural climatic transformations. Only a few studies begin to frame the need of specific future projections [3-5], but none deals with the specific matter.

2.1 The importance of Italian cloisters in the urban fabric

The Italian cloister is a square or rectangular courtyard surrounded by a semi-open space that connects the main ecclesiastical building with the remaining rooms/spaces of the convent or monastery. Cloister galleries are usually formed by an arcade of columns and the courtyard includes a well and a garden [6]. The porticoed space can, in some cases, be distributed on one or two levels creating two overlaid orders of arches. In monastery buildings, the cloister plays the role of a secluded space, informed with strong spiritual and symbolic values. It is the meeting place of monastic community life, where monks and nuns pray and enjoy the outdoors, without leaving the building. Its origins are found in the peristyle of the Greek house, of Egyptian inspiration, later furtherly developed in the Roman house [7]. The archetypal form of the Italian cloister courtyard was defined by regular polygons (rectangular, square) [8].

Figure 1:
The city of Parma (IT) and its 24 cloisters.

Source: Authors.

2.2 The Cloister of San Sepolcro

The church of San Sepolcro is located at the eastern part of Parma (latitude 44.800150, longitude 10.335580) and was built in 1100. The convent was erected in 1257, and the cloister itself dates back to 1493-95. The Renaissance cloister comprises a single-story, square plan, without any loggia on the upper storeys. It has three porticoed sides, each featuring six round arches in sandstone, while its north side was buffered in the 19nth century to create a closed, south-facing façade. The arcades of the cloister overlook the green central space, where several trees such as figs and pomegranates grew (Fig. 2).

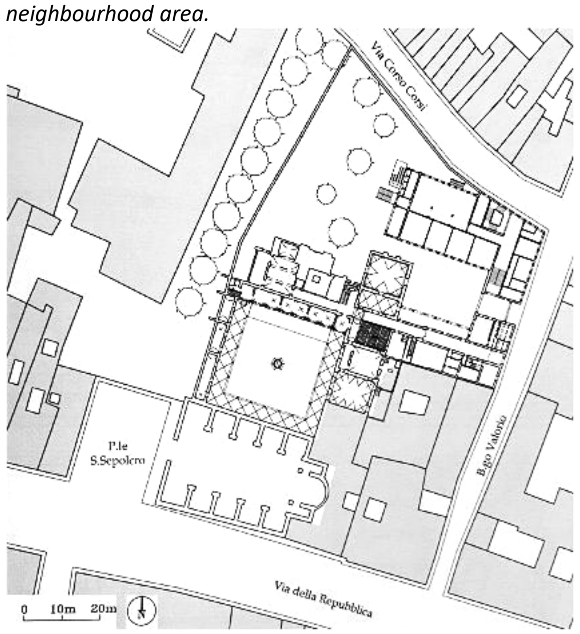
The surrounding area of the cloister consists of two open areas in the west and north (Piazzale San Sepolcro and a large courtyard), Via della Repubblica in the south and two smaller streets in the north-eastern part.

3. METHODS

The microclimate model of the cloister and its surroundings was set up in two phases. Firstly, a 3d parametric model was created in Rhinoceros [9] using Grasshopper and the Dragonfly components of Ladybug Tools [10], and then this was transferred to the ENVI-met [11] software for fine-tuning and setup of the simulation.

ENVI-met is a three-dimensional prognostic software, used to simulate the interaction between air, plants, and surfaces within an urban environment. ENVI-met supports the analysis of the impact of the Urban Heat Island (UHI) phenomenon on the outdoor thermal comforts of different urban patterns and the evaluation of heat mitigation strategies.

Figure 2:
The cloister and church of San Sepolcro and the assessed neighbourhood area.



Source: [8]

The paper assesses two different climate scenarios: the present (the year 2020 was used) and the projected 2080, based on two climate datasets. A customized EPW file of Parma was used as a contemporary climatic reference. The 5th of August was selected for simulation, considering it was the hottest day of both years, hence the most critical in terms of overheating. Preheating of building masses was considered by computing one day earlier, making the total simulation period 56 hours, starting from 00:00, 4th of August and finishing at 07:59, 6th of August.

The Meteonorm Climate Generator [12] was employed to project the 2080 climate scenario based on the Intergovernmental Panel on Climate Change (IPCC) scenario SSP2 - 4.5 [13], which is a scenario with intermediate GHG emissions and CO_2 emissions remaining around current levels until the middle of the century.

3.1 3d parametric model

The geometry of the examined district was originally extracted from OpenStreetMap [14] and imported to Rhinoceros 3D representation software in .obj form. Necessary modifications were made to the 3d model according to surveys made by the authors in July 2021. The Dragonfly components inside Grasshopper were used to create the digital spatial model with materials, which was then imported to ENVI-met for the addition of vegetation, receptor points and final preparation for the simulations.

3.2 ENVI-met model

Starting from the Envi-met database, a set of customised materials was created, to better represent local finishing materials. Building materials identified through surveys in the area were light and dark plaster, exposed brick, and roof tiles (Table 1).

Table 1:
Wall/roof material properties used for the simulation.

Material description	Absorption (%)	Reflection (%)
Light plaster	35	55
Dark plaster	70	20
Exposed brick	55	10
Roof tiles	70	20

Similarly, pavement/road surfaces identified in the study area were asphalt, red basalt (stone), granite and smashed brick (Table 2). The thermo-physical properties of the above finishings were modelled according to literature sources and inserted in the project database.

Table 2:
Pavements' material properties used for the simulation.

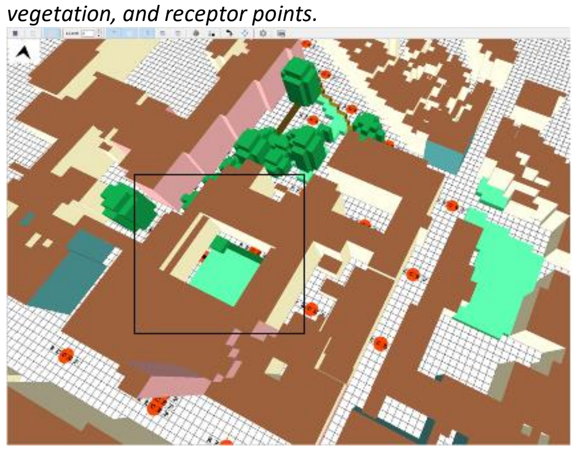
Material description	Albedo value
Red basalt road	0.80
Asphalt road	0.10
Smashed brick	0.75
Granite pavement	0.10

A grid resolution of 2.3 m (x) by 2.3 m (y) by 2.3 m (z) was used for the setup of the model, with a telescopic factor of 10% after the height of 15 meters, which covered all buildings except for the San Sepolcro church's bell tower. A total area of 276 m per 301 m was thermally assessed. Finally, four different kinds of trees with a deciduous profile and high leaf area density (LAD) were created, to account for different heights and canopy shapes, which were then inserted in the microclimate model, along with the grass surfaces of the analysed area (Fig. 3).

Several receptor points were put in place on the surface of surrounding street canyons, courtyards, and open spaces, as well as in the cloister centre, under/ in front of the three arcades, and finally in front of the closed south facade. Full forcing of all meteorological data with a 30 second update interval was used for the simulation.

All thermal parameters were accounted and utilizing the BIO-met software, the Universal Climate Index (UTCI) was calculated for the study area, as suggested by EU COST Action 730 [15]. The calculation is based on a simplified regression model by Peter Broede.

Figure 3:
ENVI-met 3d model with the representation of materials, vegetation, and receptor points.



Note: The cloister can be seen inside the square frame.

4. SIMULATION RESULTS

Simulation results reveal the thermal patterns for the area of study during the 5th of August, as the hottest day of the years 2020 and 2080, with a special focus to hour 15:00 when the worst thermal conditions occur, at the pedestrian level (height= 1.5 m). Data from 2020 and 2080 are compared by the terms of absolute difference in order to reflect on thermal resilience.

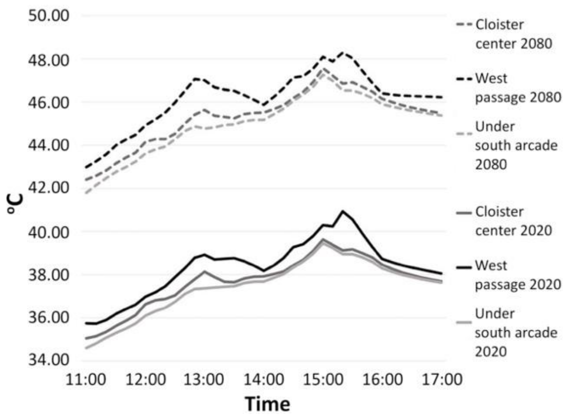
Results were produced for air temperature in front of facades (3d representation) as well as potential air temperature, wind speed, relative humidity, mean radiant temperature and UTCI (height=1.5 meters from the ground).

4.1 Air temperature

In terms of absolute values, both for 2020 and 2080, the lower parts of facades in the study area presented approximately 1ºC higher air temperature than roofs (40.40-39.20ºC for 2020 and 48.40-47.00ºC for 2080). In the cloister centre and under the three arcades, potential air temperature is observed to be 1-2ºC lower during the overheating hours both for 2020 and 2080, when compared to all surrounding receptor points placed on streets and passages. (Fig. 4) The cooling effect of the cloister morphology is maximized under the three arcades.

However, the comparative analysis (Fig. 5) shows that building roofs are more critical in terms of future thermal stress than lower parts of facades. Air in front of the facades facing open areas external to the cloister, especially with the presence of high vegetation, has increased less between the two climatic scenarios, thus implying that closed spaces such as courtyards may overheat.

Figure 4:
Air temperature diagram showing absolute values under the south arcade, in the cloister centre and at the west passage.

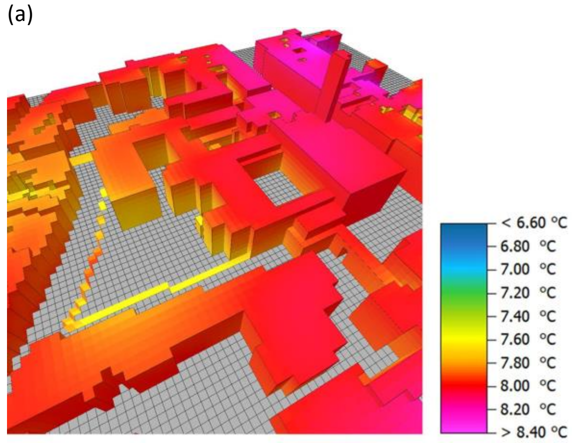


Note: The receptor point "west passage" is located at the passage with trees between the west cloister boundary and the neighbouring school building[1].

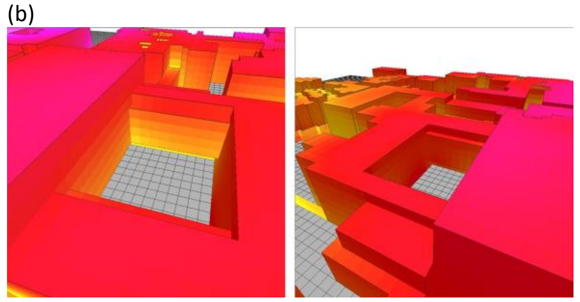
Inside the cloister itself we observe that the area under the arcades is more resilient (less increased in temperature) than the closed (south-facing) facade, which also presents higher absolute air temperature values for both climatic scenarios (Fig. 6).

[1] The south arcade was selected as the one with the lowest values and the west passage as the one with the highest ones except Via della Repubblica, to demonstrate boundary conditions regarding absolute values of temperature.

Figure 5:
Delta 3d map for air temperature in front of facades.
(a)

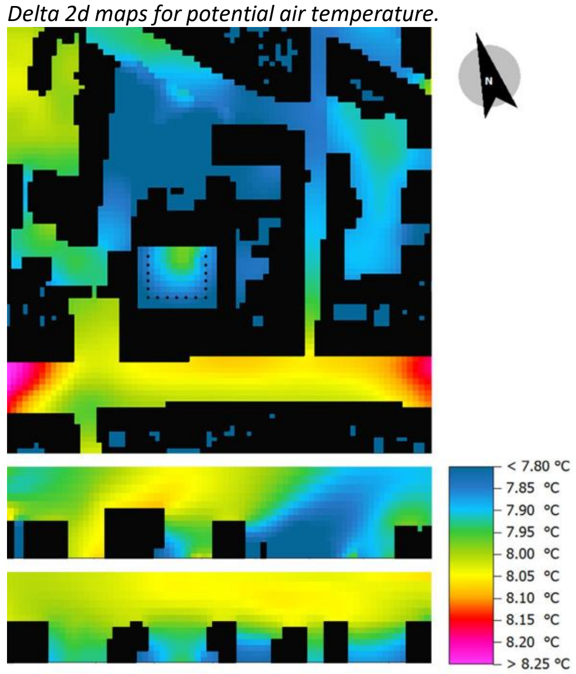


(b)



Note: Visualization of the delta Temperature (increased) values, for 15:00 on the 5th August between 2020 and 2080, (a) in the general study area and (b) zooming in the San Sepolcro cloister.

Figure 6:
Delta 2d maps for potential air temperature.



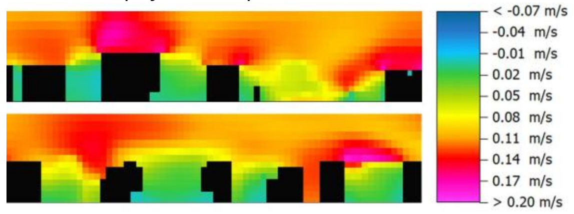
Note: Visualization of the delta (increased) values, for 15:00 on the 5th August between 2020 and 2080.

4.2 Wind speed

Wind speed analysis shows that the cloister, as well as any half-enclosed areas such as courtyards, present very low flow values (about 0.20 m/s at 15:00) because there are no air passages for the wind to move in and through. In contrast, surrounding street canyons and open areas can reach much higher values of around 0.80 m/s for 15:00 and over 3 m/s for other times of the day.

The comparative analysis shows that these values are not expected to change much. Most differences are observed over the buildings' height, where the wind can flow unobstructed (Fig. 7). This is due to the fact that the different profiles of temperature and radiation predicted in the future climate scenario are locally not significant enough to achieve different barometric pressures.

Figure 7:
Delta 2d maps for wind speed.



Note: Visualization of the delta (changed) values, for 15:00 on the 5th August between 2020 (reference) and 2080 (observation).

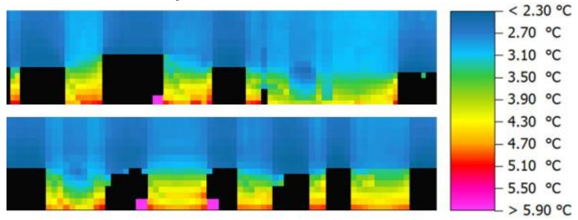
4.3 Relative humidity

Relative humidity during overheating hours in 2080 is predicted to be lower than 2020 by more than 10 percentage points. Specifically, at 15:00 on August 5th in the cloister centre, relative humidity is calculated to be 17,97% whereas in 2020 it was 29,64%. However, delta values are similar for the whole area of study, indicating that lower levels of relative humidity (by around 11%) are expected to be a generalized phenomenon, independent from urban morphology. This is an interesting piece of information supporting the idea of tropicalization of the local climate as an effect of climate change.

4.4 Mean radiant temperature

Mean radiant temperature (MRT) under the cloister arcades is simulated to be around 41ºC in 2020 and 47ºC in 2080, around 5ºC lower than the cloister centre and 10ºC lower than in front of the closed, south-facing facade. The delta values are considerably higher (6.4ºC) under overhang parts of the model, such as the arcades and other semi-open spaces compared to the general increase observed that ranges from 2.3 to 5ºC (Fig. 8). This can be attributed to the combination of the material properties and the horizontal barrier of overhang building geometry.

Figure 8:
Delta 2d sections for MRT.



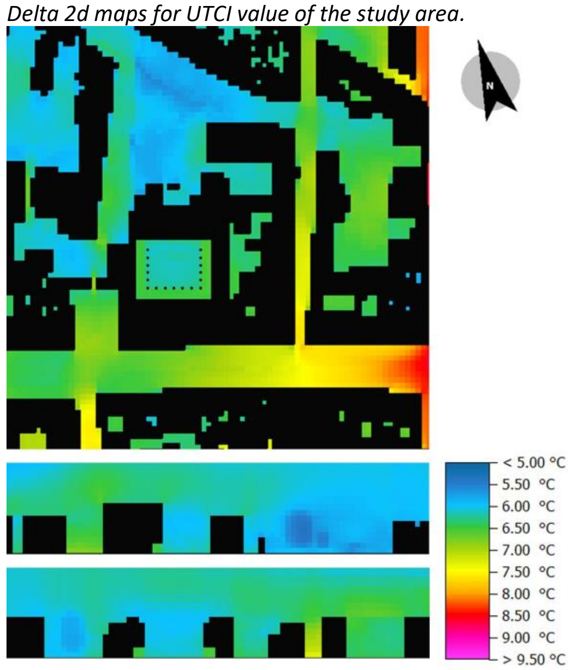
Note: Visualization for 15:00, 5th August 2020 and 2080, showing the increase of values on each part of the model.

4.5 UTCI

In the 2020 plan map, the value under the arcades ranges from 35 to 38ºC (strong heat stress-SHS according to UTCI classification) [15], whereas values from the exposed part of the cloister reach 42ºC (very strong heat stress-VSHS according to UTCI classification), similar to those of the surrounding streets. In the 2080 map, this effect is not visible, with all cloister parts (both exposed and covered) presenting a value around 43ºC (VSHS).

The comparative analysis reveals that the most resilient parts of the area are those with high LAD vegetation, suggesting that the role of evapotranspiration is crucial to the mitigation of overheating in the urban context (Fig. 9).

Figure 9:
Delta 2d maps for UTCI value of the study area.



Note: Visualization for 15:00, 5th August between 2020 and 2080 years.

4. CONCLUSION

The cloister is a very common type of building in Italian historical cities and presents several challenges with regards to climate change mitigation: its historical nature poses restrictions due to conservation needs, each of the four sides facing the courtyard has different orientation, the introverted building shape blocks air movement, the central area is highly exposed to solar radiation and the covered passages under the arcade limit the amount of natural light that enters the interior of the buildings.

Therefore, concrete research findings on the thermal patterns that characterize this morphology, today and in the future, are necessary prerequisites for adopting informed design measures to mitigate extreme heat conditions. Several environmental parameters were assessed using microclimatic simulation and the results were presented in the previous sections. The preliminary results show that the archetypal cloister form presents different behaviours in light of climate change. The main findings of this study are summarised below:

- The surrounding arcades of the cloister provide a sheltered/ shaded area for the larger part of the day and generally present a lower risk of overheating. However, in the future, when extreme temperatures will prevail during the hottest months of the year, this effect will be insignificant, and the adoption of more radical measures will be essential to combat the "tropicalization" of the Mediterranean cityscape.
- Temperature findings suggest that it is critical to work with overheating mitigation strategies on the upper parts of building facades and the roofs that are more exposed to solar radiation.
- The wind is almost stagnant inside the cloister and other closed parts of the urban fabric. The simulation shows that this is a parameter that remains constant, even though overheating is expected to become stronger.
- Humidity values will fall by more than 10 points.
- UTCI delta maps show that where vegetation is present, thermal resilience is higher. UTCI difference between cloister centre and under the arcade was visible in 2020 results but not in 2080 ones, suggesting that in overheating conditions, the cooling effect of the covered parts is not relevant anymore.

On the base of these findings, future strategies may be targeted at maximizing selective shading, creating airflows by dedicated openings into the fabric or wind catchers, and finally maximizing the areas dedicated to evaporative transpiration to overcome the hot and dry climate that is predicted to develop. Future and upcoming work attempts to test these three families of mitigation strategies.

ACKNOWLEDGEMENTS

This work has been carried out in the context of an Erasmus+ traineeship. The authors also wish to acknowledge the help of Marcello Turrini in creating the climatic files used in the simulations with the software Meteonorm.

REFERENCES

1. United Nations, (2018). The world's Cities in 2018, Data booklet, [Online], Available: https://www.un.org/en/events/citiesday/assets/pdf/the_worlds_cities_in_2018_data_booklet.pdf [21 September 2021].
2. Gherri, B., Maiullari, D., Finizza, C., Maretto, M., & Naboni, E. (2021). On the Thermal Resilience of Venetian Open Spaces. *Heritage,* 4(4), p. 4286–4303.
3. Martinelli, L. and Matzarakis, A., (2017). Influence of height/width proportions on the thermal comfort of courtyard typology for Italian climate zones. *Sustainable Cities and Society*, 29: p. 97-106.
4. Poggi, C., Rogora, A., Scudo, G., (2014). Evaluation of Environmental Control of Transitional Microclimatic Spaces in Temperate Mediterranean climate. In *Passive and Low Energy Architecture* (PLEA 2014), Ahmedabad, December 16-18.
5. Muhaisen, A. S., Gadi, M. B., (2006). Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome. *Building and Environment,* 41: p. 245–253.
6. Faure, D., Rouchon Mouilleron, V., (2001). *Cloisters of Europe: Gardens of Prayer*. Viking Studio.
7. Kinder, T., (2002). *Cistercian Europe: Architecture of Contemplation*. Grand Rapids.
8. Melley, M. E., (2012). *I Chiostri negli organismi religiosi di Parma: Geometria, Proporzioni, Architettura*. Mattioli.
9. R. McNeel & Associates, Rhinoceros, [Online], Available: https://www.rhino3d.com/ [21 September 2021].
10. Ladybug Tools LLC, [Online], Available: https://www.ladybug.tools/dragonfly.html [27 March 2022].
11. ENVI_met, [Online], Available: https://www.envi-met.com/ [27 March 2022].
12. Remund, J., Müller, S.C., Schilter, C., Rihm, B., (2010). The Use of Meteonorm Weather Generator for Climate Change Studies. In *Proceedings of the 10th EMS Annual Meeting*, 10th European Conference on Applications of Meteorology (ECAM) Abstracts, Zürich, Switzerland, September 13-17.
13. IPCC, (2021). *Climate Change 2021: The Physical Science Basis.* Cambridge University Press.
14. OpenStreetMap, [Online], Available: https://www.openstreetmap.org/ [27 March 2022]
15. Jendritzky, G., Havenith, G., Weihs, P., Batchvarova, E., (2009). Towards a Universal Thermal Climate Index UTCI for assessing the thermal environment of the human being. Final Report COST Action 730, Available: https://e-services.cost.eu/files/domain_files/ESSEM/Action_730/final_report/final_report-730.pdf [27 March 2022]

PLEA SANTIAGO 2022
Will Cities Survive?

Green Infrastructure to reduce cooling loads and heat stress in Mediterranean Climates

A building simulation and machine learning approach

MASSIMO PALME[1] ANNA MANGIATORDI[2] CAROLA CLEMENTE[2] RICCARDO PRIVITERA[3] DANIELE LA ROSA[3] CLAUDIO CARRASCO[1]

[1] Universidad Técnica Federico Santa María, Departamento de Arquitectura
[2] Università di Roma La Sapienza, Dipartimento di Architettura e Progetto
[3] Università di Catania, Dipartimento di Ingegneria Civile e Architettura

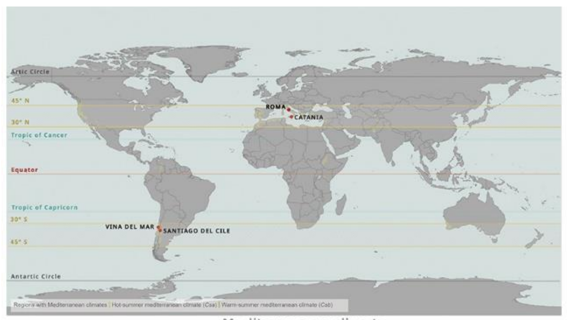
ABSTRACT: Climate change impact on cities and urban warming due to anthropogenic effects are urgent problems to be solved. Among the most beneficious strategies to reduce those impacts we can account the development of green infrastructures in cities, a kind of intervention that assure both mitigation of global warming by reducing greenhouse gases emissions, and adaptation to warmer urban environments. This work presents a building simulation and machine learning methodology to estimate the energy and comfort-related benefits that can be obtained by using a green infrastructure to shadow buildings' façades and roofs. We used previously developed simulation models to test the energy savings provided by different types of trees planted to produce shadows on buildings. Then, we tested different algorithms to predict using a machine learning approach the saving that can be obtained in different buildings-trees contexts for the cities of Catania, Rome, Santiago de Chile and Viña del Mar. Results show that the saving obtained is in the range 5-60%, mainly depending on the number of façade shadowed and on the specie of trees; and the prediction accuracy of machine learning process is over 90% for a binary classification (energy saving > 15% or <15%).

KEYWORDS: Urban Heat Island, Urban Climate, Green Infrastructure, Building Performance Simulation, Machine Learning

1. INTRODUCTION

During the last decades, global warming and land use change have intensified the urban heat stress condition, affecting energy loads of buildings and both indoor and outdoor thermal conditions. The problem is so deep that in 2021 the world experimented the record temperatures of 48.5 Celsius degrees in Canada during the summer and peaks of 29 Celsius degrees in central Chile in the middle of the winter season. Scientific community is agreeing that urgent measures should be taken to mitigate the global warming and the urban heat island (UHI) phenomenon. At the same time, there is an urgent need to develop adaptation strategies to face warmer environments, including nature-based solutions to restore ecological services in cities and reduce the probability of heat stress under heat waves [1]. Green Infrastructure (GI) is a strategy to achieve these goals, and has more benefits such as CO_2 sequestration, reduction of flood damages, visual and acoustical better environment, biodiversity development. Many authors assessed in the past the possible reduction in UHI intensity provided by trees and vegetal surfaces [2-3]. The influence of trees on indoor thermal environment has also been assessed by various studies [4-5]. In previous works, authors established a strategy to simulate not only theoretical solutions, but real configurations of trees-buildings relations, depending on availability of space in case studies sectors placed in Mediterranean climates [6]. Mediterranean climates are normally located between 30 and 45 degrees of latitude in both hemispheres, covering the Mediterranean Sea basin, the South and North America Pacific coasts, and small parts of Australia and South Africa (figure 1) [7].

Figure 1:
Mediterranean climates and cities considered in this study



Machine learning (ML), a branch of artificial intelligence that learn from a set of data to do a prediction or a classification of new configurations performance, has been used to predict the energy loads reduction in summer and the indoor heat stress probability, with the objective to help urban planners in deciding where to place the GI considering the global cost-benefits results [8].

In this work, the methodology developed in previous works is applied to the cases of Rome, Catania, Santiago de Chile and Viña del Mar, evaluating the capability of GI to reduce cooling loads and indoor heat stress as well as the accuracy of ML process to predict the results for new cases.

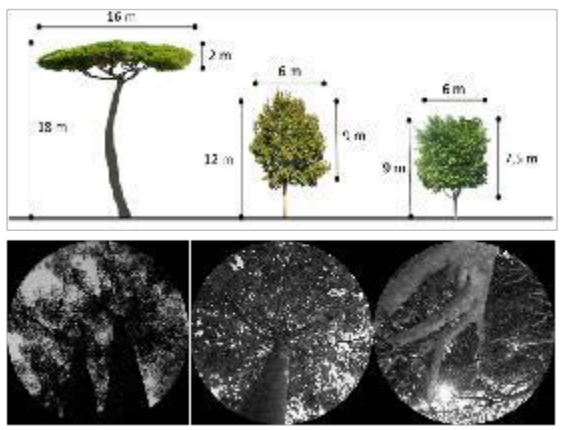
2. METHODOLOGY

To establish the capability of a GI to reduce cooling loads and heat stress probability, we followed a three steps methodology. Firstly, some real case studies has been considered (Catania, Roma, Santiago de Chile, and Viña del Mar) and a classification of effective building-trees configurations has been obtained. This process includes the identification of typical urban morphologies and buildings' shapes and design of linear GI configurations to be placed to an appropriate distance from the building's façades.

Secondly, the interaction building-trees has been modelled by using shadow masks in TRNSYS Studio version 17. The trees are represented as simplified solar shadow elements with a permeability to sunlight obtained by field assessment using fish-eye images and Gap Light Analyzer (GLA) software to process the radiation data [9]. Finally, a set of simulations was run out to obtain the base case (without trees) and the configuration performance. Buildings were modelled in TRANSBUILD type of TRNSYS and simulation was run with TRNSYS Studio.

Once obtained the simulation results, a ML technique was developed to predict the cooling load and the probability of heat stress occurrence for new configurations. We tested different algorithms to obtain two different classifications: one with a single value (15% energy saving and heat stress probability reduction) and the other with a five categories strategy to indicate the estimated amount of reduction obtained with the GI.

Figure 2:
Trees' morphology and solar permeability



Simulations were done in Mediterranean climates, characterized by slightly different behaviour determined by latitude and coast distance: Catania (Mediterranean semi-arid, on the Mediterranean Sea), Rome (Mediterranean, at 20 km from the Mediterranean Sea), Santiago de Chile (Mediterranean-continental, at 100 km from the Pacific Ocean), and Valparaiso-Viña del Mar (Mediterranean semi-arid, on the Pacific Ocean).

Weather files for selected locations have been obtained from the webpage climate.onebuilding.org [10,11] and modified by using Urban Weather Generator (UWG) tool to consider the urban heat island effect of the sectors. UWG tool was developed by Bueno et al. [12] and updated several times to improve accuracy of the prediction [13,14]. It was tested in different climates [15,16,17] locations and permits to realize parametric studies on the influence of urban form on microclimate.

UWG needs for many inputs for running. Most important are: inputs on urban morphology (as built up area, façade to site ratio, average building height, green areas, albedo values for all surfaces, anthropogenic heat production in the urban sector). Here we focused on morphological parameters to generate the representative urban weather file. Anthropogenic heat and albedo values have been left as a fixed value across the cases.

Urban heat island intensity has been found to be higher in Santiago than in the other cases. The phenomenon is positive at night and slightly negative during the day. Table 1 resumes the parameters values used for UWG simulations and table 2 shows the max and min values of UHI intensity for all locations.

Table 1:
Parameters used in UWG simulation

Location	Built Area	Fac. ratio	H (m)	Green Area
Tor Bella Monaca	0.11	2.64	24	0.25
Casale Caletto	0.12	0.62	15	0.08
Trimesteri Etneo	0.19	0.88	12	0.05
Les Condes	0.15	0.73	15	0.27
Benidorm	0.07	0.36	12	0.24

Table 2:
UHI intensity for locations studied

Location	Max UHI	Min UHI
Tor Bella Monaca	3.7	-1.0
Casale Caletto	2.4	0.6
Trimesteri Etneo	2.8	-1.1
Les Condes	6.1	-1.5
Benidorm	2.0	-0.4

2.1 Selection of urban compounds

Urban compounds to be studied were selected among urban development sectors since the ’60 decade until today in Rome (Tor Bella Monaca and Casale Caletto), Catania (Tremesteri Etneo), Santiago de Chile (Las Condes) and Viña del Mar (Benidorm). The analysis conducted on the sectors leaded to the selection of 40 specific configurations, considering the availability of space to plant trees, the building morphology and the green areas already present in the sector (figures 3-7).

Figure 3:
Casale Caletto compound and configurations analysed

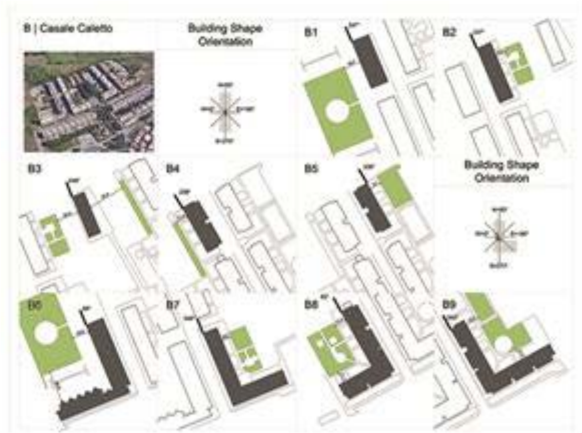


Figure 4:
Benidorm compound and configurations analysed

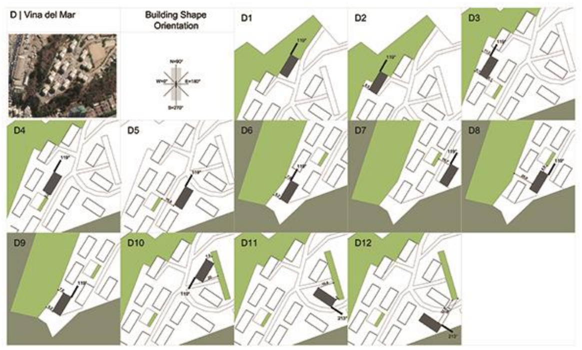


Figure 5:
Las Condes compound and configurations analysed

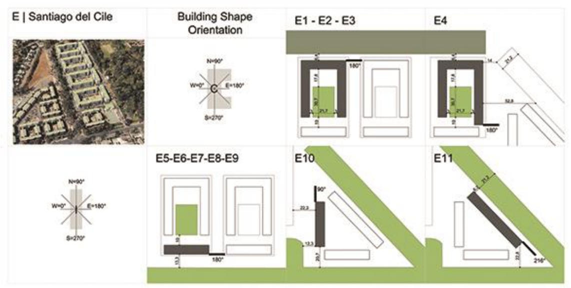


Figure 6:
Tor Bella Monaca compound and configurations analysed

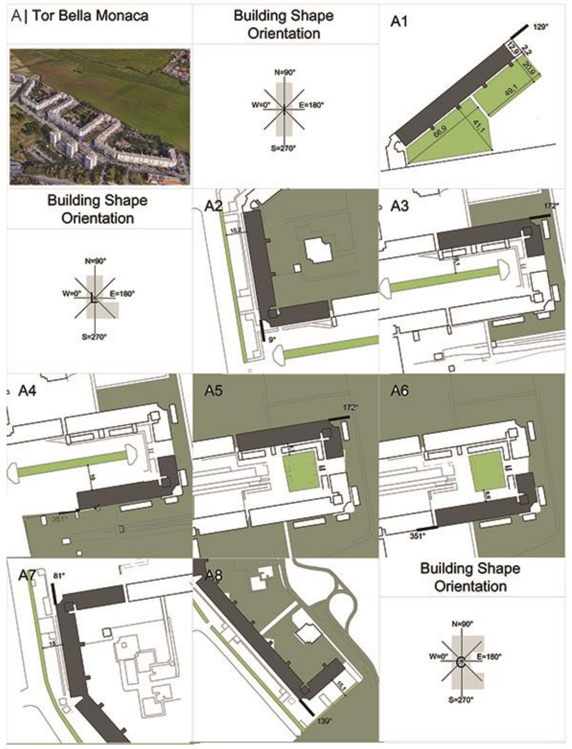
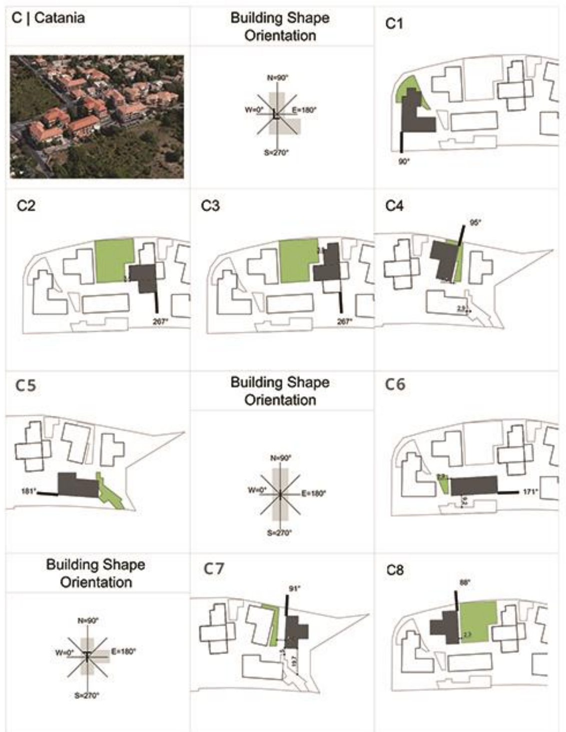


Figure 7:
Trimesteri Etneo compound and configurations analysed



2.2 Simulations of cooling loads

To simulate the cooling loads, buildings of selected compounds were firstly grouped in standard types by plan shape. We used “T”, “C”, “L” and “I” typical shapes. Each shape has its standardized dimensions and internal distributions. Figure 8 shows the plan shape of typical buildings.

Figure 8:
Standard building shapes considered in this study

Simulations consider standard materials used in Mediterranean climates, with solar absorptions and thermal transmittances for walls and roofs resumed in table 3. Windows to wall ratio depends on the building form, as shown in table 4. For all cases, radiation control was considered to simulate the use of blinds or other internal system. Table 5 shows operational settings used.

Table 3:
Envelope values for all buildings

Element	Construction	Thermal transmittance (W/m²K)	Solar absorption or g-value windows
Walls	Bricks - XPS	0.56	0.60
Flat roofs	Conc. - XPS	0.32	0.60
Windows	Alum. single	5.80	0.86

Table 4:
Windows to wall ratios for building tyipes

Shape	Floor surface	Window/wall ratio main fac	Window/wall ratio other
I	480 m²	20%	7%
C	800 m²	20%	20%
T	400 m²	20%	15%
L	528 m²	20%	20%

Table 5:
Operational settings used in the study

Description	Schedule or control	Value
Light gains	18-22 h	5 W/m²
Cooling set point	0-24 h	26 °C
People	0-24 h	1 met
Occupancy	0-24 h	50 m²/p
Solar shading open	120 W/m²	1.0
Solar shading closed	140 W/m²	0.4

In TRNSYS, shadows are simulated as geometrical masks obtained by projecting the inclination angle for minimum and maximum solar incidence on each floor. The point to see the sky or the tree was set into the middle of the façade (figure 9). Equations (1)-(6) show the calculation procedure to obtain the inclination angles.

$$\alpha_{min} = arctan \frac{a_{min}}{b} \quad (1)$$

$$\alpha_{max} = arctan \frac{a_{max}}{c} \quad (2)$$

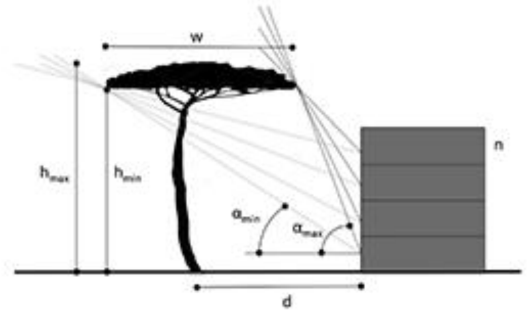
$$a_{min\,(n)} = h_{min} - [1.5 + 3 \times (n - 1)] \quad (3)$$

$$a_{max\,(n)} = h_{max} - [1.5 + 3 \times (n - 1)] \quad (4)$$

$$b = d + \frac{w}{2} \quad (5)$$

$$c = d - \frac{w}{2} \quad (6)$$

Figure 9:
Shadow mask calculation



2.3 Machine Learning

Once obtained simulation results, a machine learning strategy was developed to predict, based on certain numbers of predictors, the final cooling load reduction that can be reached by planning trees in a determined configuration. As a continuous prediction of cooling load is difficult to be obtained, we developed a classification method to divide the configurations in categories. In a first attempt, we used a 15% of reduction in cooling load as the threshold value to be used. In a more interesting attempt, we established five ranges: very low saving (0-5%), low saving (5-15%), medium saving (15-25%), high saving (25-35%) and very high saving (more than 35%). We used different algorithms to predict the results: Loess, Random Forst, KNN, GLM and a combination (ensemble) of all them. Respect to predictors, we used: climate classification, type of urban environment, altitude, latitude, sea distance, number of floors, number of façades on shadow, plan shape, orientation, distance, and tree species.

3. RESULTS

Simulation results show that the energy savings that can be reached in summertime are in a range 2-60%. Figure 9 resumes the values for 120 simulations (40 representative configurations, 3 species of trees). Figure 10 shows the average savings obtained by location, divided by tree species.

Figure 9:
Base case and improved case (with trees) cooling loads

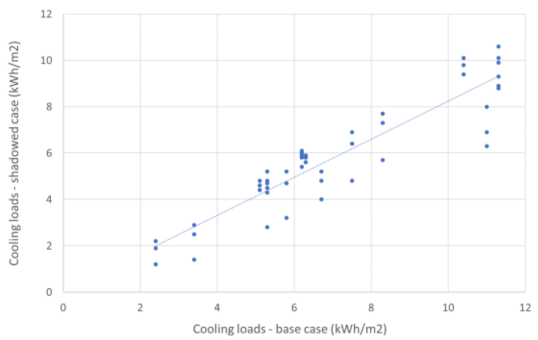
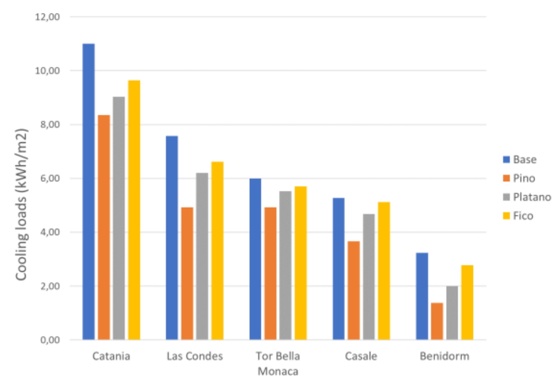


Figure 10:
Average cooling loads by location and tree specie



Looking at figure 10, it is immediate to notice that Benidorm has a summertime energy demand quite lower than other cases, around 2-3 kWh/m^2. In the sectors of Rome, cooling loads of the base case are around 5-6 kWh/m^2 year, while in Santiago loads are around 6-8 kWh/m^2 year. The hottest location is Catania, with summer cooling loads of 10-11 kWh/m^2. Influence of Pacific Ocean's breeze and latitude are the most relevant factors for this.

If the savings over 45% belongs to the case of Benidorm, where cooling loads are low even without shading, the range 2-45% apply to all studied cases. There is a big difference among 2% or 45% of cooling load reduction. So, it is interesting to understand which are the most influencing factors that explain these results.

Among the cases studied, Tor Bella Monaca is clearly the case more difficult to be shadowed. This is obvious because of the number of floors (8) of buildings in this sector, compared with the others (5-4 floors). West façades are confirmed as important façades to be shadowed, and "I" buildings are detected as easier to be shadowed respect other shapes buildings. The case of Santiago is particularly interesting because of the UHI intensity of the sector.

Green infrastructure can be used as a mitigation/adaptation strategy to reduce the impact of urban heat in the city. Table 6 resumes the number of cases analysed and the performance achieved in a 5-categories classification.

Table 6:
Classification of cooling reduction in 5 categories

Location	Very low	Low	Medium	High	Very high
Bella Monaca	3	7	1	0	1
Casale	2	14	8	0	6
Trimesteri	1	5	3	1	2
Les Condes	0	11	5	9	5
Benidorm	0	2	12	10	12
TOTAL CASES	6	39	29	20	26

More than the half of cases have a result higher than 15% reduction in cooling loads, confirming the findings of previous studies [18]. More than one third of the cases present a saving higher than 25% of cooling loads reduction. This allows stakeholders to invest in green infrastructure projects, whit a return of investment guaranteed in a relatively short time lapse.

Machine learning resulted to be quite accurate, achieving the extraordinary result of a 96% of accuracy in a binary categorization process. While a 5-categories classification is required, the accuracy is quite lower but still acceptable for the ensemble of algorithms (75%).

Among algorithms, best results are achieved by the ensemble and by random forest procedure. Random forest is particularly interesting because the output information includes the priority of predictors, putting in evidence that the number of façades on shadow is the key factor to predict the performance. This result is perfectly in accordance with previous studies [19] and with our interpretation of simulation results. The algorithm used the predictor "number of façades on shadow" in the first places of the decision tree, followed by "tree specie", "distance from the sea", "altitude", and "distance from the façade".

4. CONCLUSION

This paper showed how the development of a green infrastructure can help to prevent overheating in buildings and to reduce energy use for cooling during summertime in Mediterranean climates. This benefit must be accounted in a general analysis to establish the convenience to plant trees in urban environments. Green areas has certainly some costs, due to maintenance, water consumption and the process of planting, however the benefits in terms of several ecosystem services provided to the inhabitants shows that the development of a green infrastructure is almost always convenient.

Building performance simulation can be used as a part of the cost-benefit accounting in establishing where to place a green intervention. Machine learning processes can be useful to reduce time to be spent in simulations, allowing technicians to quickly obtain a first assessment of the convenience of the trees under an energy use point of view.

Future works will regard the simulation of different macroclimatic locations, where other factors take more importance: seasonality, heating loads increase, water needs for trees, among others.

ACKNOWLEDGEMENTS

This work was done with the support of Fondecyt Project 1200275 awarded in Chile by ANID, and of the Visiting Research founding awarded by University of Rome La Sapienza.

REFERENCES

1. Stone, B. (2012). The city and the coming climate. Climate change in the places we live. Cambridge University Press.
2. Tiwari, A., Kumar, P., Kalaiarasan, G., Ottosen, T.B. (2021). The impacts of existing and hypothetical green infrastructure scenarios on urban heat island formation. Environmental Pollution 274, 115898.
3. Santamouris, M. (2020). Recent progress on urban overheating and heat island research. Integrated Assessment of the energy, environmental, vulnerability, and heath impact. Synergies with the global climate change, Energy and Buildings 207, 109482.
4. Calcerano, F., Martinelli, L. (2016). Numerical optimization through dynamic simulation of the position of trees around a stand-alone building to reduce cooling energy consumption, Energy and Buildings 112, 234–243.
5. Balogun, A., Morakinyo, T.E., Adegun, O.B. (2014). Effect of tree-shading on energy demand of two similar buildings, Energy and Buildings 81, 305–315
6. Palme, M., Privitera, R., La Rosa, D., Chiesa, G. (2019). Evaluating the potential energy savings of an urban green infrastructure through environmental simulation. Proceedings of the Building Simulation Conference, Rome, 2-4 September 2019
7. Peel, M. C., Finlayson, B. L., McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth Systems Sciences 4, 439-473
8. Palme, M., Privitera, R., La Rosa, D., Carrasco, C. (2021). Building Performance Simulation to support tree planting for cooling need reduction: a machine learning approach. Proceedings of the Building Simulation Conference, Bruges, 1-3 September 2021
9. Frazer, G.W., Canham, C.D., and Lertzman, K.P. 1999. Gap Light Analyzer (GLA): Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.
10. Climate.onebuilding project (2015). Available on line: https://climate.onebuilding.org (last accessed on march 2022)
11. Crawley, D., Lawrie, L. (2019). Should We Be Using Just "Typical" Weather Data in Building Performance Simulation? Proceedings of the Building Simulation Conference, Rome, 2-4 September 2019.
12. Bueno, B., Norford, L., Hidalgo, J., Pigeon, G. (2012). The urban weather generator. Journal of Building Performance Simulation 6 (4), 1-13
13. Nakano, A., Bueno, B., Norford, L,.Reinhart, C. (2015). Urban Weather Generator – A novel workflow for integrating urban heat island effect within urban design process. Proceedings of the Building Simulation Conference, Hyderabad, 7-9 December 2015
14. Mao, J., Yang, J., Afshari, A., Norford, L. (2017). Global sensitivity analysis of an urban microclimate system under uncertainty: Design and case study. Building and Environment 124, 153-170
15. Mao, J. and Norford, L. (2021). Urban weather generator: physics-based, microclimate simulation for performance-oriented urban planning. In: Urban Microclimate Modelling for Comfort and Energy Studies, Springer
16. Salvati, A., Palme, M., Chiesa, G., Kolokotroni, M. (2020). Built form, urban climate and building energy modelling: case studies in Rome and Antofagasta. Journal of Building Performance Simulation 13 (2), 209-225
17. Palme, M., Inostroza, L., Villacreses, G., Lobato, A., Carrasco, C. (2017). From urban climate to energy consumption: Enhancing building performance simulation by including the urban heat island effect. Energy and Buildings 145 (5), 107-120
18. Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., James, P. (2007). Promoting ecosystem and human health using green infrastructure: A literature review. Landscape and Urban Planning 81, 167-178
19. Palme, M., Privitera, R., La Rosa, D. (2020). The shading effects of Green Infrastructure in private residential areas: Building Performance Simulation to support urban planning. Energy and Buildings 229, 110531

PLEA STGO 2022
WILL CITIES SURVIVE? ANALYSIS AND METHODS

PLEA 2022 SANTIAGO
Will Cities Survive?

Comparative analysis of Viçosa's weather files

Simulation adequacy for urban microclimate

CAIO DE CARVALHO LUCARELLI[1] MATHEUS MENEZES OLIVEIRA[1] JOYCE CORRENA CARLO[1]

[1] Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil

ABSTRACT: A microclimate denotes the distinctive climatic conditions within a few meters of a given point. The anthropogenic heat, ground cover, surrounding vegetation, shading, and &c. contribute to thermal comfort level variations within buildings and present prospects and obstacles analogized to the macro and mesoclimatic scales. In this sense, it is essential to determine the fittest weather file for building simulations to reduce propagating errors. Therefore, this study's scope was to appraise four different weather files (TMY3 and Multiyear datasets), relying on indoor and outdoor surveyed and simulated dry-bulb temperature (DBT) and relative humidity (RH) for two institutional buildings in Viçosa, Brazil (20.75° S, 42.88° W), microclimate-affected and not. We pre-selected the best datasets collecting EnergyPlus' Site Outdoor Air DBT and RH outputs and comparing them with outdoor surveyed DBT and RH, later adopting the most representative weather files for indoor simulations. We concluded that the TMY3 file conveyed the best overall results and the lowest Root-Mean-Square Error (RMSE) for RH in microclimate conditions. At the same time, the Multi3Y-High showed better temperature results for the anthropogenic-affected building. Therefore, if pre-testing a weather file is not an option, we indicated TMY3 as the best dataset.

KEYWORDS: On-site survey, Building Simulation, Root-Mean-Square Error, Weather File.

1. INTRODUCTION

A microclimate is a local set of atmospheric conditions that differ from its surrounding area in outdoor air temperature variations, surface temperatures, humidity, wind speed, and wind direction [1], [2]. Anthropogenic heat, evaporation, evapotranspiration, trees shading, and ground cover can modify latent heat exchange between buildings and the outdoors in urban areas, heavily influencing thermal comfort levels inside buildings.

The outdoor climate directly relates to indoor air quality and thermal comfort. Analyzing its relationship with building thermal environmental performance, solar access, and ventilation is a primary research goal on microclimate that will reproduce miscalculations when overlooked [3].

Access to accurate weather data denotes a barrier to more assertive analyzes of the local climate. Meteorological conditions in simulations rely upon data from weather stations, which are typically secluded. Moreover, this data is usually averaged over several years, masking the effect of the urban surroundings and possible site-specific characteristics [2].

Building simulation is a leading method for predicting interactions between indoors and outdoors. Few studies established generic models based on field surveys and statistical analyses, preventing oversimplification. For instance, Scheller et al. [3] compared three different weather files using dry-bulb and dew-point temperature and global and diffuse horizontal irradiance for 15 Brazilian cities, concluding that most analyzed weather files were precise but not.

Toparlar et al. [1] performed building energy analysis in Antwerp for microclimate simulation and characterization. Results showed higher average air temperatures at urban sites away from the park, with 13.9% less cooling demand near the park.

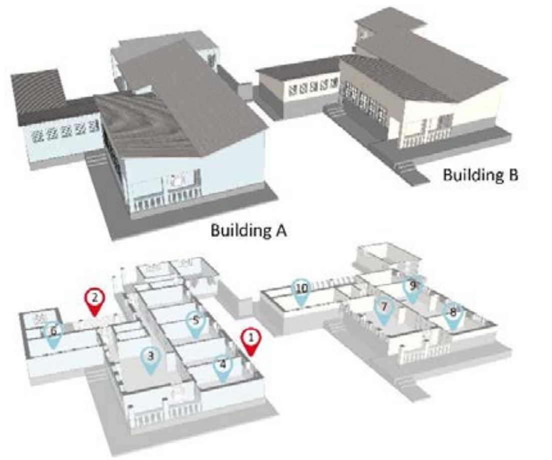
Hence, this study appraised the application of four different weather files (TMY3, Multi3Year-Low, Medium, and High) [4] through surveyed indoor and outdoor data for two similar adjacent institutional buildings in Viçosa, Brazil (20.75° S, 42.88° W), with differing surrounding conditions and microclimates. Our main goal was to pre-select the fittest weather file for microclimate assessment, analyzing its suitability when comparing collected dry-bulb temperature (DBT) and relative humidity (RH) with weather file data and later simulating and comparing indoor DBT and RH with surveyed indoor information.

2. MATERIALS AND METHODS

According to the Köppen classification, Viçosa is warm and temperate (Cwa) with hot and humid summers and cool to mild winters. Both elected buildings (Fig. 01) are part of *Universidade Federal de Viçosa's* Psychosocial Division (20.75° S, 42.88° W).

The buildings were originally designed as housing complexes for university educators and later converted into office spaces and psychological and psychiatric care. Both buildings are one-story, butterfly-roofed, and naturally ventilated. Building A is 155m², and building B is 129m². Building A presents an explicit microclimate caused by a mass of vegetation that provides shading and evapotranspiration, wind exposure, and surrounding lawn (lower ground temperatures and albedo, and constant irrigation). Conversely, building B is secluded, in-between constructions, and anthropogenic-influenced (higher surrounding surface temperatures and albedo).

Figure 1:
Building configuration and data logger's placement. Source: The Authors.



Note: red markers represent outdoor loggers, while blue represents indoor surveyed points.

We scrutinized indoor/outdoor walls, partitions, and roofing materials during the cataloging and field survey stage, adopting Weber et al.'s [5] equivalent reference models and construction layers and NBR 15.220-2's [6] material properties.

Table 1 shows the adopted building layers, thicknesses (Thk), transmittances (Ut), and thermal capacities (Ct). The material layers appear from the exterior to the interior, following EnergyPlus construction inputs. We also considered outdoor thermal absorptance of 0.40 for building A and 0.30 for building B (light blue and yellow) [6].

We collected indoor and outdoor DBT and RH in the Southern summer period from February 26th to March 12th, 2020, using HOBO data loggers (HOBO/ONSET U12 Temp/RH/Light) recording every minute. However, we only considered data between March 8th and March 12th due to the uncommon intense precipitation until March 7th. We also surveyed daily occupation patterns, users, electromechanical equipment, and natural conditioning tactics and modeled 10 thermal zones for building A and 8 compatible zones for building B since building A has an additional office space and aisle. The building calibration applied the uncertainty analysis procedure [7], considering varying occupancy and equipment loads.

We selected four comparable spaces (Fig. 01) to place the data loggers (points 3 and 7 are receptions; 4, 5, 8, and 9 are office spaces; 6 and 10 are cook-rooms) and two outdoor locations (point 1 and 2), one microclimate-affected (point 2) and one not (point 1). Point 1 is in-between buildings and presents higher neighboring surface temperatures and albedo, while point 2 is wind-exposed and vegetation-affected.

We divided the methodology into two branches. Section one concerns outdoor surveyed DBT and RH comparison with four standard weather files: TMY3, Multi3Year-Low, Medium, and High [4][1]; i.e., TMY3 (Typical Meteorological Year) is similar to a TRY (Test Reference Year) weather file that summarizes monthly data from different years to compile an artificial climate year [4]; the Multi3Year method presents a year with low temperature and radiation values (Multi3Y-Low), a year with high values (Multi3Y-High), and an average year (Multi3Y-Medium). Normally, simulations applying Multiyear files run several times, according to compiled data. However, we use the Multi3Y-Low, Medium, and High separately to reduce computational demand.

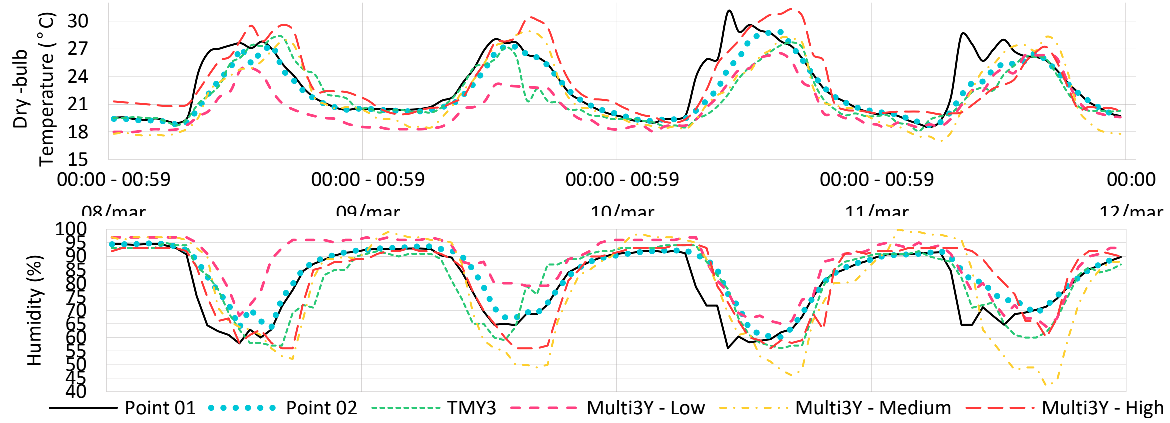
Section one applies EnergyPlus's Site Outdoor Air DBT and RH outputs for comparing simulated and surveyed data.

Table 1:
Building components for walls and roof. Source: The Authors.

indoor/outdoor walls and partitions					roof				
	material	Thk *cm*	Ut *W/m²°C*	Ct *KJ/m²°C*		material	Thk *cm*	Ut *W/m²°C*	Ct *KJ/m²°C*
9-hole hollow brick block 14x19x19 cm	outdoor plaster	0.25	1.83	11	solid concrete slab	fiber cement sheet	0.80	2.06	233
	ceramic	1.65							
	air chamber	10.70				air chamber	0.25		
	ceramic	1.65				concrete	10.00		
	indoor plaster	0.25							

[1] Guimarães [4] created all four files using climatic data from UFV's automatic weather station, assembled by INMET [7]. Also, the *Laboratório de Tecnologias em Conforto Ambiental e Eficiência Energética - LATECAE/UFV* provides said files.

Figure 2:
DBT and RH on Point 01, Point 02, TMY3, Multi3Y-Low, Medium, and High from March 8th to 12th. Source: The Authors.



We selected TMY3 and Multi3Year files considering that the Multi3Year offers the most reliable simulation results for Viçosa, Brazil [4] but presents high computational costs, while TMY3 shows promising results with a single simulation.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(\text{simulated}_i - \text{surveyed}_i)^2}{N}} \quad (1)$$

where: *RMSE - Root-Mean-Square Error*
simulated_i - predicted/simulation values
surveyed_i - surveyed data
N - total number of observations

For comparing the outdoor measured data, we adapted a methodology that assesses the highest overall variable (DBT or RH), the daily highest, the overall mean, the daily lowest, and the overall low, over a defined period (5 days) assembled into a boxplot graph [3]. We also applied the Root-Mean-Square Error (RMSE) "Equation (1)" to select the weather file representing the outdoor DBT and RH best.

Section two comprised the simulation process for both buildings using the best weather files selected in section one for each situation. We adopted EnergyPlus' Zone Air Temperature and Relative Humidity and compared the simulation results with indoor surveyed data for points 3 to 6 (building A) and 7 to 10 (building B). We reassessed the methodology adopted in section one, calculating the RMSE and presenting results as boxplot graphs.

3. RESULTS

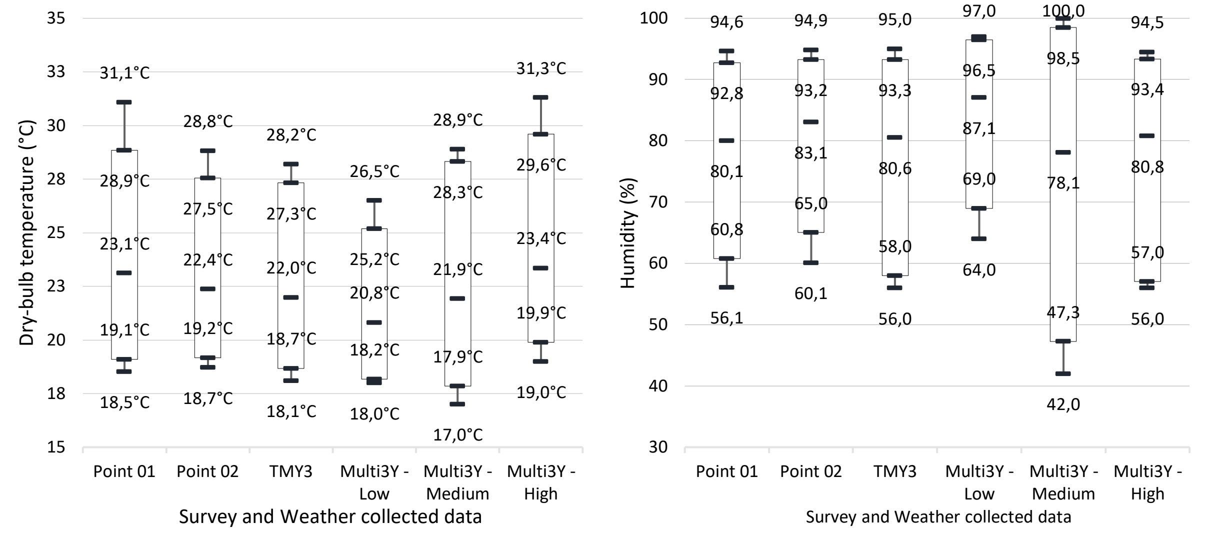
Fig. 2 shows the DBT and RH for the surveyed data (points 1 and 2) and weather files TMY3, Multi3Y-Low, Medium, and High from March 8th to 12th. For point 1, we observe that the highest discrepancy occurs with Multi3Y-Low with an overall RMSE of 3.05 for the temperature plot (Table2) due to the closeness with sun-exposed walls, concrete slabs, and other human-made materials. Higher surface temperatures influence immediate air temperatures, and consequently, weather files with lower temperatures should show higher dissimilarities.

Table 2:
DBT (first section) and RH (second section) percent divergencies for survey data and weather files. Source: The Authors.

	Point 1 x TMY3	Point 1 x Multi3Y-L	Point 1 x Multi3Y-M	Point 1 x Multi3Y-H	Point 2 x TMY3	Point 2 x Multi3Y-L	Point 2 x Multi3Y-M	Point 2 x Multi3Y-H
Min. DBT	2.27%	2.81%	8.21%	2.58%	3.26%	3.79%	9.13%	1.56%
Mean Min. DBT	2.18%	4.80%	6.50%	4.23%	2.62%	5.22%	6.92%	3.77%
Mean DBT	4.88%	9.93%	5.10%	1.06%	1.73%	6.94%	1.96%	4.41%
Mean Max. DBT	5.29%	12.66%	1.83%	2.59%	0.81%	8.52%	2.82%	7.45%
Max. DBT	9.28%	14.75%	7.02%	0.70%	2.14%	8.04%	0.29%	8.62%
Min. RH	0.17%	14.10%	25.12%	0.17%	6.86%	6.44%	30.15%	5.86%
Mean Min. RH	4.54%	13.56%	22.24%	6.19%	10.78%	6.14%	27.32%	12.32%
Mean RH	0.62%	8.76%	2.39%	0.92%	3.03%	4.81%	5.93%	2.74%
Mean Max. DBT	0.52%	4.02%	6.18%	0.66%	0.01%	3.49%	5.64%	0.14%
Max. DBT	0.39%	2.50%	5.67%	0.14%	0.14%	2.25%	5.41%	0.38%

Note: Colors represent deviation between the selected points and weather data. Colors closer to saturated green have smaller deviations, while the opposite is true for red. Comparisons between same DBT and RH (same line) classifications work best.

Figure 3:
Overall max, daily highs, overall means, daily lows, and overall low DBT and RH comparison. Source: The Authors.



Note: Information is according to headline, from top to bottom (overall max, daily highs, overall means, daily lows, and overall low).

The disparity happens due to a difference in the max temperatures of about 14.75%, which corresponds to almost 5°C dissonance (Table 2 and Fig. 3). For the RH analysis, the highest differences occur with Multi3Y-Medium, with humidity values 25% lower and an RMSE of 11.59.

Still, for point 1, the best results indicate Multi3Y-High as the fittest weather file for DBT and TMY3 for RH, primarily due to the immediacy of human-made materials. However, RH in the Multi3Y-High is also very representative, with only a few divergencies compared to the TMY3. Fig. 3 shows the parallelism between point 1 and Multi3Y-High with maximum differences of 0.8°C.

For point 2, the highest DBT divergencies also occur with the Multi3Y-Low, but with an RMSE of 1.80. Daily highs differ at 3.7°C, which corresponds to an 8.52% incongruency that is still very representative, surpassing some point 1 survey/weather data percentages. For the RH analysis, the discrepancy also occurs with Multi3Y-Medium, with RH values 30.1% lower and an RMSE of 11.31 (still lower than the RMSE for RH in point 1, which can correlate to the surrounding vegetation, evapotranspiration, shading, and irrigation).

The highest Point 2 similarities for DBT are with TMY3, with an RMSE of 2.21. Daily highs differ only 0.2°C, and the highest variance is between the minimums with 0.6°C (Table 2 and Fig. 3). TMY3, Multi3Y-Low, and Multi3Y-High are comparable for RH, with a 4% humidity discrepancy at maximum. However, Multi3Y-Low should not apply due to the DBT divergence discussed above.

Highlighting, according to França, Silva, and Carlo [9], and Guimarães [4], simulations with TMY3 already presented lower statistical deviations, while Multi3Y-Low had higher RMSE.

We employed the TMY3 and the Multi3Y-High (single simulation with no Medium and Low data) as weather files for both buildings based on the abovementioned results. Since building A is microclimate-affected (and therefore closer to point 2 results), we hypothesize that TMY3 would perform better, while Multi3Y-High (most similar to point 1 result, susceptible to building shading, surrounding impermeable paving, and wind- sheltered) would be the fittest for building B.

Table 3 shows the RMSE for the selected thermal zones in both buildings. For building A, all RMSEs (DBT and RH) are lower for the TMY3 file.

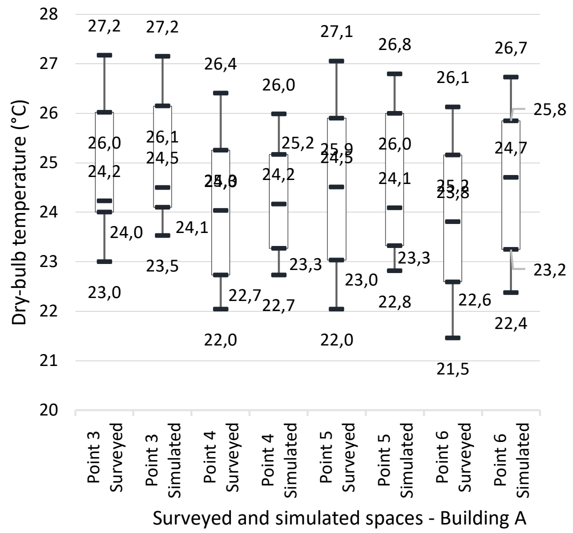
Table 3:
Indoor DBT and RH RMSE for each survey/simulation point. Source: The Authors.

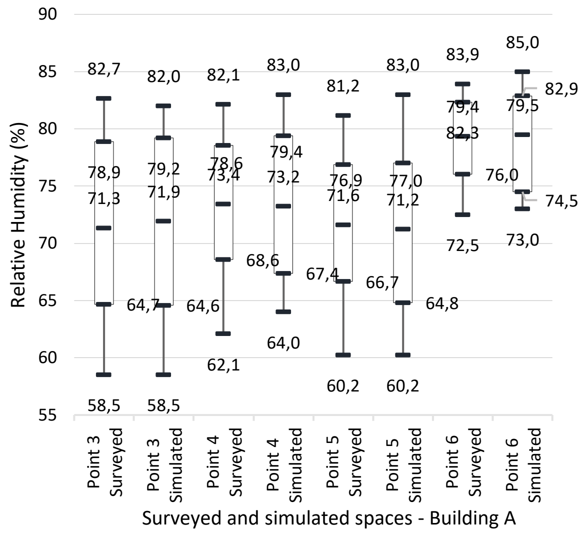
		RMSE for DBT				RMSE for RH			
Build. A	File	Point 3	Point 4	Point 5	Point 6	Point 3	Point 4	Point 5	Point 6
	TMY3	1.41	1.56	1.38	3.23	1.79	1.51	2.39	1.02
	Multi3Y-High	2.15	2.51	2.00	4.33	5.91	7.76	6.20	21.29
Build. B	File	Point 7	Point 8	Point 9	Point 10	Point 7	Point 8	Point 9	Point 10
	TMY3	1.27	1.21	1.47	2.38	7.84	8.04	11.08	12.71
	Multi3Y-High	0.80	0.93	1.37	2.37	7.14	7.48	9.91	11.84

Note: abbreviations stand for: (Build.) building. The lowest RMSEs are highlighted in green.

Figure 4:

Indoor overall max, daily highs, overall means, daily lows, and overall low DBT and RH for Building A. Source: The Authors.





The highest discrepancy for DBT is in point 6, the cook-room, which we consider a possible modeling issue due to the surrounding vegetation evapotranspiration (not included in EnergyPlus modeling file). For the best-represented space (point 5), the temperature differed 0.3°C at most; for point 6, temperatures differed 0.9°C.

Even though the Multi3Y-High performed worse than the former, RMSE is not among the worst results (up to a 9.0 RMSE for other weather files).

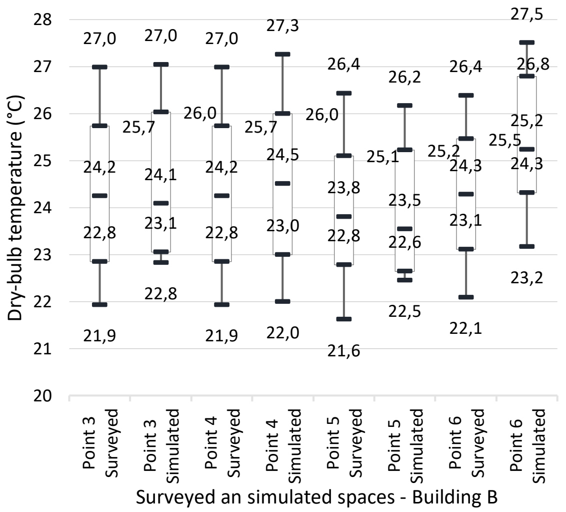
For the same building, the RH simulation using the TMY3 showed the best congruency in all results; principally considering the proximity of the survey dates to a cold front and the lack of evapotranspiration simulation. The most divergent space is point 5, with an RMSE of 2.39 and RH values 1.9% lower (Fig. 4).

As we anticipated, the Multi3Y-High presents the best results for building B. The DBT RMSE is the best amongst all simulations with the highest deviation on point 10 (also representing a cook-room in the same orientation as point 6). Due to the low RMSE, air temperatures only vary between 0.2 and 0.4°C (Fig. 5).

However, the RH analysis shows high RMSE for the file mentioned above and even higher deviations for the TMY3. We deduce that, even though the weather file represents accurate air temperatures, surface temperatures, wind speed, and wind direction, it does not account for the foliage specificities and anthropogenic irrigation of the selected sites.

We also point out that we only considered vegetation as shading geometry, not accounting for evapotranspiration, which could increase RH values.

Figure 5:
Indoor overall max, daily highs, overall means, daily lows, and overall low DBT and RH comparison for Building B. Source: The Authors.



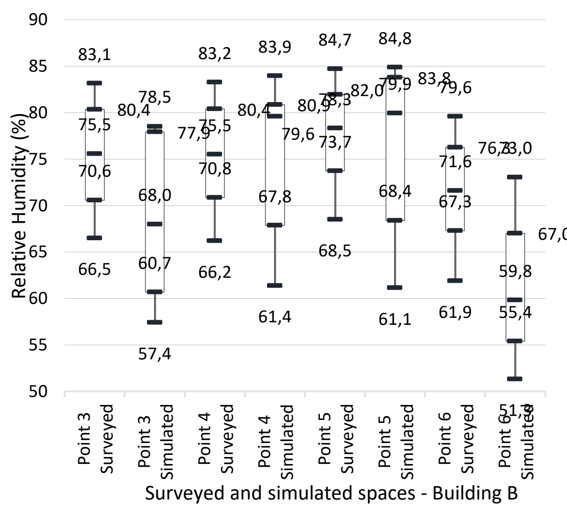


Fig. 4 and 5 show simulated results as lower than surveyed data, corroborating our analysis for both RH simulation values.

Persistently, point 10 (cook-room) showed higher deviations with an RMSE of 11.84 for building B, corresponding to 9% to 12% lower RH values, which could be due to the surveyed dates being right after a cold front with a high precipitation rate.

Since the TMY3 simulations showed the best overall results, we appoint the file as a standard selection for urban spaces, microclimate-affected or not, in Viçosa, Brazil. Even though a traditional Multiyear approach would perform one simulation for each file, we consider Multi3Y-High a possible selection for buildings in urban spaces, especially when away from vegetation (since humidity values are even lower than the TMY3), wind-sheltered spaces, and impermeable ground cover. We also point out that building A showed the best overall results because its surroundings were similar to Viçosa's weather station (approximately 1.5 km from the selected buildings and distant from anthropogenic interventions), which culminates in weather data more suitable for microclimate-affected spaces.

4. CONCLUSIONS

This paper presented a process for selecting, analyzing, and adopting a correct weather file (among TMY3, Multi3Y-Low, Medium, and High) for microclimate and anthropogenic-influenced buildings and urban sites considering single simulation procedures for saving computational time and demand.

We selected two institutional office buildings in Viçosa, Brazil, with similar floorplans but distinct surrounding conditions for surface temperatures, humidity through evapotranspiration and irrigation, and wind exposure.

We performed indoor and outdoor on-site DBT and RH surveys, adopting the outdoor data for the weather file analysis and pre-selection. After conducting the RMSE calculations, we pre-elected the TMY3 and the Multi3Y-High as the fittest datasets.

The TMY3 presented the best overall results and the lowest RMSEs for humidity in microclimate conditions. The Multi3Y-High showed better temperature results for the building with less surrounding vegetation but failed to represent the surveyed RH with an RMSE from 7.14 to 11.84, a 12% discrepancy between surveyed and simulated data.

Prevailing, building A had better results due to the Viçosa's weather station's location, heavily vegetated, near water bodies, and away from anthropogenic interventions, influencing the weather datasets and creating biased weather files that best represent microclimate-affected spaces.

Therefore, we demonstrate that the TMY3 and the Multi3Y-High present good results for both cases among the four weather files. The former best-representing RH for microclimate-affected spaces and the latter DBT for urban spaces. Finally, if pre-testing a weather file is not an option or computational demand is a limitation, we favor TMY3 as the most promising dataset since it does not require multiple simulations and presents the all-around lowest divergences.

ACKNOWLEDGEMENTS

This study was financed by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES)* – Finance Code 001 and by *Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG)*, financing notice N° 001/2021 Universal Demand - under process code APQ-00266-21.

REFERENCES

1. Toparlar, Y., Blocken, B., Maiheu, B. and van Heijst, G. J. F., (2018). Impact of urban microclimate on summertime building cooling demand: A parametric analysis for Antwerp, Belgium. *Applied Energy,* 228: p. 852-872.
2. Mosteiro-Romero, M., Maiullari, D. Pijpers-van Esch, M. and Schlueter, A., (2020). An Integrated Microclimate-Energy Demand Simulation Method for the Assessment of Urban Districts. *Frontiers of Built Environment,* 6: p. 1-18.
3. Scheller, C., Melo, A. P., Sorgato, M. and Lamberts, R., (2015). Análise de arquivos climáticos para a simulação do desempenho energético de edificações. *Report, LabEEE.*
4. Guimarães, Í. B. Análises de incertezas e sensibilidade de arquivos climáticos e seus impactos em simulações computacionais termo energéticas. (2016). *Master Thesis, Departamento de Arquitetura e Urbanismo,* Universidade Federal de Viçosa, Viçosa.
5. Weber, F., Melo, A., Marinoski, D., Guths, S., Lamberts, R. (2017) Desenvolvimento de um modelo equivalente de avaliação de propriedades térmicas para a elaboração de uma biblioteca de componentes construtivos brasileiros para o uso no programa EnergyPlus. *Report, LabEEE.*
6. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 15.220-2. (2005) Desempenho térmico de edificações Parte 2: Métodos de cálculo da transmitância térmica, da capacidade térmica, do atraso térmico e do fator solar de elementos e componentes de edificações. Rio de Janeiro.
7. Westphal, F. S. Análise de incertezas e de sensibilidade aplicadas à simulação de desempenho energético de edificações comerciais. (2007). *Master Thesis, Departamento de Engenharia Civil*, Universidade Federal de Santa Catarina, Florianópolis, 2007.
8. INSTITUTO NACIONAL DE METEOROLOGIA, NORMALIZAÇÃO E QUALIDADE INDUSTRIAL – INMETRO. *Dados Meteorológicos: Estações Automáticas*. Available in: http://www.inmet.gov.br. Access: June, 2022.
9. França, T. N., Silva, M. A. and Carlo, J. C., (2020). Análise De Sensibilidade Do Poc Em Edificações Naturalmente Ventiladas. *Brazilian Journal of Development,* 6: p. 91120–91135.

PLEA STGO 2022
WILL CITIES SURVIVE? ANALYSIS AND METHODS

PLEA SANTIAGO 2022
Will Cities Survive?

Indoor comfort and winter energy performance of lightweight steel-framed buildings in extreme climates

A case study in Barnaul (RU)

NICOLA CALLEGARO[1*], ROSSANO ALBATICI[1], IVAN KHARLAMOV[2], LYUDMILA KULIKOVA[2], TATIANA SAURINA[2], FEDERICA SCAVAZZA[3], GIOVANNI MANZINI[3]

[1] University of Trento, Trento (Italy), nicola.callegaro@unitn.it
[2] Altai State University, Barnaul (Russia)
[3] Cogi S.r.l., Caponago (Italy)

ABSTRACT: The growing challenges posed by climate change require a broader understanding of how buildings perform under extreme weather conditions. The potential of lightweight steel-frame (LSF) structures has been systematically investigated in laboratories, but there is few evidence of their actual behaviour on site. The paper presents a case study of a LSF building in Barnaul (RUS), focusing on its energy and indoor comfort performance during the cold season. Different simulation models, regarding building components as well as the whole construction, are compared to data collected from in-situ monitoring. The comparison between "as-designed" and "as-built" is complemented by a post-occupancy evaluation conducted through surveys. As a result: i) the actual building performance is in accordance with simulations, although an accurate calibration process is necessary; ii) the thermal bridges are confirmed as the main critical aspect of these structures: monitored performances are worse than expected; iii) thermal comfort perceived by the users is not in line with theoretical calculations: occupants behaviour and cultural values strongly affect the performance of the building; iv) the design of construction details is fundamental in this type of structures, especially when external climatic conditions are prohibitive.
KEYWORDS: Building Simulation and Monitoring, Lightweight steel-frame structures, Thermal Performance, Extreme Climate Condition, Post-occupancy Evaluation

1. INTRODUCTION

New and recent challenges posed by climate change are driving the need to find new building technologies that can handle an increase in cooling and heating demand [1]. Situations with low potential for renewable energy production will become increasingly common, and greater climate resilience will generally be required [2].

For this reason, it is nowadays essential to quantify the influence of extreme climate on demand trends and consequently on the design of buildings and energy systems. In this field, a considerable amount of literature has been published on the energy and environmental benefits of Lightweight Steel-Framed (LSF) constructions [3],[4]. Due to its flexibility of use, this material offers ease of fabrication and several recycling options, resulting in considerable life-cycle energy savings. Quick transportation and fast and convenient assembly allow also for mixed solutions that can adapt to different climates and locations [5]. Despite this potential, there remains a paucity of evidence on the actual on-site energy behaviour and indoor comfort level achieved in LSF residential buildings. Research on the topic has mostly been limited to the comparison of simulated models [6],[7]. The performance of LSF walls has been extensively analyzed, but only a few studies have systematically investigated the difference between simulations and monitored data in real buildings [8], [9]. Previously published studies on the effect of extreme climates in inhabited buildings are not consistent and none seem to consider real-time occupant feedback on the topic.

As several cross-sectional studies highlight a significant gap between the "as-designed" and the "as-built" [10], this paper attempts to comprehensively describe the predicted and measured energy performance and post-occupancy evaluation (POE) of a partially prefabricated residential building in Barnaul (RU), providing an important opportunity to advance the understanding of the optimal energy design of steel framed elements in buildings under extreme winter weather conditions.

2. MATERIALS AND METHODS

In this section, the case study, the monitoring system, as well as the measured parameters are described. Furthermore, the characteristics of the simulation model, the calibration and comparison techniques between the simulated and monitored data are highlighted. Finally, the POE approach for gathering user feedback is outlined.

2.1 The case study

The case study is a steel-framed experimental house built in Barnaul (RU), southern Siberia (Fig.1-2). The extreme climate conditions of the location expose the building to average monthly winter temperatures of -10°C in January (with lows of -34°C) and average monthly summer temperatures in July of 21°C (with highs of +37°C). The building is equipped with energy and environmental sensors to monitor its behaviour 24 hours a day.

Figure 1:
Floor Plan of the building with envelope specifications.

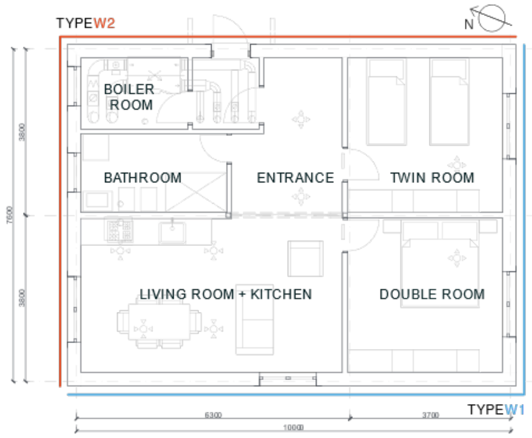
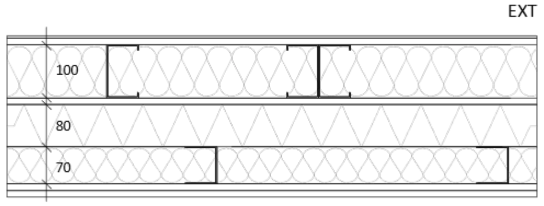
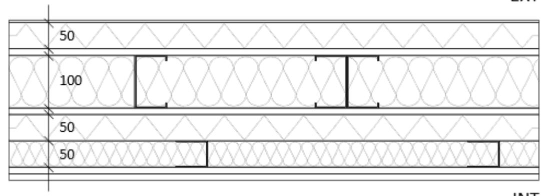


Figure 2:
The building during and after construction.

The building has two different vertical envelope solutions (Fig. 1-3), whose expected thermal performance (Tab. 1-2) was benchmarked and validated using temperature and heat flux monitoring data.

Figure 3:
The building walls: W1 (above), W2 (below)





The roof and ground floor thermal transmittance are, respectively, 0.146 and 0.309 W/m²K.

Table 1:
Thermophysical properties of the wall W1.

W1				
Layers (int. to ext.)	s [cm]	λ [W/mK]	ρ [kg/m³]	c [J/kgK]
Plasterboard	2.5	0.2	800	836.8
Insulated Counter-wall	7	0.072	101.24	1024.3
Glasswool	8	0.035	35	1030
Plasterboard	1.25	0.2	800	836.8
SteelMAX® Structure + insulation	10	0.067	143.78	1022.6
Cement board	1.25	0.35	1150	836.8
Total thickness [cm] = 30				
Total thermal transmittance [W/m²K] = 0.194				

Table 2:
Thermophysical properties of the wall W2.

W2				
Layers (int. to ext.)	s [cm]	λ [W/mK]	ρ [kg/m³]	c [J/kgK]
Plasterboard	2.5	0.2	800	836.8
Insulated Counter-wall	5	0.068	101.2	1024.2
Glasswool	5	0.035	35	1030
Plasterboard	1.25	0.2	800	836.8
SteelMAX® Structure + insulation	10	0.067	143.78	1022.6
Cement board	1.25	0.35	1150	836.8
EPS insulation	5	0.038	21	1260
Total thickness [cm] = 30				
Total thermal transmittance [W/m²K] = 0.186				

The building is equipped with an underfloor heating system powered by a condensing boiler. A heat recovery mechanical ventilation system is installed to provide proper airflow rate while limiting the direct entry of the extremely cold external air through the windows.

The monitoring system consists of:

- Environmental sensors for indoor temperature, relative humidity, and CO_2
- Surface temperature sensors (internal, external and interstitial surface temperature of walls, floor and roof)

- Heat flux meter
- Window opening/closing sensors
- Heat consumption meter
- Electric consumption meter
- Weather station

The designed data monitoring and visualization system provides remote access via the cloud to the measured data. From the web platform, any information can be downloaded in .csv format and then processed and analysed with any data analysis tool.

2.2 Building performance simulation

A simulation energy model was created and run in EnergyPlus™ to verify the consistency between predictions and actual observations. The model was calibrated for the winter period according to the guidelines of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [11]. The model calibration was conducted for each thermal zone by comparing simulated and measured energy consumption and ambient temperatures. Table 3 shows the results in terms of Normalized Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Square Error CV(RMSE).

Table 3:
Model calibration calculated indices.

Thermal zone	NMBE(%)	CV(RMSE) (%)
Entrance	1.83	6.62
Living Room + Kitchen	-2.49	7.70
Double room	-2.94	8.35
Twin room	-1.33	6.74
Bathroom	3.89	9.17

According to [11] CV (RMSE) must be <30 and NMBE <±10

To better comprehend temperature trends within the building components, on-site monitoring was coupled with finite-element simulation in THERM™. Particular attention has been paid to thermal bridges which can have a huge impact due to the high thermal conductivity of steel elements.

Finally, the installation of the thermal heat flux meter on the north-east wall W2 has allowed the calculation of the thermal conductance of the wall to verify if the values predicted in the design phase are close to the real ones. Since in the transient state the surface temperatures of the wall change continuously, the value of the in situ thermal conductance was calculated using LORD software [12], which also considers the influence of the thermal capacity of the wall.

2.3 The comfort survey

To evaluate the indoor comfort of the building, in parallel with the measurement of environmental conditions, a survey on the inhabitants' satisfaction with the environment was carried out. It was thus possible to establish a correlation between the users' responses and the expected comfort, calculated using Fanger's comfort theory [13]. The survey was administered to the inhabitants remotely, through the "Google Forms" service. After a few circumstantial questions about location, clothing, and type of activity conducted, the users were asked to state:

- their own thermal sensation
- the description of the environment from a thermal point of view;
- their thermal preference (if they could have a change);
- their acceptance of the environment from a thermal point of view;
- (optional) the sources of thermal discomfort;
- the description of the environment from an air quality point of view;
- air quality acceptance;
- (optional) the sources of discomfort related to air quality.

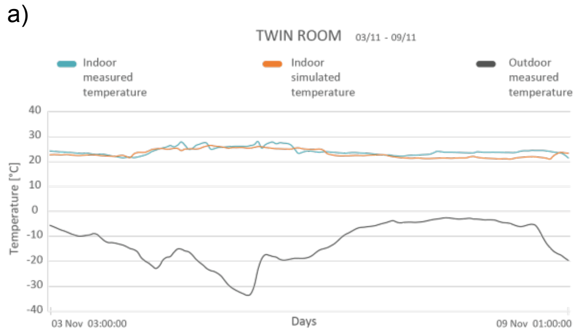
The survey was conducted in accordance with UNI EN ISO 10551:2019 and UNI EN ISO 28802:2012.

3. RESULTS AND DISCUSSION

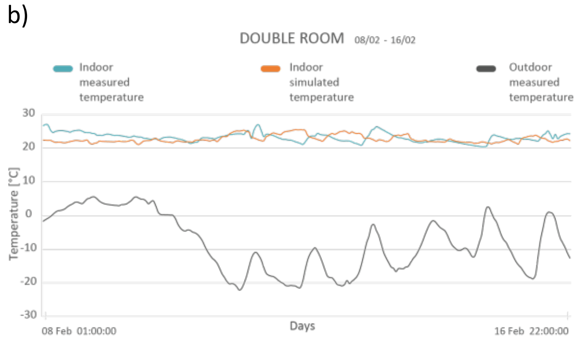
The simulation model, accurately developed in EnergyPlus™, can correctly forecast the indoor temperatures in the different thermal zones. The indices in Tab. 3 are confirmed by the graphs shown in Fig. 4. The temperature trend in the two bedrooms for two different winter weeks is shown as an example.

Figure 4:
Winter indoor temperature differences between the model and the real building: a) twin room b) double room.

a)



b)



The model calibration process required considerable effort and time. It involves a large amount of monitoring data analysis and many hypothesis, often based on the modeler's experience, about several different parameters. In this case study, the most complicated assumptions involved occupancy, equipment, heating set-point, and air infiltration rate schedules. A relevant sensitivity analysis was conducted on all these variables.

Once calibrated, the simulation model was used for comparative analysis. Different weather files were used to calculate the heating energy consumption of the building - unmodified in any of its components - in other locations with extreme weather conditions. The results of the analysis, although preliminary, are shown in Table 4. In their simplicity, the results show that there is no certain linear correlation between outdoor weather conditions and energy consumption, but that it is often how the building heating system is used and operated and the type of occupant that matter the most [14].

Table 4:
Heating energy demand of the building for different extreme outdoor weather conditions.

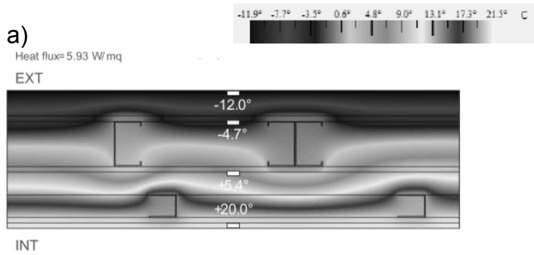
Location	Heating design temperature* (°C)	Annual Heating Energy demand (kWh)
Barnaul (Russia)	-32.7	12111.91
Utqiaġvik (Alaska)	-37.6	27281.99
Mayo (Canada)	-44.9	17445.59
Jakutsk (Russia)	-48.5	24357.07
Unorganized (Greenland)	-58.7	33412.71

*The temperature in Celsius that ASHRAE recommends using to size a heating system to meet a building's sensible heating demand. The value represents the coldest temperature of the year for which only 1.0% of the hours are below.

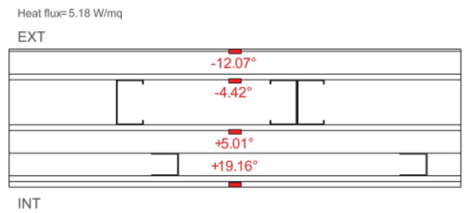
Regarding the estimation of temperature trends inside the building walls, the simulation in THERM™ proves to be extremely reliable. As shown in Fig. 5, the temperature trends inside the W2 stratigraphy are totally consistent when the same boundary conditions are applied to the exterior and interior surfaces.

Figure 5:
Simulated (a) and monitored (07AM - 01/12/2019) (b) temperature trend in W2.

a)



b)



The same software was then used to evaluate thermal bridges. Fig. 6 shows the horizontal section of the corner construction detail and the measurement points. In contrast to what was observed in the previous analysis, the expected temperatures differ widely from those measured in situ (Tab. 5).

Figure 6:
Thermal bridge: construction detail and temperature sensors position.

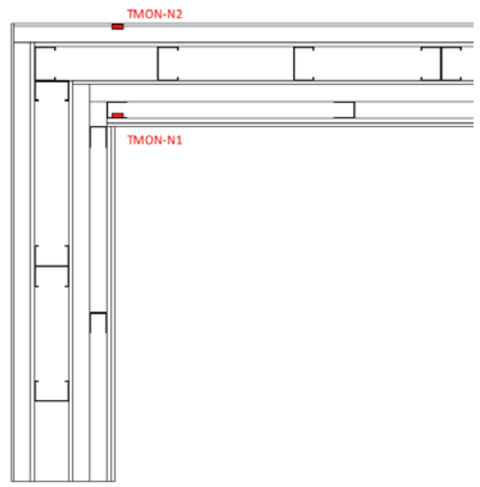


Table 5:
Comparison between the simulated and monitored temperatures at the thermal bridge.

	TMON-N2 (°C)	TMON-N1 (°C)
THERM™ simulation	-11.8	+17.1
14/12/2019 - 6PM	+5.5	+17.2
16/11/2019 - 5PM	-11.9	+6.2
10/02/2020 - 10AM	+5.6	+17.1
11/01/2020 - 3AM	-11.9	+4.6
06/02/2020 - 6AM	+1.1	+12.6
16/02/2020 - 11AM	-4.6	+9.2

*Boundary conditions:
- external surface temperature: -12°C
- internal surface temperature: 22°C

It must be said that the analysis of a thermal bridge should take into account the thermal capacity of the wall that, in the finite-element simulation, is not considered, resulting in a less accurate simulation. However, the geometric thermal bridge is confirmed as an extremely sensitive point for steel-framed structures. The collected monitoring data indicate a poor local energy performance with consequent unwanted heat loss and potential hygrometric criticalities.

The analysis suggests that the primary load-bearing structure should be decoupled from the interior counter-wall. To do this, at least 50 mm of lightweight, soft insulating material (rockwool or equivalent) must be placed between the two structures. This type of insulation, which is easy to install, can absorb any potential errors during assembly and prevent air leakage between the interior and exterior. To reduce thermal bridging, the distance between the mullions of the two structures (bearing and counter-wall) should be designed to keep them staggered and not aligned.

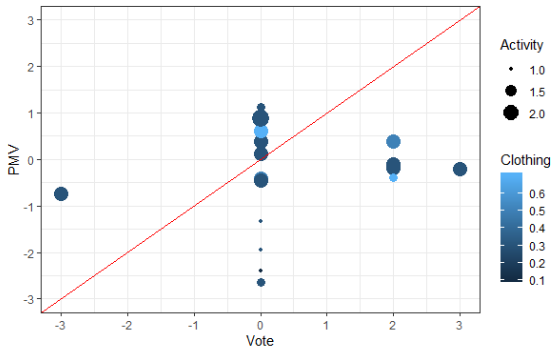
Steel elements also have a strong influence on the thermal transmittance of the wall: the SteelMAX® structure and the interior counter wall, even if filled with rockwool, cannot be considered fully insulating layers. The wall is therefore modelled in THERM®. The calculated thermal transmittance was taken as a reference and the thermal conductivity values of the individual materials were modified accordingly (Tab. 2). For the W2 East wall, the theoretically measured thermal conductance is:

- 0.145 W/m^2K (neglecting the effect of the steel frame)
- 0,192 W/m^2K (considering the effect of the steel frame)

The thermal conductance measured in situ and processed through the LORD application, equal to 0.177 W/m^2K, is right between the two theoretical values. This confirms both the validity of the calculation and, above all, the good performance of the structure.

Regarding the entire building's thermal behaviour, a post-occupancy evaluation (POE) survey was conducted alongside the simulation and monitoring. The predicted mean vote (PMV) determined according to UNI EN ISO 7730:2006 was compared to the users' thermal sensation. The results are presented in Fig. 7.

Figure 7:
Correlation between calculated PMV and user thermal votes.



The correlation is very weak: users rated neutral environmental conditions that have a PMV between -2.64 and 1.13. The number of responses, 17, is rather limited, making it difficult to draw conclusions. However, as other studies have shown [15], it can be stated that the theoretical calculation of expected comfort suffers from many limitations and that thermal sensation does not depend exclusively on measurable physical-environmental factors.

4. CONCLUSION

The paper describes the simulation, monitoring and POE of a lightweight steel-framed building in Russia, exposed to extreme climatic conditions. The goal is to test the building's thermal comfort performance and compare it to the design predicted values, helping to close a still wide literature gap. Several simulation tools have been used (Energyplus™, THERM™, LORD) and an energy-environmental monitoring system (indoor and outdoor) has been installed on site. The POE was carried out by administering an online survey to users, which were requested to answer on different days and at different times of the day.

The results show a good match between as-designed and as-built. The simulation, when compared to the data collected from the on-site monitoring, proves to be reliable on many aspects. The calibration of predictive models, however, has shown to be crucial, and required time and essential skills. Through the calibrated model it was possible to assess the building's response in other contexts, even more extreme. It was also feasible to evaluate the impact of different variables on global energy consumption. In this case study the user behaviour, which affects the occupancy schedule, internal gains, and thermostat heating set-point, has represented the most relevant factor. The main differences between expected and actual performance are found in thermal bridges, a weak point of steel framed structures. The values measured on site deviate significantly from those predicted. This emphasizes the importance of a rigorous construction details design, as well as a proper components and building materials assembly and installation. The POE proved to be crucial in determining if the building meets thermal comfort users' needs. However, the study shows a lack of active participation by inhabitants, prompting researchers to consider alternative methods of collecting thermal preferences, less invasive and more user-friendly. The POE also emphasizes a socio-cultural aspect that should not be underestimated. The theoretical models of comfort with which users' votes have been compared to, are not tailored to occupants' way of living: for example, the habit of keeping the heating system at 26 °C, which is common in this region of Russia, makes the PMV, the main parameter for the evaluation of indoor comfort, not suitable. As a result, it is highlighted how, in the future, it will be important to correlate the performance of buildings in extreme climatic conditions with the habits of people living in these places, which may vary and strongly affect the building's overall performance. Future developments of the article will include, also through the calibrated simulation model, more in-depth analyses on the energy consumption of steel-frame buildings, in order to better understand the environmental impact of indoor comfort requirements in such particular climates. These studies will also be able to better confirm the benefits and drawbacks of lightweight steel-frame structures, particularly in terms of their thermal inertia.

ACKNOWLEDGEMENTS

This work was realized within the project IsolMAX funded by Cogi Srl - Italy and supported by the Operative Program FESR 2014-2020 of the Autonomous Province of Trento. The authors would like to thank arch. Basilio Guerra of Enerconsult Srl – Brescia (Italy) for his valuable contribution in the monitoring campaign, and to remember geom. Mario Guidotti, head of the project, who recently passed away.

REFERENCES

1. A. T. D. Perera, V. M. Nik, and J. L. Scartezzini, "Impacts of extreme climate conditions due to climate change on the energy system design and operation," Energy Procedia, vol. 159, pp. 358–363, 2019, doi: 10.1016/j.egypro.2019.01.002.
2. IPCC, Climate Change 2021: The Physical Science Basis Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. In Press., 2021.
3. N. Soares, P. Santos, H. Gervásio, J. J. Costa, and L. Simões da Silva, "Energy efficiency and thermal performance of lightweight steel-framed (LSF) construction: A review," Renew. Sustain. Energy Rev., vol. 78, pp. 194–209, Oct. 2017, doi: 10.1016/J.RSER.2017.04.066.
4. H. A. H. A. Büyüktaşkın, "A Study on Steel Framed Residences in Terms of Energy Performance," MEGARON / Yıldız Tech. Univ. Fac. Archit. E-Journal, 2019, doi: 10.14744/MEGARON.2019.30092.
5. P. Santos, "Energy Efficiency of Lightweight Steel-Framed Buildings," Energy Effic. Build., Jan. 2017, doi: 10.5772/66136.
6. N. Soares, P. Santos, H. Gervásio, J. J. Costa, and L. Simões da Silva, "Energy efficiency and thermal performance of lightweight steel-framed (LSF) construction: A review," Renew. Sustain. Energy Rev., vol. 78, pp. 194–209, 2017, doi: 10.1016/J.RSER.2017.04.066.
7. A. P. Gomes, H. A. De Souza, and A. Tribess, "Impact of thermal bridging on the performance of buildings using Light Steel Framing in Brazil," Appl. Therm. Eng., vol. 52, no. 1, pp. 84–89, Apr. 2013, doi: 10.1016/J.APPLTHERMALENG.2012.11.015.
8. E. Roque, R. Vicente, and R. M. S. F. Almeida, "Opportunities of Light Steel Framing towards thermal comfort in southern European climates: Long-term monitoring and comparison with the heavyweight construction," Build. Environ., vol. 200, p. 107937, Aug. 2021, doi: 10.1016/J.BUILDENV.2021.107937.
9. Q. Zhan, Y. Xiao, F. Musso, and L. Zhang, "Assessing the hygrothermal performance of typical lightweight steel-framed wall assemblies in hot-humid climate regions by monitoring and numerical analysis," Build. Environ., vol. 188, p. 107512, Jan. 2021, doi: 10.1016/J.BUILDENV.2020.107512.
10. P. De Wilde, "The gap between predicted and measured energy performance of buildings: A framework for investigation," Autom. Constr., vol. 41, pp. 40–49, May 2014, doi: 10.1016/j.autcon.2014.02.009.
11. D. R. Landsberg et al., "Measurement of Energy, Demand, and Water Savings," ASHRAE Guidel. 14-2014, vol. 2014, 2014, [Online]. Available: www.ashrae.org/technology.
12. O. Gutschker, "Parameter identification with the software package LORD," Build. Environ., vol. 43, no. 2, pp. 163–169, Feb. 2008, doi: 10.1016/J.BUILDENV.2006.10.010.
13. P. O. Fanger, "Thermal comfort. Analysis and applications in environmental engineering.," Therm. Comf. Anal. Appl. Environ. Eng., 1970.
14. F. Stazi, F. Naspi, and M. D'Orazio, "A literature review on driving factors and contextual events influencing occupants' behaviours in buildings," Build. Environ., vol. 118, pp. 40–66, Jun. 2017, doi: 10.1016/J.BUILDENV.2017.03.021.
15. J. van Hoof, "Forty years of Fanger's model of thermal comfort: comfort for all?," Indoor Air, vol. 18, no. 3, pp. 182–201, Jun. 2008, doi: 10.1111/j.1600-0668.2007.00516.x.

PLEA STGO 2022

WILL CITIES SURVIVE? ANALYSIS AND METHODS

PLEA 2022 SANTIAGO

Will Cities Survive?

Optimisation of Housing Design Options for Human-Centric Lighting

Impacts of architectural parameters on daylight

KELVIN HOANG[1] TERRI PETERS[1]

[1] Toronto Metropolitan University, Canada

ABSTRACT: Design for daylight is important for energy-efficient, sustainable, and healthy housing. There is a growing awareness of the benefits of designing for human-centric, circadian lighting at home to provide natural light as a stimulus for regulating the biological clocks of inhabitants. This paper summarizes results of a simulation-based study of apartment unit floorplans that were evaluated for daylight availability and healthy lighting, testing various design options to see which met LEED v4.1 and WELL v1 requirements. Parameters tested included: eight unit orientations, varied window-to-wall ratio, different interior layouts, and varied interior finishes. The findings showed that even small, single aspect units can be optimized for daylight and healthy lighting and that unit aspect ratio is a key determinant for healthy lighting conditions. Unit aspect ratio must be limited to 1:3 or better. Moreover, balconies can act as beneficial shading for overlit unit perimeters. Light-coloured floor and wall finishes are more beneficial for healthy lighting and daylight. This study was part of a larger investigation of healthy apartment housing and future studies will include resident satisfaction using surveys and the influence of artificial lighting to build on the findings from this paper.
KEYWORDS: healthy lighting, environmental simulation, Equivalent Melanopic Lux (EML), Daylight Availability (DA), apartment housing

1. INTRODUCTION

There is a growing awareness of the benefits of healthy, human-centric lighting, which emphasizes the use of natural light as a stimulus for regulating the biological clocks of building occupants [1,2,3]. In the building industry, there are rating systems that assign credits for appropriate quantities of daylight availability and circadian lighting, such as LEED v4.1 [4] and WELL v1 [5]. Recently, some studies have focused on trade-offs in design for daylighting and healthy lighting in office spaces [6,7] but design for residential environments remains understudied. In this paper, typical multi-unit residential building (MURB) units in Toronto, Canada were compared. This typology typically consists of compact, deep floorplates with small balconies and are illuminated primarily from one side [8]. This paper analysed daylight availability and circadian lighting design potential in several design options for units using environmental simulation software. Artificial lighting was not considered in this type of dwelling as individual tenants select their own lighting for their units, thus making assumptions more challenging. The goal of this study was to identify design options and trade-offs that maximize daylight availability and human-centric lighting in MURB. Design options were evaluated using the LEED v4.1 Daylight Credit and WELL v1 Circadian Lighting Credit as standard criteria. The findings from this paper could be used to inform practitioners hoping to achieve LEED or WELL credits in MURB. This paper provides specific findings related to unit geometry, material finishes, and balcony designs.

2. METHODS

Climate-based daylight modelling (CBDM) was utilised to simulate daylight in dwellings [9,10]. ClimateStudio (CS) [11] and Adaptive Lighting For Alertness (ALFA) [12] software were used to generate simulations daylight and circadian effects respectively. Design options were evaluated using the LEED v4.1 Daylight Credit which uses Spatial Daylight Autonomy (sDA) [13] and WELL v1 Circadian Lighting Design Credit which measures the biological effects of light on humans using Equivalent Melanopic Lux (EML). This study did not assume automatic blind use, because this is not typical in MURB. This study was inspired by recent research relating to daylighting and residential design by Dogan and Park 2019 [14] which was critical of existing metrics for daylight availability in this housing type and the work of Nabil and Mardaljevic 2005 [15] who proposed Useful Daylight Autonomy (UDI) as a preferred way to understand "useful" light levels for residents.

2.1 Modelling and Simulation Assumptions

To reflect current trends of building construction in Toronto, Canada, MURB unit design options were modelled for the lighting simulations as one bedroom, single-aspect, side-lit volumes with a ceiling height of 2400mm. To test interior daylighting conditions resulting from varied parameters, the base case for all modelled units included a fully glazed facade (100% WWR) with balconies modelled in a staggered façade arrangement. Each unit balcony was modelled with a glazed balustrade, allowing for maximum daylight penetration. Furthermore, units were modelled as clusters of nine to simulate the effects of the staggered balcony arrangement, which factor in impacts from adjacent units. Shown in Figure 1, the building context was modelled as a typical high-density neighbourhood in Toronto at the intersection of Yonge St. and Bloor St. East. A Toronto weather file was used in simulation.

Figure 1: Context model with unit cluster enlarged. The unit on the bottom middle row was simulated.

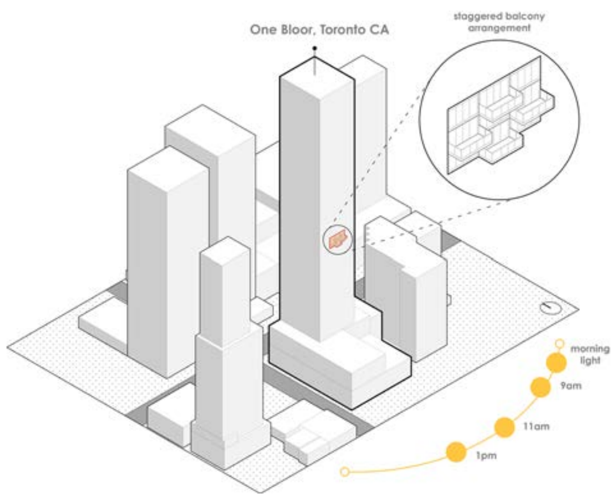


Table 1: Simulation assumptions

	ClimateStudio	ALFA
Sensor Grid spacing	600 mm	600 mm
Task plane	horizontal	vertical
Sensor height	760 mm	1200 mm
Occupancy	8am-6pm DST	n/a

For the daylight availability simulations, this study assumed units were occupied 8am-6pm with Daylight Savings Time (DST) invoked, and produced annual simulations as required for LEED sDA analysis. However, for the healthy lighting simulations, point-in-time simulations were performed at 9am, 11am, and 1pm for both solstices and equinoxes to correspond with requirements of Feature 54 in the WELL v1 Building Standard. An additional consideration was evaluated given that these are residential environments, and it makes sense to consider daylight before a 'workday' begins. Therefore, this study also examined the effects of daylight approximately one hour after sunrise for each point-in-time simulation.

2.2 Unit Design Parameters Tested

Previous research tested the impacts of design parameters on daylighting in MURB, including orientation and balconies [16]. Studies have also reported on healthy lighting with varying parameters for viewer and building orientation, window head height, and room depth [17]. Building on previous studies, the present study investigated the impacts of four variable parameters in this study:

1. Unit orientation – 8 cardinal directions
2. Window-to-wall ratio (WWR) – 40%, 60%, 80%, 100%
3. Interior layout – altered simulation grid
4. Interior finishes – light, dark, colour

Firstly, unit orientation was explored with respect to the eight cardinal directions. Secondly, window-to-wall ratios (WWR) were tested in 20% increments, starting at 40% and ending with 100%. In this study, WWR included the glazed door and the window glazing that spanned the entire width of the facade. The WWR affected the depth daylight was able to penetrate into the unit, which also impacts circadian potential and daylight quantity. Thirdly, when investigating the first two parameters of orientation and WWR, the units were simulated using shoebox models without furniture or partition walls, and with the grid covering the entire floor area. However, to understand layout and finishes, it was decided to test the impacts of interior partitions and different space types (regularly occupied vs other spaces), and so different simulation grids and target areas were evaluated as shown in Figure 2. This was inspired by the different rating systems such as the LEED v4.1 which specifies "regularly occupied spaces" [4] and WELL which specifies required lighting values for bedrooms, bathrooms, and rooms with windows [5]. This study assumed that only living spaces, bedrooms, and kitchens are regularly occupied spaces in MURB and as stated, this study required that all lighting come from daylighting. Although WELL includes bathrooms in its certification, these spaces were not counted as regularly occupied in this study as they are expected to achieve target values through electrical lighting, which is not evaluated in this scenario.

Figure 2: Units with different geometries, interior layouts and assumptions about 'regularly occupied areas'.

Fourthly, this study explored the effects of different material finishes on daylight availability and healthy lighting. Base materials for interiors are listed in Table 2. Typical neutral-toned finishes were selected for floors, walls, and ceilings. Finishes of varying colours or material are shown in Table 3.

Table 2: Materials from the Radiance library used in the simulations.

	ALFA		CS
Building Element	Photopic /T(pho)*	Melanopic /T(mel)*	Rvis /Tvis*
Wall	81.2%	76.8%	80.7%
Floor	63.4%	58.3%	52.0%
Ceiling	82.2%	77.4%	70.0%
Balcony (floor)	82.4%	82.9%	82.4%
Balcony (balustrade)	88.3%*	89.0%*	87.7%*
Interior Door	78.9%	74.9%	86.0%
Furniture (fabric)	83.3%	76.5%	56.1%
Furniture (hardwood)	4.6%	4.6%	5.4%
Furniture (kitchen)	85.2%	83.9%	85.2%
Mullion	19.8%	19.9%	4.6%
Glazing	70.1%*	70.1%*	69.6%*
Ground	20.1%	19.1%	21.0%
Context	20.0%	18.9%	20.0%

Table 3: Darker interior finishes were tested to understand the impacts on healthy lighting

	ALFA		CS
Element	Photopic	Melanopic	Rvis
Wall	7.8%	7.8%	7.8%
Floor	10.7%	6.4%	7.7%
Ceiling	5.1%	5.1%	5.1%
Balcony (floor)	20.0%	18.9%	22.0%
Interior Door	4.9%	4.3%	9.2%
Furniture (fabric)	3.7%	4.0%	5.1%
Furniture (hardwood)	4.6%	4.6%	5.4%
Furniture (kitchen)	22.7%	12.4%	8.3%

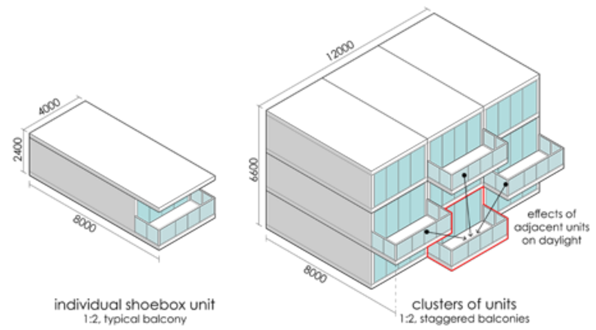
3. RESULTS

The results from the simulations showed unit design options where the LEED Daylight Credit requirements are met, where requirements for WELL Circadian Lighting Design credit are met, and where both are achieved. While both LEED and WELL allow lighting quantity to be from both daylight and artificial lighting, the present paper evaluated only based on daylight, given that assumptions for electric lighting in MURB should be considered unreliable given the fact that different tenants can install different fixtures. The study results are summarized in this section as four main findings in connection with the architectural parameters investigated.

3.1 Evaluating Daylighting on Façade vs Units

Existing studies [16,17] evaluated apartment units in daylighting simulations by modelling them as discrete shoebox models. However, a defining feature of MURB is that all units are connected with cohesively designed facades and floorplates. Thus, as noted in the Methods section, MURB units were modelled in clusters of nine. This allowed for simulations to account for the influence of adjacent unit balconies, which act as shading devices. Simulations were performed on the unit in the middle of the bottom row in Figure 3.

Figure 3: *Conventional shoebox unit versus cluster model*



By evaluating units with adjacent balconies on the façade, daylight availability and circadian values were determined in a more realistic way, and when compared to results from singular shoebox models, this resulted in values differing by +/- 5%. Moreover, an interesting finding about using the staggered balcony facade was discovered regarding WWR. For all 40% WWR units, ASE decreased by approximately 6-7% (Table 4). This is significant for practitioners interested in acquiring LEED v4.1, as a value of ASE below 10% is difficult to attain and required for certification. Having a 40% WWR can also aid in acquiring certification for the Toronto Green Standard, a local voluntary green building standard [18].

Table 4: *Results of Annual Sunlight Exposure (%) of single shoebox (S) versus cluster (C) model – south orientations*

WWR Aspect Ratio	40% S | C	60% S | C	80% S | C	100% S | C
1:1	17 | 10	20 | 23	24 | 23	26 | 27
1:2	15 | 8	18 | 20	20 | 21	20 | 25
1:2.5	11 | 4	14 | 16	17 | 16	17 | 18
1:3	8 | 3	10 | 11	12 | 11	12 | 16

3.2 The Need for Orientation-Specific WWR Configurations in MURB

New MURB in Toronto are often designed with excessively high WWR on all facades [8]. Such high WWR in deep floorplans generally results in overlit perimeter spaces and overheating, with many spaces within the unit receiving inadequate daylight. For these reasons, varying WWR should be considered when designing the various facades and orientation of a MURB. In the studies examining building orientation, the simulation results were as anticipated, with south and south-east facing units acquiring the most daylight during the day, but also the most glare. Surprisingly, it was discovered that all units met the minimum requirement for LEED credits, although south and south-east facing units performed best (Table 5). This is also the case for circadian stimulus, with 100% of views south and southeast achieving at least 200 EML for all simulations 9am-1pm so those units met LEED and WELL requirements. It was not so difficult to achieve the EML requirements in most units tested. Furthermore, It was discovered that all other orientations receive ample EML values for approximately 89-99% of views, with the exception of 1:2.5 and 1:3 units. As long as the unit aspect ratio is 1:2 or better, all orientations meet the WELL Standard requirement for Circadian Lighting Design. For 1:2.5 and greater, targeted EML values were not met solely in December. For LEED requirements, the unit aspect ratio must be 1:3 or better to satisfy requirements.

Table 5: Best Daylight Autonomy results for units with varying aspect ratios with 100% WWR

Aspect Ratio	SE	S
1:1	100%	100%
1:2	100%	100%
1:2.5	100%	100%
1:3	74.4%	73.7%

WWR was tested in different variations with glazing centered at head-height (1200mm). Through altering WWR, it was discovered that EML values plateaued once reaching 60% WWR, with 100% of views achieving 200 EML for all simulations 9am-1pm. Therefore, units that increase WWR beyond 60% do not necessarily improve EML levels. Results for daylight availability were as predicted, with ASE and DA decreasing as the window area is lowered.

3.3 Impacts of Using Dark Finishes on Interiors

In MURB, every unit is painted, furnished, and customised according to its owner's preference, impacting the building's overall performance. In this study, different materials were tested to see the impacts on lighting. We found surface material has no impact on ASE, assuming household finishes with typical reflectance values are used. However, the use of dark finishes (such as black paint) was found to significantly inhibit the DA of a space by 20-30% and the EML by approximately 30-50%. Thus, it was deduced that the penetration of daylight into a space is partially influenced by reflections, which is impacted by surface material. Figure 4 illustrates the differentiating qualities between light and dark finishes.

Figure 4: Light interior finishes versus dark interior finishes

In terms of colour, previous studies indicated that the spectral properties of light were influenced by not only transmission, but also by the reflective properties of architectural surfaces [19]. Thus, we tested the effects of yellow walls, blue walls, and dark flooring as visualized in Figure 5. It was determined that neither yellow nor blue painted walls had a significant impact on the daylight availability or circadian values of the unit. Yellow walls showed decreases of 2-5% and blue walls 5-15%. Dark floors had a similar effect to blue walls, with decreases of 5-15%. It is recommended that white/neutral finishes be applied to maximize daylight and circadian potential.

Figure 5: Fisheye Images of coloured walls and darkened floor

3.4 Acceptable Scenarios for 1:3 Unit Aspect Ratios

Orientation and aspect ratio were found to have the biggest impact on unit lighting. In Toronto, Canada many units are 1:3 or 1:4 or even deeper so an aim of this study was to test the thresholds of unit depth, and what other parameters would need to be met to still achieve healthy lighting. It was found that a 1:3 aspect ratio unit (4m x 12m x 2.4m) achieved adequate light levels in select scenarios. To satisfy both LEED and WELL requirements, a 1:3 unit would need to be south or south-east facing, with a near 100% WWR. This assumes the typical empty shoebox model, without consideration of interior partitions or furniture. The simulations that tested interior layouts with interior partitions and furniture for the 1:3 units failed to achieve required light and circadian values for LEED v4.1 and WELL v1.

4. DISCUSSION

The three main findings are summarized and discussed in this section.

4.1 Significance of Design Decisions on Daylight and Healthy Lighting

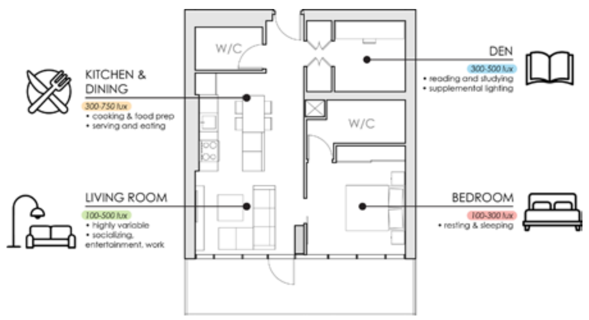
The results of this preliminary study showed the significance of architectural design parameters on the visual and non-visual effects of daylight in a MURB unit. For example, materials and colours used within unit interiors impact how light is experienced. Units with dark surface materials resulted in reductions of DA by 20-30% and EML by 30-50%. Although designers or inhabitants may want to apply dark surface finishes, they may not realize that they are preventing maximum daylight and healthy lighting qualities. An alternative to these options may be the use of coloured walls, which only impact daylight and circadian values marginally. It was also found that dark flooring is acceptable as it has no impactful effects on daylight.

In the context of COVID-19, private outdoor space in the form of balconies is more important than ever [20]. In this study, small protruding balconies were modelled, and their arrangement on the facade was tested in a 'staggered' arrangement, rather than one directly above the other. The staggered balcony arrangement resulted in decreases of glare in some orientations. This can be significant for designers when trying to mitigate visual discomfort in a building as the balcony acts not only as an extension of the unit interior, but also as a shading device. This may also be critical in acquiring an ASE value lower than 10% for achieving LEED v4.1 Daylighting credit.

4.2 What is 'well-lit' at Home?

Given that many MURB in Toronto and elsewhere are small and deep in plan, this study tested how deep a unit floorplan could be to still maintain good daylighting quality. A finding was that there were some instances where 1:2.5 or even 1:3 aspect ratios in dwelling units provide acceptable daylight and circadian stimulus. Such units must be south-facing with high WWR (80-100%). To achieve certification for the LEED v4.1 Daylighting credit and WELL Circadian Lighting Design feature, "regularly occupied spaces" such as living rooms, bedrooms, and especially kitchens must be located nearest to the glazing, allowing for sufficient illumination and circadian stimulus during daytime hours. This study revealed upper thresholds that should not be exceeded to maintain healthy lighting. For instance, units with the study parameters that are deeper than 1:3 aspect ratio will not be acceptable for healthy lighting. As such, practitioners should be aware of the trade-offs between access to daylight and the financial pressures for more units per floor (and therefore deeper floorplans). Furthermore, the study findings relate to COVID-19 and how people are using their dwellings for a wide variety of tasks including exercising, teleworking, e-learning and other things. Future studies should survey users to better understand what light levels people prefer and expect at home.

Figure 6: Recommended lux values in a typical apartment unit



4.3 Home Customization and Future Research

Although simulation tools provide users with reliable approximation of daylight within a space, this study encountered inconsistencies that should be considered. For instance, personalization varies widely across units, as occupants have different preferences for unit interiors. Virtual models typically do not account for this variability in units nor the imperfections in surface material based on prolonged use. Future research in this field could focus on evaluating a variety of different layouts and furnishings with a higher degree of detail, potentially with information such as realistic occupancy schedules and interior furnishings provided by MURB occupants. Future studies can also incorporate electric and supplemental lighting alongside daylight to determine the circadian effects of light outside of peak daylight hours.

Current daylighting metrics, such as Spatial Daylight Autonomy (sDA), are informative for evaluating commercial spaces. However, assumptions regarding these metrics make them less reliable for residential environments. In MURB, blinds are not automated, and a uniform target illuminance is not expected, as unique spaces require different illuminances. Thus, new daylighting metrics should be developed and tested, catering particularly to MURB.

5. CONCLUSIONS

This study evaluated daylighting and circadian potential of typical MURB units, to explore relationships between design parameters. Certain design options illustrated trade-offs between architectural features and daylight penetration. The findings showed that even small, single aspect units can be optimized for daylight and healthy lighting and that unit aspect ratio is a key determinant for healthy lighting conditions. Unit aspect ratio must be limited to 1:3 or better in order to achieve LEED Daylighting Credit and the WELL Circadian Design Feature. This study showed that balconies can act as beneficial shading for overlit unit perimeters. Furthermore, light-coloured floor and wall finishes were more beneficial for healthy lighting and daylight. This study was part of a larger investigation of healthy apartment housing and future studies will include resident satisfaction using surveys and the influence of artificial lighting to build on the findings from this paper. Future research could focus on evaluating a variety of different layouts and furnishings with a higher degree of detail, potentially with user input such as realistic occupancy schedules and interiors provided by MURB occupants.

ACKNOWLEDGEMENTS

This research was partly supported by a grant from the Dean's Research Fund Undergraduate Research Opportunity Program at Toronto Metropolitan University.

REFERENCES

1. Veitch, J. A. (2015). Light for life: Emerging opportunities and challenges for using light to influence wellbeing. *Information Display*, 31(6).

2. Figueiro M. G. (2017). Disruption of Circadian Rhythms by Light During Day and Night. *Current sleep medicine reports*, *3*(2), 76–84.

3. Brown, T. et al. (2022). Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. *PLoS Biol* 20(3): e3001571.

4. U.S. Green Building Council. (2019). *Leadership in Energy and Environmental Design v4.1*. LEED v4.1 | U.S. Green Building Council. Retrieved March 24, 2022, from https://usgbc.org/leed/v41

5. International WELL Building Institute. (2019). "WELL v1 Building Standard." International WELL Building Institute, 2019, www.wellcertified.com/certification/v1.

6. Konis, K. (2017). A novel circadian daylight metric for building design and evaluation. *Building and Environment*, *113*, 22–38.

7. Figueiro, M. G., Kalsher, M., Steverson, B. C., Heerwagen, J., Kampschroer, K., & Rea, M. S. (2019). Circadian-effective light and its impact on alertness in office workers. *Lighting Research and Technology*, *51*(2), 171–183.

8. Peters, T., Kesik, T., & O'Brien, L. (2019). *MURB Design Guide: Enhancing the Liveability and Resilience of Multi-Unit Residential Buildings*. www.bchousing.org/publications/MURB-Design-Guide-V2.pdf

9. Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *LEUKOS*, *3*(1), 7–31.

10. Bodart, M., Kleindienst, S., & Andersen, M. (2008). Graphical Representation of Climate-Based Daylight Performance to Support Architectural Design. *LEUKOS*, 5(1), 39–61.

11. Solemma. (n.d.). ClimateStudio. Retrieved from https://www.solemma.com/climatestudio

12. Solemma (n.d.). ALFA. Retrieved from https://www.solemma.com/alfa

13. Illuminating Engineering Society of North America & Rea, 2000. *The IESNA Lighting Handbook: Reference & Application. Illuminating Engineering*; 9th edition.

14. Dogan, T., & Park, Y. C. (2019). A critical review of daylighting metrics for residential architecture and a new metric for cold and temperate climates. *Lighting Research and Technology*,*51*(2),206–230.

15. Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: A new paradigm for assessing daylight in buildings. *Lighting Research and Technology*, 37(1), 41–59.

16. Peters, T., Alkhalili, N., Kesik, T., & Brien, W. O. (2020). Challenging Conventional Approaches for Climate-Based Daylight Simulations of Multi-Unit Residential Buildings, *Building Performance Analysis Conference and SimBuild* September 29-October 1 2020, Chicago, Illinois. p. 103-110

17. Altenberg Vaz, N., & Inanici, M. (2020). Syncing with the Sky: Daylight-Driven Circadian Lighting Design. *LEUKOS - Journal of Illuminating Engineering Society of North America*

18. City of Toronto. (2022, January 21). *Toronto green standard*. City of Toronto. Retrieved March 24, 2022, from https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/

19. Inanici, M., Brennan, M., & Clark, E. (2015). Spectral Daylighting Simulations: Computing Circadian Lighting. University of Washington , Department of Architecture , Seattle , WA , USA ZGF Architects , Seattle , WA , USA. *International Building Performance Simulation Association (IBPSA) 2015 Conference*, 1245–1252.

20. Peters, T., Halleran, A. How our Homes Impact our Health: Using a COVID-19 Informed Approach to Examine Apartment Housing, *Archnet-International Journal of Architectural Research,* Vol. 15(1), 2020, p.10-27.

PLEA SANTIAGO 2022
Will Cities Survive?

Data-driven design for climate adaptation

Validating Ladybug Tools for street-scale microclimate design

SINEAD NICHOLSON[,2], MARIALENA NIKOLOPOULOU, RICHARD WATKINS[1], CARLO RATTI[2]

[1]University of Kent, Canterbury
[2]Carlo Ratti Associati, Turin

ABSTRACT: Small, street-scale microclimatic design offers significant advantages in adapting to extreme temperatures expected due to climate change by improving the thermal comfort of outdoor urban space. This can improve health and wellbeing of city inhabitants, reduce energy demands and improve individual adaptive capacity to extreme temperatures. Designing, however, for outdoor thermal comfort is complex due to the dynamic nature of microclimate. Environmental simulation offers a tool to connect microclimate science to design but if used in design, is more likely to be applied to site analysis or evaluation of a project. This paper compares measured versus simulated surface temperatures to validate a workflow which relies on the parametric environmental analysis plugin for Rhino: Ladybug Tools to analyse the effect of a shading canopy on the thermal environment within a street canyon. Ground and Canopy surface temperature show a 0.868 and 0.901 r^2 value, respectively, indicating good prediction capability from Ladybug Tools. Ladybug Tools interface with 3D modelling software Rhinoceros, fast simulation time and parametric capabilities facilitate a feedback process between microclimate science and design helping to embed microclimate into design practice.
KEYWORDS: Outdoor thermal comfort, microclimate simulation, Ladybug Tools, shade canopy

1. INTRODUCTION

Outdoor urban space is as important to the survival of cities as the buildings it surrounds, providing not just connecting space but also a place for leisure, refuge, social and political life. In a post Covid world, urban outdoor space has taken on even greater value and new functions; entertainment, sport, education and important life celebrations, have moved (or returned) to the streets and city squares.

Rising temperatures due to climate change alongside the Urban Heat Island significantly affect the usability of this space and thus the liveability of cities[1]. On a large-scale, climate adaptation measures may not succeed in counter-acting the predicted rise in urban air temperatures[2]. However, improving the microclimate and thermal comfort of outdoor urban space at the street scale can offer multiple advantages that can contribute to the overall resilience of a city to climate change. Comfortable microclimates improve health and wellbeing and reduce energy demands by encouraging people to spend more time outdoors.[3,4] Thermally comfortable outdoor space can also support a level of individual adaptation at the pedestrian scale by providing cool 'refuges' that allow citizens to find relief during extreme heat events.

To design thermally comfortable outdoor space is complex, with multiple variables from physical surrounds, climate and the individual characteristics of users interacting to produce continually changing thermal sensations over time and across space. Designing for such a complex characteristic requires climate-responsive, data-driven design, grounded in a qualitative and quantitative understanding of how design decisions influence the microclimate of the space and the thermal experience of the user. Environmental simulation can provide a platform to designers to connect microclimate science & research to practice by allowing them to visualise site conditions and analyse and test the effects of projects on thermal comfort. If applied in the early stages of design, it becomes a tool to develop data driven design projects for climate adaptation.

Much of the existing software for outdoor microclimate analysis, however, does not lend itself well to the design process, either requiring a prohibitive amount of time for preparation and analysis of the model or significantly restricting the scale and geometry that can be tested.[5,6] This paper presents the validation of a microclimate model that uses design tools and easily accessible methods of data collection to analyse and visualise a microclimate mitigation design strategy on urban surface temperatures. A built design project of a shade parasol is used to study the effect of shading and materials on the thermal environment, providing a case study of one of the most simple yet effective methods of microclimate mitigation at a scale relevant to designers.

2. CONTEXT

2.1 Solar Radiation and Shading

The shade parasol offers a valuable case study because the moderation of solar radiation in the urban environment can have significant impact on thermal comfort.[7] Shade reduces direct heat gain by users as well as surrounding urban surfaces, directly improving thermal comfort both outdoors and indoors and reducing building energy use.[8,9] As a design strategy, shade canopies can offer extreme flexibility in terms of design and installation and target the microclimate variable most sensitive to design intervention (solar radiation). They provide small-scale rapid adaptation strategies that can be easily implemented in pre-existing urban areas and easily adapted to the local space. As such they represent one of the most common strategies used to improve outdoor thermal comfort.

2.2 Microclimate Simulation

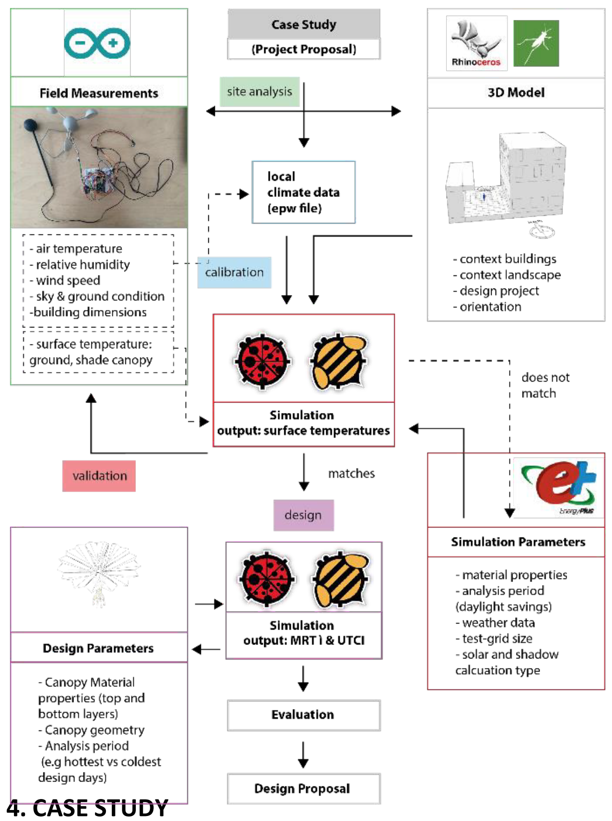
The model uses Ladybug Tools (LBT)[10] a plugin for Grasshopper of Rhinoceros 3D[11], that is already widely used in design offices. Recent studies have found acceptable similarity between EnviMet (considered most accurate for outdoor microclimate modelling) or field measurements and LBT in assessing thermal comfort at the neighbourhood scale.[12,13] The greatest advantage it offers over other microclimate modelling software is the parametric capabilities: once validated, the model can be used to test multiple design parameters such as canopy dimensions, or material properties; as well placed in different street forms and climates, without re-modelling. Being parametric, the set up allows for the designer to adjust the type of analysis needed for the project. Thus, radiation studies, energy modelling or Computational Fluid Dynamics analysis may be run separately, and different outputs collected and visualised, from irradiance values to UTCI index. With this flexibility, the simulation time can be extremely rapid in comparison to other microclimate simulation software creating a feedback process between design and effect that allows the designer to gain a strong understanding of the microclimatic impact of their design. There is also very little restriction on the 3D geometry modelling allowing for the analysis of small-scale projects and fine detail. As such the tool facilitates an important iteration/evaluation process in the initial stages of design.

The downside of such flexibility can result in unreliable results if the designer does not understand the data needed, the parameters they are changing, or what kind of analysis is necessary. There is a balance to find in the use of Ladybug tools for microclimate simulation, however, the need for greater climate sensitivity in design versus complete accuracy weighs in favour of a rapid visualisation tool, that when supported by an active forum and detailed resources can offer a powerful design tool.

3. METHODOLOGY

Figure 1 illustrates the workflow to set up the microclimate model for calibration and illustrates the next steps for use as a design tool. The workflow was adapted from two example scripts used to simulate UTCI in a street canyon, and surface temperatures underneath a tree canopy.[14,15] Both environmental monitoring and modelling are combined in the workflow: the exact process followed is explained further in Section 4 using a shade parasol as case study.

Surface temperatures are the selected data for validation. While LB (radiation analysis) alone could be sufficient for understanding the microclimatic effect of shading strategies in the initial stages of design, this analysis focuses on simulating surface temperatures through HB because they are a relatively simple data type to collect and, they provide a common unit of information in understanding the effect of materials and shading on thermal comfort, as well as linking outdoor and indoor conditions. This is particularly relevant where materials such as photovoltaics, or 'cool materials' are used because their use results in significantly different surface temperatures when compared to ambient temperature. If modelled solely as a 'shade', the canopy would be assumed to follow the surrounding air temperature.



4. CASE STUDY

Figure 1| *Ladybug Tools Microclimate design workflow*

The case study is a redesign of the traditional beach umbrella, incorporating a foldable parasol integrated with thin film amorphous silicon photovoltaics. It measures 2.51m high with a 3.16m diameter and was developed by design firm Carlo Ratti Associati (CRA), for an installation in Milan to provide a 'cool' leisure space in one of the city's main parks during August.

Figure 2| *Canopy installation and sensor set up at test site*

The parasol was installed at CRA's factory (fig. 2), located in a mixed industrial/residential area northeast of Turin centre (lat: 45.1° N, 7.7° E). The site itself is a narrow 'canyon' bordered by a cement wall with an overhanging walkway on the western edge, and the factory on the eastern edge. The ground is a cement grid infilled with soil and sparse grass. The photovoltaics were not active during monitoring.

4.1 Monitoring

Data on ground temperature, the temperature of the underneath layer of the canopy and air temp, relative humidity and wind speed were collected to calibrate the model. Fig. 3 shows the location of sensors while the exact equipment and corresponding standards[16] are presented in Table 1. Standards for measuring outdoor thermal comfort don't exist, however, the sensors used comply or come close to compliance with those used for indoors. The anemometer was compared against a validated anemometer for verification since specifications were not provided.

Table 1 | Sensor specifications used in measuring outdoor microclimate variables.

Variable	Sensor	Range	Accuracy	ASHRAE 55
Air Temp °C	AHT20	-40 to +85	±0.3	±0.2
Rel. Humidity %	AHT20	0 to 100	±2	±5
Wind Speed m/s	WH-SP WS01	unknown*	unknown*	±0.05
Canopy Temp °C	Mlx90614	-40 to 125	±0.5	±1
Ground Temp °C	Tiny Tag Plus 2	-40 to +85	±0.01	±1

On the day of testing (17th September 2021) the weather conditions were clear and dry with no precipitation in the preceding days. From 10.00 to 18.00 hrs measurements were taken at five-minute intervals. Soil composition, cloud cover and shading patterns were also observed.

4.2 Modelling

Grasshopper is used to link 3D modelling of the site to LBT. The radiation analysis and energy modelling functions of LBT were used for the analysis: Ladybug (LB), to analyse climate data, create a shade map for comparison with field observations and visualise results; and Honeybee (HB), which creates an interface between the grasshopper/rhino platform and validated building energy modelling engine, EnergyPlus (EP)[17] to calculate surface temperatures of modelled thermal zones.

4.2.1 Climate Data

The local area weather file, in EnergyPlus weather format (EPW) can be downloaded through LB by connecting to a database of the world's currently available opensource weather data.[18] The collected site data alongside cloud cover observations were used to find the best matching 24-hour period in the EPW file. The epw air temp, RH and wind speed were replaced with the collected data and solar radiation values kept in order to calibrate the model to the specific local conditions of the site. EP also relies on the EPW file for the warmup period of the simulation, using weather data from the previous days until convergence is reached, from a minimum of 6 up to 25 days.

4.2.2 Geometry

Surrounding built form and ground geometry were modelled parametrically in Grasshopper, based on observations and measurements taken physically at the site and through GoogleEarth's 3D modelled buildings. A shading map generated by LB's 'Incident Radiation' component was compared to photos of modelled vs real geometry. The geometry to be evaluated for surface temperatures was converted to separate thermal zones with the outdoor exposed surfaces of the ground and canopy broken into small grids of 0.5m in order to capture the shading effects of small-scale geometry.

4.2.3 Materials

Construction materials were based on those defined in the EP constructions database or, for the case of the non-standard surfaces, derived from data collected on site, specific references found in literature or general theory when an exact reference could not be found (type and corresponding references indicated in Table 2 & 3). Two specific HB components: 'Opaque Material No Mass' and 'Vegetation Material' were used to represent ground and canopy. Default values embedded in the component were used where the value was unknown. The underside canopy layer is not included since a 1mm layer of PVC coated polyester would have very little effect on the thermal transmission of the PV layer and therefore negligible effect on surface temperature. This was confirmed in the simulation once calibrated.

Table 2| *Assigned Canopy material properties*

Properties	Amorphous silicone photovoltaic
R-value (W/m.K)	0.2[21]
Roughness	Very Smooth[o]
Thermal Absorptivity	0.2[19]
Solar Absorptivity	0.85[19]
Visible Absorptivity	0.85[19]

Table 3 | *Assigned ground material properties*

Properties	Grass & Moist Clay Soil
Plant Height (m)	0.05 [o]
Leaf Area Index	0.75[o]
Leaf Reflectivity	0.22[d]
Leaf Emissivity	0.95[d]
Soil Reflectivity	0.3[d]
Soil Emissivity	0.9[d]
Stomata resistance (s/m)	180 [d]
Thickness (m)	0.2 [o]
Conductivity (W/m-K)	3[20]
Density (kg/m³)	2000[20]
Spec. Heat Capacity (J/kg-K)	1500[20]

o = observed *d = default* *# = reference*

4.2.4 Energy Loads

The buildings were assigned default construction and energy load schedules for a warehouse (bottom floor) and medium office (remaining floors) based on the EP database. Ground was converted to zero loads through the 'Make Ground' Honeybee component and the canopy also converted to zero energy loads through 'Plenum Zone' component.

4.2.5 Canopy Thermal Zone

To successfully run in EP, all thermal zones must be closed 'rooms' composed of planar surfaces. This results in an enclosed volume of air within the zone and limit on the minimum thickness of the zone. To work around these limitations the canopy was modelled as the roof of a thermal zone, consisting of walls with 95% surface area made up of 'windows' scheduled to remain open at all times (Fig. 3**)** In this way the canopy could be modelled without an air gap that could affect heat transfer and with the representative thickness of 3mm.

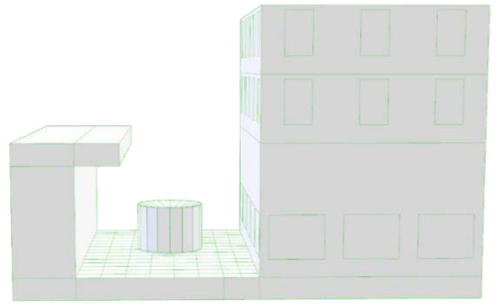


Figure 3| *Canopy modelled as roof of enclosed room*

4.2.6 Simulation Parameters

The model was connected to EP with a 24-hour analysis period of 12 timesteps/hr (5-minute intervals) and polygon counting for shadow calculation method. All other parameters were left as default. Surface temperatures and surface energy flow were specified outputs. The run time is approximately 5 minutes on a laptop computer with intel core i7-1065G7 and 1.30Ghz CPU. Once validated and run with 1 timestep/hour simulation time can be further reduced significantly.

4.2.7 Visualisation

The outer surface temperatures were extracted for the entire model and visualised through 'HB colour faces' component on the Rhino 3D model. This can then be displayed as average outer surface temperatures or surface temperatures for every time step of the analysis period. Further analysis and visualisation were performed by selecting the grid face of the canopy and ground surface corresponding to the sensor locations on the site. The values for the 24-hour period were then extracted through Ladybug data analysis components and exported to a csv file to be analysed.

5. RESULTS

As the results in Figure 4 and Table 4 below indicate, simulated temperatures for both canopy and ground can be considered acceptable for the purposes of design comparison with an R^2 value of 0.86 for ground and 0.9 for canopy. Temperatures followed measured data closely up until 12H, where slightly higher peak temperatures were reached both by the simulated canopy and ground. As temperatures decrease around 15H, greater agreement is reached in ground temperatures while canopy temperatures remain up to 10K higher. The

Table 4| *Coefficient of determination statistical tests for measured vs simulated temperatures.*

	Ground	Canopy
R^2 Value	0.868	0.901

PLEA STGO 2022
WILL CITIES SURVIVE? ANALYSIS AND METHODS

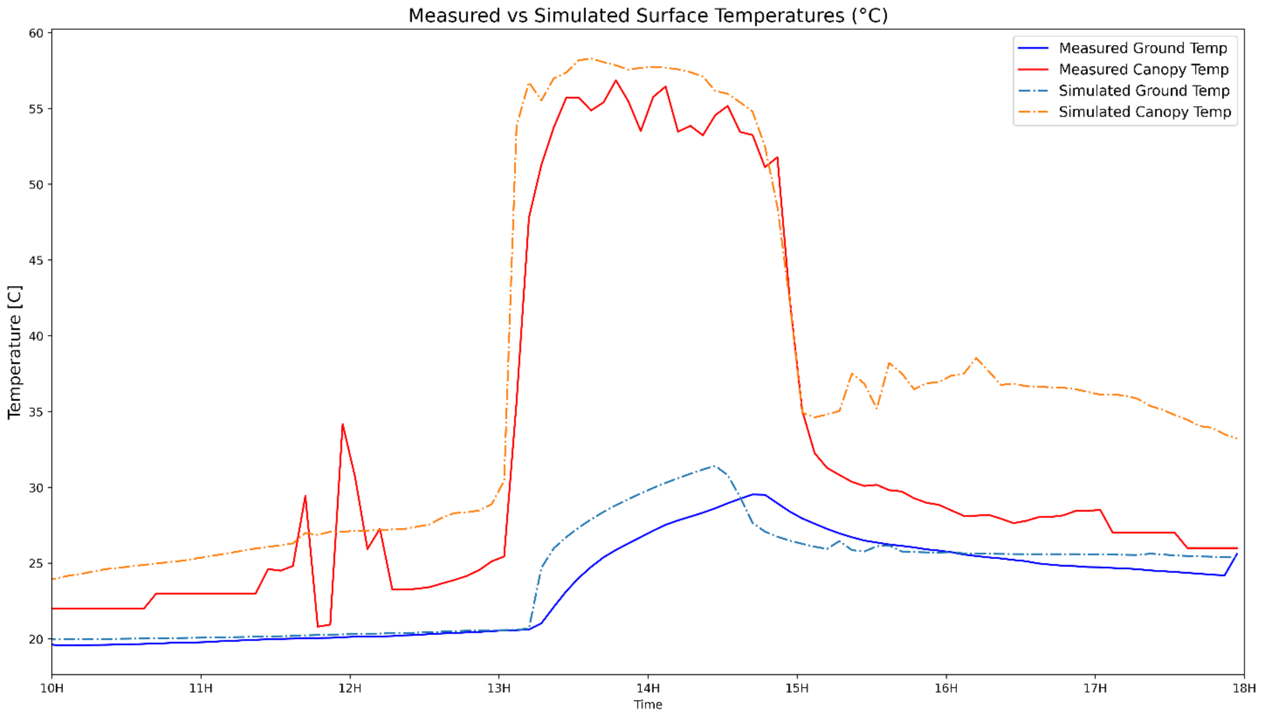


Figure 4 | *Measured vs Simulated Surface Temperatures for Shade canopy case study using Ladybug Tools*

rapid gain in temperatures can be attributed to direct solar radiation reaching the sensor points both in the simulation and at the test site indicating the major role direct sun plays in surface temperatures. The differences between simulated and observed temperatures could be due to the inaccuracy of the material property inputs. The reliance on mostly EPW weather data, particularly the radiation values could also have affected accuracy of the simulation. To be further investigated, is the reason for the small peaks between 15H and 17H for both canopy and ground simulated temperatures and the increase in simulated canopy temperature in late afternoon (probably related to modelling the canopy as a room) Measured Canopy results show errors in the sensor set up encountered during the morning due to a faulty wire connection.

6. DISCUSSION

An effort was made to simplify the modelling and simulation process to maintain user friendliness, with as many inputs as possible left as default. Canopy geometry and materials carry the most complexity for the user and can significantly affect accuracy of results. EP provides many pre-defined materials and constructions based on standard buildings, however, when applying non-standard materials such as photovoltaics, custom properties need to be derived either from literature, measurements or theory. The use of the 'No Mass Opaque material' component allowed for the representation of a very thin material, requiring only five defined properties, simplifying the process of simulating canopy materials with unknown thermal properties. However, despite the more simplified inputs, this stage adds extra complications for the user, requiring knowledge in areas not usually familiar to architects and urban designers.

Other parameters with noticeable effects on results included time steps, context building heights and orientations and the analysis grid size. In a more exposed site, where wind speeds are greater, CFD or more detailed wind speed measurements may also be needed to provide a more accurate representation of the effect of wind.

It is recommended that, to create a more direct connection between designer, design, microclimate and user, the model, once validated, is used to calculate more communicative indices, such as the UTCI, which can be calculated using LBT components. A further step in this research would be to use the calibrated model in designing an optimised shade canopy design for thermal comfort, and in testing its effect in different microclimatic contexts thus linking microclimate to design.

5. CONCLUSION

The described methodology, using already established design software for simulation, paired with field measurements, was adopted in order to assist in an in-depth analysis of the shade parasol case study and provide an example of how design and microclimate can be linked. The software is parametric with extremely rapid processing time and this, in addition to the Arduino sensor kit allowing for easy and localised data collection, provide an accessible design tool that allows designers to study how both material and shade contribute to thermal comfort in urban settings.

The simulation can be used to optimise microclimate strategies such as shade canopies and through careful assignment of accurate material properties, to understand the effects of more advanced cool materials, photovoltaics and double skin structures that are beginning to be applied to urban surfaces as climate adaptation measures. The speed of simulation and additional scheduling and optimisation capabilities that LBT and native Grasshopper components allow also means responsive structures that adjust to environmental conditions throughout the day can be modelled allowing further design development of this fast-growing field.

ACKNOWLEDGEMENTS

This research is part of a project funded by the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No. 86119.

REFERENCES

1. Santos Nouri, A., Costa, J., Santamouris, M., & Matzarakis, A. (2018). Approaches to Outdoor Thermal Comfort Thresholds through Public Space Design: A Review. *Atmosphere*, *9*(3), 108. https://doi.org/10.3390/atmos9030108
2. Middel, A., & Krayenhoff, E. S. (2019). Micrometeorological determinants of pedestrian thermal exposure during record-breaking heat in Tempe, Arizona: Introducing the MaRTy observational platform. *Science of The Total Environment*, *687*, 137–151. https://doi.org/10.1016/j.scitotenv.2019.06.085
3. Santamouris, M., & Kolokotsa, D. (Eds.). (2016). *Urban climate mitigation techniques*. Routledge.
4. Chokhachian, A., Santucci, D., & Auer, T. (2017). A Human-Centered Approach to Enhance Urban Resilience, Implications and Application to Improve Outdoor Comfort in Dense Urban Spaces. *Buildings*, *7*(4), 113. https://doi.org/10.3390/buildings7040113
5. Naboni, E., Meloni, M., Coccolo, S., Kaempf, J., & Scartezzini, J.-L. (2017). An overview of simulation tools for predicting the mean radiant temperature in an outdoor space. *Energy Procedia*, *122*, 1111–1116. https://doi.org/10.1016/j.egypro.2017.07.471
6. Naboni, E., Coccolo, S., Meloni, M., & Scartezzini, J.-L. (2018). Outdoor comfort simulation of complex architectural designs: A review of simulation tools from the designer perspective. *Infoscience*, Article CONF. 2018 Building Performance Analysis Conference and SimBuild co-organized by ASHRAE and IBPSA-USA.
7. Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Building and Environment*, *41*(11), 1455–1470. https://doi.org/10.1016/j.buildenv.2005.05.031
8. Garcia-Nevado, E., Beckers, B., & Coch, H. (2020). Assessing the cooling effect of urban textile shading devices through time-lapse thermography. *Sustainable Cities and Society*, *63*, 102458. https://doi.org/10.1016/j.scs.2020.102458
9. Ata Chokhachian, Katia Perini, Sen Dong, & Thomas Auer. (2017). How Material Performance of Building Façade Affect Urban Microclimate. In *Powerskin 2017*. TU Delft Open.
10. Chris Mackey & Mostapha Roudsari. (2022). *Ladybug Tools* (1.4) [Python]. Ladybug Tools. https://www.ladybug.tools/about.html#team
11. David Rutten. (2022). *Grasshopper: Algorithmic Modeling for Rhino* [Python]. Robert McNeel & Associates. https://www.grasshopper3d.com/
12. Ibrahim, Y., Kershaw, T., & Shepherd, P. (2020). *A methodology For Modelling Microclimates: A Ladybug-tools and ENVI-met verification study*.
13. Evola, G., Naboni, E., Margani, G., & Magri', C. (n.d.). *Modeling Outdoor Thermal Comfort in Urban Canyons: Presentation and Validation of a Novel Comprehensive Workflow*. 3288–3295. https://doi.org/10.26868/25222708.2019.210402
14. Chris Mackey. (2016). *Outdoor Microclimate Map* (Code example) [Computer software]. http://hydrashare.github.io/hydra/viewer?owner=chriswmackey&fork=hydra_2&id=Outdoor_Microclimate_Map&slide=0&scale=1&offset=0,0
15. Chris Mackey. (2016). *Trees in Outdoor Thermal Comfort* (Code example) [Computer software]. http://hydrashare.github.io/hydra/viewer?owner=chriswmackey&fork=hydra_2&id=Trees_in_Outdoor_Thermal_Comfort&slide=0&scale=6.062866266041592&offset=-2887.559959576377,-582.9333700083878
16. ASHRAE. (2021). *Standard 55-2020, Thermal Environmental Conditions for Human Occupancy (ANSI Approved) Preview*. https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_55_2020
17. *EnergyPlus* (9.6). (2021). [Computer software]. U.S. Department of Energy Building Technologies Office. https://energyplus.net/
18. Ladybug Tools. (n.d.). *Epwmap*. Retrieved 21 March 2022, from https://www.ladybug.tools/epwmap/
19. Gracia Amillo, A., Huld, T., Vourlioti, P., Müller, R., & Norton, M. (2015). Application of Satellite-Based Spectrally-Resolved Solar Radiation Data to PV Performance Studies. *Energies*, *8*, 3455–3488. https://doi.org/10.3390/en8053455
20. Abu-Hamdeh, N. H. (2003). Thermal Properties of Soils as affected by Density and Water Content. *Biosystems Engineering*, *86*(1), 97–102. https://doi.org/10.1016/S1537-5110(03)00112-0

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE URBAN DEVELOPMENT

DAY 02
12:00 — 13:30

CHAIR
MAGDALENA VICUÑA

PAPERS
1624 / 1466 / 1404 / 1226

22TH PARALLEL SESSION / ONSITE

PLEA SANTIAGO 2022
Will Cities Survive?

Outdoor thermal comfort studies in the pedestrian corridor between two high-rise buildings in the Mediterranean climate

SOULTANA (TANYA) SAROGLOU [1] ISAAC A. MEIR [1]

[1] Department of Civil and Environmental Engineering, Faculty of Engineering Sciences, Ben-Gurion University of the Negev

ABSTRACT: This paper studies the wind climate that is created at the pedestrian corridor between two high-rise buildings in the Mediterranean climate of Tel Aviv. High-rise buildings affect the microclimate around them and at pedestrian level affect the activities that take place there. The topic of urban winds and high-rise buildings is of special interest, since buildings that are considerably higher than their surrounding urban canopy, block wind and deflect it at higher speeds down to street level. The focus is on outdoor pedestrian thermal comfort towards the realization of successfully designed outdoor urban spaces, a topic that currently lacks the scientific background that it requires. The methodology used spot measurements, micro-meteorological weather stations, and field studies. Questionnaires were handed to people occupying the pedestrian corridor between two high-rise buildings, documenting their thermal perception of the area, while the local environmental conditions were being recorded. Results confirmed a locus specific microclimate at the base of the high-rise buildings. The importance of field studies is especially emphasized in the understanding of outdoor thermal comfort, with this case study revealing different behaviours according to seasonal variations that point out the need / necessity for the establishment of seasonal design strategies.
KEYWORDS: Wind climate, high-rise buildings, outdoor pedestrian thermal comfort, field studies

1. INTRODUCTION

The Covid-19 pandemic required social distancing brings the realization that public open spaces may have a much more prominent role in daily life than previously considered, pointing out the importance of their appropriate design within the urban fabric. High-rise buildings affect the microclimate around them, not least at ground level and, as a result, also affect the pedestrian activities that take place there. Buildings that are considerably higher than their surrounding urban canopy, block wind and deflect it at higher speeds down to street level. This phenomenon becomes especially problematic when dealing with public open spaces. The increasing numbers of high-rise buildings within the urban environment bring into focus the nexus of *high-rise buildings, urban public spaces and outdoor thermal comfort*. A sustainable urban future with a number of high-rise buildings needs to carefully consider the above relationships, in order to create a vibrant pedestrian realm. This paper studies the urban microclimate in the pedestrian corridor between two high-rise buildings in the Mediterranean climate of Tel Aviv, Israel. The focus is on the wind climate that is created between the towers at ground level, and its effect on pedestrian thermal comfort according to seasonal variations based on field surveys.

2. URBAN WINDS AND PEDESTRIAN COMFORT

Successfully designed outdoor spaces invite people to stay outdoors, while they promote social interaction through cultural and recreational events (Stender & Walter, 2019). However, outdoor thermal comfort is a multi-faceted subject that depends on a number of parameters not easily quantifiable (Coccolo et al., 2016). Regarding thermal comfort and environmental variables, the underlined differences between indoors and outdoors are significant, e.g., air velocities. For example, a light breeze outdoors may be defined as comfortable while exceeding the velocities defined as comfortable indoors (ASCE—American Society of Civil Engineers, 2003). Regarding urban winds, while their effect on buildings is highly analysed today and summarized in international wind loading building codes and standards (Robertson & Naka, 1980), the topic of urban winds and pedestrian comfort lacks the same level of detailing, while no universal wind comfort criteria for pedestrians exist to-date. Current standards are based on research studies (field studies and thermal simulations) (Blocken et al., 2016; Melbourne & Joubert, 1971), while guidelines on how to evaluate these are also lacking (Johansson et al., 2014).

In regards to urban winds and tall buildings, currently there are recorded examples of people having difficulties retaining their balance at pedestrian level of tall buildings when wind speeds escalate to 10m/s, while in Great Britain gust speeds that reached 25m/s resulted in the death of two older women (Lawson & Penwarden, 1975; Melbourne & Joubert, 1971). The establishment of a safe and comfortable outdoor environment for pedestrians is a must, validating the need of further studies, especially in relation to potentially problematic situations, like the ones created on the ground level around high-rise buildings.

2.1 Pedestrian Wind Comfort

Currently, NEN 8100, 2006 in the Netherlands is the only code on pedestrian wind comfort assessment. Up-to-date data from meteorological stations in the Netherlands in combination with detailed roughness mapping, assist planning professionals in successfully incorporating wind comfort into building design (Willemsen & Wisse, 2007). However, in different countries different comfort criteria become applicable. In addition, while there are a number of thermal comfort indexes, e.g., Fanger's, PET, etc., commonly agreed criteria see no human discomfort with wind speeds up to 5m/s, unpleasant feelings from 5-10m/s, strongly unpleasant feelings above 10m/s, and the possibility of danger beyond that. These findings are mainly based on computer simulations, wind tunnel tests, and on-site monitoring.

However, pedestrian wind comfort is a multifaceted matter and involves the combination of mechanical and thermal effects of wind on people. Mechanical effects describe the effect of wind force, while the thermal ones are a combination of physical, physiological, and psychological parameters of people's comfort conditions (Nikolopoulou & Steemers, 2003). Examples of the above refer to a person's age, weight, surface area, physical fitness, physiological acclimatization and cultural background (Chen et al., 2015), as well as environmental variables not easily measurable or controlled, like mean wind and gust speed and duration, dry bulb temperature, relative humidity, and more. In addition, it becomes relevant to physical activities, where for example, walking, sitting down, and relaxing, have a completely different effect.

Conventional thermal comfort theory describes thermal comfort as the condition of the mind that expresses satisfaction with the thermal environment, assessed by subjective evaluation (Coccolo et al., 2016; Gehl, 2011). As far as outdoor thermal comfort is concerned, while seasonal variations and weather conditions play an important role, people's perception is also based on their psychological state. A study on outdoor thermal comfort conducted in Tel Aviv between an urban park, an urban square and a street canyon, revealed that the thermal tolerance of the interviewees was the lowest at the urban park, probably due to their higher expectations for better conditions there (Balslev et al., 2015).

Therefore, on the road towards understanding outdoor thermal comfort, above and beyond the important tools used such as micrometeorological instruments and experimental design, the value of empirical data through field surveys is pivotal as it enriches the understanding between *microclimatic and comfort conditions* that can lead to successful urban design decisions. Empirical data studies have been increasing in recent years, but their current numbers are still not sufficient for developing strategies on outdoor thermal comfort (Andrade et al., 2011; Matzarakis et al., 1999). This study focuses on the accumulation of empirical data as an important parameter in the formation of outdoor thermal comfort guidelines.

3. METHODOLOGY

In situ micro-meteorological stations (HOBO USB Microstation H-21) were installed for a summer and a winter day (24hrs) in the pedestrian corridor between two high-rise buildings in Tel Aviv recording wind and gust speed (m/s), wind direction (degrees), relative humidity RH (%) and temperature (°C) (Figure 1). Gust wind speed refers to smaller duration wind speed fluctuations, lasting 2-3

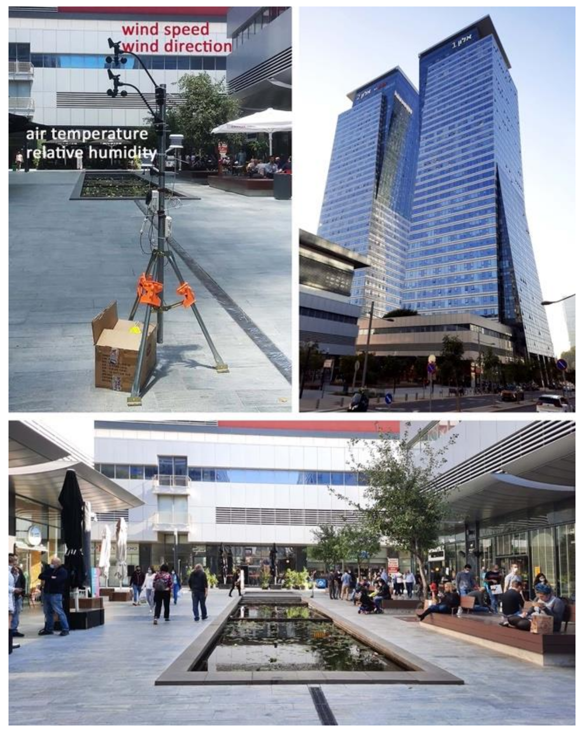


Figure 1: *(Top left) view of micrometeorological station; (Top right) view of case-study high-rise buildings; (bottom) view of pedestrian corridor at pedestrian level of the high-rise buildings*

seconds, and it's their maxima that people feel the most, while velocities usually reach twice the ones of wind speed (Hunt et al., 1976).

Tel Aviv has a Mediterranean climate (Csa) and is located in Climatic Zone A in Israel that refers to a coastal, hot and humid climate. Average annual temperatures range around 20°C, with the lowest averages of 13°C in January and the highest of 27°C in August. Annual relative humidity is high throughout the year with averages between 60-70%. Wind speed has a W / NW orientation and averages range between 3-5m/s. Global radiation may reach 3.43 MJ/m^2 in the summer, and 1.53 MJ/m^2 in winter (Bitan & Rubin, 1991). Tel Aviv is characterized by its long summer period that spans from about mid-March to the end of October that, in combination with the high relative humidity, may cause thermal stress conditions during the months of July and August.

In addition to the collection of micro-meteorological data, spot measurements were conducted in the streets surrounding the high-rise buildings, to gain a better understanding of the wind stratifications between the pedestrian corridor of the high-rise buildings and the surrounding areas. For the spot measurements LUTRON LM-8102 professional environmental measuring instruments were used certified with ISO-9001, CE, and IEC1010. The thermal perception of the people visiting the corridor was obtained through the use of questionnaires alongside with the microclimatic recordings.

The 24-hours study period commenced from 12:00 on day one, to 12:00 the following day, while questionnaires were administered mainly between 12:00-20:00, and 06:00-12:00, both for the winter and summer days. The focus was on lunch time hours when the area is mostly occupied. While there were challenges accommodating this part of the work within Covid-19 constraints, the surveys took place when restraints were lifted. The authors consider the numbers of completed questionnaires as accurate and representative of the people frequenting the pedestrian corridor under study.

3.1 The thermal comfort questionnaires

The thermal comfort questionnaires required a variety of information relating to people's demographic data, such as age and gender, as well as questions relative to their thermal adaptation. More precisely, they indicated whether or not they were in a conditioned environment beforehand and for how long, what is their familiarity with the site, e.g., how often they visit there, activity level at the time they were interviewed, for how long they occupy the area, and what is their level of

TEMPERATURE				
very cold	cool	neutral pleasant	hot	very hot
WIND SPEED				
no wind	weak	neutral pleasant	strong	very strong
HUMIDITY				
very dry	dry	neutral pleasant	humid	very humid

Table 1: *Thermal perception section of questionnaire*

acclimatization with the local climatic conditions, e.g., timeframe of residency if they are not local.

The aim of the following section of the questionnaire was to document the interviewees' thermal sensation while the meteorological stations were recording the environmental data, i.e., air temperature, wind speed, and relative humidity. The effect of solar radiation was not taken into consideration as the pedestrian corridor is mostly shaded, especially during mid-day when pedestrian activity is high. People's perception of the thermal environment was evaluated through a thermal sensation scale, comparable to the conventional ASHRAE 7-point TSV scale (American Society for Heating Refrigerating and and Air-Conditioning Engineers in America, 1989), for temperature (very cold, cool, neutral/pleasant, hot, very hot), wind speed (no wind, weak, neutral/pleasant, strong, very strong), and humidity (very dry, dry, neutral/pleasant, humid, very humid) (Table 1). The interviewees responded how they feel at the time of the interview by circling the right answer. The option of 'neutral/pleasant' shows contentment with the thermal environment.

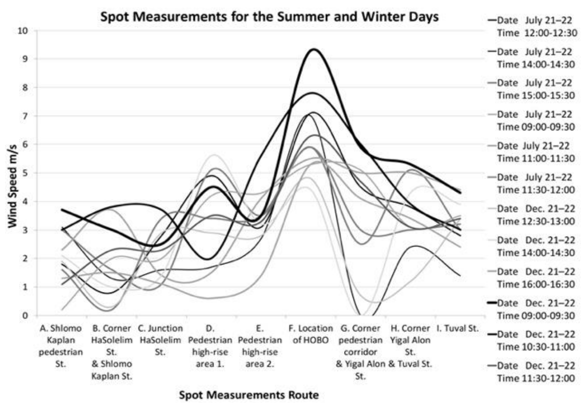


Figure 2: *Results of spot measurements at different time intervals between and in the surroundings of the high-rise buildings under study during the 24hrs summer and winter monitoring.*

4. RESULTS

Figure 2 depicts the wind recordings of the spot measurements in the areas between the high-rise buildings and their surroundings. Results highlight the importance of microclimatic studies at pedestrian level of high-rise buildings by confirming higher wind velocities between the two towers in relation to the streets nearby. They also underline the importance of field studies towards an understanding of the interconnections between urban microclimate and outdoor thermal comfort.

Regarding the questionnaires, the evaluation of the interviewees' thermal sensation votes mainly focused on the lunch-time hours that pedestrian activity is high for both the summer and winter days. The responses were divided into half-hour intervals, e.g., 12:30-13:00, and related to the perception of wind speed, temperature, and relative humidity, juxtaposed with the recorded environmental data averages for the same timeframe (Figure 3). The aim of the study was to draw conclusions between people's perception on thermal comfort, in relation to the recorded environmental variables for the specific microclimatic conditions that are created between the two high-rise buildings. An important parameter in this research work are the differences between seasonal variations.

Monitoring results confirm high local temperatures all year round. An analysis of the interviewees' responses according to Figure 3 shows that during the summer day even though averages reach 30°C, the increased wind velocities (wind speed 3.9m/s, gust speed 6m/s) are perceived as positive summer breezes, under the high temperature and RH values. On the other hand, during the winter day, low wind velocities (wind speed 2m/s, gust speed 3.5m/s) with high temperature averages of about 19°C, still increased peoples' level of discomfort.

5. DISCUSION

This study focused on the wind climate that is created at the pedestrian corridor between two high-rise buildings in the Mediterranean climate of Tel Aviv. Due to the mild climatic conditions there, no extreme weather phenomena were observed, however, the results were sufficient to draw conclusions on the effect of tall buildings on the pedestrian realm and the importance of seasonal variations in the understanding of outdoor thermal comfort.

In this process the importance of field studies is especially highlighted. Currently there is a lack of wind comfort criteria as well as common parameters for the establishment of guidelines. While the

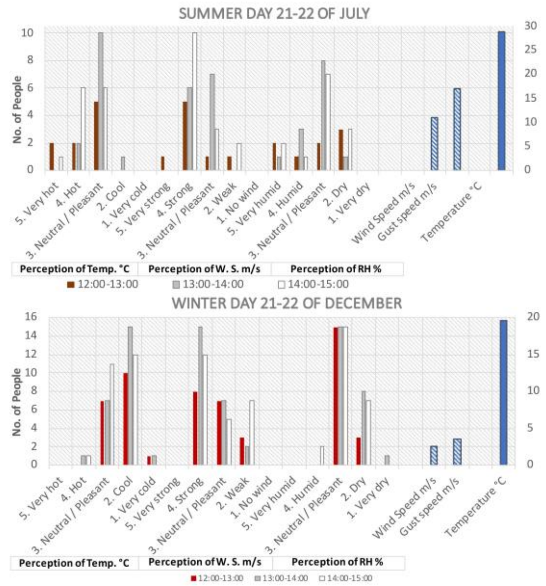


Figure 3. *Recorded environmental variables and thermal perception of people for the summer and winter days.*

standardization of common methods and reporting is crucial, this study points out the significance of field studies for an understanding of the human parameter. Results revealed that seasonal variations played an important role in the relationship between microclimatic and comfort conditions.

5. CONCLUSION

Increasing world population and urbanization demand an increase in building activity, while the typology of high-rise buildings is promoted as an important high-density living solution. Visions, aims and goals towards reducing the environmental impact of cities become increasingly vital towards a sustainable urban future. At the same time existing urban infrastructures need to be also studied and possibly improved. One such example is the design of urban spaces and pedestrian comfort, a subject especially important since 2020 due to the Covid-19 restrictions.

This case study highlights the significance of understanding the human parameter towards the establishment of outdoor comfort guidelines in line with specific climatic conditions, while further studies are suggested in hot and humid climates. The results indicate the need for creating seasonal design strategies at pedestrian level, especially in the vicinity of high-rise buildings.

Planning professionals, i.e., architects, urban planners, etc., need to expand their knowledge on outdoor thermal comfort and urban planning, while pedestrian strategies need to be incorporated into planning building practices. This study focused on the topic of *public open spaces and high-rise buildings*.

ACKNOWLEDGEMENTS

This research is supported by the Department of Civil and Environmental Engineering, Faculty of Engineering Sciences, Ben-Gurion University of the Negev (BGU), and The BGU Center for Energy and Sustainability [https://in.bgu.ac.il/en/ensus/Pages/about.aspx].

REFERENCES

1. American Society for Heating Refrigerating and and Air-Conditioning Engineers in America. (1989). *Ventilating and air-conditioning engineers*. ASHRAE Fundamentals Handbook.
2. Andrade, H., Alcoforado, M. J., & Oliveira, S. (2011). Perception of temperature and wind by users of public outdoor spaces: Relationships with weather parameters and personal characteristics. *International Journal of Biometeorology*, *55*(5), 665–680. https://doi.org/10.1007/s00484-010-0379-0
3. ASCE—American Society of Civil Engineers. (2003). *Outdoor Human Comfort and its Assessment: State of the Art. Task Committee on Outdoor Human Comfort.*
4. Balslev, Y. J., Potchter, O., & Matzarakis, A. (2015). Climatic and thermal comfort analysis of the Tel-Aviv Geddes Plan: A historical perspective. *Building and Environment*, *93*(P2), 302–318. https://doi.org/10.1016/j.buildenv.2015.07.005
5. Bitan, A., & Rubin, S. (1991). *Climatic Atlas of Israel for Physical and Environmental Planning and Design*. Ramot.
6. Blocken, B., Stathopoulos, T., & van Beeck, J. P. A. J. (2016). Pedestrian-level wind conditions around buildings: Review of wind-tunnel and CFD techniques and their accuracy for wind comfort assessment. *Building and Environment*, *100*, 50–81. https://doi.org/10.1016/j.buildenv.2016.02.004
7. Chen, L., Wen, Y., Zhang, L., & Xiang, W. N. (2015). Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai. *Building and Environment*, *94*, 644–653. https://doi.org/10.1016/j.buildenv.2015.10.020
8. Coccolo, S., Kämpf, J., Scartezzini, J. L., & Pearlmutter, D. (2016). Outdoor human comfort and thermal stress: A comprehensive review on models and standards. *Urban Climate*, *18*, 33–57. https://doi.org/10.1016/j.uclim.2016.08.004
9. Gehl, J. (2011). Life Between Buildings: Using Public Space. In *Landscape Journal* (Vol. 8, Issue 1). Island-press. https://doi.org/10.3368/lj.8.1.54
10. Hunt, J. C. R., Poulton, E. C., & Mumford, J. C. (1976). The effects of wind on people New criteria based on wind tunnel experiments. *Building and Environment*, *11*(1), 15–28. https://doi.org/10.1016/0360-1323(76)90015-9
11. Johansson, E., Thorsson, S., Emmanuel, R., & Krüger, E. (2014). Instruments and methods in outdoor thermal comfort studies - The need for standardization. *Urban Climate*, *10*(P2), 346–366. https://doi.org/10.1016/j.uclim.2013.12.002
12. Lawson, T. V., & Penwarden, A. D. (1975). The effetcs of wind on people in the vicinity of buildings. *Proceedings 4th International Conference on Wind Effects on Buildings and Structures*, 605–622.
13. Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology*, *43*(2), 76–84. https://doi.org/10.1007/s004840050119
14. Melbourne, W. H., & Joubert, P. N. (1971). Problems of wind flow at the base of tall buildings. *Preprints 3rd Int. Conf. on Wind Effects on Buidlings and Structures*, 105–114.
15. Nikolopoulou, M., & Steemers, K. (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings*, *35*(1), 95–101. https://doi.org/10.1016/S0378-7788(02)00084-1
16. Robertson, L. E., & Naka, T. (1980). *Tall Building Criteria and Loading*. ASCE Publications.
17. Stender, M., & Walter, A. (2019). The role of social sustainability in building assessment. *Building Research & Information*, *47*(5), 598–610. https://doi.org/10.1080/09613218.2018.1468057
18. Willemsen, E., & Wisse, J. A. (2007). Design for wind comfort in The Netherlands: Procedures, criteria and open research issues. *Journal of Wind Engineering and Industrial Aerodynamics*, *95*(9–11), 1541–1550. https://doi.org/10.1016/j.jweia.2007.02.006

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

Walkability and solar radiation exposure for diverse users

Climate-responsive urban design to enhance accessibility to outdoor spaces

MARIKA TOMASI[1,2], MARIALENA NIKOLOPOULOU[1], RENGANATHAN GIRIDHARAN[1], JUAN CARLOS ROMERO[2], MONIKA LÖVE[2], CARLO RATTI[2]

[1] Kent School of Architecture and Planning, University of Kent, Canterbury CT2 7NR, UK
[2] CRA—Carlo Ratti Associati, 10131 Turin, Italy

ABSTRACT: Urban designers can contribute to improve microclimatic comfort by adapting outdoor spaces to users' need for comfortable and safe microclimatic conditions. The proposed methodology evaluated outdoor spaces from the user experience point of view, focusing then on pedestrians. Walkability was evaluated through analysis of exposure to solar radiation, along with the time pedestrians of different physical abilities would take on the paths. Overlaying walking speeds with solar radiation exposure maps enabled designers to evaluate how much time pedestrians would spend under the sun. Time graphs presented sunny and shaded time along the paths; the total time spent in each condition was then calculated. The methodology was tested on a case study master plan. Testing different spatial configurations of shading devices enabled the optimization of the design, considering users' need for shaded or sunny places, according to different seasons. The installation of shading devices in summer increased the time spent in the shade by 55% for pedestrians walking with an assisting device. The proposed tool aims to give priority to users' comfort in urban design practice. The additional focus on users with different physical abilities contributed by drawing attention to more inclusive cities.
KEYWORDS: Solar radiation, Walkability, Climate-responsive, User experience

1. INTRODUCTION

Among the issues surrounding public spaces highlighted by the COVID-19 pandemic, accessibility, flexibility and unequal distribution across the city are key issues [1]. Climate affects outdoor accessibility, and the rise of exceptional conditions makes cities increasingly vulnerable environments, where ever-growing populations live in spaces with limited adaptability to environmental risks [2]. Reducing climate-related health risks in urban spaces is becoming mandatory to tackle present and future hazards; urban designers can contribute to this challenge.

Excessive exposure to solar radiation and lack of cool areas threaten people's comfort (and even health) even in ordinary conditions [3]. The directional character of solar radiation enables designers to investigate its interaction with shading devices, from the local to the urban scale: this facilitates the implementation of climate-responsive solutions in urban space. In addition to nature-based solutions such as trees and vegetated pergolas, artificial devices can be used to screen solar radiation outdoors. These devices ensure climate resilience even under exceptional conditions: they maintain their effectiveness during drought periods and may be designed to allow solar radiation exposure when needed. Adaptability of outdoor areas through spatial configurations changing on a seasonal or even daily basis can create diverse and responsive spaces, able to adapt also to temporary issues such as the recent redefinition of social distances. Moreover, thermal diversity in urban spaces is important to allow people to choose the preferred environmental conditions spatially and temporally [4].

The proposed methodology refers to the field of climate-responsive urban design, i.e., the combination of spatial elements to provide protection from negative and exposure to positive aspects of climate [5-6]. Microclimatic conditions of outdoor spaces were evaluated based on two user experiences: staying in a specific area and walking within a space. Walkability was evaluated through the analysis of exposure to solar radiation, along with the time pedestrians of different physical abilities take for the various paths.

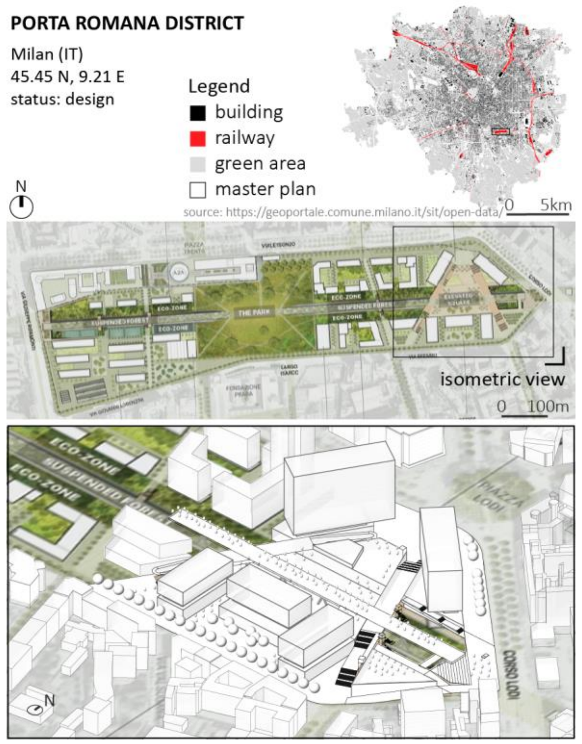
The methodology was tested on the Porta Romana master plan in Milan (IT), a project involving the industry partner CRA—Carlo Ratti Associati. The presented design proposal was a preliminary submission for the Municipality of Milan; changes were possible because of the still ongoing authorisation process. The case study master plan is part of a railway yard's redevelopment (Figure 1). The area under consideration is the eastern part of the master plan and it will mainly host offices. Buildings are located around an elevated square, above the railway line; access to the square is by stairs, elevators and ramps. Various trees are located in the central part of the square, as part of an urban forest in the east-west direction (the so-called "Suspended Forest"). In the north, a restaurant faces the square; the southern part gives access to office buildings. Even though the buildings' function would call for a defined typology of user - office workers, the presence of a metro station to the north and buildings of broad interest to the south (e.g.: Fondazione Prada) led to the inclusion of a more varied catchment. In particular, the designers proposed to create new connections in the north-south direction. Analysis of the solar exposure of the user paths would thus provide valuable information to implement in the design phase.

2. METHODOLOGY

2.1 Modelling the case study

The selected case study was modelled using Rhino software [7]. This choice had two advantages: to import the massing of the buildings directly from the designers' model and to simulate solar radiation through Ladybug [8] - a plugin for Grasshopper, the visual scripting interface for Rhino [9]. This software allowed to test design options without the need to import the model into a different simulation

Figure 1:
Introduction of the case study master plan.



software, and to simulate solar radiation with relatively short computational time compared with other tools. User paths drawn in Rhino corresponded to the main connections around and crossing the area and secondary paths to reach hot spots. The hot spots were defined as attraction points for pedestrians: shops, restaurants, public transport stops, and other places equipped for sitting and gathering.

The incident radiation component in Ladybug is the sum of diffuse and direct radiation reaching the surfaces. The two summer and winter solstice days were simulated to represent the extreme conditions. Three time periods were simulated, to cover the time of maximum exposure: 11:01 am - 12:00 pm, 2:01-3:00 pm and 5:01-6:00 pm (hereinafter referred to as 11 am, 2 pm and 5 pm). To prioritize people's activities at specific times, the summer times were determined by taking into account daylight saving hours. The geometry on which solar radiation exposure was simulated corresponded to the public outdoor space, including ramps and stairs. The surrounding buildings and shading elements such as trees and artificial devices were defined as elements sheltering the space from solar radiation.

The first phase of the analysis phase included a collection of maps in which solar radiation exposure of user paths was indicated. The linear paths were divided into points drawn every two meters, i.e. the same grid size of solar radiation maps. The value of solar radiation for each point corresponded to the one assigned to the closest pixel of the map. In this way, solar radiation exposure of user paths in different hours was obtained.

2.2 Measuring space with time

In the second phase, the user experience was further developed to include the concept of time into the design. It proceeded to evaluate how much time a pedestrian spends under the sun when taking these paths. First, walking speeds needed to be defined. In order to make the design more inclusive, pedestrians with different physical abilities of varying walking speeds were considered. These included standard pedestrians and pedestrians using assisting devices (such as cane, crutch, or walker) and walking speeds were determined from literature. Bosina & Weidmann conducted an exhaustive review of pedestrian speeds [10], while Oxley et al. focused on pedestrians with different levels of physical ability, distinguished among assisting devices [11]. The walking speeds employed in this work are shown in Table 1. For stairs, horizontal walking speeds were adapted from Fujiyama & Tyler [12], from graphs relating horizontal walking speeds to stair gradients,

for young and elderly users. The average value was selected for ascending and descending movements.

By measuring space not metrically, but through the time needed by a pedestrian to cover a defined distance, it was possible to further analyse and modify the design proposal. User paths were measured according to the walking speeds: the amount of time a pedestrian spends in uncomfortable, or even harmful, microclimatic conditions was identified. Based on this analysis, areas where further intervention was needed to improve the microclimate were highlighted and provided the focal point of the final phase.

Table 1:
Walking speeds for users of different physical abilities.

User	Speed (m/s)	Speed (m/minute)	Adapted from
standard	1.34	80	[10]
assisting device	0.70	42	[11]

2.3 Climate-responsive solutions

The microclimatic evaluation of user paths was followed by the design phase, in which the arrangement of shading devices was defined to improve the user experience. Four solutions were modelled: two trees and two artificial devices (Figure 2). Trees were modelled according to the report "Public space - Design guidelines", attached to the Air and Climate Plan developed by the Municipality of Milan [13]. Two sizes of trees were selected (III and IV, according to [13]) to represent deciduous species planted in the surroundings that suit the master plan. Tree canopies were modelled as meshes; the script was based on an example provided by Roudsari [14]. The canopy density was differentiated according to the season, based on images analysis (winter 33%, summer 100%). The artificial shading devices were the stand-alone canopy "Parelio" [15] and a large textile cover. The large cover was divided into a grid and its density was set up to 80% to simulate partial transparency of the textile material. Simulating the screening effect of devices into the master plan enabled to adjust the proposal accordingly. This climate-responsive methodology addressed issues highlighted by implementing the microclimatic analysis into the master planning process. Moreover, the use of removable solutions created dynamic outdoor spaces that could provide outdoor comfort in different seasons.

3. RESULTS

3.1 Solar exposure of the master plan

First, the master plan was analysed to identify user paths. Specific hot spots were highlighted, such as the restaurant and the metro station, while gathering points also emerged. Accesses to the elevated square were identified (Figure 3).

Input weather data to simulate solar radiation were downloaded from the Energy Plus website [16] – station: Milano-Linate 160800 (IGDG). Direct and diffuse solar radiation from the input weather

Figure 3:
Functional analysis of the master plan.

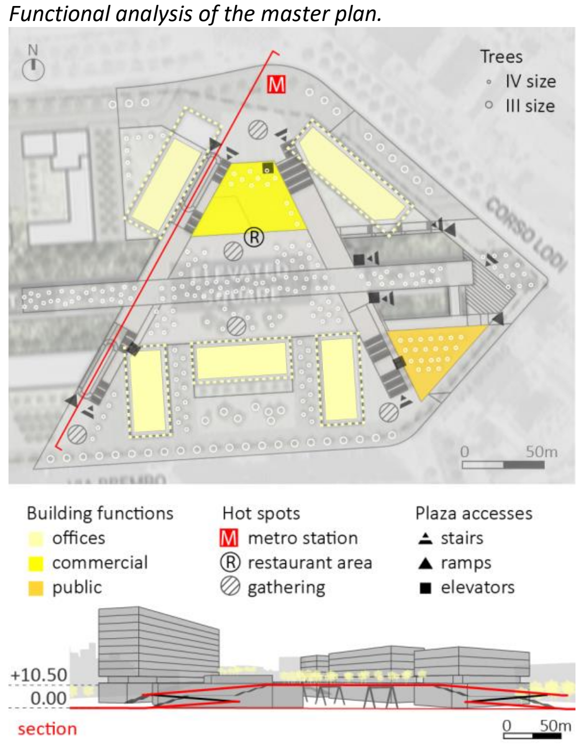


Figure 2:
Description of climate-responsive solutions implemented into the master plan design.

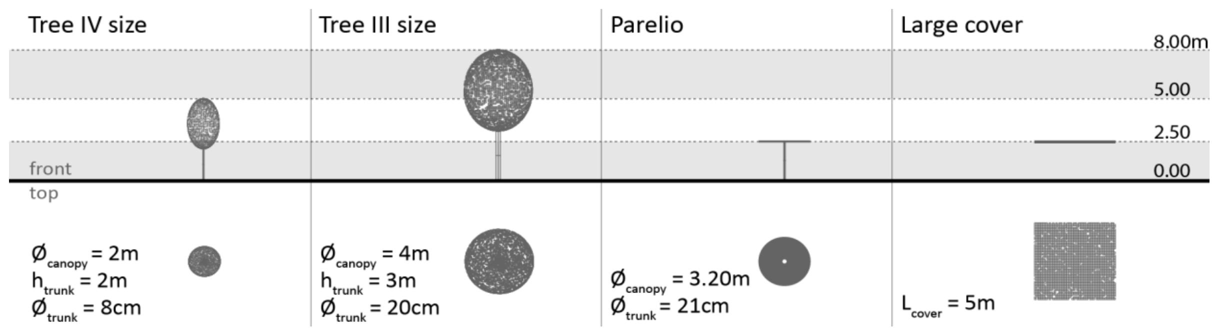
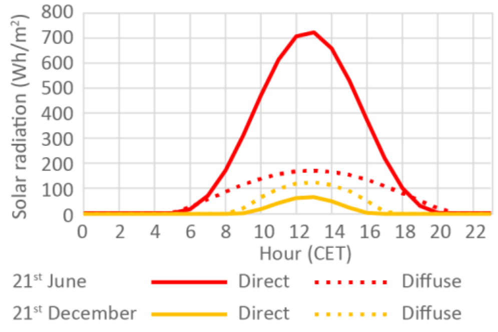


Figure 4:
Direct and diffuse components of solar radiation on horizontal surface on summer and winter solstice days.



file are displayed in Figure 4 for both solstice days. Figure 5 reports solar radiation exposure maps simulated during the two selected days. In winter, the simulation of the 5 pm time period is not displayed as the results were not meaningful. The most immediate information provided by the maps was the screening effect of buildings on the ground. Since the solstice days were selected, the displayed shapes corresponded to the maximum and minimum extent that shadows can reach. Trees were also shading the ground; nevertheless, since their reduced height (from 5 to 8 m, due to design constraints such as the reduced soil depth in the elevated square), their impact was limited. The rooftop of the restaurant and the northern plaza had a large potential as gathering spots since they were largely sunny in winter. Installing temporary devices to provide shade in the summer could make them valuable spots during the hottest days, adapting the space in response to seasonal changes.

Overall, gathering spots were evaluated consistently in terms of thermal diversity and solar radiation exposure. On the other hand, walking paths needed further investigation.

3.2 User experience

Focusing on the walking areas, these were mostly exposed to the sun in the summer. Considering the physiological thermal load from the solar exposure combined with the higher metabolic rate from walking, it was important to address this. Figure 6 presents this issue for two paths. The map refers to 11 am CEST on 21st June, focusing on the walking paths. Two different walking speeds were assessed, for a standard pedestrian and one with an assisting device. The simulated paths corresponded to origin-destination travels in the south-north direction through different accesses (stairs and ramps). Horizontal walking speeds were calculated for the inclination of the stairs (26.6°), with the results presented in Table 2.

In case of pedestrian with an assisting device, it was clear that users could access the elevated square through elevators. Nevertheless, the aim was to explore the experience provided by the space if users preferred to spend time outdoors.

Table 2:
Horizontal walking speeds on stairs – stair gradient: 26.6°.

Movement	Speed (m/s)	Speed (m/minute)	Adapted from
ascending	0.57	34	[12]
descending	0.65	39	[12]

Figure 5:
Simulation of solar radiation on outdoor surfaces at different times of the day on the two solstice days.

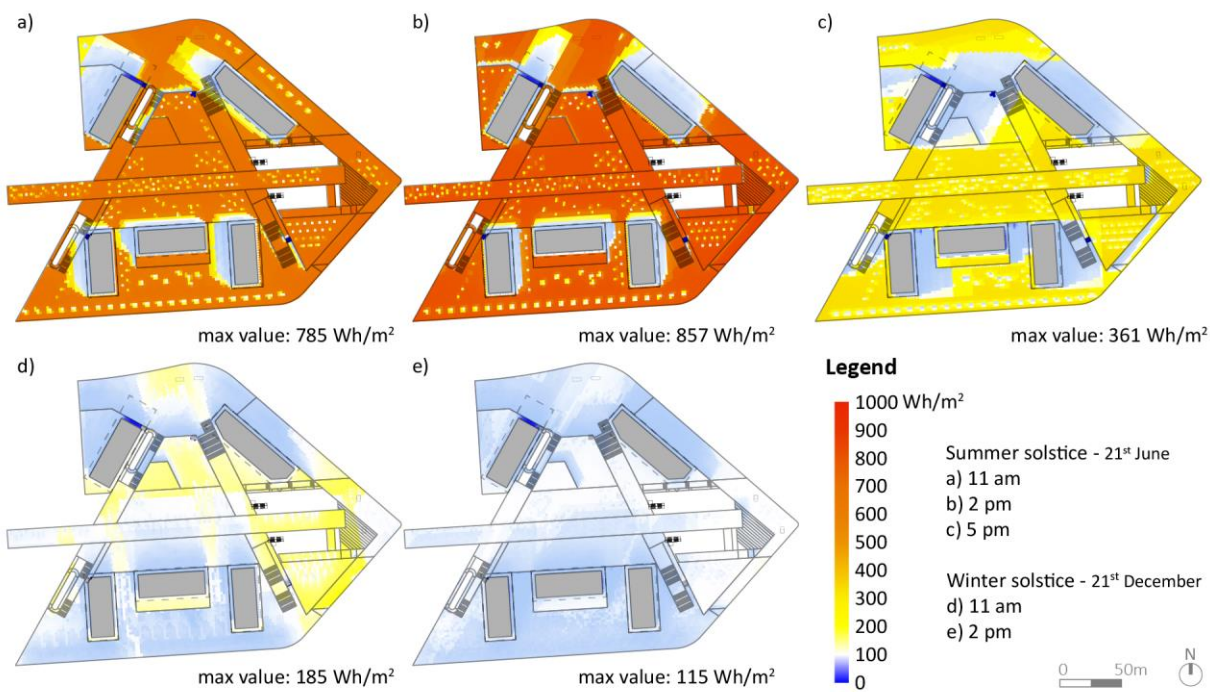
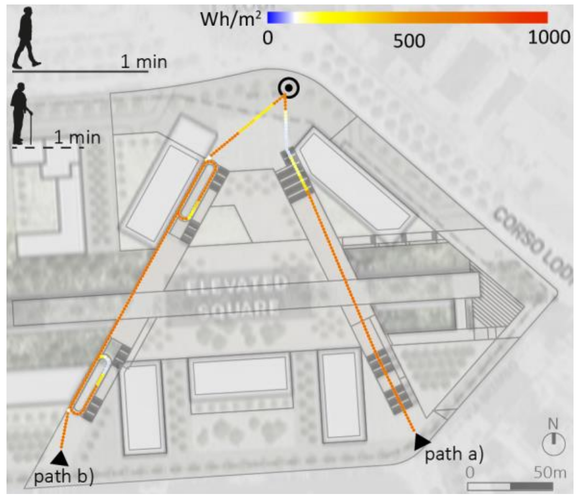


Figure 6:
Solar radiation exposure of paths (experiences) taken by two diverse users.



The user experience was further analysed using a chart (Figure 7). Such analysis has the advantage to represent in a meaningful way the experience provided in the proposed space by relating the numerical results with the paths. As reported in Table 3, the first path was estimated 3'34" long for a standard pedestrian. Except for the final stairs, the journey resulted exposed to the sun. The second path was estimated almost 10 minutes long for a pedestrian with an assisting device. The graph showed more variety in solar radiation exposure than the previous one; a few spots in the shade on the ramp were provided by the ramp on the upper level. Furthermore, five minutes were spent under the sun without any relief (from minutes 2 to 7).

Figure 7:
Solar radiation exposure of two user experiences in time.

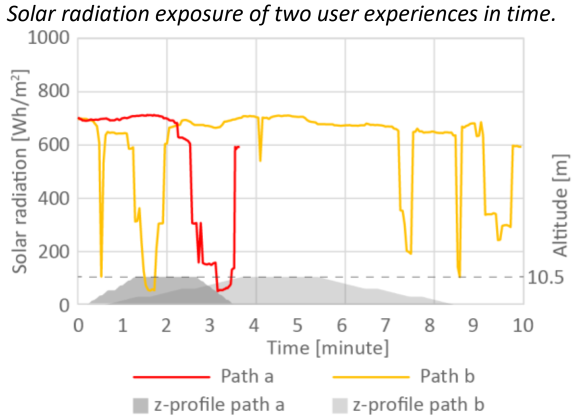


Table 3:
Time spent in sun/shade.

Path	Total time	Time in the shade	Time in the sun
a	3'34"	58"	2'36"
b	9'57"	1'43"	8'14"

3.3 Design proposal

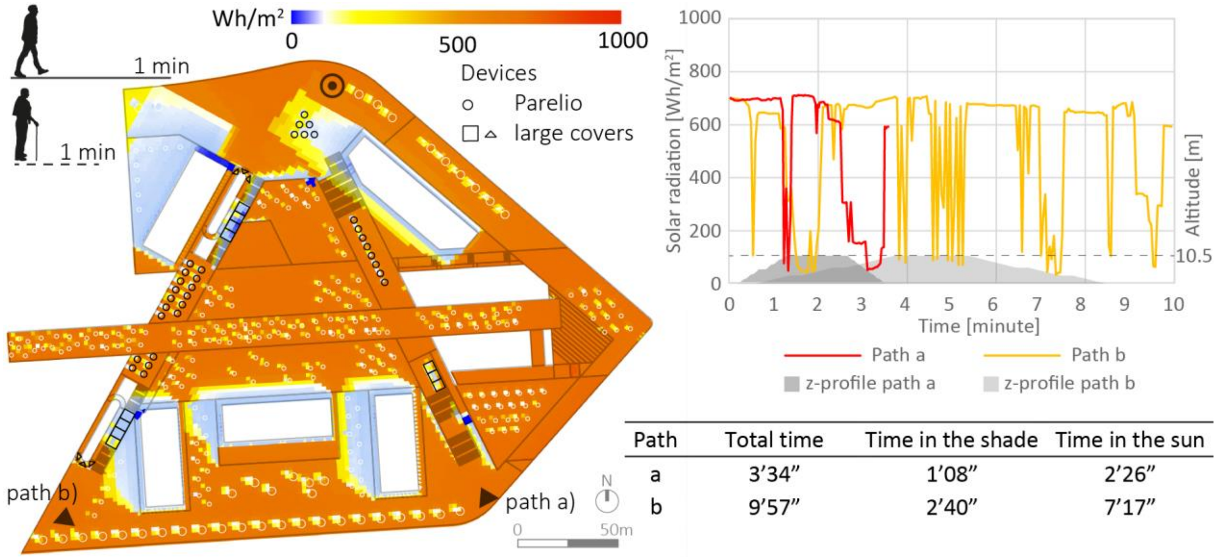
The main aim of the design proposal was to provide users with shaded spots along walking paths in summertime. In winter, the exposure of walking paths to solar radiation was considered adequate; this characteristic needed to be maintained. For that, a non-permanent strategy was adopted, installing Parelio devices and large covers along the paths, ensuring they provided shade on pedestrians most of the time. Using large covers could shade landing areas on the elevated square and along the ramps, to enable people to rest from the physical effort. Due to the absence of soil outside the planted areas, they could provide additional shade in spots where trees could not be planted; furthermore, their complete removal in winter would maintain solar radiation exposure. Artificial devices could also become a dynamic component of the space, maintaining sufficient distance from planted areas (such as the Suspended Forest, a signature space of the project), but creating dialogue with nature. Walking paths across the elevated square were screened using Parelio devices. Their location could not become an obstacle for pedestrians: several simulations were performed to optimize the results.

Figure 8 presents the final proposal in summertime, with the additional devices shown in black. The graph shows additional shaded spots along walking paths. The table reports the updated time periods: in both cases, time spent in the shade increased. Path (a) shows a shaded landing after climbing the stairs. Even though the time in the shade did not increase much (10"), the graph shows a relief spot in between climbing the stairs and crossing the elevated square. Path (b) presents more thermal variety than before, due to the installation of triangular-shaped covers along the ramps and Parelio devices across the square. Time spent in the shade increased by +55%, and most importantly, shaded spots were distributed along the journey.

4. CONCLUSION

This paper presented an innovative methodology to implement microclimatic analysis into urban design practice. The workflow was developed to be usable by designers: tools were selected to include climatic information into the design process. The focus was on the interaction of solar radiation with outdoor spaces, as design can intervene on urban morphology; as a result, this can be addressed from the local to the master planning and urban scale. The time analysis contributed by informing designers about how the solar exposure of the proposed space could affect the pedestrians. Space was not described based on its morphology,

Figure 8:
Design proposal to improve solar radiation protection to user paths in summertime.



Path	Total time	Time in the shade	Time in the sun
a	3’34”	1’08”	2’26”
b	9’57”	2’40”	7’17”

but on the experience provided to users. The conceptual shift of measuring space not metrically, but through the time needed to cover a certain distance, was translated into practical support that made urban designers benefit from the research.

Defining walking speeds added the layer of user experience to the space, providing meaningful information to fine-tune the master plan design. The additional focus on users of different physical abilities contribute to making cities more inclusive.

ACKNOWLEDGEMENTS

This research is part of the SOLOCLIM project that has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 861119.

REFERENCES

1. UN-Habitat. (2020). *Public Space and COVID-19: UN-Habitat*. [Online], Available: https://unhabitat.org/sites/default/files/2020/06/final_public_space_key_messages_covid19_14_june_2020.pdf [23 August 2021].
2. Revi, A.; Satterthwaite, D.E.; Aragón-Durand, F.; Corfee-Morlot, J.; Kiunsi, R.B.R.; Pelling, M.; Roberts, D.C.; Solecki, W. Urban areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 535–612). Cambridge University Press. [Online] Available: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap8_FINAL.pdf [10 april 2021].
3. WHO. (2019). *Healthy Environments for Healthier Populations: Why Do They Matter, and What Can We Do?* [Online] Available: https://apps.who.int/iris/bitstream/handle/10665/325877/WHO-CED-PHE-DO-19.01-eng.pdf?ua=1 [29 June 2021].
4. Nikolopoulou, M. and Steemers, K. (2003). Thermal Comfort and Psychological Adaptation as a Guide for Designing Urban Spaces. *Energy and Buildings*, 35 (1): p. 95–101. https://doi.org/10.1016/S0378-7788(02)00084-1
5. Nikolopoulou, M., ed. (2004). *Designing Open Spaces in the Environment: A Bioclimatic Approach. RUROS: Rediscovering the Urban Realm and Open Spaces*. Centre for Renewable Energy Sources.
6. Tamminga, K., Cortesão, J. and Bakx, M., (2020). Convivial Greenstreets: A Concept for Climate-Responsive Urban Design. *Sustainability (Switzerland)*, *12* (9). https://doi.org/10.3390/su12093790.
7. Rhinoceros. https://www.rhino3d.com/.
8. Ladybug. https://www.ladybug.tools/.
9. Grasshopper. https://www.grasshopper3d.com/.
10. Bosina, E.; Weidmann, U. Estimating pedestrian speed using aggregated literature data. *Physica A: Statistical Mechanics and Its Applications*, *468*: p. 1–29, doi:10.1016/j.physa.2016.09.044.
11. Oxley, J., Fildes, B. N., and Dewar R. E., (1999). Safety of Older Pedestrians. *Transportation Research Board Conference Proceedings, 27*: p.167–191.
12. Fujiyama, T.; Tyler, N. Predicting the walking speed of pedestrians on stairs. *Transportation Planning and Technology*, *33*(2): p. 177–202. doi:10.1080/03081061003643770.
13. Municipality of Milan; Agenzia Mobilità Ambiente e Territorio (AMAT). Public space - Design guidelines. In *Air and Climate Plan* [Online], Available: https://www.comune.milano.it/piano-aria-clima [15 December 2021].
14. Roudsari, M.S. *Tree Modelling in Radiance*. https://discourse.ladybug.tools/t/tree-modelling-in-radiance/1522 [21 May 2021].
15. CRA - Carlo Ratti Associati. (2021) *Parelio for Sammontana* [Online], Available: https://carloratti.com/project/sammontana-beach-umbrella/ [21 February 2022].
16. EnergyPlus *Weather data* [Online], Available: https://energyplus.net/weather [30 August 2021].

Impact of urban neighbourhood layouts on outdoor thermal comfort in European cities with temperate climate

YEHAN WU [1,2] AGNES PATUANO [1] BARDIA MASHHOODI [1] SANDA LENZHOLZER [1]
ANDY ACRED [2] LAURA NARVAEZ ZERTUCHE [2]

[1] Wageningen University and Research, Wageningen, The Netherlands
[2] Foster + Partners, London, The United Kingdom

ABSTRACT: Highly urbanised cities are susceptible to increasingly severe heat stress. Within this context, it is crucial to provide urban planners with guidelines for improving outdoor thermal comfort at the neighbourhood scale and to incorporate microclimate knowledge in their decision-making and design processes. However, although there are some discussions on certain street canyon types, only a few limited studies have been done at this scale to analyse the thermal comfort performance of neighbourhood layouts, which is more complex and more practical to inform urban climate-responsive strategies. This research aims to understand the combined thermal comfort effects of specific morphological parameters in different heat-prone neighbourhood typologies. Using the simulation tool ENVI-MET, this paper examines the thermal comfort performance of four generic typologies with different combinations of street widths, street orientations and vegetation distribution. The results of thermal comfort evaluation indicate for each typology the most problematic areas that need further prioritised cooling interventions. The comparisons of areas with the same street profiles across different neighbourhood typologies also show that neighbourhood typologies with different combinations of morphological parameters can play a role in affecting microclimates.
KEYWORDS: PET, thermal comfort, neighbourhood, urban form, ENVI-met

1. INTRODUCTION

Highly urbanised cities are severely suffering from heat stress [1]. Due to climate change, the intensity of urban heat stress is predicted to increase in the near future, and we need to be prepared for increasingly frequent periods of extreme weather Within this context, urban planners and designers need to incorporate microclimate knowledge in their decision-making process [2].

Especially at the neighbourhood scale, outdoor climate-responsive interventions can be quick to implement and achieve cooling effects [3]. Following [4], neighbourhood microclimate studies should be typology-based and consider the complex thermal comfort effects of different neighbourhood layouts. However, although there are already discussions on the effects of certain street canyon types or building block typologies on microclimates [5], studies on outdoor thermal comfort in different neighbourhood typologies are limited. Most current case studies choose specific neighbourhood cases in cities to analyse certain morphological parameters with regard to thermal comfort, instead of proposing a holistic approach to analyse neighbourhood typologies that can be considered for other cities.

In this paper, four heat-prone neighbourhood typologies for study are focused on by considering the combined effects of different microclimate-related urban design parameters in three major European cities with temperate climates (Amsterdam, London and Paris). The methodology of how these typologies were proposed is presented in [6]. Real-world neighbourhoods (n=656) of the three cities and their morphological parameters were analysed. It was found that the most variant parameters across the neighbourhoods are the combinations of street canyon orientation, street Height-to-Width ratios and tree coverage (Fig. 1 and Table 1). Our proposed four neighbourhood typologies represent the most distinct neighbourhoods across the heat-prone areas of the three cities.

Although these typologies have been found to be commonly present in the most problematic local climate zone in these cities, more information is needed to understand how thermal comfort is spatially varied within these neighbourhoods. This, in turn, can inform the design and planning of cooling interventions at the pedestrian level.

Therefore, this study uses ENVI-met to evaluate the thermal comfort of these four neighbourhood typologies. ENVI-met is a CFD-based holistic microclimate simulation software [7] that can simulate heat and moisture transfer between building materials, soil surfaces, vegetation and the atmosphere. In the new version 5.0 of this software, the algorithm for mean radiant temperature was improved to make the result more precise for outdoor thermal comfort simulation. By conducting the thermal comfort analysis in ENVI-met 5.0, this study aims to identify specific areas within these typical neighbourhoods which are particularly problematic and can be targeted for more effective outdoor climate-responsive interventions.

2. METHODOLOGY

2.1 Neighbourhood typologies

The neighbourhood typologies used in this study are characterised by various combinations of street canyon orientations and Height-to-Width ratios (Fig. 1). All buildings have a height of 20m and have the same form, with a central courtyard. The typical block length and width are 80m and 50m, respectively [6]. Vegetation is modelled as 15m high trees with a 9m crown diameter. Trees have cylinder shapes and large trunks, with a leaf area density of 2. The distance between trees is 15m.

Fig. 1 Four neighbourhood typologies selected in this study

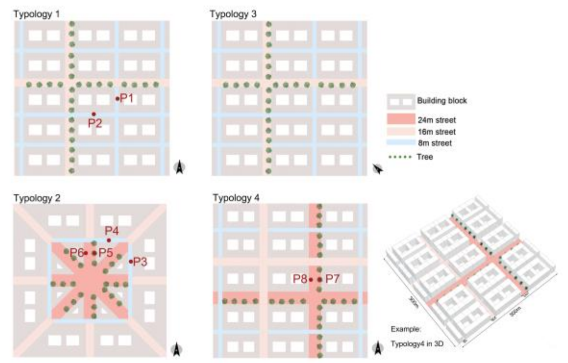


Table 1 Description of four studied typologies

Typology ID	Key properties
Typology 1	Predominantly N-S and E-W oriented streets, with trees on main roads (16m).
Typology 2	Four principal street directions (N-S, NW-SE, E-W, NE-SW) divided by 45 degrees, with trees on wide (24m) streets.
Typology 3	As typology 1 but with NW-SE and NE-SW oriented streets.
Typology 4	As typology 1 but with some wide (24m) major roads.

2.2 ENVI-met simulation

To analyse the thermal comfort performance of the four neighbourhood typologies, ENVI-met was employed with specific inputs for the simulations (Table 2).

Table 2 ENVI-met simulation inputs

Variations	Settings
Size and resolution	350 x 350 x 40 m X= 2m, Y= 2m, Z=2m
Location	48.8677N, 2.3415E
Climate type	Cfb
Simulation day	Typical hot day, 18th, July
Simulation duration	24h, from 7:00am (July 18th) to 7:00am (July 19th)
Wind speed	3m/s at 10m
Wind direction	Southwest
Albedo	Asphalt road=0.2
	Building wall/roof=0.3

The domain size of the simulation is 350×350×40m with a resolution of x=2m, y=2m and z=2 m.

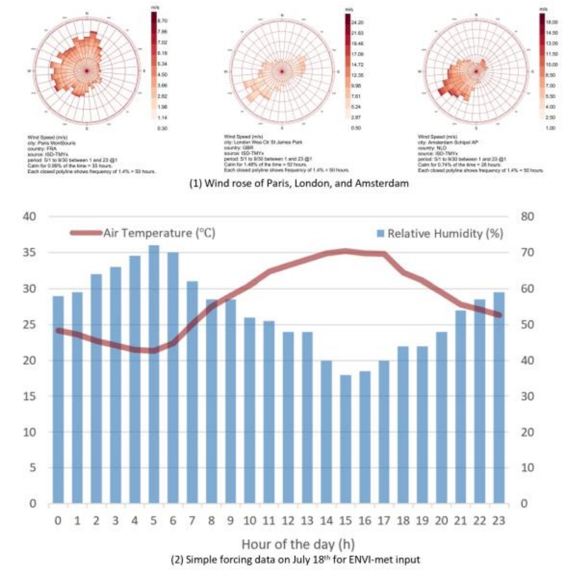
The EnergyPlus Weather (EPW) file of Paris Mont Souris weather station was used as the simple forcing inputs for the simulation. According to the EPW data, July 18th is a representative day within the hottest week of the year and is used for this study. The simulated time starts from 7am, July 18th to 7am, July 19th, with southwest wind as the prevailing wind direction and 3m/s as the freestream wind speed (Fig. 2(1)). The air temperature ranges from 21.3 to 35.2℃ and relative humidity from 36% to 72% throughout the day (Fig. 2(2)).

Physiological Equivalent Temperature (*PET*) is adopted as an index of its extensive application to analyse thermal comfort in different climates and its measurement unit (°C), which makes results easy understandable to urban planners or decision makers [8]. Four atmospheric variables are used as impact factors to compute PET: air temperature (T_a), mean radiant temperature (T_{mrt}), wind speed (V_a) and relative humidity (*RH*). These climate indicators were all measured at 1.4m above ground level to indicate pedestrian level thermal comfort.

14:00 was selected as the focused time for thermal comfort evaluation as this is when the air temperature and representative mean radiant temperature is highest. The results of *PET*, T_a, T_{mrt}, V_a, and *RH* are mapped by LEONARDO which is embedded in ENVI-met.

Specific points on the streets of the four neighbourhood typologies were selected to compare whether the combination of different parameters in each typology yield different PET values (Fig. 1). In Typology 1, P1 is in N-S 8m street and P2 is in E-W 8m street. In Typology 2, P3 is in N-S 8m street, P4 is in E-W 8m street, P5 is in SW-NE 24m street with tree shades, and P6 is in SW-NE 24m street without tree shades. In Typology 4, P7 is in SW-NE 24m street with tree shades, and P8 is in SW-NE 24m street without tree shades.

Fig. 2 Wind rose of the three cities (1); the air temperature and relative humidity on the day selected for simulation (2)



3. RESULTS AND DISCUSSIONS

3.1 Air temperature analysis

The visualisation for the four typologies in ENVI-met illustrates the spatial distribution differences in air temperature (Fig. 3).

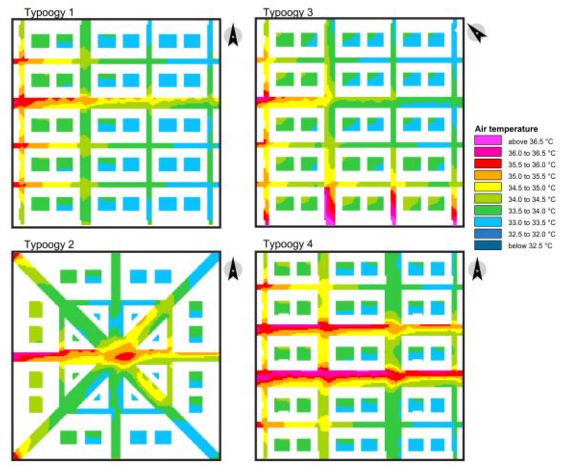
In typology 1, the 8m streets in North-South (N-S) and East-West (E-W) orientations produce similar air temperatures of 33.5-34°C. However, the 16m E-W streets are 2-3°C hotter than 16m N-S streets. Additionally, the crossings between 16m and 8m streets show a temperature 0.5-1°C higher compared to the crossings between 8m and 8m streets.

In typology 2, the air temperature in the central open area (which can be regarded as a major junction or square in reality) is 35.5°C, which is the highest value across all locations. The 24m E-W streets are also about 1°C higher than 24m Southeast-Northwest (SE-NW) and Southwest-Northeast (SW-NE) streets. The east side of the central area with its SE-NW and SW-NE streets is also 1°C higher than the west side.

In typology 3, the difference between SE-NW and SW-NE 16m streets are less important compared to the N-S and E-W 16m streets in typology 1. The air temperature in most areas is less than 34°C, with the SW-NE 16m streets slightly 0.5°C higher.

In typology 4, the 24m streets in both SE-NW and SW-NE orientations all have air temperatures of 35-36°C. And the area with the highest air temperature is found in the crossing between 24m SE-NW and 16m NE-SW streets, which is 0.5°C higher than 24m street crossings and 16m crossings in both directions. The influential street length (buffer zone) of the crossings is around 50m.

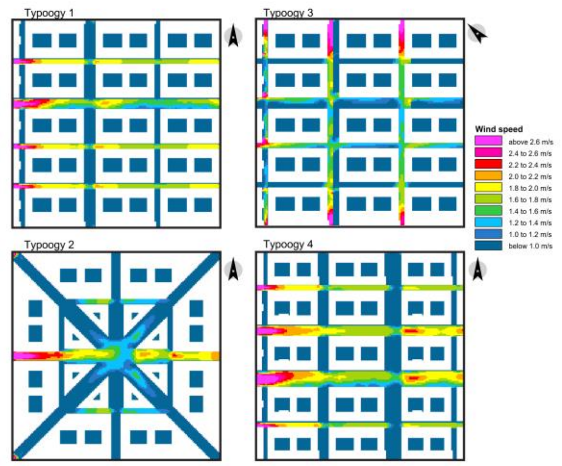
Fig. 3 Air temperature variations of the four typologies



3.2 Wind velocity analysis

The visualisation for the four typologies in ENVI-met illustrates the effect of different spatial distributions on wind speed (Fig. 4).

Fig. 4 Wind velocity variations of the four typologies



In typology 1, all N-S streets exert wind velocity below 1m/s. For E-W streets, however, higher wind speeds are present at around 2m/s. At the same time, the 16m E-W streets have lower wind speed compared to 8m E-W streets. Especially on the south side of the 16m E-W streets, the wind speed is between 1-1.4m/s.

In typology 2, it has similar patterns of typology 1 with only E-W streets varying in wind speed. Other directions of streets are less than 1m/s. Wind speed on 24m E-W streets can reach 2.2m/s, and the highest wind speed in 8m E-W streets is 1.6m/s. It should be noted that the central area is around

1.3m/s, faster than other surrounded directions of streets except E-W streets.

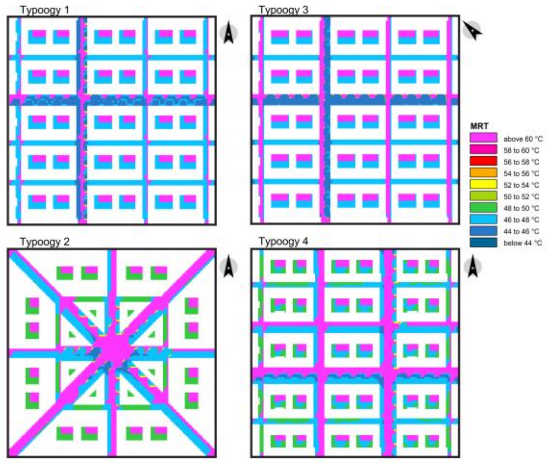
In typology 3, all the streets have in general an average speed of 1.6m/s. Only the SE-NW 16m streets have lower speed, especially on the SW side of the street where the wind speed is less than 1m/s.

In typology 4, the 24m SW-NE streets have a low wind speed of around 1.2m/s. Same values exist in both SE-NW and SW-NE 24m streets. Especially in the crossing of 24m streets in both directions, the wind speed is 1m/s with a buffer zone of 40m. The wind speed is fastest in the SE-NW 16m streets.

3.3 Mean radiant temperature analysis

The visualisation for the four typologies in ENVI-met illustrates the effect of different spatial distributions on mean radiant temperature (T_{mrt}) (Fig. 5).

Fig. 5 Mean radiant temperature variations of the four typologies



In typology 1, the T_{mrt} are highest in the middle of 16m N-S streets, as well as north side of 16m E-W streets and east side of 8m N-S streets. In these areas the T_{mrt} is above 60°C. The east side of 16m N-S streets and tree-shaded areas of 16m E-W areas have T_{mrt} below 44°C. The rest streets are around 46°C in T_{mrt}.

In typology 2, the area without trees in the 24m streets are above 60°C, except that the SW side of the SE-NW streets are 46°C due to the effect of building's shades. The 8m street all have a T_{mrt} of 50°C.

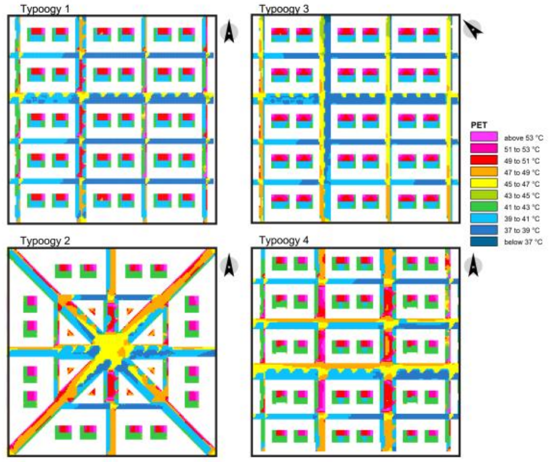
In typology 3, the T_{mrt} in SW-NE 16m streets is above 60°C on the side without tree shades. At the same time, the SE-NW 16m streets are below 44°C in T_{mrt}. Regarding the SE-NW 8m streets the T_{mrt} is 46°C.

In typology 4, the T_{mrt} in SW-NE 24m streets are above 60°C on the side without tree shades. And it is 46°C on the side with tree shades, 2°C higher than that of 16m in typology 2. For 16m SE-NW streets, the NE side of the street is above 60°C and the N-E side of the street is 46°C.

3.4 PET on pedestrian analysis

The visualisation for the four typologies in ENVI-met illustrates the spatial distribution differences in Physiological Equivalent Temperature (*PET*) (Fig. 6).

Fig. 6 PET variations of the four typologies



In typology 1, the worst PET is found in the east side of 8m N-S streets (53°C) and the middle of 16m N-S streets, followed by the north side of 16m E-W streets (45°C). These three areas are highest, with T_{mrt} making the highest contribution. The latter one is higher in air temperature and in wind speed, resulting in a lower PET value. This shows that the wind speed is more effective in influencing PET compared to air temperature in this case. By comparing P1 and P2, the effects of street orientation on PET value can range from 2-7°C.

In typology 2, the worst PET is 49°C and located in the 24m N-S streets, followed by 24m SE-NW and SW-NE streets (47°C). Wind speed of 0.2-0.4m/s slower in the former area results in a higher PET. In the central area, although the high wind speed lessens the value of PET, but the high T_{mrt} and high air temperature still result in the comparative high PET of 45°C.

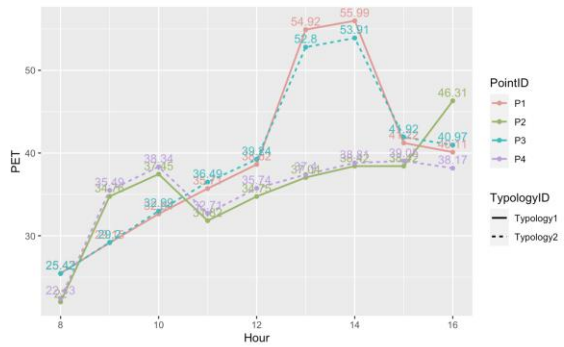
In typology 3, heat problems are prominent in SW-NE streets of 16m areas without trees and 8m whole streets, where T_{mrt} is the main contributor. Also, the 8m streets of SW-NE orientation can result in PET more than 7°C than SE-NW streets, much higher than the difference between N-S and E-W streets.

In typology 4, SW-NE streets of both 24m and 16m have a PET pf around 47°C. The PET in tree shaded areas is different in the two directions, where the SE-NW 24m streets have the PET of 1-2°C lower due to the air temperature, while in both streets the wind speed and T_{mrt} do not vary much. Additionally, the effects of tree shades can result in 7℃ difference in PET between the two sides of the streets from 11:00-13:00.

3.5 Comparison of PET in different typologies

The PET value of the Point 1,2,3 and 4 shows that variations occur across the neighbourhood typologies even with the same street profile (Fig. 7). By comparing P1 (in Typology 1) and P3 (in Typology 2), which are both located in N-S 8m streets and without tree shades, it was found that the pattern of PET changes is similar, but the maximum differences are 2℃ at 14:00, which can be explained by the fact that both ends of the street are surrounded by trees. Regarding the difference between P2 (in Typology 1) and P4 (in Typology 2), which are both located in E-W 8m streets and without tree shades, it was found that the PET difference can reach 6℃ at 16:00, which is a result of T_{mrt} increase according to the sun path at 16:00.

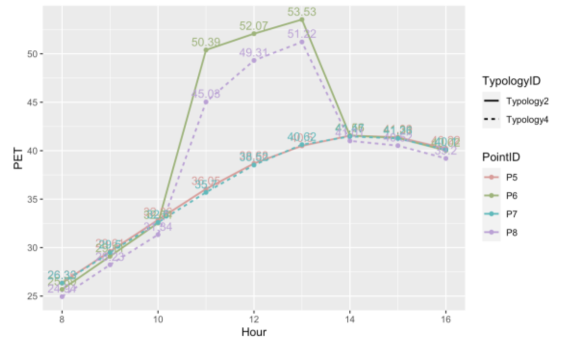
Fig. 7 Comparison of PET value at daytime for point P1, P2, P3, and P4



Regarding the PET value of Point 5, 6, 7, and 8, it was found that the PET differences across the typologies cannot be neglected as well (Fig. 8). By comparing P5 (in Typology 2) and P7 (in Typology 4), which are both in N-S 24m streets and with tree shades, it was found that P5 are in general at all hours very similar to P7. However, regarding P6 (Typology 2) and P8 (Typology 4) which are both in N-S 24m streets and without tree shades, the PET is high and the value is different between the two streets from 11:00 to 14:00. It was found that P6 is about 2-5℃ higher than P8. This can be explained by the effect of the large open area in Typology 2, which results in the surrounding area with higher air temperature.

The comparisons of PET across different neighbourhood typologies show that even streets with the same profile in terms of orientation, width, and height-to-width ratio, can produce different thermal comfort conditions across different neighbourhood typologies. This variation is not very notable in the areas with shading but is more prominent in the sunlit area where T_{mrt} is high. The variations of different neighbourhood typologies might be explained by the synergistic effects of different parameters, including surrounding open space area location, surrounding vegetation planting, etc [9, 10].

Fig. 8 Comparison of PET value at daytime for point P5, P6, P7, and P8



3.6 Recommendations for designers

According to the analysis of thermal comfort variation on the three factors (Section 3.1, 3.2, 3.3) and PET (Section 3.4), as well as the effect of typologies on thermal comfort (Section 3.5), we conclude for each typology the problematic areas with high PET that need cooling actions in priority. Then the problematic factor or the reason contributing to the high PET is examined. After that, the respective recommendations for specific areas to improve thermal comfort are proposed. In general, Typology 4 has more areas that are likely to suffer heat stress, followed by Typology 2, Typology 1, and Typology 3. The summary is presented in Table 3.

Table 3 Summary of recommendations

Typology ID	Typology 1	Typology 2
Problematic area	N-S oriented 8m	N-S oriented 24m (west side)
Problematic factor	High T_{mrt}; low wind speed	High air temperature due to surrounding large open space; high T_{mrt}; low wind speed
Recommended intervention	Tree planting on the east side of 8m alley	Central open area transformed into green space with vegetated soil; tree planting on the no-tree side of 24m wide street

Typology ID	Typology 3	Typology 4
Problematic area	NE-SW 8m; NE-SW direction 16m (NW side)	N-S 16m (east side); E-W 16m (north side); E-W 24m (north side)
Problematic factor	High T_{mrt}	High T_{mrt}, high air temperature
Recommended intervention	Tree planting on the NW side of 8m alley; tree planting on NW side of 16m road	Tree planting on the east side of N-S 16m street; tree planting on the north side of E-W 24m wide street

For urban neighbourhoods in temperate climate that have similar morphological combinations as the typologies proposed in this study, designers can refer to the recommended interventions in their climate-responsive design process.

4. CONCLUSION

This paper examines the thermal comfort performance of four heat-prone neighbourhood typologies in three large European cities with temperate climates. The results of thermal comfort evaluation indicate for each typology the most heat-prone areas that need prioritised cooling interventions, and the elements which should be targeted for these interventions.

Although the street trees, street orientations, and street Height-to-Width ratios play an important role in affecting outdoor thermal comfort, the neighbourhood typology itself with different combinations of neighbourhood layouts can also make an impact on outdoor thermal comfort. This result confirms the value of proposing neighbourhood typologies instead of only simulating single street canyons or buildings, as the synergy of these elements and their surroundings can produce different conditions of outdoor thermal comfort.

The simulation results could be of value to designers and planners wanting to propose new interventions with the maximum cooling effect regarding the heat-prone neighbourhood types in European cities with temperate climates.

ACKNOWLEDGEMENTS

This work received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 861119.

REFERENCES

1. Chun, B., & Guldmann, J.-M. (2014). Spatial statistical analysis and simulation of the urban heat island in high-density central cities. Landscape and Urban Planning, 125, 76–88.https://doi.org/10.1016/j.landurbplan.2014.01.016
2. Lenzholzer, S., Carsjens, G.-J., Brown, R. D., Tavares, S., Vanos, J., Kim, Y., & Lee, K. (2020). Awareness of urban climate adaptation strategies –an international overview. Urban Climate, 34, 100705. https://doi.org/10.1016-/j.uclim.2020.100705
3. Roe, J., & McCay, L. (2021). Restorative Cities: Urban design for mental health and wellbeing. Bloomsbury Publishing.
4. Pan, W. (2019). Diverse environmental performances of urban villages and insights for enhancing quality of urban renewal in Shenzhen. HKU Theses Online (HKUTO).
5. Jamei, E., Rajagopalan, P., Seyedmahmoudian, M., & Jamei, Y. (2016). Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. Renewable and Sustainable Energy Reviews, 54, 1002-1017.
6. Wu, Y., Mashhoodi, B., Patuano, A., Lenzholzer, S., Narvaez Zertuche, L., & Acred, A. (2022). Heat-prone neighbourhood typologies of European cities with temperate climate. Sustainable Cities and Society, 87, 104174. https://doi.org/10.1016/j.scs.2022.104174
7. Bruse, M. (2004). ENVI-met implementation of the Jacobs A- gs Model to calculate the stomata conductance. Bochum.
8. Martinelli, L., & Matzarakis, A. (2017). Influence of height/width proportions on the thermal comfort of courtyard typology for Italian climate zones. Sustainable Cities and Society, 29, 97–106. https://doi.org/10.1016/j.scs.2016.12.004
9. Yin, S., Lang, W., & Xiao, Y. (2019). The synergistic effect of street canyons and neighbourhood layout design on pedestrian-level thermal comfort in hot-humid area of China. Sustainable cities and society, 49, 101571.
10. Elbondira, T. A., Tokimatsu, K., Asawa, T., & Ibrahim, M. G. (2021). Impact of neighborhood spatial characteristics on the microclimate in a hot arid climate – A field based study. Sustainable Cities and Society, 75, 103273. https://doi.org/10.1016/j.scs.2021.103273

PLEA SANTIAGO 2022
Will Cities Survive?

Discussion on sustaining old street without losing integrity of local identity

Focused on old street at Jeju, Korea

YUN KYU YI [1] YONGKYU YI[2] MANAL ANIS[3]

[1] University of Illinois at Urbana-Champaign, Champaign, IL, USA
[2] Jeju National University, Jeju, South Korea
[3] University of Illinois at Urbana-Champaign, Champaign, IL, USA

ABSTRACT: Jeju is an island in South Korea. Jeju is a popular holiday destination and a sizable portion of the economy relies on tourism. Jeju is notorious for its wind, since the island was surrounded by the ocean, the wind speed was typically high. Because of harsh wind, in a village or city area has a special street called "Olle" was developed in island. Olle is a word in the local dialect that refers to the paths between houses and public roads. There are still several existing Olle with traditional alley characteristics around Jeju Island. Currently, redevelopment and renovation of tourist attraction areas (seaside villages, villages where popular tracking route area) the narrow and tangled old Olle were facing a dilemma of preservation or improvement for safety, accessibility and increasing building gross floor area for maximum cost-benefit from the redevelopment. This paper examines the current status of one of Olle in the area called "Woljeong-Rie" area. The place becomes an attractive area for tourist. Since its popularity, new developments were noticeably increased. The paper analysis recent Olle Street condition and compare its condition that is before development. Comparison between before and after developments will share in-sight on how to preserve Olle.
KEYWORDS: Jeju, Olle, Simulation, Performance, Optimization.

1. INTRODUCTION

Jeju is an island in south Korea. The island contains the natural world heritage site "Jeju Volcanic Island and Lava Tubes" [1]. Jeju has a moderate climate; even in winter, the temperature rarely falls below 0 °C. Jeju is a popular holiday destination and a sizable portion of the economy relies on tourism [2]. Total population of Jeju increase from 577,187 (year 2010) to 678,772 in year 2017, within 7 years population growth almost 100,000 [3]. Jeju is the only province which shows a continuous increase in population in South Korea [4]. Also, Jeju is famous for its wind, since the island is surrounded by the ocean, wind speed is typically high and the first commercial wind farm in south Korea opens on the western coast of island [5].

Due to harsh wind conditions, village and city areas have a special street called "Olle" which was developed in an island. Olle is a word in the local dialect that refers to the paths between houses and public roads [6]. Recently, part of its pathway around the coastline became tourist attractions and called 'Jeju Olle Gil' or simply, 'Jejuolle' in Korean. The courses pass through small villages, cross beaches, wind through farms and orchards, twist through forests, and climb oreums (low parasitic volcanoes) across Jeju Island [5].

There are still several existing Olle with traditional alley characteristics, in and around Juju Island. Currently, the redevelopment and renovation of tourist attraction areas, seaside villages, villages where tracking is popular, the narrow and tangled old Olle were facing a dilemma of preservation or improvement for safety, accessibility and increasing building gross floor area for maximize cost benefit from redevelopment.

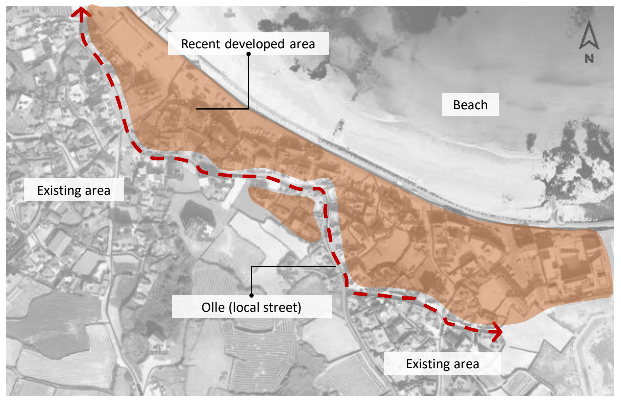


Figure 1: Woljeong-rie area in Jeju Island in South Korea.

This paper examines the current status of one Olle in the area called "Woljeong-rie" area. The place has become an attractive area for tourists as Ollegill has become a popular attraction. Since its popularity, new developments were noticeably increased. Figure 1 shows the Woljeong-rie area indicating newly developed and existing local street with buildings.

Figure 2 Street view of Test Street between 2010 and 2018

Figure 2 shows two different street views along Olle, which clearly shows dramatic changes of the street view. Within eight years, traditional stone wall has been demolished, and street canyons are deeper.

The deeper canyon creates unfriendly environments around the traditional pathway, which creates more shadows, less view of sceneries, and increases adverse wind in the street canyon. For this reason, the paper first investigates what difference new development brought to the street pathway. The paper calculates how many hours direct sunlight can reach the street and investigated a sky view ratio to understand how much the new buildings block sky view from street. Finally, a CFD (Computational Fluid Dynamics) analysis has been conducted to understand how new buildings changed wind patterns around the street.

2. CURRENT CONDITIONS

The paper analyses current Olle Street conditions and compares it to what it was before development. The comparison shares in-sight into what has been changed in the Olle street.

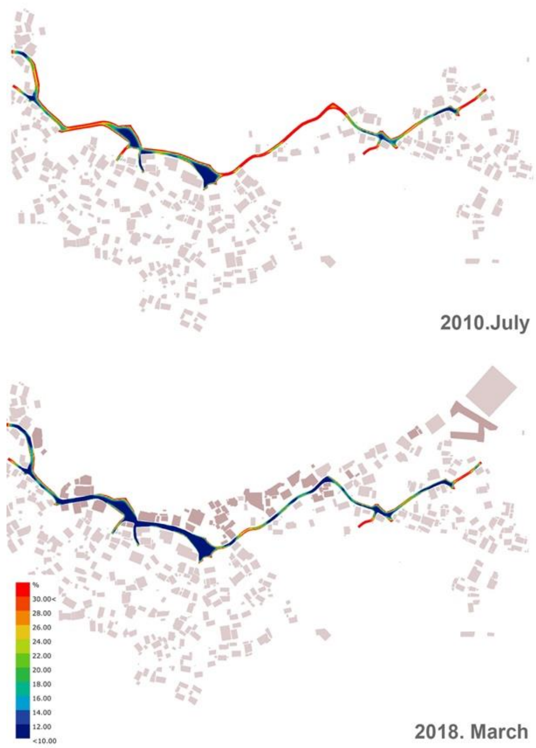


Figure 3: Sky view ratio

The test conducted was simulating the sky view ratio to measure how much the street can see open sky without being blocked by buildings. For this test, the paper used Honeybee [7] to calculate sky view ratio. In honeybee several methods can be used to measure sky view ratio, Yi, identified the limitations of current methods and the one that produces a result most close to an actual sky view is called sky exposure factor [8]. The paper uses this for the sky view calculation. The grid size for the measuring point was 1x1m. The test result shows that before the development, average sky view was 27.31% and after the development the sky view was down to 16.80%. On average, almost 10% of view to the sky was blocked by new development which reduces the merit of the traditional street's identity. (Figure 3)

The direct sun hours and wind conditions were also analysed. Average hours that streets received direct summer solstice sun, were reduced from 11.74 hours to 10.92 hours, while in winter, solstice solar hours reduced from 8.79 hours to 7.85 hours. The decrease in summer direct solar hours might be beneficial for cooling in summer, however it reduced winter solar hours that are an important resource of heat energy in winter.

The paper also investigates summer and winter average wind speed to understand its impact on the street. For wind test, the paper used Eddy3D [9] tools for measure wind speed. It uses openFOAM as its engine and was validated. Annually, wind speed increased from 0.90 m/sec to 2.64m/sec, which indicates new buildings create adverse wind conditions around the street.

Figure 4: Selected test area with result of solar hours

Based on the three analysis, the street near the new development was worse after the development. For this reason, the paper selected one of the worst condition areas and studied it further to find the possible strategies to improve conditions. Within the resultant area, a smaller area was selected for further study, shown in Figure 4, which has new buildings around the local street.

Figure 5 shows the test area buildings and their corresponding heights. The highest building in the test site was 12.80m while most of the building are higher than 4m. To find a better design, the current condition was simulated to find a baseline for the test.

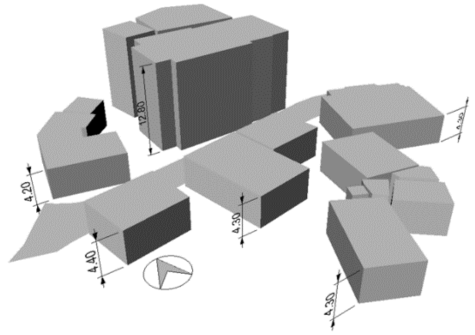


Figure 5: Test site building layout and heights

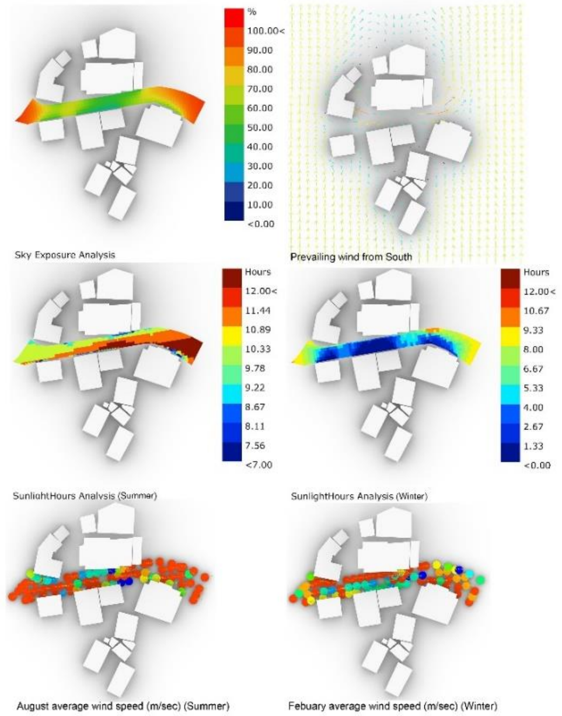


Figure 6: test site simulation results

Figure 6 shows results of various simulations conducted for the current test site. The average sky view ratio was 70.25%. Average hours that streets received direct sun, during the summer solstice, was 10.61 hours, while winter solstice solar hours were 6.16 hours. From the local weather data, August is the month that has most cooling degree days and February is the one with most heating degree days. Based on the cooling and heating degree days, the paper uses February as the month that would represent winter period and August has been selected for summer period. The average wind speed for both August and February were calculated from CFD simulation. Average summer wind speed was found to be 0.57 m/sec and average winter wind speed was 0.59m/sec. Figure 6 also shows local wind directions when prevailing wind is coming from south.

3. Methodology

The main purpose of this paper is to find a design strategy that can reduce the impact of new buildings on the existing street. For this reason, the paper uses the multi-objective optimization to find optimal building height along the street, which could minimize the impact on the street while maximizing the building height. It will able to guide stakeholders to find better solutions that can keep the integrity of a traditional Olle Street.

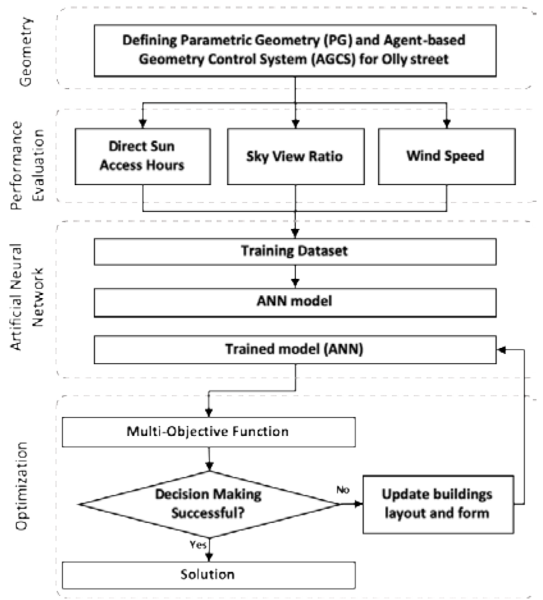


Figure 7: Overall process

Figure 7, shows the overall process for obtaining an optimal high that has minimal impact on the street condition. The process is divided into four main sections, where the first step of the method is to prepare the Parametric Geometry (PG) model and Agent-based Geometry Control System (AGCS) of a site and buildings. This allows to control building heights more easily.

After the geometry was set up, the next step was to simulate the model to obtain the three performance criteria. The criteria that were considered to evaluate the street's environmental conditions were sky view ratio, sunlight hours, and wind speed. However, the main difficulty of using several simulations specially, CFD simulation for optimization comes with a major hurdle that the simulation requires a significant amount of computational time. To overcome this limitation of using multi simulations for optimization, the paper proposes an Artificial Neural Network (ANN) as the next step to reduce computational time. A random sample of geometry configuration were simulated, and these results and parameters were

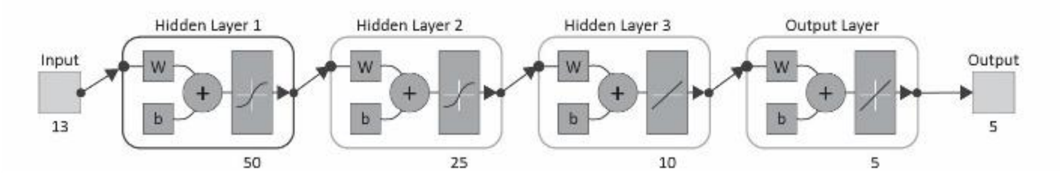


Figure 8: ANN model used for the test

used to train the ANN model. Once the ANN model was trained, it replaced simulations and predicted performances. The results from ANN were used as the fitness values for the optimization.

After the objective value was obtained from the simulations, the next step was the optimization phase. The data obtained from the previous step was plugged into an evolutionally algorithm. If the objective function is satisfied, then that geometric set-up is a possible solution. If not, then an algorithm generates the next population of agent points. The ANN simulation should be re-run to find its performance and see if the changed geometry fulfils the goal. This loop continues until either the objective value satisfied its goal, or the maximum generation has been reached.

3.1 Defining Parametric Geometry and Performance evaluation

The Parametric Geometry (PG) model was used to control height of the buildings. Each buildings height was set as optimization variables. 13 height variables were set for the test site. Heights can shift between 2m to 12m. Following figure 8 shows how PG were set up for the test.

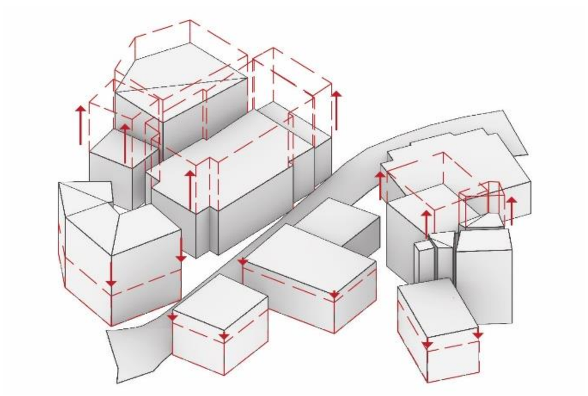


Figure 9: Building height variables for the test

3.2 Artificial Neural Network (ANN)

In the field of architecture, specifically with CFD, ANN helped to reduce the computational power. Early research using ANN with CFD can be found in the author's previous paper [10]. First a random sample of geometry configuration was simulated to find performance value of different geometries, its result and parameters were used to train the ANN model. Once the ANN model was trained, it replaced the simulation of CFD and other calculations and ANN model predicted wind speed, solar hours, and sky views around the street which was used as the fitness value for the optimization.

Figure 9 shows the structure of the neural network training used for the test. It consists of four layers: the three hidden and one output layer. The input and output contain the training dataset and the hidden layer is where the neural network is trained to find the transfer function from the training dataset. For this test, 13 inputs were set, the first hidden layer has 50 and second layer has 25 neurons with hyperbolic tangent sigmoid transfer function. Third hidden layer has 10 neurons and the linear transfer function was used. For the output layer, 5 neurons were used with linear transfer function and output is 5 values.

Once the ANN model was set, the paper trained the model with following training inputs and targets. The 13 height variables were set as training inputs and the result of sky view ration, summer and winter sunlight hours and summer and winter average wind speeds were set as the training output. To improve the predictions, all inputs were normalized to have the same scale range from 0 to 1. Figure 10 shows the regression result. The regression values for training, validation and test are all above 99% that shows the model is well fit within the data.

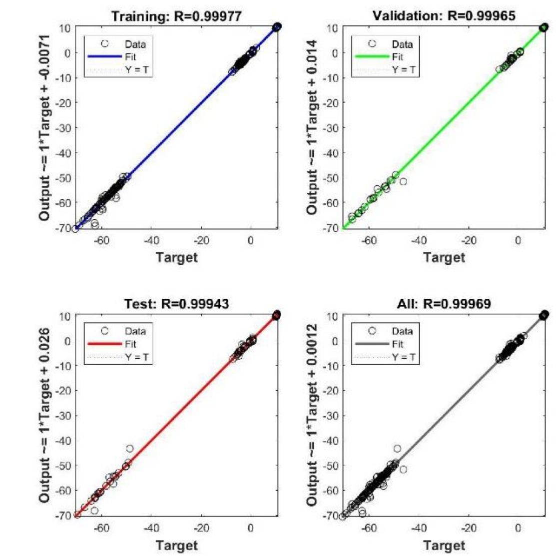


Figure 10: Trained data set's regression results

3.3 Multi objective optimization (MOO)

For optimization, this paper used Matlab [11] as a tool for optimization. The trained ANN model is also built by Matlab and can share its data with MOO without coupling tools. The objective function for the paper can be written as follows:

$$\min_{x \in X} f(x) = [f_1(x), f_2(x), f_3(x), f_4(x), f_5(x)] \quad (1)$$

The goal of the test was to find a solution that minimizes all five objectives. The $\boldsymbol{f_1(x)}$ is the average sky view of the street and $\boldsymbol{f_2(x)}$ is hours of direct sun that reached the street on June 21st from 8 am to 6pm and $\boldsymbol{f_3(x)}$ is hours of direct sun that reached the street on December 21st from 8 am to 6pm. $\boldsymbol{f_4(x)}$ is summer average wind speed at 1.5m high from the street level. $\boldsymbol{f_5(x)}$ is winter average wind speed at 1.5m high from the street level. The goal of $\boldsymbol{f_1(x)}$, $\boldsymbol{f_3(x)}$, and $\boldsymbol{f_5(x)}$ should be maximized, however since MOO goal is set to minimization, these three objective functions were multiplied by -1 to convert the function from maximization to minimization. Following equations show the objectives functions for the optimization. For this paper, Non-dominated Sorting Genetic Algorithm II (NSGA-II) was used for the multi-objective optimization process. Population size of one generation was setup with 200 individuals.

$$\boldsymbol{f_1(x)} = -\left(\frac{\sum_{i=1}^{n}(r_{sky\ view})_n}{n}\right) \quad (2)$$

$$\boldsymbol{f_2(x)} = \left(\frac{\sum_{i=1}^{n}(r_{summer\ solar\ hours})_n}{n}\right) \quad (3)$$

$$\boldsymbol{f_3(x)} = -\left(\frac{\sum_{i=1}^{n}(r_{winter\ solar\ hours})_n}{n}\right) \quad (4)$$

$$\boldsymbol{f_4(x)} = \left(\frac{\sum_{i=1}^{n}(r_{summer\ wind\ seped})_n}{n}\right) \quad (3)$$

$$\boldsymbol{f_5(x)} = -\left(\frac{\sum_{i=1}^{n}(r_{winter\ wind\ speed})_n}{n}\right) \quad (4)$$

where,
n – Number of measuring points;
$r_{sky\ view}$ – Sky view value;
$r_{summer\ solar\ hours}$ – Number of hours that reached measuring point on June 21st from 8am to 6pm;
$r_{winter\ solar\ hours}$ – Number of hours that reached measuring point on December 21st from 8am to 6pm;
$r_{summer\ wind\ speed}$ – Average wind speed at measuring point on summer season;
$r_{winter\ wind\ speed}$ – Average wind speed at measuring point on winter season;

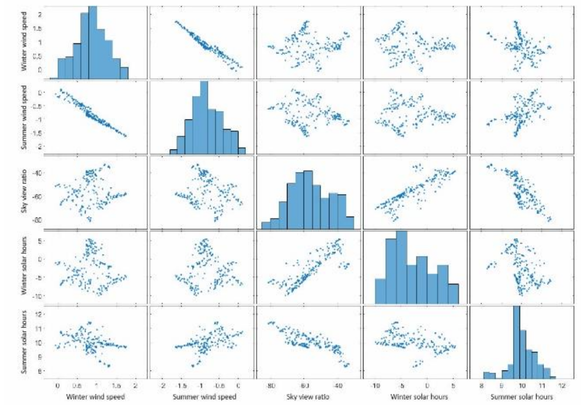


Figure 11: total scatter plot

MOO reached its goal by 138 iterations by an average change in the spread of Pareto front solution. Figure 11 shows the Pareto fronts for five objectives, the scatter plot of the columns of one measure against another measure.

Table 1 shows the objective values of 14 individuals from the findings. Case 13 shows best result for winter wind speed and sky view ratio, case 6 has most high wind speed on summer, and case 5 shows most solar hours in winter.

Table 1: 14 individuals' objective values

No.	Wind speed[m/sec]		Sky view ratio [%]	Sun hours[hrs]	
	Winter	Summer		Winter	Summer
1	1.09	1.13	68.92	9.28	9.99
2	0.92	0.97	66.80	8.90	9.89
3	0.80	0.74	68.23	7.86	10.37
4	0.77	0.79	70.05	8.72	10.27
5	1.01	1.06	69.48	9.35	10.01
6	1.14	1.15	66.98	8.77	9.98
7	0.63	0.64	69.49	8.26	10.34
8	1.06	1.07	68.51	8.11	10.15
9	1.04	1.05	66.23	8.19	10.02
10	1.11	1.06	64.13	7.30	10.01
11	1.13	1.12	64.44	7.90	9.93
12	1.08	1.10	66.94	8.45	9.98
13	0.59	0.59	70.51	7.20	10.50
14	1.18	1.11	65.06	7.31	10.13

Compared to the current condition, case 13 shows better result on all five goals. In terms of wind speed, winter average wind speed was reduced by 0.01m/sec and summer wind speed was increased by 0.01m/sec. Sky view ratio was also increased by 0.26%. Most importantly, winter solar hours were increased by 1.05 hrs, but summer solar hours were reduced by 0.11 hrs.

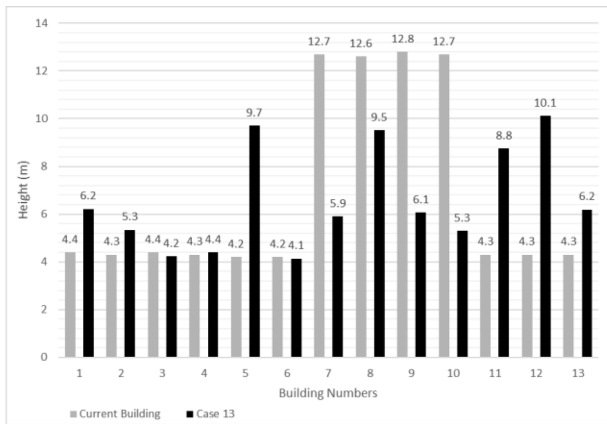


Figure 122: Building heights between current and optimized

Figure 12 shows each building height as current condition and as case 13's building heights. It clearly shows that building 7, 8, 9, and 10 should have a lower height to improve current condition. However, it is interesting to note, building 1, 2, 5, 11, 12, and 13 can increase in height and achieve better street conditions than current condition. The average height between current condition and case 13 was 6.88m and 6.61m, which is less than a meter difference. Figure 14 shows the difference of current condition and case #13. The buildings next to the street were shorter compared to current conditions, but buildings away from the street were taller or stayed a similar height. The interesting finding was that the building heights gradually increase from centre to the street.

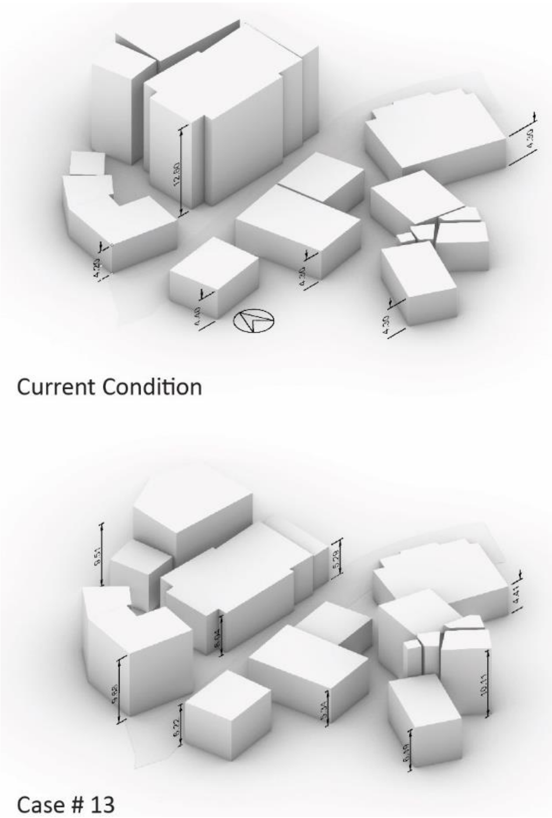


Figure 14 overall building height between current conditions and optimized

4. CONCLUSION

This paper tries to find a way to preserve traditional street alley called Olly's characteristics. The paper investigates one of the tourist attraction areas that was developed and renovated. Three analysis was conducted to find how the street condition was changed. Based on the three analyses, the street near the new development was worse after the development. Next, the paper investigates to find a design strategy that can improve the street condition and also able to develop the area. For this reason, the paper used MOO to find the best height that can improve the street condition.

The paper proposed to use three different simulation tools to measure different design configurations. However, running several simulations for more than thousands of cases for optimization requires a significant amount of computational time. For this reason, the paper introduced ANN to reduce the number of running different simulations. The trained ANN model was able to predict street conditions within a reasonable error range.

After training the ANN model, the paper uses it to find optimal building heights that can satisfy five objectives. The MOO was able to find several designs that could improve the current street condition.

One of the solutions was compared with the current condition. The result shows some buildings should lower than current conditions but also some buildings can increase their height.

The paper only selects one specific area for optimization and it requires further investigation. It requires investigating more areas to find if there is a certain rule between building heights and distance from the street. If a general rule can be found it can be used to develop a guideline. It can be us for further development to make sure it can preserve traditional streets characteristic.

REFERENCES

1. Unesco names World Heritage sites, BBC News, [Online], Available: http://news.bbc.co.uk/2/hi/asia-pacific/6248244.stm [22 July 2017].
2. Jeju Island Wikipedia, [Online], Available: https://en.wikipedia.org/wiki/Jeju_Island#cite_note-2 [22 July 2017]
3. 2017 Jeju island census, [Online], Available: https://www.jeju.go.kr/download.htm?act=download&seq=1084796&no=12 [22 July 2017]
4. Korean Statistical Information Servce, [Online], Available: http://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1YL20621 [22 July 2017]
5. Korea's first commercial wind farm opens on Jeju, The Korean Herald, [Online], Available: http://www.koreaherald.com/view.php?ud=20171117000524 [22 July 2017]
6. Jeju Province, Wikipedia, [Online], Available: https://en.wikipedia.org/wiki/Jeju_Province [22 July 2017]
A10. Zhang, J., Heng, C. K., Malone-Lee, L. C., Hii, D. J. C., Janssen, P., Leung, K. S., & Tan, B. K. (2012). Evaluating environmental implications of density: A comparative case study on the relationship between density, urban block typology and sky exposure. Automation in Construction, 22, 90-101. doi: 10.1016/j.autcon.2011.06.011
7. Ladybug, Mostapha Sadeghipour Roudsari, [Online], Available: https://www.food4rhino.com/app/ladybug-tools [25 Feb 2020]
8. Yi, Yun Kyu, and Hyungsub Kim, "Universal Visible Sky Factor: A method for calculating the three-dimensional visible sky ratio," Building and Environment vol. 123 (October, 2017): pp 390-403.
9. Kastner, P., & Dogan, T. (2019). A cylindrical meshing methodology for annual urban computational fluid dynamics simulations. Journal of Building Performance Simulation, 13(1), 59-68.
10. Yi Yun Kyu, Malkawi Ali, "Integrating neural network models with computational fluid dynamics (CFD) for site-specific wind condition," Building Simulation: An International Journal vol. 4, (September 2011): pp 245-254.
11. The MathWorks, Inc [Online], Available: https://www.mathworks.com/products/matlab.html [25 Feb 2020]

PLEA STGO 2022
WILL CITIES SURVIVE?
SUSTAINABLE URBAN DEVELOPMENT

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 02
12:00 — 13:30

CHAIR
SUSEL BIONDI

PAPERS
1179 / 1227 / 1490 / 1330 / 1241

23TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

A life cycle perspective on vertical densification

Embodied impact assessment of vertical building extensions

ROLAND REITBERGER[1], CARSTEN SCHADE[1], FARZAN BANIHASHEMI[1], WERNER LANG[1]

[1] Technical University of Munich, Institute of Energy Efficient and Sustainable Design and Building

ABSTRACT: Life Cycle Assessment (LCA) of densification is gaining importance due to rising efforts to counteract climate change while expanding living space in urban areas. We propose a methodology to split vertical building extensions into separated building elements for LCA calculation. Thereby, we show how existing and new building parts relate to the embodied impact of such projects. In a case study, the approach is exemplarily used to compare embodied Global Warming Potential (GWP) and embodied Primary Energy (PE) resulting from vertical densification to newly built living space. The results showed the roof type of the existing building as important information for the goal of low carbon densification. The proposed methodology can serve as a base for further development and allows decision-makers to take a wide variety of possible building constructions into account, especially in the early design stages.
KEYWORDS: Life Cycle Assessment, LCA, Vertical Densification, Reinforcement, Early Design Stage

1. INTRODUCTION

The increase in global population, as well as the rising level of urbanization, require a rapid expansion of urban living space (United Nations, 2019). The need for additional building structures is associated with high resource consumption, conflicting with ongoing efforts to reduce CO_2e emissions. Given that the building sector is responsible for 37% of CO_2e emissions worldwide (United Nations, 2021), there is great potential to address the challenges of urban growth while sustainably transforming the building stock. Expanding existing buildings enables more intensive use of existing structures and infrastructure, thereby reducing the amount of used materials. Our work aims to clarify whether synergies or conflicts prevail in case of urban densification from a lifecycle perspective. Currently, there is insufficient knowledge about these densification approaches, and research on quantifying their lifecycle based impact is limited. Therefore, an extension of the existing lifecycle approaches is necessary to evaluate the potential of densification compared to conventional techniques, especially in the early design stages when little information on existing buildings is available. In this paper, we want to answer the following research questions:

- How is the embodied impact (Global Warming Potential (GWP) and Primary Energy (PE)) of vertical building extensions affected by building stock and added structures?
- What is the potential of vertical building extensions in terms of embodied impact?

From these research questions, we hypothesize that living space generated through vertical densification has a lower CO_2e footprint than newly built living space.

2. STATE OF THE ART

Based on densification scenarios in Vienna and Linz, Loibl et al. showed that integration into existing structures offers high potential to meet the rising demand of living space. According to them, story adding can increase floor area up to 25% on a city scale (Loibl et al., 2021). A similar conclusion is given by Dagmar Everding, who investigated extensions of existing neighborhoods in Frankfurt and showed possibilities to save embodied CO_2e by integration into existing structures (Everding, 2017).

Hafner et al. proposed a procedure to analyze the lifecycle impacts of vertical building extensions and compared different materials. Their methodology allows considering impacts from the demolition of existing and newly added structures in separation (Hafner & Storck, 2019). They conclude that vertical building extensions offer environmental potential and that further research is needed in this area. Tools for Life Cycle Assessment (LCA) of new buildings in early design stages have been developed, such as Bombyx (Basic et al., 2019) or CAALA (CAALA, 2022). However, there is no tool that integrates the particularities of vertical densification projects and only little information about the specific constructions used in such projects is available. Therefore, a split of normative based LCA calculation (e.g. DIN EN 15978 – Environmental performance of buildings) for single building parts (called 'layers' in the following) is proposed.

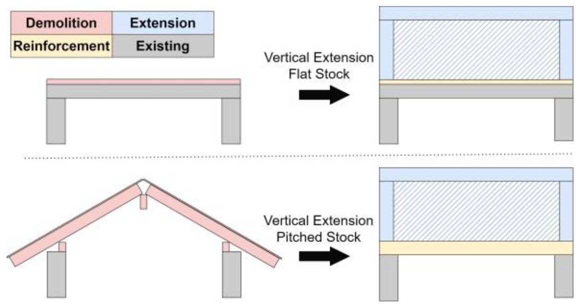
3. METHODOLOGY

This section explains our methodological approach for calculating the LCA of vertical densification. Furthermore, it shows how we compare living space from densification to newly built living space.

3.1 Life Cycle Assessment of densification

LCA is frequently applied for new construction, where clear structures and methodologies exist. As building extensions combine both, existing buildings and new constructions, they have mutual dependencies, which are not well covered by current guidelines (Vilches et al., 2017). We show how considering these dependencies improves decision-making in early design stages by identifying intersections and solving their requirements, leading to reduced ecological impacts. This keeps effort low but allows the investigation of a wide variety of material and construction combinations in LCA while applying current norms and programs. Therefore, we propose a split of regarded building parts (layers) into stock, demolition, extension, and reinforcement, as Fig. 1 shows.

Figure 1:
Layer split of regarded building parts.



Note: Existing building and extensions can each be modelled with a pitched or flat roof.

The reinforcement layer includes all constructive building components necessary to add an extension to an existing building (yellow layer in Fig. 1). The extension and demolition of existing parts are calculated separately (blue and red layer in Fig. 1). From the existing building (grey layer in Fig. 1), we extract properties that influence the design of the reinforcement layer. Furthermore, impact from the existing building due to the vertical extension is included, e.g. the demolition of roof structure. We utilize the German norm for LCA DIN EN 15978, which considers the environmental performance of buildings and apply the impact assignment described in (Hafner & Storck, 2019). The proposed split into building layers extends the methodology to a more detailed investigation. This achieves the decoupling of existing and newly added constructions, allowing evaluation of a wide variety of options in terms of ecological impact. This is especially useful for decision-making in early design stages when information is low and a vast variety of constructions is possible. Our methodology allows choosing the reinforcement layer depending on the properties of the existing building and the extension. In literature and expert talks, we identified four important aspects for the choice of this layer, which are: *roof type*, *structure*, *fire safety*, and *acoustics* (Mooser et al., 2014), (Kaufmann et al., 2017), (Hess et al., 2012). In the following, the dependencies of the reinforcement layer with the four aspects of choice are pointed out and their consideration is explained.

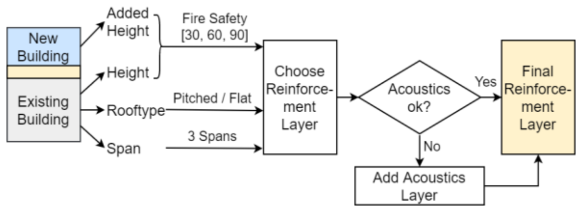
First, the *roof type* of the stock building is essential for the choice of construction in the reinforcement layer. Pitched roofs are supposed to require an additional load-bearing ceiling in case of a vertical extension. On the contrary, flat roofs are found to offer the chance of removing loads which makes it often possible to use the flat roof as an interior ceiling after the extension (Fath et al., 2019). Due to that, we propose considering new, load-bearing ceilings if a pitched roof is found in the stock. In contrast, we include a balance layer and bearings along the building's perimeter for flat roofs, as proposed in (Fath et al., 2019).

Secondly, as pitched roofs in existing buildings are supposed to require an additional ceiling, the span of the load-bearing *structure* impacts its material consumption and thus the LCA results. To consider these variations in our calculation, we divide buildings into three categories for spans and take different dimensions of the load-bearing construction elements into account (<3m, 3m – 5m, 5m – 7m) (Hess et al., 2012).

Thirdly, *fire safety* is addressed by the consideration of the building height after the vertical extension, thus being dependent on existing and new structures. The building height relates to the fire regulations of specific countries. For this paper, we use the Bavarian building code requirements of REI30 (< 7m to top floor), REI60 (< 13m to top floor), and REI90 (> 13m to top floor) requirements. High-rise buildings (> 22m to top floor) are not included in this study.

Finally, we check the obtained constructions for their *acoustic* performance. If the current technical standards are not met, an acoustic improvement is considered for the LCA. Fig. 2 summarizes the explained dependencies of the reinforcement layer.

Figure 2:
Influence of new and existing building parts on the reinforcement layer.



Besides the reinforcement layer, vertical extensions cause the deconstruction of parts from the existing building. For the LCA of the deconstruction, we consider the whole roof structure for pitched roofs and the sealing layers for flat roofs. We apply a building component approach for the newly added parts of vertical extensions. As it is not possible to prove the load capacity of the stock building within this research, we assume that it has sufficient load reserves to support the extensions, which is often the case in Germany (Tichelmann et al., 2019). In general, the options for the different layers should be adapted when detailed information is available.

The proposed layer split of the extension measure allows analyzing different component's contribution to the results. The overall impact can be calculated by summing up the parts. We include the LCA phases A1 – A3 (production), B4 (usage), and C3 – C4 (deconstruction and disposal). The results in phase D (benefits beyond the system boundaries) are reported separately. The freely available LCA-Database Oekobaudat (2020-II, BMWSB) is used for the calculations. The Reference Service Life (RSL) of the existing and new parts is set to 50 years. The functional unit is one square meter of net floor area. The considered building parts are exterior walls, baseplate, roof, ceilings, and windows.

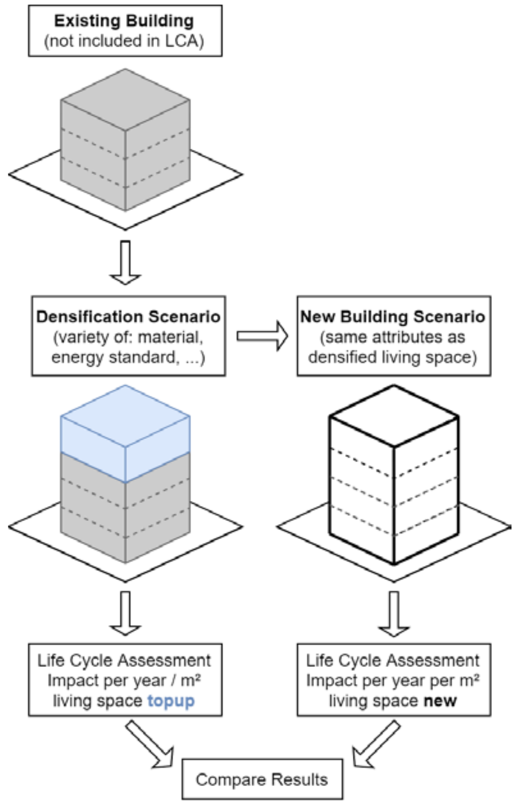
3.2 Comparing densification and new buildings

To investigate the LCA potential of vertical building extensions, we compare their embodied impact to newly constructed buildings on a per square meter basis. Therefore, LCA is calculated for a hypothetical new building with the same attributes as the extension (material selection, energy standard). For the geometry of the new building, we use the union of the existing building and the vertical extension, as new buildings would mostly be built higher than only up to three stories (our max extension volume). Fig. 3 summarizes the method of comparison. We focus on embodied GWP and embodied PE as indicators. Therefore, we calculate the deviation of results for each possible combination as in Equation (1):

$$\text{Deviation} = (\sum LCA_{new} / \sum LCA_{vert.ex.}) - 1 \qquad (1)$$

where Deviation - Ratio of impact new / vertical ext.
$\sum LCA_{new}$ - LCA results of the new building
$\sum LCA_{vert.ex.}$ - LCA results of the vertical ext.

Figure 3:
Method to compare the ecological impact of densification with new building scenarios.



4. CASE STUDY

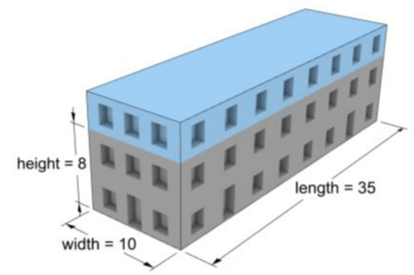
This section describes the gathering of information for the existing buildings and introduces the assumptions regarding LCA and new building's construction.

4.1 Properties of the existing buildings

The proposed methodology is implemented for a multistory residential unit (Fig. 4). Necessary information on e.g., the materials and roof types is retrieved from the TABULA building typology. This typology provides a variety of example buildings in different building age classes (BAC) and information about building materials used (Loga et al., 2015). The environmental impact resulting from the demolition of existing building parts (e.g., the roof) is calculated by combining the material with LCA data from Oekobaudat. In case a combination is not available (e.g., multifamily house with pitched roof in BAC C), we use the constructions from the next higher BAC.

As we want to investigate the impact of the structural span on the results, we assume varying bearing situations inside the building. Structural checks are out of the scope of this research. Thus, it is assumed that adding up to 3 stories is possible. Fig. 4 shows the basic geometry of the case study.

Figure 4:
Example building geometry used for the study. All units in meters.



4.2 Constructions for extension and new building

For the constructions of newly added structures, we use typical material combinations (timber frame, timber massive, masonry) and vary the insulation layer according to the German legislation (GEG), improved legislation (EE55), and passive house standards. For the reinforcement layer, we used the references described in section 3.1 for the basic requirements and retrieved example constructions from the sources shown in Table 1. If a construction would not be possible due to building legislation in Germany (e.g. Timber beam in REI90), it was excluded from the results.

Table 1:
Constructions used for the reinforcement layer

Material	Constructions or Layers (top to bottom)	Sources
Board pile	tdmnxs01	(dataholz.eu, 2022)
Timber beam	gdrnxa05a gdrnxa05b	(dataholz.eu, 2022)
Concrete	Cement screed, Sound insulation, reinforced concrete (150-260mm)	(Pech et al., 2020) (Hess et al., 2012)
Bearing timber (concrete)	wood bearing (40x240mm) concrete (40x300mm)	(Fath et al., 2019) Expert talk
Bearing (concrete)	concrete (200x300mm) steel (3 %)	(Fath et al., 2019) Expert talk
Balance	cement screed mineral wool	(Fath et al., 2019)

Note: Bearing and Balance layers are used for flat roofs only, the rest for pitched roofs.

Overall, the assessment includes 12 BACs, 1-3 stories of vertical extensions, three energy standards, two roof types for the new roof, one geometry, three span categories, three materials for new building elements, and three (two) reinforcement constructions for pitched (flat) existing roofs. This results in 5832 combinations for pitched and 3888 combinations for flat existing roofs.

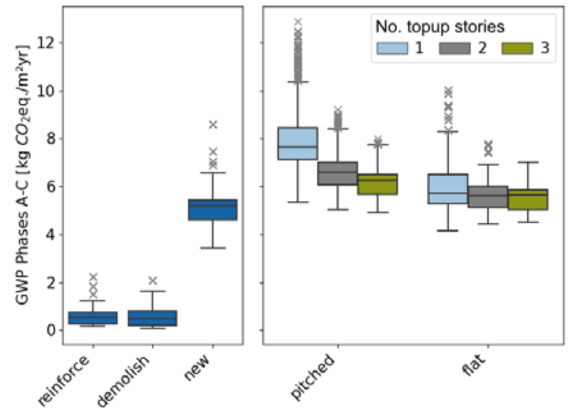
5. RESULTS

This section summarizes the results relevant for answering our research questions. Therefore, we first focus on analyzing the proposed layer split of the LCA. Second, we compare the overall embodied impacts from vertical densification to new construction.

5.1 Embodied emissions split

The split into the proposed layers showed new added building parts as the primary source of GWP in LCA phases A-C. Reinforcement structures and demolition of existing building parts (mainly the roof) contributed roughly equally to the impact (Fig. 5 – left). Flat roofs showed better results for the resulting GWP of vertical building extensions than pitched ones. Impacts decreased when expanding the number of added stories (Fig. 5 – right). When LCA phase D was taken into account, the order stayed the same, but the difference between new and demolished/reinforced parts decreased. For Primary Energy (PE) renewable and non-renewable, the share of demolished parts decreased for phases A-C and A-D.

Figure 5:
Impact of the proposed layer split in LCA methodology for vertical building extensions (left). Difference in sum, split for the number of added stories and the roof type of existing buildings (right).

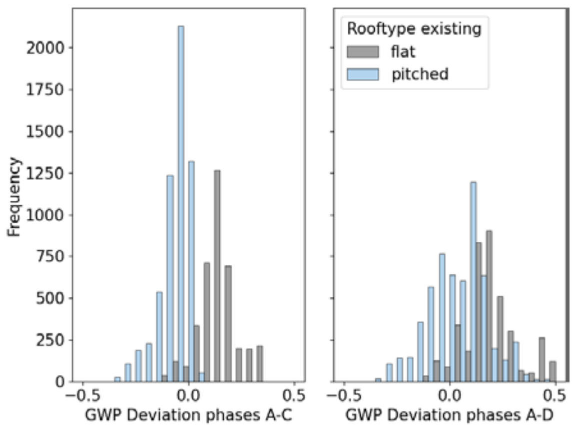


5.2 Comparison to new buildings

The calculation of deviations as given in Equation (1) showed values above zero mainly for flat roofs. These indicate GPW reductions of up to 40% by creating living space through vertical extensions instead of new construction (phases

A-C). Pitched roofs are mostly located below zero, meaning vertical extensions on existing buildings that have pitched roofs did hardly outperform new housing (Fig. 6 - left). This changed when LCA phase D was taken into consideration (Fig. 6 – right). For PE, the results showed a similar trend, except for non-renewable PE, where extensions on existing buildings with pitched roofs outperformed flat roofs.

Figure 6:
Deviations of GWP impact from vertical extensions compared to new buildings for LCA phases A-C (left) and LCA phases A-D (right).



Note: Values above zero mean vertical densifications do outperform new construction. For values below zero the opposite is observed.

6. DISCUSSION

The proposed split of LCA into demolition, reinforcement and new construction layers allows to identify the main sources of embodied impacts for vertical building extensions. The existing building's roof type is highly important, as it influences the necessary reinforcement type for the extension and the environmental impacts related to the demolition of building parts (Hafner & Storck, 2019). Our approach shows that general conclusion on the environmental potential of vertical extensions is hardly possible, as their performance in terms of GWP and PE varies depending on the existing building and material selection. Our results show possible trade-offs, especially for existing buildings with pitched roofs, where demolition of roofs and necessary reinforcement contradict the goal of reducing ecological impacts. This knowledge is especially important in the early design stages when information on existing buildings needs to be collected for decision-making. Including phase D improves the environmental performance of vertical building extensions. Thus, recycling or reusing the existing roof structures should be enhanced.

Nevertheless, vertical building extensions outperform new buildings regarding surface sealing, which makes them a highly suitable option for future urban development (Fatone et al., 2012). We compared impacts by using a geometry consisting of existing building and extension for the new building, assuming urban space and building legislation allow that. If the new building has to be built smaller than that, impacts increase due to a rising share of influences from, e.g., building foundations.

This research is based on German building legislation, thus limited to this context. A sensitivity and uncertainty analysis should be performed to obtain more general conclusions, with varying building and extension geometries. This should also include checking the load capacities of existing buildings. In this research, only the reinforcing layer was modelled dependent on fire safety. For a more accurate comparison with new buildings, their construction and also necessary enhancements of fire safety in the existing building should be included. The proposed methodology can serve as a base for this development.

7. CONCLUSION

Vertical building extensions are essential for future urban development as cities become denser and space is a contested resource. This paper proposed a methodology to analyze their embodied impact from a lifecycle perspective. The introduced reinforcement layer allows investigating the performance of different material combinations in early design stages, depending on existing building's and vertical extension's properties. Compared to newly built structures, vertical building extensions offer potential regarding their environmental impact. Our application with example buildings from TABULA showed, that flat roofs are beneficial for vertical building extensions in terms of embodied impact.

Nevertheless, there are cases where new constructions performed better than vertical extensions. Thus, we partly confirm our hypothesis. Living space built through vertical densification can have a lower CO_2e footprint than new buildings, but new buildings might lower their impact by a higher building volume. As new buildings are rarely possible without restrictions in urban areas, we conclude that both approaches are suitable for specific areas of application and depend on the existing building's properties. The proposed methodology allows designers to focus on the critical aspects of vertical building extensions in decision-making processes and provides support for the identification of main contributors to ecological impact. Vertical building extensions do not necessarily outperform new buildings in terms of embodied GWP and PE. Splitting up into different building parts (existing, reinforcement, demolition, extension) makes optimization potentials visible and increases the ability to test additional material and construction combinations.

While this paper focuses on embodied impact, building extensions can also influence operational impact (Leskovar et al., 2018). A combination of both is essential to show potential synergies and trade-offs in LCA. Future research should also consider combined scenarios, as building extensions are frequently applied in conjunction with refurbishment of the existing building, which offers synergetic potentials (Conci et al., 2019). Another future direction is including more details of constructions and dependencies with the building stock and the new structures. Also, expanding the methodology to horizontal building extensions would be valuable.

ACKNOWLEDGEMENTS

This work was carried out within the research project 'Densification in the Context of Climate Change', funded by Bavarian State Ministry of the Environment and Consumer Protection (StMUV) and the TUM Centre for Urban Ecology and Climate Adaptation (ZSK).

REFERENCES

Basic, S., Hollberg, A., Galimshina, A., & Habert, G. (2019). A design integrated parametric tool for real-time Life Cycle Assessment – Bombyx project. *IOP Conference Series: Earth and Environmental Science*, *323*, Article 012112, 1–10. https://doi.org/10.1088/1755-1315/323/1/012112

BMWSB - Federal Ministry of the Housing, Urban Development and Building (BMWSB). (2022). Oekobaudat Database Version 2020-II. Retrieved March 3, 2022, from https://www.oekobaudat.de/.

CAALA GmbH (2022), Computer-Aided Architectural Life Cycle Assessment (CAALA), Available at: www.caala.de.

Conci, M., Konstantinou, T., van den Dobbelsteen, A., & Schneider, J. (2019). Trade-off between the economic and environmental impact of different decarbonisation strategies for residential buildings. *Building and Environment*, *155*, 137–144. https://doi.org/10.1016/j.buildenv.2019.03.051

dataholz.eu (2021). Online catalogue of wood and wood-based materials, building materials, components and component connections for timber construction. Retrieved January 25, 2022, from https://www.dataholz.eu/

Everding, D. (2017). Energetische Potenziale und klimatische Grenzen der Nachverdichtung städtischer Quartiere am Beispiel der Region Frankfurt - Rhein - Main. *REAL CORP 2017 Procceedings*, 691–697.

Fath, M., Storck, M., Kurzer, C., Willmy, S., Schridde, J., Sieder, M., Hafner, A., Winter, S., & Kessel, T. (2019). *Leitlinie zur Vereinfachung der Planung und Durchführung von Aufstockungs- / Erweiterungs-maßnahmen als Nachverdichtungsmaßnahme in innerstädtischen Bereichen*. Stuttgart. Fraunhofer IRB Verlag.

Fatone, S., Conticelli, E., & Tondelli, S. (2012). Environmental sustainability and urban densification. *WIT Transactions on Ecology and the Environment* (155), 217–228. https://doi.org/10.2495/SC120191

German Institute for Standardization (2012), DIN EN 15978:2012-10, 2012-10: Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. DOI: https://dx.doi.org/10.31030/1917049.

Hafner, A., & Storck, M. (2019). Life Cycle Analysis of Vertical Building Extensions – Environmental Impacts of Different Material Selection. *IOP Conference Series: Earth and Environmental Science*, Article 012046, 1–8. https://doi.org/10.1088/1755-1315/290/1/012046

Hess, R., Schlaich, J., Schneider, K.-J., Volz, H., Widjaja, E., Schneider, K.-J., & Widjaja, E. (2012). *Entwurfshilfen für Architekten und Bauingenieure: Faustformeln für die Vorbemessung, Vorbemessungstafeln, Bauwerksaussteifung*. Beuth Verlag.

Kaufmann, H., Krötsch, S., & Winter, S. (2017). *Atlas Mehrgeschossiger Holzbau: DETAIL Atlas*. DETAIL. https://doi.org/10.11129/9783955533540

Leskovar, V. Z., Lesnik, M., & Premrov, M. (2018). Building refurbishment by vertical extension with lightweight structural modules. *1st Latin American SDEWES Conference, Rio De Janeiro*.

Loga, T., Stein, B., Diefenbach, N., & Born, R. (2015). *Deutsche Wohngebäudetypologie: Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden (TABULA)*. Darmstadt. Institut Wohnen und Umwelt.

Loibl, W., Vuckovic, M., Etminan, G., Ratheiser, M., Tschannett, S., & Österreicher, D. (2021). Effects of Densification on Urban Microclimate—A Case Study for the City of Vienna. *Atmosphere*, *12*, Article 511, 1–23. https://doi.org/10.3390/atmos12040511

Mooser, M., Forestier, M., Pittet-Baschung, M., & Büren, C. von. (2014). *Aufstocken mit Holz - Verdichten, Sanieren, Dämmen*. Birkhäuser. https://doi.org/10.1515/9783038212829

Pech, A., Kolbitsch, A., & Zach, F. (2020). *Decken. Baukonstruktionen: Vol. 5*. Birkhäuser. https://doi.org/10.1515/9783035621389

Tichelmann, K., Blome, D., Günther Matthias, & Groß, K. (2019). *Deutschlandstudie 2019: Wohnraumpotenziale in urbanen Wohnraumpotentiale in urbanen Lagen*. Aufstockung und Umnutzung von Nichtwohngebäuden.

United Nations - Department of Economic and Social Affairs. (2019). *World Urbanization Prospects: The 2018 Revision*. New York.

United Nations Environment Programme. (2021). *2021 Global Status Report for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector*. Nairobi.

Vilches, A., Garcia-Martinez, A., & Sanchez-Montañes, B. (2017). Life cycle assessment (LCA) of building refurbishment: A literature review. *Energy and Buildings*, *135*, 286–301. https://doi.org/10.1016/j.enbuild.2016.11.042

Obispo 204

Application of sustainable strategies in a building in Old Havana

TALIA QUESADA CAMPAÑA [1]

[1] Oficina del Historiador de la ciudad de La Habana

ABSTRACT: The project of the new branch of "Antonio Núñez Jiménez" Foundation is located in one of the 2500 buildings in Old Havana, which have grade III of protection and are in urgent need of intervention. The main aims of the project were to conceive the most sustainable building possible in the historic centre and also to produce a learning tool for architects and developers to increase sustainability in architectural restoration in Cuba. To achieve these goals it was necessary to identify the strategies that can be applied in the Cuban context and the actors and partners that have the resources to help on the endeavour, as part of a development project, some principles of Circular Economy were used in the conceptualization. Some of the chosen strategies were energy saving enhancing daylight use, natural ventilation and solar control; production and use of energy using renewable sources and reduction of carbon footprint, using ecological materials and minimizing constructive interventions. The project has been approved by the heritage institutions that enforce regulations in Havana's historic centre and is under construction.
KEYWORDS: Heritage, Sustainable intervention, Circular Economy

1. INTRODUCTION

40 years after the declaration of Havana's historic centre as a World Heritage Site by UNESCO in 1982, the city shows a very successful image for tourism. In 1993, the government recognized Old Havana as a prioritized area for conservation and gave to the Office of the Historian legal power to implement an alternative scheme of heritage management. Nowadays, there is a consolidated structure within the Office for the intervention and conservation of the built environment and the intangible heritage of the city. However, despite all the work done, Old Havana has been classified as an "emergency zone" due to the high rate of decay of its buildings. The renovation process, although constant in these four decades, is not fast enough due to reasons intrinsic to the intervention of old buildings and also the impact of Cuba's economic crisis. Authorities have calculated that every three days two buildings collapse in this part of the city. Although the Office have intervened in most of the 500 structures which have the highest grade of protection, 2500 buildings classified as grade III, which are the ones that define the harmony of the district, are in need of urgent action (Plan Maestro, 2016).

In this context, the Office of the Historian has established a development plan for the historic centre for 2030. One of the main objectives of this plan is to work towards the sustainable development goals; therefore, it promotes the use of technologies, techniques and materials aligned with environmental concepts in all projects situated in the prioritised area of preservation (Plan Maestro, 2016). This is a difficult task for architects and urban planners working in the historic centre as compliance with heritage conservation regulations are mandatory in any intervention in Old Havana.

Furthermore, the Office of the Historian has the intention to implement an integral scheme of circular economy with the support of international cooperation, especially with "Habana Circular" project with the Spanish institution Tecnalia. Among the valuable initiatives there is a plant for recycling demolition waste which processes all the waste material extracted from construction sites in the historic centre.

2. THE BUILDING

The project of the new branch of "Antonio Núñez Jiménez" Foundation is located in one of those 2500 buildings in Old Havana, which have grade III of protection and need intervention. Its history can be traced to the colonial period, as it is located in one of the foundational blocks of the city. The parcel belonged to the building complex called "Galbán Lobo", property of one of the richest families in Cuba before the Revolution. These buildings were offices and warehouses for the sugar business of Mr Julio Lobo. That is the reason why the structure displays several constructive systems: timber floors from the 1700s or reinforced concrete columns from the 1950s.

Figure 1:
Façade of the building towards Obispo Street

The new headquarters of the Foundation will housed not only public spaces but also two nationally important archives and offices. On the ground floor, it will be located a lobby, technical rooms and a space for art shows. An exhibition space dedicated to the life of Antonio Núñez Jiménez, a library, guests' rooms and a conference hall will be on the first level. The second floor will housed the most private spaces with the offices and the archives of the institution. An open terrace for social activities, a green roof and a space for co-working will be at the top floor. The idea of the organization is to showcase on the project its principles of care for the environment, sustainability as well as the promotion of sciences like Geography and Anthropology. At the same time, the Office of the Historian has embraced the project as an opportunity to have a sustainable restoration scheme in Old Havana.

The main aim of the project is not only to conceive the most sustainable building possible, but also this will be a pilot project that can be used as a learning tool for architects and developers to increase sustainability in architectural restoration. In consequence, the designers have considered the design and the construction stages as important as the final realisation of the building, because through promotion and consultation, it will be possible to make alliances with the private and academic sector as well as promote environmental design on heritage. To achieve these goals, the design team has identified the strategies that can be applied in the Cuban context and the actors and partners that have the resources to help on the endeavour.

3. APPROACH

In order to fulfil the objectives of the project, the designers have taken several steps. The first one was to study the building, its context and climate. A structural survey was done to assess the load bearing capacity of the building, as well as a historic investigation. Also, using Ladybug and Honeybee on Grasshopper software, the architect evaluated the influence of the climatic variables on the structure, testing specially the influence of the plot's subdivision on daylight access and ventilation.

The second part was to identify the environmental fields of intervention for the project and the possible strategies to address them. Based on the main environmental problems drawn in the Special Plan for Development for 2030 of Old Havana (PEDI) (Plan Maestro, 2016), four areas of action were chosen: energy, water, carbon footprint and biodiversity.

Another stage of the project was to evaluate and assess the strategies regarding economic and technical feasibility in the Cuban context, as well as compliance to heritage codes and building regulations. The designers researched the legal framework for sustainable interventions in Havana and it was found that Old Havana urban regulations allow the introduction of environmentally friendly equipment and approaches in grade III of protection buildings. Regarding renewables, the government is currently supporting the introduction of photovoltaic systems on the urban fabric, given incentives and facilitating the sale of the remaining energy produced by this type of installations. The legal context for residual and rainwater reuse is less beneficial, being the introduction of isolated strategies of black and even grey water treatment in buildings almost impossible to achieve. Therefore, only rainwater collection and its use on toilets or irrigation were possible on the project.

Afterwards, there was a period of research about the economic and technical feasibility of the proposed strategies in Cuba. In the early stages of the project, workshops and presentations were arranged to show the ideas to different collaborators, scientific researchers, private entrepreneurships, architects, construction material suppliers and producers. In this endeavour it was crucial the role of the Foundation, that called its partners from Cuba and around the world to discuss the solutions. From this step, the design team obtained valuable partnerships and feedback. New materials produced in Cuba were discovered like "Ecomadera", composite structural elements made 100% of recycled plastics, produced by a cooperative. This initiative helped to visualize what it is done in the country and the world in terms of sustainable interventions and its benefits were felt not only in the project of Obispo 204 but in other projects in Old Havana.

The architect and engineers involved in the project did the final evaluation of the proposed strategies using software simulations and calculations. For example, it was calculated the solar panels yield, the forced ventilation parameters and the rainwater harvest. Furthermore, to use daylight as much as possible, it was applied an evidence-based approach in which design decisions were taken using computer simulations. First, the structure was modelled on Rhinoceros and then; using Grasshopper, Ladybug and Honeybee, Daylight Autonomy (DLA) and Useful Daylight Illuminance simulations were performed in each level of the building.

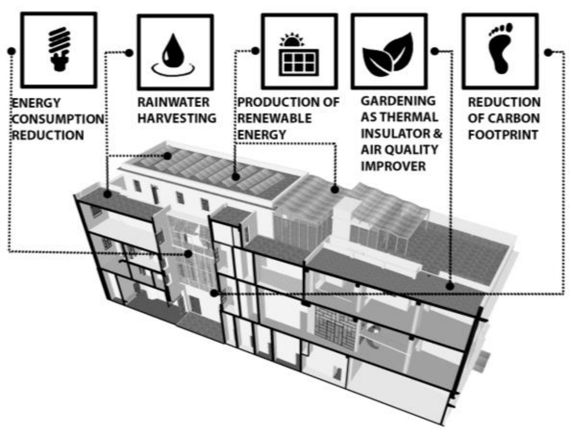
4. STRATEGIES EXPLAINED

After the analysis of the building and the examination of different scenarios, the designers determined five main strategies that could work in the context of the historic centre in Havana to tackle some of the main environmental issues of the city's district (Fig.1).

The strategies were:

- Energy saving enhancing daylight use, natural ventilation and solar control.
- Production and use of energy using renewable sources.
- Rainwater harvesting and use for toilets and irrigation.
- Reduction of carbon footprint, using ecological materials and minimizing constructive interventions.
- Gardening and greenery strategically placed for thermal insulation and air quality improvement.

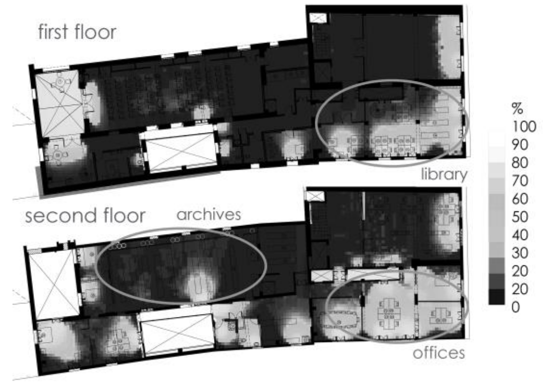
Figure 2:
Building's main sustainable strategies.



4.1 Energy savings

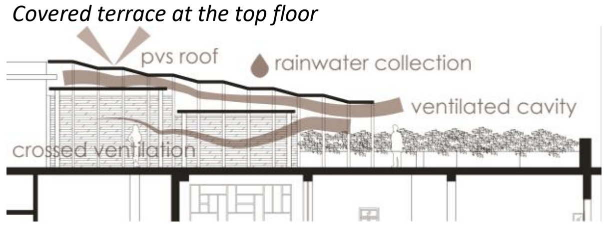
One of the areas of work of this strategy was the access to daylight with the objective to reduce as much as possible the use of artificial lighting. The approach was to put on the brightest places functions like the library and the offices. Conversely, spaces like the archives and the conference room were located in the darker areas because in these cases too much daylight can be harmful or unwanted. Also, with the help of daylight simulations the architect detected an area where there was not enough daylight access because of the new subdivision of the plot. It was decided then, to open a new patio to give a new source of light and natural ventilation (Fig.3).

Figure 3:
Daylight Autonomy for 500lux in the first and second level



Solar protection and natural ventilation were other factors studied as part of the energy saving strategy. Hence, the designers explored ways to passively achieve thermal comfort. Especially, for the terrace at the top of the building it was designed a double roof in order to reduce the effect of the solar radiation. The top layer will be built with solar panels and will collect rainwater (Fig. 4).

Figure 4:
Covered terrace at the top floor

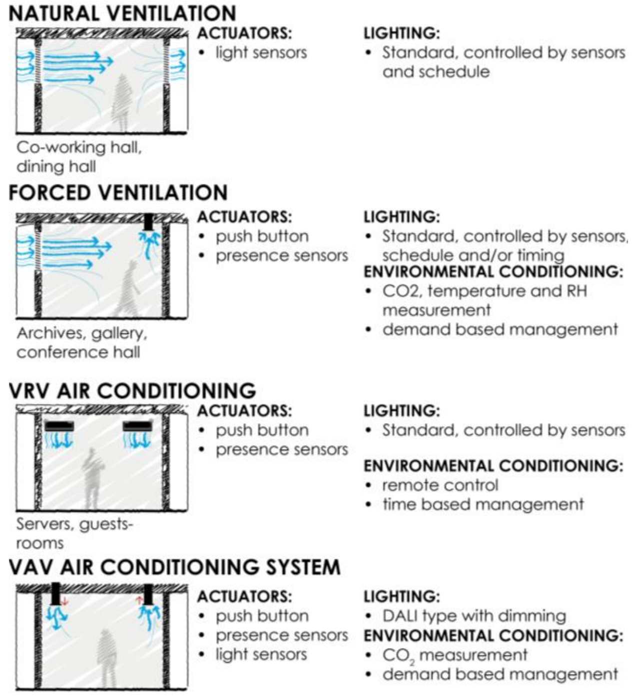


In addition, an automatic system will manage several aspects of the functioning of the edifice and will allow the control and visualization of the environmental performance during operation (Fig. 5).

Figure 5:
Fields controlled by the automatic system

Despite the designers' ambition to reduce the consumption of energy by enhancing the use of natural ventilation the nature of some of the functions in the building and the client's request to mechanically air-condition the offices resulted in a different scheme. The strategy was to divide the spaces and functions in four different conditioning zones. The first one with naturally ventilated spaces like the co-working space at the top floor, the second group with "forced natural ventilation" for the archives, the conference room and the gallery, and lastly two groups with mechanically conditioned spaces, the bigger rooms such as the offices with a centralized system and the isolated smaller spaces like the servers room with a multi-split system (Fig. 6).

Figure 6:
Types of environmental conditioning and control scenarios in the building



Note: VRV: variable refrigerant volume, VAV: variable air volume

A major reason of concern for the consumption of energy was the conditioning of the archives in the building. Usually, spaces that store old documents and heritage pieces require a controlled environment with stringent values of temperature and relative humidity for 24 hours. Nevertheless, the designers in collaboration with authorities of the Cuban National Archives have chosen a different strategy for the project. It has been long discussed that pieces in tropical climates can withstand high values of temperatures and relative humidity (Toledo, 2007). In addition, there have been dire consequences for valuable collections in Cuba with too stringent environments dependable on air-conditioning equipment in a context where electrical supply is unsteady. Researchers have stated that drastic changes in the environmental conditions of archives make more damage than constant high temperatures, therefore a space with crossed ventilation and provisions to prevent insect's entrance would make a good environment for the pieces (Borrego, 2019). Most of the archives will be located in a large room conditioned with crossed ventilation achieved by windows to the patio, tubular fans that support the attainment of the required air changes per hour and extractor fans located on the roof which exhaust air through conducts. The idea is to achieve an average air speed between 0.25 to 0.30 m/s, to prevent dust particles to settle on surfaces. Ceiling fans will help in the achievement of thermal comfort. The mechanical engineer of the project calculated the sizing and final design of the system, using a steady-state worst case scenario method (Table 1).

Table 1:
Inputs for the archives' calculations

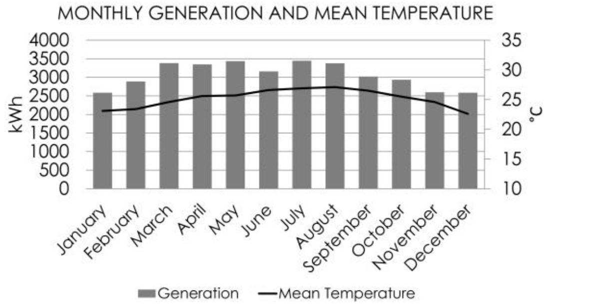
Exterior conditions	
Dry bulb temperature	32.0°C
Wet bulb temperature	26.5°C
Relative humidity (RH)	62%
Daily temp. difference	8.0°C
Mean wind speed	7km/h
Interior conditions	
Air changes per hour	6
Air speed	0.25 -0.30 m/s

4.2. Production and use of renewable sources´ energy.

In a country like Cuba, dependent on fossil fuels that are scarce in its territory, implementation of renewable energy projects is essential. However, in Old Havana until this date there are few examples of a photovoltaic systems integrated to a building; therefore, the Foundation project will be one of the first incursions in this field.

The photovoltaic panels will be located in two different arrays, one over a portion of the building's roof and the second will be the upper layer of the new double roof. This will be a stepped structure where some modules will have an inclination of 15° (ideally for Cuba's latitude) and the others with an angle of 5° in altitude to create steps that will reduce the speed of the running rainwater and prevent bottlenecks in the drainage system. Additionally, with the location of the systems, the designers ensured that the panels cannot be seen from the street to comply with heritage regulations.

Figure 7:
Projection of the monthly generation of the photovoltaic system



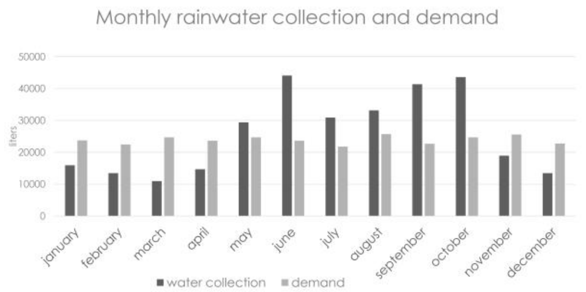
The whole photovoltaic system is composed by the panels and two invertors connected to the building´s electric network and the national grid, there will not be batteries. As a result, the energy not consumed by the Foundation will be injected directly into the grid. The calculation of the yield and efficiency of the system was done by Cubasolar; a Non-Governmental Organization specialized in solar systems in Cuba. The calculations were performed using the photovoltaic panel that is produced in the country, a standard module of 270Wp of power and size of 1.66 x 0.9 meters. The system is expected to produce 36.76MWh/year, which is 79.06% of the actual consumption of the Foundation in its current headquarters (Ledón, 2020) (Fig.7). The demand in the new building will be different and probably higher; however, it has been estimated that it will be sufficient to meet the electrical demand of the project excluding air-conditioning consumption.

4.3. Rainwater harvesting and use

To reduce the consumption of potable water in the project, it was decided to implement a system of rainwater harvesting and use the harvest to supply the toilets, to water the plants and to clean. The roof's portions that will collect water will not have public transit, to ensure that the collected water will be as clean as possible. In addition, filtering will be used in different parts of the collecting system and chlorine will be added on the underground deposit, in order to comply with the local regulations.

With a collection area of 311.42 m^2 and the monthly average values of precipitation for Havana, it was calculated the possible amount of water that can be collected with an efficiency of 80%. At the same time, it was estimated the quantity of water used by the toilets in the building and it was concluded that 108% of the yearly demand of water can be met by the collected rainwater. However, if the data is monthly analysed, it can be observed that in the drier months the demand surpass the harvest and vice versa in the rainy season (Fig. 8). Due to the size of the available deposit it is not possible to store water from one season to the other; nevertheless, toilets can be supplied with rainwater more than 70% of the year.

Figure 8:
Monthly rainwater collection in 311.42m2 and toilet and irrigation demand.



4.4. Carbon footprint reduction

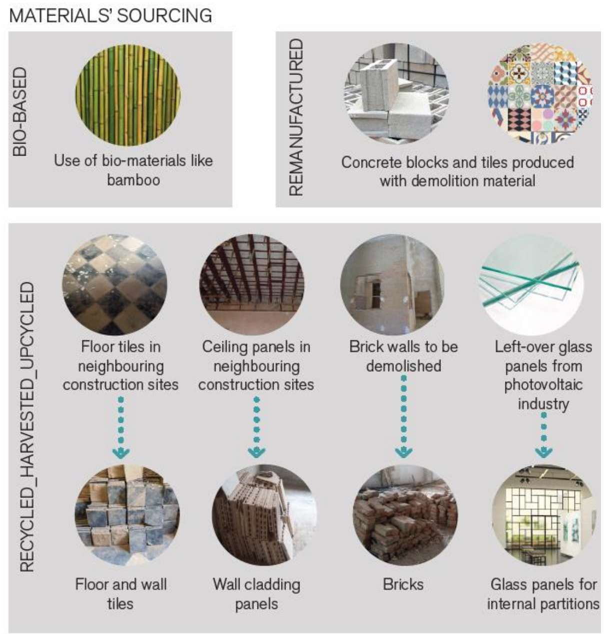
Besides making the most of the structure of the building and the reduction to a minimum of the interventions on the original walls, in the strategy of reduction of the carbon footprint; it has been a priority the use of local and ecological building materials. Fortunately, Old Havana's institutions offered a positive context for the use of alternative materials. For example, in the framework of international cooperation projects and "Habana Circular" initiative the recycling plant of demolition material have been improved. Hence, concrete blocks and pavement tiles on the buildings will be made with waste from construction sites of the historic centre.

On the other hand, leftovers glass panes from the only photovoltaic manufacturer in Cuba will constitute windows and interior partitions in the building. The architect decided also, the use of natural materials like bamboo for the elements of solar protection.

In addition, as the construction progresses, it has been found unattended ways to reuse and recycle waste materials. The contractors as well as the management team have developed a framework in which no material is discarded. On site, there is a group of two workers in charge of preparing, classifying and quantifying the demolition and recycled material to reuse on the building (Fig.9). At the same time, pavement tiles and ceramic ceiling panels from neighbouring construction sites are used on the structure (Fig. 10).

Figure 9:
Workers classifying waste material on site

Figure 10:
Source of materials used on site



4.5. Greenery and gardening use

As part of the strategy to use plants as thermal insulation and air quality improver the design team decided to install several green walls and one green roof. The localisation of the gardens was determined according to the solar analysis to protect the surfaces which have a higher incidence of the sun.

The green walls would be of different type and dimensions, the biggest one would be located to the exterior in the western façade, where the effect of insulation would have a greater impact. In the same way, the garden roof would be situated in the South-western corner of the building, which is the area with more solar load and the roof of the offices, where more people will remain daily.

Figure 11:
Rendering image of the green roof at the top floor.

5. CONCLUSION

This endeavour has marked a route for sustainable interventions in Old Havana and the Office of the Historian has embraced the project and has decided to implemented at full. The plans and documentation of the project was presented to Havana's Heritage Commission (Comisión Provincial de Monumentos) for approbation and it was accepted the whole intervention. As a positive proof of the influence of Obispo 204 it can be mentioned that some solutions and suppliers of ecological materials, first discovered with the project, are already been implemented in other buildings in the historic centre.

On the other hand, it must be mentioned that the scope of the strategies was possible because the building was classified as a Grade III of protection; therefore, the same approach would be hard for a building with Grade I or II of protection in Cuba. Regarding the photovoltaic system, it is expected that only a small portion of the energy consumption can be meet by the system, as the air-conditioning equipment of the building is too extensive despite the zoning implemented. Therefore, it would have being better to have the building running completely passively.

Even though the chosen strategies need to be tested, the approach has been positive especially in a context of resource scarcity during the pandemics; with imports drastically reduced the only available materials are reused or local ones.

ACKNOWLEDGEMENTS

The author wants to acknowledge the Historian's Office of Havana and "Antonio Núñez Jiménez" Foundation for providing permission to publish. In addition, the author thanks the architect Belmont Freeman for his collaboration and support.

REFERENCES

1. Borrego, S. (2019) *Lineamientos para el local de archivo de la nueva sede de la Fundación Antonio Núñez Jiménez.* La Habana: Archivo Nacional de Cuba.
2. Ledón, N. (2020) *Estudio para la instalación de un sistema fotovoltaico para aportar electricidad a la Fundación Antonio Núñez Jiménez*. La Habana: GenSolar, Cubasolar.
3. Plan Maestro. (2016). Plan Especial de Desarrollo Integral de La Habana Vieja 2030. La Habana: Oficina del Historiador de la ciudad de La Habana.
4. Toledo, F. (2007) Museum Passive Buildings in Warm, Humid Climates. *Contribution to the Experts' Roundtable on Sustainable Climate Management Strategies*. Tenerife, Spain. The Getty Conservation Institute. [Online] Available from: http://www.getty.edu/conservation/our_projects/science/climate/paper_toledo.pdf

PLEA 2022 SANTIAGO

Will Cities Survive?

Decarbonization at the campus scale

Evaluating the life-cycle carbon impacts of deep energy retrofits of three university building typologies

ALLISON HYATT[1], CATALINA PÉREZ-AGUIRRE[1], ADAM YARNELL[1], JONATHAN GRINHAM[1]

[1]Harvard Graduate School of Design

ABSTRACT: To meet 2050 decarbonization goals, institutional leadership will need to reduce operational energy use while preserving the existing building stock. This study investigates life-cycle carbon retrofit impacts for university buildings. The team selected one representative structure for each of the three most energy-intensive typologies on campus: laboratories, dormitories, and offices. The team then employed operational energy simulation and life-cycle assessment software to model a code-minimum retrofit, deep energy retrofit, and code-minimum new construction scenario for each building type (considering window, exterior wall, and roof assembly upgrades). By comparing the carbon payback period of the retrofit and new construction scenarios and changes to the payback period based on linear decarbonization of the electric grid, the study identifies strategies and materials with the greatest potential to affect carbon reductions at academic institutions.

KEYWORDS: Carbon payback, embodied carbon, campus, retrofit, life-cycle assessment

1. INTRODUCTION

Many large institutions, corporations, and governments have committed to decarbonizing their energy supply by 2050 [1]. They cannot claim climate neutrality, however, unless this shift is coupled with aggressive reductions in embodied carbon emissions. Currently, materials and construction are responsible for roughly 27% of building-related global greenhouse gas emissions [2], but this percentage is expected to rise as the electricity grid decarbonizes and institutions enact stricter performance standards [3]. Life-cycle carbon, which considers both operational and embodied carbon, is a more appropriate metric for evaluating building interventions [4,5]. If large institutions wish to meet these commitments in good faith, the additional embodied carbon they invest in building upgrades should be offset by operational carbon savings by 2050 at the latest.

This paper introduces a method to guide renovation planning based on life-cycle carbon. Previous studies have detailed retrofit prioritization tools for campus energy efficiency [6,7], and many others have built workflows to balance operational and embodied energy, but the authors found no literature that ordered academic campus buildings by potential life-cycle carbon reduction.

1.1 Context and Literature Review

This study builds upon previous work that assesses the balance between embodied and operational carbon in buildings. Researchers have compared direct and indirect building energy inputs as early as 1976 [8]. In 1987, scholars calculated a period of 5.5 years for operational energy to overtake initial construction energy [9]. Likewise, HVAC and lighting energy quickly surpassed the initial embodied emissions for all structural options in a study on life-cycle emissions from office buildings [10]. Subsequent studies have presented cases where embodied carbon dominates total life-cycle emissions [11], but researchers disagree on whether or not the pursuit of higher performance results in higher absolute embodied emissions [12,13]. Scholars have presented cases where the life-cycle carbon of net-zero, off-grid, or passive house structures exceeds or negligibly differs from that of poorer-performing alternatives [14,15].

Compared to new construction, retrofits offer a greater opportunity to reduce operational carbon with minimal input of embodied carbon [16]. Modest upgrades to existing buildings typically result in lower life-cycle carbon emissions than all but the most energy-efficient new buildings [17]. Retrofits can be further justified due to rapid life-cycle carbon returns on investment, which are typically less than 10 years [18] and nearly always less than the new material's service life [12,19].

2. SCOPE AND METHODOLOGY

The team focused on university buildings at an existing historic campus as a controlled model to assess various decarbonization strategies. Per the IECC climate zone map, the campus is located in cool, humid Zone 5A [20]. Operational and embodied impacts were measured by comparing energy simulation results to whole-building Life Cycle Assessment (LCA) results. Using the university's energy reporting platform, one representative structure was selected for each of the three most energy-intensive building typologies: laboratories, dormitories, and offices. Buildings with high operational carbon intensity (OCI) per area, few building renovations, mid-range gross floor areas, and aesthetics representative of the campus were prioritized. The following buildings were selected:

Building	Constr. (yr)	Area (sqm)	Description
Laboratory	1884	4640	Masonry; wood floors
Dormitory	1948	6710	Masonry; conc. floors
Office	1894	560	Wood-framed

Table 1: Summary of buildings selected for case study.

PHYSICAL LABORATORY	Envelope upgrade	Scenario						
		0. Base case	1. Code-min retrofit		2. Deep-energy retrofit		3. Code-min new construction*	
Operational carbon assessment	roof insulation	RSI-3.7 (R-21)	RSI-6.7 (R-38)		RSI-10.6 (R-60)		RSI-6.7 (R-38)	
	wall insulation	RSI-3.2 (R-18)	RSI-3.5 (R-20)		RSI-7 (R-40)		RSI-3.5 (R-20)	
	windows	2x pane, air fill	2x pane, air fill, 1x low-E		3x pane, argon fill, 2x low-E		2x pane, air fill, 1x low-E	
	u-value	2.8 W/m2K	1.6 W/m2K		0.7 W/m2K		1.6 W/m2K	
	SHGC	0.74	0.38		0.34		0.38	
	VLT	0.80	0.62		0.57		0.62	
	infiltration	ac/hr 1.3	ac/hr 1.0		ACH50 1.0		ac/hr 1.0	
Embodied carbon assessment			1A. High carbon	1B. Low carbon	2A. High carbon	2B. Low carbon	3A. High carbon	3B. Low carbon
	roof assembly		XPS insulation	polyiso insulation	see code-min retrofit case		see code-min retrofit case	
			spray foam	cellulose			*It is assumed that new construction replicates the construction of the existing building with the addition of a higher performing envelope	
	wall assembly		XPS insul	polyiso insulation				
			steel furring	wood furring				
	windows		aluminum frame	wood frame				

Table 2: The matrix above indicates the project scope, retrofit scenarios, and envelope upgrade targets for the Physical Laboratory.

minimums, so the research team adopted the National Grid Deep Energy Retrofit Pilot Program's targets of R-60 for roof insulation and R-40 for above-grade walls [22].

The team then ran energy simulations to obtain the annual operational energy consumption for each building and each scenario (see Sections 2.1 and 3.1). Next, within each scenario, the embodied carbon associated with two material palettes were compared: one using highest carbon feasible materials and the other using lowest carbon feasible materials (see Sections 2.2 and 3.2). With the resulting Global Warming Potential (GWP) from each palette, the team calculated the carbon payback for each scenario. By using extremes, the team could ascertain a reasonable range of embodied carbon while limiting the number of design parameters. Likewise, calculating the difference of two antipodal values provided a quick estimation of the sensitivity of material choice, and many previous studies have shown that material choice is a key determinant of embodied emissions [23,24].

For each building, the team compared the as-built scenario to three building upgrade scenarios: code-minimum retrofit, deep energy retrofit, and code-minimum new construction (see Table 1). The scope was limited to envelope upgrades including wall insulation, roof insulation, windows, and air barriers.

The as-built conditions were based on architectural drawings, satellite images, and geo-spatial data. In cases where it was difficult to infer the as-built assemblies, the team assumed assemblies that would have been common at the time of construction. Assumptions for the Physical Laboratory have been outlined in Table 1.

The targeted envelope upgrade values for the code-minimum retrofit scenario were based on the Ninth Edition of the Massachusetts State Building Code [20]. To ensure code-compliant R-values for the upgraded exterior wall and roof assemblies, the team calculated the minimum amount of each type of insulation needed to comply with the target R-value. They then used the thinnest standard insulation product that would still comply with code in each assembly.

For the deep energy retrofit scenarios, targeted envelope upgrade values—including air tightness, window U-value, and Solar Heat Gain Coefficient—were largely based on EnerPhit standards [21]. EnerPhit-recommended R-values, however, were lower than code

2.1 Energy Performance Simulations

The team employed DesignBuilder [25] to compute the energy reduction for each proposed scenario (see Section 2). Each floor was modelled as one continuous zone and interior partitions were not considered. The activity templates, occupancy schedules, and mechanical system specifications were determined by applying the office, laboratory, and dormitory templates internal to DesignBuilder. The target values associated with each scenario are summarized in Table 1.

The base case scenario represents the existing building's current level of insulation with a high air infiltration rate. Thus, the energy simulation results for site energy for cooling and heating approximate the fuel consumption of each existing building. The real fuel demand was obtained through the university's web-based monitoring platform based on year 2018 data. The four fuel types surveyed among the studied buildings are steam, chilled water, electricity, and natural gas. This platform, however, did not provide information about end-uses for each fuel type. The team assumed the fuel distribution per Table 3.

	Cooling			Heating		
	%	Fuel	$kgCO_2e$/Btu	%	Fuel	$kgCO_2e$/Btu
Lab	100	Chilled water	0.021	99	Steam	0.068
Dorm	7.9	Electricity	0.114	32.3	Natural Gas	0.053
Office	35.2			97		

Table 3: Assumed fuel and demand for each building typology and carbon Intensity per fuel (kgCO2e/Btu).

Operational carbon emission calculations were based on campus-wide energy metering data. The team used the carbon-intensity-per-fuel metrics currently used by the institution to ensure consistency (see Table 3). Carbon intensity rates were multiplied by the current energy demand and simulated reductions to obtain the projected annual operational carbon emissions after performing different levels of retrofit per Equation (1).

$$OC_{retrofit} = \left(ED_{current} * CI_{fuel} * ER_{\%}\right)_{cooling} + \left(ED_{current} * CI_{linear} * ER_{\%}\right)_{heating} \quad (1)$$

Where, $OC_{retrofit}$ - annual operational carbon emissions for cooling and heating after retrofitting (kgCO2e/yr);
$ED_{current}$ - current building energy demand (Btu/yr);
CI_{fuel} - Carbon Intensity factor per fuel (kg CO_2e/Btu);
$ER_{\%}$ - simulated energy demand reduction (%).

2.2 Embodied Carbon Modeling

The assemblies in the life cycle inventories of the larger masonry buildings (dormitory and laboratory) differed slightly from the those of the office. For example, the team assumed that the stud cavity in the office's wood-framed construction could be filled with cellulose insulation, whereas the masonry construction of the dormitory and laboratory necessitated adding interior rigid insulation on steel furring channels. Additionally, because the masonry buildings had historic value, the team assumed any upgrades to those buildings should not impact the appearance of the masonry facades.

Using Tally [26], a Revit plug-in that utilizes GaBi 2018 LCA databases, the team conducted a LCA study to quantify the environmental impacts of the high-carbon and low-carbon palettes for each building upgrade scenario. The service life of these materials was set to 30 years to compute the impact by 2050. The assessment considers LCA stages A1-A5 and B2-B5 and excludes end-of-life. Likewise, the embodied carbon that had already been spent in the original construction of the existing structures was excluded from the analysis, per convention [27]. Finally, the authors modeled biogenic carbon as a negative GWP flow as permitted in Tally.

The team assumed replacement in kind for finishes in all code-minimum and deep-energy retrofits. For the new code-minimum construction scenario, it was assumed that the building was constructed with the same structure as the existing building but upgraded to comply with current code requirements.

2.3 Carbon Payback Calculations

Per Equation (2), the total carbon payback was calculated by dividing the total embodied carbon emissions associated with each scenario (code-minimum retrofit, deep energy retrofit, and code-minimum new construction) and material palette (high-carbon materials and low-carbon materials) by the annual operational carbon reduction associated with the same scenario.

$$P_{retr} = \frac{EC_{retr}}{OC_{base} - OC_{retr}} \quad (2)$$

where P_{retr} - carbon payback period of retrofit (yrs);
EC_{retr} - retrofit's embodied carbon ($kgCO_2e$);
OC_{base} - base case operational carbon ($kgCO_2e$/yr);
OC_{retr} – retrofit's operational carbon ($kgCO_2e$/yr).

After this point, the carbon savings from better energy performance will have eclipsed the initial embodied carbon expenditure.

2.4 Life-Cycle Carbon Reduction Potential

To estimate a maximum Life-Cycle Carbon Reduction Potential (LCCRP) for each typology, the team computed the cumulative GWP savings per area, over 30 years (2020-2050) of using low-carbon retrofit materials and assuming linear decarbonization of Massachusetts's electric grid (Equation 3).

$$LCCRP = \frac{OC_{base} - OC_{retr} + EC_{retr\_LC}}{FA_{bldg}} \quad (3)$$

where $LCCRP$ - Life-cycle carbon reduction potential ($kgCO2e/m^2$);
OC_{base} - base case operational carbon ($kgCO_2e$);
OC_{retr} - deep retrofit operational carbon ($kgCO_2e$);
EC_{retr_LC} - embodied carbon of retrofit with low-carbon material palette ($kgCO_2e$);
FA_{bldg} - Floor area of case study building (m^2).

The results of Equation (3) were then fed into a Retrofit Priority (RP) equation (Equation 4) for each building:

$$RP = LCCRP * FA_{bldg} \quad (4)$$

where RP - retrofit priority.

Each typology was assigned only one LCCRP value, so floor area was the greatest determinant of priority.

2.5 Weighted Retrofit Priority

The methods in the previous section proved useful for estimating savings on the campus scale, but the analysis's insensitivity to building service life limits its utility for guiding retrofit decisions. Consequently, an alternative metric factoring building age—the weighted retrofit priority (WRP)—was developed (Equation 6).

The WRP sums two building characteristics that correlate with greater retrofit need: age and operational carbon intensity. First, the values for each building were unitized to produce values from 0 to 1 (Equations 5-1 and 5-2). The bounds establish a representative distribution, but rigorous statistical analysis was not applied.

$$Age_{unit}\colon\ 0 \le \frac{Age - B_{age\_lo}}{B_{age\_hi} - B_{age\_lo}} \le 1 \quad (5\text{-}1)$$

$$OCI_{unit}\colon\ 0 \le \frac{OCI - B_{oci\_lo}}{B_{oci\_hi} - B_{oci\_lo}} \le 1 \quad (5\text{-}2)$$

where Age - building age (yrs);
Age_{unit} - building age, unitized (yrs);
B_{lo} – score low bound (0 for Age and OCI);
B_{hi} – score high bound (200 for Age; 260 for OCI);
OCI - operational carbon intensity ($kgCO_2e/m^2yr$);
OCI_{unit} - operational carbon intensity, unitized ($kgCO_2e/m^2yr$).

The unitized values were then fed into the WRP equation to produce a score for each building. For simplicity, a_1 and a_2 were set to one in order to weight Age and OCI equally.

$$WRP = a_1 Age_{unit} + a_2 OCI_{unit} \quad (6)$$

where WRP - weighted retrofit priority;
a – weighting coefficient.

3. RESULTS

3.1 Operational Energy

The team found a range of 19% - 71% reduction in total operational heating and cooling energy depending on construction type, program, and insulation level of the retrofit. Operational carbon (OC) reductions ranged from 11% - 79% depending on fuel type (see Table 5).

	Base-case EUI (Wh/m2)	
	Heating	Cooling
Lab	77.36	109.23
Dorm	39.94	13.77
Office	69.54	37.17

Table 4: Base Case Energy Use Intensity (EUI) from the energy model were used to calculate operational energy (OE) reductions.

		Code-compliant Retrofit			Deep-Energy Retrofit		
		H (%)	C (%)	T (%)	H (%)	C (%)	T (%)
Lab	OE.	-30	-11	-19	-99	32.0	-22
	OC	-29.6	-11.2	-10.8	-99.2	31.9	-18.8
Dorm	OE	-53	-10.6	-42	-96	-0.2	-71
	OC	-52.6	-10.6	-12.4	-96.1	-0.2	-34.7
Office	OE	-27	-12	-22	-93	10.0	-57
	OC	-43.3	-18.8	-37.9	-94.7	10.4	-78.9

Table 5: OE reductions from energy models and calculated OC reduction potential. H - Heating demand reduction; C - Cooling demand reduction; T - Total energy reduction.

3.2 Embodied Carbon

On average, renovations to the wood-framed office building resulted in the lowest embodied emissions per area. The difference in GWP between the high-carbon and low-carbon materials was largest in the deep energy retrofit scenario, where large quantities of new materials were needed to reach higher performance targets. Generally, embodied carbon increased with the intensity of the building upgrade. However, the wood-framed office building saw average embodied emissions decrease in the new-construction scenario, likely due to the credit taken for biogenic carbon in the added wood structure.

	GWP ($kgCO2e/m^2$)		Payback (yrs) No decarb.		Payback (yrs) Linear decarb.	
Palette	**Low**	**High**	**Low**	**High**	**Low**	**High**
Laboratory						
CR	9.94	74.15	0.82	6.12	1.64	12.24
DR	15.8	305.22	0.75	14.46	1.5	28.91
NC	273.13	301.25	22.5	24.87	45.09	49.74
Dormitory						
CR	8.5	111.7	0.63	8.21	1.26	16.43
DR	11.5	208.2	0.47	8.48	0.94	16.96
NC	167.9	286.4	12.4	21.1	24.7	42.14
Office						
CR	-17.26	82.67	0	5.99	0	11.97
DR	-8.89	248.91	0	8.66	0	17.32
NC	24.07	166.62	1.74	12.06	3.49	24.13

Table 6: GWP and carbon payback period comparison among building upgrade scenarios; CR - code-level retrofit; DR - deep energy retrofit; NC - new code-level construction.

3.3 Carbon Payback

As seen in Figure 1, the payback period increases significantly as the grid becomes less carbon-intensive, suggesting that building retrofits will be an increasingly important tool to reduce emissions as electric grids continue to decarbonize.

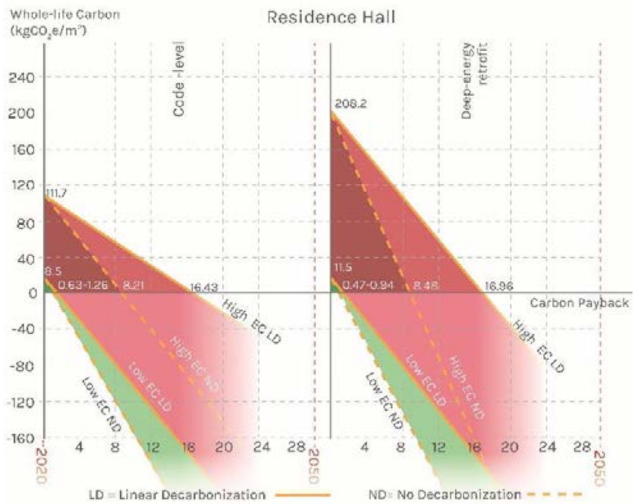


Figure 1: The payback period for the low- and high-carbon material palettes is shown for a business-as-usual case (indicated by the dashed gold line) and a case in which the Massachusetts grid decarbonizes, achieving carbon neutrality in 2050, at a linear rate (indicated by the solid gold line). The green area under the curve represents carbon emissions associated with the low-carbon material package, while the red area represents the high-carbon alternative.

3.4 Retrofit Prioritization

Equation (4) heavily rewards office buildings with large floor areas. If all campus buildings with complete data—approximately 500,000 sqm—underwent immediate deep energy retrofits with low-carbon materials, the institution could reduce life-cycle emissions by more than 184,000 tCO2e through 2050.

Equation (6) weighted age and operational carbon equally. The maximum WRP of 2.0 indicates the greatest retrofit need. Actual scores varied from 0.28 (a 54-year-old dormitory with an OCI of 0.29 $kgCO_2e/m^2/yr$) to 1.32 (a 193-year-old office with an OCI of 91.21 $kgCO_2e/m^2/yr$). In general, compared to RP, the WRP scores were higher for smaller buildings.

To compare the agreement of both methods, the team curated identical sets of buildings by removing any entry with incomplete data for floor area, typology, OCI, or age. These buildings were then ranked by Equations (4) and (6), and only one property—a ~20,500 sqm laboratory built in the 1930s—appeared in the top ten of both scores. In fact, the ordered lists only achieved a Kendall's τ coefficient of 0.14, which indicates a weak correlation.

4. DISCUSSION

4.1 Contributions

Though the study scope was limited to a subset of campus buildings in New England, the findings could be applied across cities more widely and suggest that retrofits will play a critical role in future decarbonization efforts. For instance, all renovation scenarios achieved payback, whereas two of six new construction scenarios did not pay back by 2050 with linear grid decarbonization. The results also indicate that materials have a significant impact on the life-cycle carbon payback period of a construction project. Low-carbon materials often resulted in a payback period far shorter than that of comparable high-carbon materials, particularly in retrofit scenarios (see Table 6). Thus, although all retrofit actions paid back before the end of their technical service life, the rapid returns of 10 years or less seen in literature are highly dependent on material choice. These findings could be useful for many institutions—university or otherwise—looking to target embodied carbon in their decarbonization planning.

4.2 Limitations

The team used the BIM LCA tool Tally to streamline the workflow, and while such tools have been shown to produce comparable results between platforms [28], researchers still report discrepancies with complete LCA studies [29]. Though the use of extreme cases provided a basic estimate of sensitivity, proper quantifications of uncertainty and sensitivity analyses would add robustness to the team's methods. And, if compared to methods in EN 15978 [27], the team's treatment of biogenic carbon likely overestimated wood's sequestration potential.

To study the impacts of decarbonizing Massachusetts's electric grid, the team assumed-linear decarbonization targeting a net-zero grid by 2050. The carbon payback period for each retrofit scenario is highly sensitive to the grid's carbon intensity, and a more nuanced decarbonization prediction model would yield more accurate results for the carbon payback period.

Finally, the team modeled each floor as one zone for expediency, but core-perimeter auto-zoning would have produced more accurate results [30]. Likewise, although previous studies have validated modeling representative buildings and extrapolating results to a larger stock [31], caution should be taken in applying this paper's results to varied contexts.

4.3 Future Work

This study presents a proof of concept for a methodology to assess the carbon payback of fabric-first retrofits and prioritize campus buildings for renovation based on which structures could achieve the greatest life-cycle carbon reductions. As noted in Section 2.4, the prioritization tools are basic, and effort should be spent to map results more accurately to broader campus buildings and set proper coefficients for the weighted score. Additionally, though the authors did not have access to this data, the number of years since last renovation could be added to the score to more accurately reflect which buildings have the greatest potential for carbon reductions.

Additionally, HVAC upgrades are an effective energy conservation measure, and recent research suggests that building services' contributions to life-cycle carbon emissions is underestimated [32], [15], so future studies should include mechanical systems in their scope. Subsequent assessment studies could also utilize a submetering system per end use rather than fuel type to estimate existing energy consumption more accurately.

Finally, the insulation-heavy retrofits explored in this study work well for retaining heat but may pose a challenge for passive survivability in warming climates [33]**.** Subsequent research should investigate natural ventilation and alternative envelope interventions to counteract summer overheating.

REFERENCES

[1] Net Zero Tracker | Welcome, (n.d.). https://zerotracker.net/ (accessed March 5, 2022).
[2] United Nations Environment Programme, 2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector, Nairobi, 2021.
[3] A. Akbarnezhad, J. Xiao, Estimation and Minimization of Embodied Carbon of Buildings: A Review, Buildings. 7 (2017) 5.
[4] ISO: 14040, International Organization of Standardization. Environmental management—life cycle assessment—principles and framework (ISO 14040: 2006), (2006).
[5] ISO 14044: 2006. Environmental management. Life cycle assessment. Requirements and guidelines, ISO Geneva, Switzerland, 2006.
[6] S. Nagpal, J. Hanson, C. Reinhart, A framework for using calibrated campus-wide building energy models for continuous planning and greenhouse gas emissions reduction tracking, Appl. Energy. 241 (2019) 82–97.
[7] A. Arias, I. Leon, X. Oregi, C. Marieta, Environmental Assessment of University Campuses: The Case of the University of Navarra in Pamplona (Spain), Sustainability. 13 (2021) 8588.
[8] B.M. Hannon, R.G. Stein, B. Segal, D. Serber, C. Stein, Energy use for building construction. Final report, March 1, 1976--December 31, 1976, Illinois Univ., Urbana (USA). Center for Advanced Computation; Stein (Richard G.) and Associates, Architects, New York (USA), 1976.
[9] J.N. Connaughton, The Energy Cost of Construction, in: D.O. Pedersen, J. Lemessany (Eds.), Build. Econ. CIB Proc. Fourth Int. Symp. Build. Econ., Danish Building Research Institute, Copenhagen, 1987.
[10] R.J. Cole, P.C. Kernan, Life-cycle energy use in office buildings, Build. Environ. 31 (1996) 307–317.
[11] T. Ibn-Mohammed, R. Greenough, S. Taylor, L. Ozawa-Meida, A. Acquaye, Operational vs. embodied emissions in buildings—A review of current trends, Energy Build. 66 (2013) 232–245.
[12] L.J. Hurst, T.S. O'Donovan, A review of the limitations of life cycle energy analysis for the design of fabric first low-energy domestic retrofits, Energy Build. 203 (2019) 109447.
[13] J. Kneifel, E. O'Rear, D. Webb, C. O'Fallon, An exploration of the relationship between improvements in energy efficiency and life-cycle energy and carbon emissions using the BIRDS low-energy residential database, Energy Build. 160 (2018) 19–33.
[14] A. Stephan, R.H. Crawford, K. de Myttenaere, A comprehensive assessment of the life cycle energy demand of passive houses, Appl. Energy. 112 (2013) 23–34.
[15] B. George, L.H. Clara, R. Levey, Understanding the Importance of Whole Life Carbon in the Selection of Heat-Generation Equipment, in: CIBSE Tech. Symp., 2019.
[16] H. Baker, A. Moncaster, Embodied carbon and the decision to demolish or adapt, in: ZEMCH Zero Energy Mass Cust. Home Int. Conf. Melb. Aust., 2018.
[17] P. Frey, L. Dunn, R. Cochran, K. Spataro, J.F. McLennan, R. DiNola, B. Heider, The greenest building: quantifying the environmental value of building reuse, Preserv. Green Lab Natl. Trust Hist. Preserv. (2011).
[18] F. Ardente, M. Beccali, M. Cellura, M. Mistretta, Energy and environmental benefits in public buildings as a result of retrofit actions, Renew. Sustain. Energy Rev. 15 (2011) 460–
[19] H. Nydahl, S. Andersson, A.P. Åstrand, T. Olofsson, Building Refurbishment from a Life Cycle Perspective—An Environmental Return on Investment Approach, in: D. Johansson, H. Bagge, Å. Wahlström (Eds.), Cold Clim. HVAC 2018, Springer International Publishing, Cham, 2019: pp. 253–263.
[20] International Code Council, 2021 International Energy Conservation Code (IECC), (2021).
[21] Ninth Edition of the MA State Building Code 780, Board of Building Regulation and Standards, Commonwealth of Massachusetts, 2017.
[22] Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard, (n.d.). https://passiv.de/downloads/03_building_criteria_en.pdf. (accessed December 16, 2020).
[23] National Grid Deep Energy Retrofit Pilot: Massachusetts and Rhode Island, DOE Building Technologies Program, 2014.
[24]F. Pomponi, A. Moncaster, Embodied carbon mitigation and reduction in the built environment – What does the evidence say?, J. Environ. Manage. 181 (2016) 687–700.
[25] C. Thormark, The effect of material choice on the total energy need and recycling potential of a building, Build. Environ. 41 (2006) 1019–1026.
[26] DesignBuilder v5.5.2.007, DesignBuilder Software Ltd, 2019.
[27] Tally 2020.06.09.01, Building Transparency, 2020. https://choosetally.com/ (accessed December 10, 2020).
[28] 15978: 2011 Sustainability of Construction Works—Assessment of Environmental Performance of Buildings—Calculation Method, Brussels, Belgium, 2011.
[29] J. Schultz, K. Ku, M. Gindlesparger, J. Doerfler, A benchmark study of BIM-based whole-building life-cycle assessment tools and processes, Int. J. Sustain. Build. Technol. Urban Dev. 7 (2016) 219–229.
[30] C. Bueno, M.M. Fabricio, Comparative analysis between a complete LCA study and results from a BIM-LCA plug-in, Autom. Constr. 90 (2018) 188–200.
[31] T. Dogan, C. Reinhart, P. Michalatos, Autozoner: an algorithm for automatic thermal zoning of buildings with

unknown interior space definitions, J. Build. Perform. Simul. 9 (2016) 176–189.
[32] A. Stephan, A. Athanassiadis, Quantifying and mapping embodied environmental requirements of urban building stocks, Build. Environ. 114 (2017) 187–202.
[33] B.X. Rodriguez, M. Huang, H.W. Lee, K. Simonen, J. Ditto, Mechanical, electrical, plumbing and tenant improvements over the building lifetime: Estimating material quantities and embodied carbon for climate change mitigation, Energy Build. 226 (2020) 110324.
[34] A. Baniassadi, D.J. Sailor, E.S. Krayenhoff, A.M. Broadbent, M. Georgescu, Passive survivability of buildings under changing urban climates across eight US cities, Environ. Res. Lett. 14 (2019) 074028.

PLEA 2022 SANTIAGO
Will Cities Survive?

Redefining happy cities of the post-pandemic era

ALEXANDER KADER [1] NUSRAT KAMAL RITU [2]

[1] LXK Kader + Architekten
[2] Hasselt University

ABSTRACT: When the Covid-19 pandemic forced the world to remain indoors and function remotely, the two cardinal points of home and work shaping the way we flow within our cities became subjacent. As the world opens once more and the traditional "work-home" axis becomes footloose with minimized needs to commute to work, the principal factors considered in city design can be revised. This paper aims to envision our cities with redefined driving forces in the post pandemic era that focus on factors such as mental and physical wellbeing, livability, social inclusion, and adaptability. The approach to develop and present these proposals is premised in three different cultural and climatic urban environments – Brussels, Muscat, and Sao Paolo. By setting a framework of priorities for city planning that prioritizes factors like healthy population-density, proximity, urban green, social-equality and fossil-fuel free transport solutions, our city models could offer regenerative solutions including to achieve cities of resilience that respond better to the current crises and alleviate our living standards.
KEYWORDS: post-pandemic, resilience, liveability, social inclusion

1. INTRODUCTION

Since the dawn of our first cities, the course of our settlements has been dictated by mankind's most major advancements from agriculture to industrialization, from motorization to digitalization. Today, while digitalization has long reformed how we live, perceive and function within our day-to-day lives, recent months of the Covid-19 pandemic along with the ever-building climate crisis has brought us to the cusp of yet another urban revolution. When the pandemic forced the world to remain indoors and function remotely, the world in turn found a new rhythm, one that could most likely redefine the way our cities are molded. For decades the two cardinal poles of home and work have dictated the way we live and flow within our cities. This spatial relationship embedded in the daily patterns of our lives have helped create and carry communities [1]. Today, even as we start to open our world up once more and begin to develop a "new" normal, does our newfound option to work from within our homes allow us to re-envision our cities with mental and physical wellbeing as driving forces? With fewer people commuting to work daily, could our margin for livability be redefined to cater to green pocket spaces for physical wellbeing along with large green spaces such as community gardens to encourage physical interactions that allow inter-group distancing? Perhaps it is time we question the fundamental aspects of our living habits. What other driving forces could emerge and overtake the traditional "work-home" axis that we have followed for so many years? Could this pandemic be harnessed to rethink our living patterns in a way such that our carbon footprints are reduced? The following mind-map summarizes the structure and intention of the paper.

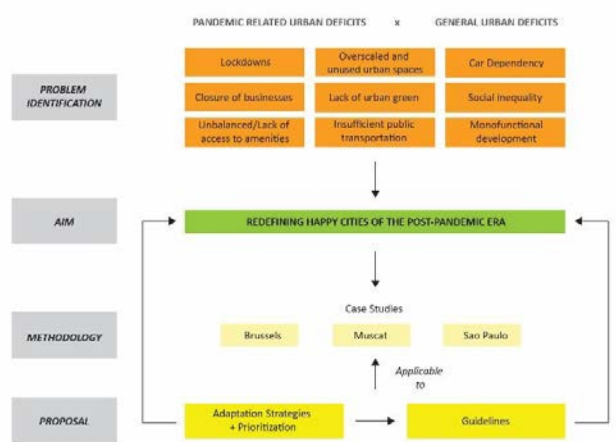


Figure 1: Strategical approach towards happy cities of the post-pandemic-era

2. READING OUR CITIES – METROPOLIS OR SUBURB?

Cities once emerged as a central metropolis with congregations of amenities and communities close together to minimize traveling longer distances for necessities. Here flourished diversities of economies and cultures from a critical threshold of population and

PLEA STGO 2022

WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

capital. Despite everything the city presents, it remains true that the motor of most cities is the factor of employment, thus influencing where people live, eat and build. Yet, a large proportion of our cities today suffer from urban sprawl and inefficient planning – resulting in long commute hours and experiencing none of the pleasantries that urban life has to offer. Most city plans today fail to cater to the densities of population and infrastructure in them. This has resulted in residences being pushed to the periphery of cities, leading to increased dependency on private automobiles while negatively impacting green reserves, forests and arable lands [2]. Furthermore, our norms of car-borne planning have outlined several deep-rooted social and economic inequalities in cities, thus becoming the centre for unsustainable practices. However, confronted with the restrictions and lockdowns of the pandemic, our cities were presented with an open-ended question – or rather an epiphany of open-ended possibilities. What happens when this key factor of "going to work" is taken out of the equation? How much of our city spaces could then be dedicated to other factors that have re-emerged to be crucial for our well-being that include open green spaces for recreation, allotments to grow food within the cities for better food security, and spaces for temporary health centres in the event of a national emergency. [3].

3. COVID 19: THE FALL OF URBANITY

It is undeniable that the emergence of the pandemic has exposed vulnerability of our cities, having had a massive impact on thousands of industries. As cities became the epicenter of Covid-19, the pandemic has not only exposed major ambiguities in the health center but has also shed light on socio-economic issues, governance policy shortcomings and transportation and urban design related catastrophes. Several cities have been faced with food crises resultant from an increased reliance on supermarket and hypermarket-bought products whose long supply chains were disrupted due to global lockdowns. In addition to that, lockdowns and movement restrictions resulted in hundreds of buildings being left unattended and unoccupied for months on end. There has been a plethora of articles describing a mass migration out of big cities directly in response to Covid-19 [4]. While this might be debatable, it is definite that the pandemic has not only brought forth several changes in the urban scenario but has also forever altered the way we live and interact within our cities. Most importantly, it has brought to the fore the necessity of acquiring better knowledge of not only the underlying patterns and dynamics of pandemics, but especially their effects on cities and the necessary preparation, response and adaptation measures needed [5].

4. THE POST-PANDEMIC ERA: REALIGNING OUR CITIES

Despite many cities already looking to minimize their carbon footprints due to climate adversities, the pandemic brought about a boost towards achieving sustainability in cities by forcing planners to think of alternatives to the conventional parameters of planning. Some of these changes have already become apparent as soon as the pandemic struck. For example – increase in use of bicycle as encouraged by the city during the pandemic not only led to numerous health benefits but also helped people maintain better and healthier social contact with one another while adhering to health protocols. The impact of bicycles on ecological mobility became more apparent in cities like Berlin in Germany, where setting up of two temporary bike lanes gained popularity quickly, further leading to long term policies being discussed on the subject [6]. Other large cities like New York, Beijing and Copenhagen saw further increase in bicycle usage as more and more people who were no longer obligated to commute longer distances to their work destinations and urban residents re-discovered the joy of riding a bicycle or walking by foot to basic services within proximity [2]. For planners and policymakers, there is a need for radical rethinking along with innovative measures to ensure that we plan cities that continue to function even during a pandemic. Susan Parnell in her paper "The Enabling Conditions of Post-pandemic city growth" suggested the necessity of "pandemic proofing cities", a concept in line with urban climate-proofing or localizing the United Nations Sustainable Development Goals [7]. She emphasized the need for major adjustments in the rationale, management, functioning, and power dynamics of the governments of cities to enable this. While a government cannot define an urban strategy alone, it is impossible to achieve resilient cities without a well-informed, effective government implementing the right vision with credibility and capacity at a local scale. Despite the admission of numerous flaws within our city planning, the pandemic has created an opening to shift towards a future-oriented reconfiguration of city networks, sidewalks, public transport systems, health and safety regulations, and social safety nets could now be envisioned as a post-pandemic city.

5. THE CASE STUDY CITIES – BRUSSELS, MUSCAT AND SAO PAULO

This paper re-envisions our cities with redefined driving forces. Through a literature review of journals, newspaper articles, and books, the following section premised on three cities of differing cultural, climatic, and economic urban environments presents a general image of the pandemic's impact on cities worldwide. This data is then translated into ascertainable problems common to one or more of the three case study cities. The succeeding section then presents definite solutions to counter the problems identified in the literature review.

5.1 Brussels

The capital region of Belgium, Brussels is a highly populated city with a population density of 7501 inhabitants/ km^2. There has been a historical lack of long-term spatial planning all over the country, resulting in a large spread of the population residing outside the city centers in large suburbs of sorts [8]. As in the case of several other large cities in the world, the Covid-19 pandemic pushed most workplaces to adapt teleworking operations, leading to a large portion of the community spending more time indoors. Subsequently, this resulted in people flocking towards the limited number of urban green spaces scattered across the city more often as the only respite from the stringent lockdown measures. However, such conditions also brought to light unjust accessibility options to urban green between sociodemographic groups. There was a major difference in perception of the importance of urban green between those that had private gardens, those that had access to public green spaces within close proximity, and those that were deprived of such facilities due to living in cheaper, more crammed quarters with jobs in sectors that continued to require physical presence (services, care-giving, etc.) [9]. In general, vulnerable groups were deprived of green spaces whether public or private, and were disproportionately affected by the pandemic. However, the entirety of the city benefitted from the measures in the mobility domain enabling regional walks and bicycle rides by constructing more dedicated bike lanes in the capital and extension of pedestrian areas in the historic city center. This saw a 44% rise in bike use, positively impacting the mental and physical health of city dwellers [10].

5.2 Muscat

The little port-city of Muscat, Oman was once characterized as a dense city with streetscapes oriented to the human scale, catering to the local climate. Today, Muscat has transformed to a linear city with old, poorly maintained dense city quarters on one end and sparsely located single-villa typology on the other end, leading to suburban situations and urban fringes stretching throughout the course of the city. There is a clear lack of mixed-use neighborhoods in the newer residential areas of the city, with the most dominant typology being the single villa housing. As a result of the density imbalance, the pandemic saw higher rates of infections in the closer, more crammed quarters at the start of the pandemic, while the more affluent parts of the city functioned with imminent normalcy. Due to the closure of public transportation systems and several supermarkets, social groups without private cars had limited accessibility to basic amenities and services. The city's lack of infrastructure for soft mobility such as pedestrians and bicycles only worsened the situation. Moreover, the city imposed a closure of public parks, beaches, and playgrounds to avoid large gatherings and mitigate the virus, thus resulting in people being confined to their homes with no access to green spaces for recreation, physical exercises, or any other benefits. While residents with private gardens were able to get some fresh air, the lower income groups of the city were subjected to the most consequences. Furthermore, the suburban nature of housing topped off with the boundary walls around every plot throughout the city also restricted any social life or connection to the "outside world", leading to a city that remained dormant for months. Further to this, the hypermarkets often saw an influx of buyers during opening hours due to lack of services within proximity to residential quarters, leading to further spreading of the virus.

5.3 Sao Paulo

As one of the most populous cities worldwide, the financial center of Brazil consisting of 44 million inhabitants experienced heavy reductions in the level of economic activity in response to the pandemic. This was highlighted by a reduction in the volume of vehicles circulating in the streets. As the pandemic revealed the impact of housing conditions, population density, the precariousness of sanitary and transport infrastructure, and the imminent lack of access to healthcare, the glaring social differences facilitated by the city's planning became increasingly apparent. This led to the city's government attempting to understand the production of urban spaces and their relationship with health and diseases, and the societies' response to epidemics. It was soon derived that public health and urban planning had a strong positive correlation, particularly in the case of infectious diseases. Special attention was also drawn to the relationship between rapid urbanization and ambient air pollution, as the city's vehicular lockdowns showed noticeably cleaner air [11]. This eventually gave rise to discussions within the local government to adopt stricter legislation for the emission of pollutants, develop mechanisms to encourage adoption of cleaner processes by industries and enforce sustainable, more compact neighborhoods and transportation systems by promoting fossil fuel-free transport like walking and cycling.

5.4 Relevant factors which have led to pandemic-related deficits

The table below summarizes the various issues which emerged during the pandemic, and their applicability to the three case studies.

Table 1: Relevant factors which have led to pandemic-related deficits

	Muscat	Brussels	Sao Paulo
1. Imbalanced density throughout the urban fabric with very high concentrations in some regions and very low concentrations in others	x		x
2. Rapid spread of infections in high-density spaces. This was further worsened by unsanitary conditions, air pollution, unclean water, etc.		x	x
3. Centralized urban models with amenities concentrated far away from most residential spaces leading to social groups without private transport facilities being unable to obtain basic daily goods due to closure of public transportation systems.	x	x	
4. Unequal distribution of urban green spaces, leading to large portions of the population being deprived of any contact with nature during the pandemic.	x	x	x
5. Food shortages among more vulnerable low-income groups due to heavy reliance on imported goods and little to no local food production.			x
6. Buildings left empty for months due to movement bans, lockdowns, remote working, and other measures, leading to economic implications in the real estate market.	x	x	
7. Heavy financial losses in gyms, hotels, restaurants, and other hospitality industries due to heavy reliance on indoor-based activities	x	x	x
8. Increase in mental health issues due to isolation and movement restrictions. No infrastructure to facilitate soft mobility	x		
9. Mono functional neighborhoods leading to virtually no movement during the pandemic leading to increased risk of crimes since “no eyes on the street”.	x		x
10. High influx of people flocking to centralized parks, hypermarkets and other public facilities making them breeding grounds for the virus.	x	x	x

7. ADAPTATION STRATEGIES TO CULTURE, CLIMATE AND ECONOMY

The following table sets forth a set of adaptation strategies coupled with their levels of prioritization (1 – Highest priority level, 2- Second priority level, 3 – Third priority level) to inspire a feasible approach towards city-planning and urban design following the various lessons learned from the pandemic.

Table 2: Adaptation strategy

Priority level	Strategy	Muscat	Brussels	Sao Paulo
1	Planning for a healthy population density. Revisiting extreme high- and low-density areas of the city and enforcing a feasible built area to open space ratio	x		x
1	Decentralization of public facilities, services, and amenities to ensure accessibility for all sociodemographic groups	x	x	x
1	Decentralization of healthcare facilities to reduce response time and save operational costs	x	x	x
2	Balanced juxtaposition of home and services not only to reduce car mobility but also contain epidemic spreading by limiting mass gatherings at facility sites as well as public transports to reach facility sites	x	x	x
1	Address social inequalities by ensuring accessibility to public green spaces, and local small-scale parks for all socio-demographic groups	x	x	x
1	Introduction/Expansion of bicycle lanes and pedestrian lanes to encourage shift towards soft mobility	x	x	x
2	Facilitate pedestrian movement by introducing appropriate infrastructure including shading elements to protect from sun and rain, porous ground surfaces to minimize urban heat islands in hot arid climate and absorb rainwater in tropical climate, etc.	x		x
3	Shift from universalization of cities to a more tailored approach incorporating heritage, culture, and social context into infrastructural planning	x	x	x
2	Inserting (small) neighborhood centers with basic services into the monofunctional residential areas	x		x
2	Health placed at the center of decision-making for urban life, urban planning, and public space design		x	x
3	Less focus on malls/indoor entertainment culture and development of open-air alternatives while adhering to the climatic and social context	x		
1	Encourage mixed-use building typology laid out to create positive, multi-purpose urban spaces along with proximity to essential services	x	x	
1	Facilitate local markets selling fresh produce to minimize dependence on supermarket goods and long supply chains	x		x
1	Emphasis on designing buildings that can be adapted for various functions – ensuring that the building remains active through different users and functions throughout the day	x	x	x

7. TOWARDS A NEW WORK-LIFE BALANCE

As the world opens once more, the traditional “work-home” axis has become significantly footloose with more and more companies realizing the benefits of working from home and thus reducing the physical presence required at workplaces. This in turn has minimized the need for a large proportion of the urban population to commute regularly to work, offering planners with the opportunity to envision our living patterns in new light. For starters, a post-pandemic city planned for reduced dependency on cars could not only improve overall health standards but also have positive financial implications. Urban dwellers would benefit from comparatively reduced costs when using alternative, more sustainable modes of transport like bicycles, public transport or simply walking. A rise in popularity of community based urban services and appreciation of soft mobility would be key to revolutionizing the way we see and experience cities. With minimized need to commute to work, more emphasis could be placed on investing in proximity-based needs. One such example would be the case of micro-markets created by Timmermans [12] to help relieve overcrowding in local supermarkets and ensure local accessibility to basic services within proximity. When exploring proximity-based cities, the 15-minute city concept coined by Carlos Moreno in 2016 could be investigated especially as a parameter to create happy cities of the post-pandemic era [2]. Moreover, novel digital innovations such as bike-sharing technologies could now be prioritized during the planning process, further improving livability of cities. With better proximity of basic needs, services and the option of more home offices, the post pandemic city would focus on renewed participation of citizen and residents alike, transforming the social landscapes of our cities. An actual implementation of such a vison would require the reinterpretation of existing infrastructures – for example some car-oriented infrastructure could now be returned solely to cyclists and pedestrians. More bus lanes and public transportation options would also have to be introduced, thus reducing solo travel especially in cities lacking public transportation opportunities like Muscat. Our existing cities today concentrate primarily on accessibility to opportunities rather than accessibility to basic services and amenities. This in turn is associated with job opportunities, which interestingly strongly relates to automobile usage. However, a city focused on proximity-based services and amenities would propose more inclusive building typologies such as mixed use housing models, promoting not only compactness but also drawing local traffic to improve revenue flow and job opportunities while also capitalizing on unique qualities such as a city's heritage, culture, art and education.

8. CONCLUSION: RECOMMENDATIONS FOR THE POST-PANDEMIC CITY

As planners, experts, decision makers and city dwellers, it is necessary to learn from all that the recent worldwide disasters have taught us; not only regarding the pandemic and the need for healthier cities, but also the impending climate crisis resulting in bush fires, locust swarms, floods, and hurricanes. Although many cities have already begun to steer the wheel towards more sustainable solutions, most cities are yet to develop a feasible, phase-oriented solution that can be realistically implemented. However, it would be more feasible to begin with simple approaches, like to optimally ensure cities have sufficient land reserved for recreational areas such as playgrounds, walking and bicycle lanes while achieving essential sustainability components such as proximity, diversity, density and ubiquity. Furthermore, learning from the upsurge of fossil-fuel powered vehicles in cities following reduction/closure of public transport systems during the pandemic, the post-pandemic city would have to emphasize on and encourage the use of renewable energy powered mobiles. This would have to be facilitated on an industrial level as well as the government level. Moreover, abandoned buildings of residential, commercial, and other typologies could now be seen in new light as potential adaptive reuse projects with more flexible floor plans that can cater to multiple uses as demanded by the city – such as temporary vaccination centers, exhibition spaces, healthcare buildings, residences (e.g.: for refugees), etc. The pandemic has also shone new light upon the concept of globalization and the vulnerabilities that nations have faced due to heavy reliance on imported goods, foods and medical equipment among other things. [13] Thus, the post pandemic city would refashion and encourage local supply chains and integrate several small-scale industries to encourage local production, positively influencing the local economy and the city standards in general. Overall, existing knowledge shows that the COVID-19 crisis entails an excellent opportunity for planners and policy makers to take transformative actions towards creating city models that offer regenerative solutions including green pockets, shorter distances, and far more adaptive structures to achieve cities of resilience that respond better to the current crises and alleviate our living standards.

REFERENCES

1. Lennon, M., (2021) Planning and the Post-Pandemic City, *Planning Theory & Practice*, DOI: 10.1080/14649357.2021.1960733, 2021
2. Moreno, C., Allam, Z., Chabaud, D., Gall, C. & Pratlong, F. (2021) Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. *Smart Cities* 2021, 4, 93–111. https://doi.org/10.3390/smartcities 4010006
3. Andres, L., Bryson, J.R., & Moawad, P. (2021) Temporary Urbanisms as Policy Alternatives to Enhance Health and Well-Being in the Post-Pandemic City. *Curr Envir Health Rpt 8*, pp. 167–176, https://doi.org/10.1007/s40572-021-00314-8
4. Martel, E. (2020) Are People Really Moving Out of Cities Due to the Pandemic?, *Forbes Biz Council*, Accessed 10 March 2022 at https://www.forbes.com/sites/forbesrealestatecouncil/2020/12/01/are-people-really-moving-out-of-cities-due-to-the-pandemic/?sh=6311cc356279
5. Connolly, C., Ali, S.H., Keil, R. (2009) On the relationships between COVID-19 and extended urbanization. *Dial. Hum.* Geogr, 213–216
6. District Office Berlin. Temporary Installation and Expansion of Bicycle Traffic Facilities during the Pandemic Crisis. Available online:https://www.berlin.de/ba-friedrichshain kreuzberg/aktuelles/pressemitteilungen/2020/pressemitteilung.911780.php (accessed on 5 November 2021).
7. Parnell, S. (2020) The enabling conditions of post-pandemic city government. *Environment and Planning B: Urban Analytics and City Science*, doi: 10.1177/2399808320950041
8. Poelmans, L., Rompaey, A. V. (2009) Detecting and modelling spatial patterns of urban sprawl in the Flanders-Brussels region (Belgium). *Landscape and Urban Planning*
9. da Schio, N., Phillips, A., & Fransen, K., Wolff, M., Haase, D. & Ostoić, S. K., Živojinović, I., Vuletić, D., Derks, J., Davies, C., Lafortezza, R., Roitsch, D., Winkel, G., De Vreese S. K (2021) The impact of the COVID-19 pandemic on the use of and attitudes towards urban forests and green spaces: Exploring the instigators of change in Belgium. *Urban Forestry & Urban Greening*. 65. 127305. 10.1016/j.ufug.2021.127305
10. Angiello, G., (2020) Toward greener and pandemic-proof cities: EU cities policy responses to Covid-19 outbreak. *Tema. Journal of Land Use, Mobility and Environment*, pp. 471-477. http://dx.doi.org/10.6092/1970-9870/7251
11. Gouveia, N., & Kanai, C. (2020) Pandemics, cities and Public Health. *Ambiente & Sociedade* [online]. [Accessed 10 March 2022], e0120. Available from: doi.org/10.1590/18094422 asoc20200120vu2020L3ID
12. S. Davies (2020) This is How Coronavirus Could Reshape Our Cities Forever, *World Economic Forum*, Available online: https://www.weforum.org/agenda/2020/05/coronavirus-change-cities-infrastructure/(accessed on 10 March 2022),
13. Batty, M. (2020) The Coronavirus crisis: What will the post-pandemic city look like? *Environment and Planning B: Urban Analytics and City Science*, pp. 547-552. doi:10.1177/2399808320926912

A case study: Remodelling using green remodelling certification index in Korea

Use G-SEED system to verify feasibility for green remodelling

SANG-HEE HWANG[1], SUNG-WAN KIM[1], KYUNG-HOI LEE[1] AND MYUNGKYU PARK[1]

[1]Korea Research Institute of Eco-Environmental Architecture, Republic of Korea

ABSTRACT: This study reviewed the effect of applying the criteria in Korea's Green Standard for Energy and Environmental green remodeling certification evaluation to a daycare center building remodeling. The standard presents items that need green remodeling improvement by dividing them into five areas. Selecting items in the remodeling planning stage is convenient because the assigned importance is dependent on the analysis results of the improvement of each item on the environmental impacts. In addition, since the level of performance improvement can be intuited from the overall score, whether the remodeling target level has been achieved can be determined. Simultaneously, the economic feasibility can be reviewed, confirming the usefulness of the tool.

1. INTRODUCTION

As of 2020, there were 7.2 million buildings in Korea. Among them, 2.8 million buildings were older than 30 years, accounting for more than 1/3 of the total number of buildings. Because these old buildings are designed according to insulation design standards, they are significantly inferior in energy performance, including insulation, compared to buildings that comply with recent standards. Korea's building insulation regulations were first introduced in 1979. At that time, the insulation standard for exterior walls was to install 50 mm of glass wool or polystyrene foam. Since then, this regulation has been subdivided according to building type and part, as well as region, and the regulations have been continuously improved. As of 2018, the current standard specified 225 mm of insulation on the exterior walls of apartment houses in Seoul and 155 mm on the exterior walls of general buildings. Notably, the energy performance of old buildings is three to four times worse than that of recent buildings. Therefore, improving the energy performance of buildings through remodeling is urgent and needed. The Korean government recently developed and implemented policies to promote green remodeling, such as offering financial support to improve the energy performance of old buildings. However, the effects have been marginal due to the low response from building owners.

On the other hand, green remodeling certification, which evaluates the eco-friendliness of remodeled buildings, was recently incorporated into the government's green building certification system. However, it is hard to find buildings that have been certified. Therefore, this thesis evaluates the usefulness of the certification system through a case study of green remodeling using Korea's green remodeling certification evaluation and seeks to suggest policy improvements for green remodeling.

2. GREEN REMODELING CERTIFICATION BASED ON G-SEED

The Green Standard for Energy and Environmental Design (G-SEED) is a system that was developed and is currently operated as Korea's eco-friendly building certification standard under the Green Building Support Act [1]. This system was introduced in 2002 for apartment houses. Following several revisions, the types of buildings subject to certification have been expanded, and the evaluation criteria have been supplemented. G-SEED was initially applied to new buildings, and a section for existing buildings was added in 2011. In the 2016 revision, a green remodeling section was also added. G-SEED classifies buildings by usage type and utilizes different evaluation items and standards according to the use characteristics. In addition, the evaluation criteria for green remodeling are separately regulated (Table 1). G-SEED evaluates eight specialized fields: land use, energy, environmental pollution, materials and resources, management related to water circulation, maintenance, ecological environment, and indoor environment. However, in the evaluation of green remodeling, land use and ecological environment items are excluded. A score of 75 points or more is an "excellent" grade, a score of 65 points or more is a "very good" grade, a score of 55 points or more is a "good" grade, and a score of 45 points or more is a "fair" grade; the total score is 100 points.

Table 1: Areas and items for green remodeling certification evaluation.

area	certification items	points
1. land use	not applicable certification items	0
2. energy and environmental pollution	energy performance improvement	50
	energy monitoring and maintenance support device	10
3. materials and resources	use of environmental product declaration (EPD) products	10
4. management related to water circulation	use of water-saving devices	10
5. maintenance	retention of information related to green remodeling	5
	management of green remodeling construction	5
6. ecological environment	not applicable certification items	0
7. indoor environment	indoor comfort improvement	10
	total points	100

Note : items in shaded fields are required

3. A CASE STUDY: REMODELING OF A DAYCARE CENTER

3.1 Investigation and measurement of the current state of the building

The target building is a daycare center in Jinju, a childcare facility for children under seven years old, located in the southern part of South Korea. The weather condition in Jinju was annual temperature of 13.8 ºC, the highest temperature of 33.0 ºC, the lowest temperature of -5.5 ºC., sunshine duration of 6.24 hr/day, annual precipitation of 1,736 mm in 2016. The two-story reinforced concrete building was built in 1984, which has a site area of 356 m2 and a total floor area of 304.74 m2 (Fig. 1, Fig. 2).

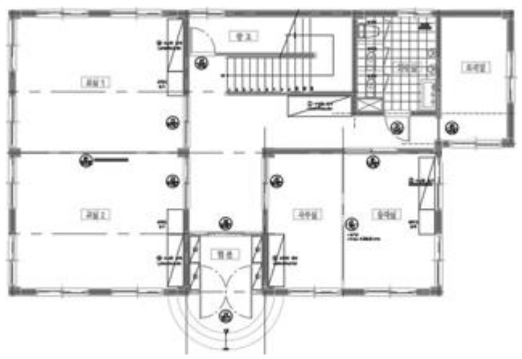


Figure 1: First-floor plan of the daycare center.

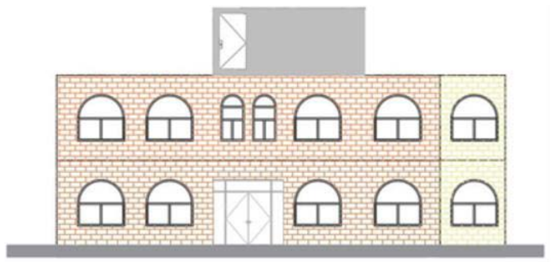


Figure 2: Front elevation of the daycare center.

Before remodeling design, the structure of the building, the interior and exterior conditions, building facilities, and the indoor environment were surveyed [2]. The survey was conducted for one month, beginning from September 2017. First, the building users were asked about their satisfaction with the residential environment through a survey. Notably, the primary users of the building are children. However, they were too young to question directly; thus, the nursery teachers participated in the survey instead. Most complaints were on cold drafts during winter as well as external noise. Moreover, there were many complaints that indoor lighting was not bright. Finish deterioration and the condition of the windows were investigated through a visual inspection and using a glass thickness gauge, respectively. The wall thermal transmittance value, airtight performance, thermal bridge, indoor air quality, indoor environment, and indoor illuminance were measured using a special measuring device (Fig. 3 and Fig. 4).

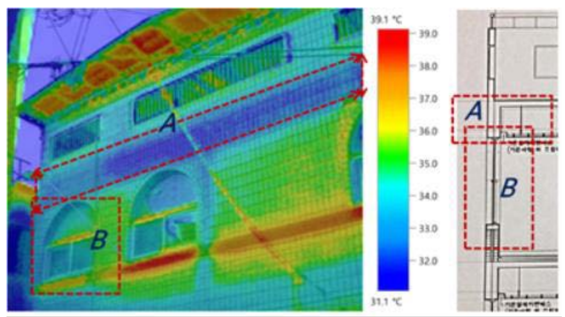


Figure 3: Detection of thermal bridges using a thermal imaging camera.

Figure 4: Locations of airtight performance and indoor environment (PMV) measurement.

The thermal transmittance of the wall and glass window were found to be 1.977 $W/m^2 \cdot K$ and 3.1 $W/m^2 \cdot K$, respectively. Korea's current standards for thermal transmittance of walls and glass windows are 0.320 $W/m^2 \cdot K$ and 1.8 $W/m^2 \cdot K$, respectively. Therefore, significant performance improvement is necessary. The airtight performance determined using the pressurization method and a blower door at 50 Pa was 5.86 times/h and significantly exceeds Korea's current requirement in the energy evaluation program of 1.5 times/h, accounting for the complaints about cold drafts. In the case building, most of the cold drafts occurred at the entrance. Therefore, performance improvement is required. The predicted mean vote (PMV) and indoor air quality met current standards. An electric heat pump (EHP) was available in each room for heating and cooling, and an oil boiler supplies hot water; both have been in use for more than 10 years. A ventilation fan was present in the cooking room for ventilation.

After the on-site survey, the energy performance of the building was evaluated via a simulation program based on the building drawings and actual measurements. The ECO2 program—used for evaluating building energy performance, developed by the Korea Institute of Construction Technology (KICT) for application in Korean contexts, and based on ISO 13790–was used to quantitatively measure the improvement in energy performance after remodeling. The energy performance simulation results showed that the annual demanded and consumed energy were 173.8 kWh/m2 and 208.9 kWh/m2, respectively. When converted to primary energy, it was 281.6 kWh/m2 (Table 2). This level of energy performance corresponds to intermediate performance when evaluated based on Korea's energy efficiency rating.

Table 2: Simulation results for the energy performance of the daycare center (unit: kWh/m2·yr).

division	heating	cooling	water heating	lighting	sum
energy demanded	102.4	23.6	24.9	22.8	173.8
energy consumed	145.6	7.6	33.0	22.8	208.9
primary energy consumed	161.5	20.8	36.5	62.8	281.6

Note: items in shaded fields are required.

3.2 Establishment of the remodeling plan

Before establishing the remodeling plan, the fundamental problems and improvement methods identified from the on-site survey and measurement were conducted and summarized as shown in Table 3. Due to the aged exterior finishing materials of the building, there was a risk of water leakage in some areas due to microcracks. In addition, there was a risk of heat loss and condensation because of the low insulation performance of the outer wall. As an improvement method, finishing the exterior wall and roof with external insulation materials was first considered. The drafts (air infiltrations) reportedly occurred at the door entrance. Therefore, replacing it with a door for excellent airtight performance is necessary. The insulation and airtight performance of the windows also need improvement. Replacing the existing fluorescent lamp with a high-performance LED lamp for the poor indoor lighting problem was considered. In addition, it is necessary to accurately set the target level, thereby improving the energy performance and indoor environment of the building by remodeling. In this case study, the target level was set to “excellent” in the G-SEED green remodeling certification, which facilitates an objective judgment of the overall remodeling performance. In addition, this facilitates quantitative predictions during the review process.

Table 3: Review proposal for items that need improvement at the daycare center and suggested improvement methods.

items	current state	improvement plan
building structure and insulation	damage on the exterior finish, water leakage, and condensation	exterior insulation and window replacement
(cold) drafts	low airtightness	replacement of entrance door and windows
noise	outside noise	replacement of entrance door and windows
illuminance	indoor low light	replacement with LED light
grades for green remodeling	a grade that does not meet the standard	excellent grade

3.3 Selection of items for improvement and establishment of target levels

To obtain an excellent grade in the green remodeling certification, the total score of the certification evaluation items in Table 1 must be 75 or higher. Identifying other items to be corrected and setting the target level for each item should be realized before this goal can be achieved, in addition to the improvement items reviewed in Table 3. Moreover, it is essential to analyze the cost effectiveness of the process. In this study, we sought to find the optimal improvement plan through quantitative analysis after selecting the items that need improvement based on the evaluation items for green remodeling in Table 1.

Among the evaluation items shown in Table 1, “energy performance improvement” had the highest points (50), which accounted for half of the total score. In the evaluation criteria, the score is based on the predicted energy-saving rate of the building. A saving rate of over 35% is 50 points, 30–35% is 40 points, 25–30% is 30 points, and 20–25% is 20 points. Because this is a required item, a saving rate of 20% or more must be achieved. The energy-saving rate is calculated as follows.

$$\text{Energy saving rate (\%)} = \frac{\text{Energy consumption before remodeling} - \text{Energy consumption after remodeling}}{\text{Energy consumption before remodeling}} \times 100 \quad (1)$$

This study set a goal to achieve an energy-saving rate of at least 30% in the initial stage. However, while reviewing the plan, the target was revised to achieve the maximum 50 points by achieving a reduction rate of 35% or more. The review results revealed that obtaining a score of 26 or higher with the other evaluation items mentioned below is difficult due to problems associated with the building, such as the condition and cost. In other words, the goal was revised to obtain a total score of 75 points, which are required to receive an excellent grade in Green Remodeling: the ultimate goal of this project.

Ten points are assigned to “energy monitoring and maintenance support device,” which requires installing a building energy measurement system (BEMS) to manage the building energy. Even though the corresponding device was not installed in the target building, the small-scale building requires an expensive system, which is costly to operate. According to the evaluation criteria, a minimum of 4 points and a maximum of 10 points are applied, depending on the level of the installed BEMS. Therefore, we aimed to obtain four points by applying the lowest-level BEMS.

The “use of environmental product declaration (EPD) products” item was placed last in the order of application because the cost of replacing existing materials with new ones is high. For “use of water-saving devices,” points are obtained according to how many of the five types of water-saving devices are used. This study was designed to obtain 6 out of 10 points by only installing water-saving faucets, showerheads, and toilets. In addition, a “waterless urinal” item can be used to earn more points. However, the cost burden should also be considered. Among the two evaluation items related to maintenance, “retention of information related to green remodeling” provides owners, managers, and users with the following five types of information related to green remodeling for building. Points are obtained depending on how many types of information are utilized.

① construction details
② instructions for operation manual and administrator
③ maintenance and repair guidelines and inspection intervals
④ contact information related to remodeling for companies and persons in charge
⑤ other information related to maintenance

All the above information was considered in this study to obtain five points. The second item related to maintenance, “management of green remodeling construction,” pertains to minimizing the deformation in the existing structure through a systematic remodeling construction plan and ensuring that the building is quickly available for use. Eight types of documents, including process plan, facility and pollution prevention management plan, construction site noise and dust prevention plan, and construction site waste treatment plan, are used, and points are allocated according to the number corresponding to this information. This study utilized more than six types of information, obtaining a total of five points.

Table 4: Predicted outcomes for green remodeling certification evaluation.

area	certification items	points	predicted scores
1. land use	not applicable certification items	-	-
2. energy and environmental pollution	improvement in energy performance	50	50
	energy monitoring and maintenance support device	10	4
3. materials and resources	use of environmental product declaration (EPD)	10	0
4. management related to water circulation	use of water-saving devices	10	6
5. maintenance	retention of information related to green remodeling	5	5
	management of green remodeling construction	5	5
6. ecological environment	not applicable certification items	-	-
7. indoor environment	indoor comfort improvement	10	6
total points		100	76

Table 5: Items that need improvement and the effect of the improvement (a draft for the improvement).

item	improvement	saving rate (%)	cost (KRW)	cost vs. improvement (KRW/kWh)	ranking
insulation	exterior wall insulation PF board 50 mm (0.020 W/m²K)	20.0	33,099,800	793,760	1
window	Low-E pair-glass window (4.19→2.1 W/m²K)	2.2	13,507,052	2,936,316	4
light	LED light (8.3→5.56 W/m²)	1.9	3,880,800	970,200	2
door	windshield replacement	1.2	2,607,395	1,133,650	3
ventilation	door and window replacement (5.86→1.46 times/h)	4.2	-	-	-
	sum	31.0	53,095,047	820,634	

Lastly, in the “indoor comfort improvement” category, points are given depending on how many of the four environmental factors—indoor thermal environment, light environment, air quality, and sound environment—have been improved and what percentage of the building area was improved. This study aimed to obtain eight points by improving the thermal environment by improving the insulation performance, light environment by replacing existing lights with LED lights, and sound environment by replacing windows and doors with high-performance products. As for air quality improvement, the existing conditions were good. Therefore, an expensive air cleaning system for further improvement was omitted due to the significant economic burden. In addition, during the subsequent review, it was concluded that the windows could not be replaced with high-performance products due to limitations in the construction budget. Therefore, the sound environment was excluded from the improvement target. The target score was lowered to six points by only improving two category types.

Table 4 shows the results of the green remodeling certification evaluation predicted by reflecting the reviewed improvement items and target level. Therefore, it will be possible to achieve an excellent grade, which is the goal of the project, by obtaining 76 points.

Table 6: Items that need improvement and the improvement effect (an alternative improvement approach).

item	improvement	saving rate (%)	cost (KRW)	cost vs. improvement (KRW/kWh)	ranking
insulation 1	exterior wall insulation PF board 50 mm (0.020 W/m²K)	20.0	33,099,800	793,760	2
insulation 2	roof exterior insulation rigid spray form 22mm (0.021 W/m²K)	11.6	3,900,000	160,494	1
light	LED light (8.3→5.56 W/m²)	1.9	3,880,800	970,200	3
door	windshield replacement	1.2	2,607,395	1,133,650	4
ventilation	door and window replacement (5.86→4.1 times/h)	1.7	-	-	-
	sum	35.1	43,487,995	592,479	

3.4 Analysis of energy-saving rate

Among the certification evaluation items for green remodeling, energy performance improvement accounts for half the total score. Therefore, in this study, this item was the most intensively analyzed. The ECO2 program was repeatedly applied to find a cost-effective optimal insulation performance. The optimal combination achieved the overall target level by changing the performance values for various factors affecting the energy performance of the building, such as wall and roof insulation, windows and doors, lighting, and boilers. Among them, boiler performance improvement was excluded during the initial review process considering cost-effectiveness.

Table 5 shows the initially planned improvement items, energy consumption improvement effect (saving rate), and cost of each item. The saving rate is the ratio of the reduced energy consumption to the annual energy consumption of 208.9 kWh/m2 of the existing building for each item. Therefore, because the saving rate (31.0%) in the sum is the total saving rate obtained when all techniques are combined, its value differs from that (29.5%) obtained by the sum of each item. Improving the five items in Table 5 resulted in the energy performance improving by 31% and 40 points being obtained from the “improvement of energy performance” item in Table 4. Because 26 points were obtained as the sum of items other than energy performance in Table 4, a new strategy for obtaining additional points should be reviewed to obtain 75 points. As mentioned above, it is difficult to obtain an additional score of nine or more by improving items other than “energy improvement” due to the state of the building; therefore, we decided to obtain additional points by improving the energy performance. To obtain more points for the same cost, a method of achieving a total saving rate of 35% or more, which involves modifying roof insulation instead of replacing windows and is the lowest cost-effective improvement in Table 5, was first reviewed. Table 6 shows the review results when applying these alternatives.

Therefore, changing “replacement with high-performance windows” greatly improved the insulation performance. The saving rate can be improved by 35.1% by reducing the annual energy consumption to 135.5 kWh/m2. However, the airtight performance was lower than the draft improvement because the window was not replaced. However, the effect of roof insulation offsets this. As shown in Table 4, the total score was 76 points when alternative improvements were applied. Therefore, an “excellent” grade has been achieved in the green remodeling certification. Interestingly, the cost of construction decreased despite the increase in performance. Therefore, we confirmed that alternatives with excellent energy performance and economic feasibility could be selected by utilizing the certification criteria of green remodeling when planning remodeling construction.

4. CONCLUSION

When establishing a green remodeling plan, it is important to reasonably set the target level for energy and environmental performance improvement. A tool for selecting the items that need optimal improvement and analyzing their effects is convenient. The green remodeling certification evaluation criteria included in Korea's G-SEED suggest items that need improvement for green remodeling in five areas. Therefore, it can be used for this purpose because importance is based on the analysis results from the impact of each item on the environment. In this study, we applied this standard to an eco-friendly remodeling project of an old building used as a daycare center and examined the corresponding effect. Selecting items in the remodeling planning stage using the list of evaluation items of the certification evaluation criteria was convenient. Because the level of performance improvement can be intuited from the overall score, it was easy to determine whether the remodeling target level was achieved. In addition, the economic feasibility could be simultaneously examined, serving as a valuable tool.

The central and local governments should promote the green remodeling certification pilot project and improve the performance of buildings using quantitative data for remodeling. In addition, a system that officially recognizes the value of a building that has received green remodeling certification would attract a lot of attention from building owners, managers, and users. Further, incentives, such as tax benefits to buildings that have received the certification, are necessary.

REFERENCES

1. Korea Institute of Construction Technology (KICT), Korea Research Institute of Eco-Environmental Architecture (KRIEA), et al., (2020), G-SEED manual.
2. LH (Korea Land & Housing Corporation), KRIEA, (2017), Jinju Saeddeul-maeul(village) green remodeling construction final report

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

ARCHITECTURE FOR HEALTH AND WELL-BEING

DAY 02
12:00 — 13:30

CHAIR
ANDREA MARTÍNEZ

PAPERS
1148 / 1294 / 1412 / 1483 / 1201 / 1220

24TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Pre- and post-COVID-19 synergies between research and practice in health and the built environment

ALTAF ENGINEER[1] SANDRA BERNAL[1]

[1] University of Arizona

ABSTRACT: Residents of the United States, even in pre-pandemic times, spent upwards of 92% of their time indoors on average.[1] The onset of the pandemic increased this time, leading to mental and physical health concerns related to one's built environment settings. This study examines how research and practice in health and the built environment (HBE) in design firms were impacted by COVID-19. It helps us understand how the pandemic impacted and potentially transformed the nature of health research in architectural practice. The first phase of this study was conducted in 2019, pre-COVID-19. The first six months of the pandemic itself, however, resulted in an increase in HBE research and activity as indicated by architecture firm websites. We, therefore, decided to conduct a post-COVID-19 second phase of the same study in 2021, to discover new synergies between HBE research and practice. In both phases, we conduct a systematic content analysis of 58 international design firms' websites and publications related to HBE. A mapping exercise then categorizes these studies into different design and research typologies and goals. Finally, it analyses the research methods and findings presented in these sources and discusses their implications for HBE-related design, professional practice, and future research studies.

KEYWORDS: COVID-19, health and wellbeing, built environment, synergies in research and practice, design industry

1. INTRODUCTION

The frequency of pandemics from diseases such as SARS, MERS, Ebola, influenza, and now COVID-19, are a rapidly growing concern. The likelihood for surges in pandemics stems from increased global travel, urbanization, changes in land use, and exploitation of the natural environment. If preventative measures are not enacted with better global preparedness, pandemics will cause irreversible damage to livelihoods and economies [1]. Past pandemics have influenced the designs of the built environment to minimize the risk of spreading infectious diseases. For example, spatial interventions are necessary to minimize infection risk via social and physical distancing and accommodate the increasing use of technology for online, remote working, and distance learning. Risk mitigation strategies such as improved ventilation strategies are widely being used to ensure safety indoors. Post COVID-19 built environment design will likely prioritize physical health and mental health, social connectedness, sustainability, and accessibility on a larger scale.

Although human-centered design as an area of design inquiry has existed for a long time [2], in recent years, design firms' approach to solutions and work processes in their publications, websites, whitepapers, and advertisements became more frequently described as being human-centric or evidence-based. Design practitioners now increasingly use evidence-based design recommendations suggested by researchers to study and create spaces that have healthy outcomes for people as indicated by the work of the AIA-ACSA Design and Health Consortium, a multi-disciplinary network to translate design and health research into practice for professionals, policy makers, and the public [3].

Evidence-based design is meant to develop prescriptive knowledge and solutions that serve to improve health outcomes and design practice. It involves decision-making, and design-making grounded in research and tested in practice [4]. The outcomes of these processes are ideally revealed in built projects, but these methodologies and processes often remain invisible due to a lack of proper documentation and dissemination to a wider audience. A systematic, analysis, therefore, is necessary to study and create an awareness of research and design processes conducted by firms invested in the field of heath and the built environment (HBE). As part of this study, we looked for pre- and post-COVID-19 methodologies and work processes as well as mentions of broader (i.e., not exclusively COVID-19-focused) human-centered designs or evidence-based solutions that emerged from post-pandemic increased research activity by a sample of design firms across the globe [5]. Professional practice trends in design and health revealed by this study demonstrate the influence, outcomes, and limitations brought about by the COVID-19 pandemic. They, however, also reveal the amount and type of HBE-related research and design activity in response to the emergency.

1.1 The COVID-19 pandemic and its impact on HBE research and practice

Residents of the United States, even in pre-pandemic times, spent upwards of 92% of their time indoors on average [5]. The onset of the pandemic has only increased this time for most, which in turn has led to mental and physical health concerns closely related to one's immediate built environment settings. In the beginning of the COVID-19 pandemic in late 2019 and early 2020, design professionals were challenged with understanding the science of Sars-Cov-2 transmission in built environments very quickly, with limited resources and research to draw from on the subject. Their primary goal became to mitigate risk and create safe, healthy environments for building occupants. As lockdowns occurred, many employees shifted to working remotely. Architecture firms began to re-evaluate the ways in which they communicate, work, and the ways in which different spaces are used and occupied. Virtual communication methods, business websites, and updates on social media sites became top priorities. Preliminary data reviewed from a small sample of architecture firms post-COVID-19, exhibited an increase in website updates on these issues within the first six months of the pandemic (December 2019 – May 2020) compared to updates and activity, pre-pandemic. Many of these communications were about HBE initiatives and projects with an increased interest in human-centered and evidence-based design processes, which typically include decision-making grounded in research and tested in practice [4]. Healthcare design also received more attention during the COVID-19 pandemic since these spaces became crowded and overwhelmed. Discussions around temporary as well as permanent healthcare or health-related design solutions became more common.

1.2 Goals of this study

This study examines the ways in which research and practice in HBE in design firms, have been impacted by COVID-19. Specifically, it evaluates this impact by delving into and comparing how practitioners conducted and disseminated research and design outcomes in the HBE field, pre- and post-COVID-19. This study, therefore, is useful not only in understanding the impact of the pandemic on the field, but also the potentially transformational impact of health-related research in architectural practice.

As part of this study, we connect design and health-focused practitioners to the identification of any HBE research and design methods that they may have used. The goal is to reveal the influence, outcomes, and limitations of these research and work processes. The study also compares the documentation of actual built projects (for e.g., images of completed projects) versus the documentation of their research and design processes. We hypothesize that several methodologies and mechanisms in HBE processes or practices are invisible to educators and researchers in academia or other fields and organizations, and industry colleagues. Research knowledge that is presumably developed for problem-solving and practice becomes limited in its influence in the HBE field if it is not documented and disseminated effectively.

An initial review of design firms' websites and publications in HBE pre-and post-COVID-19 led to the following key questions: What communication outlets or venues do design firms use to disseminate their research and design work in HBE to a wider audience, and how do they use them? What types of research and design processes related to health and the built environment did practitioners use or develop pre- and post-pandemic? Were there any actual healthy or safe built environment outcomes during this period? What are the different research focus areas in the HBE field?

3. METHODOLOGY

The first phase of this study was conducted in 2019, pre-COVID-19, with no intention of another follow-up phase. We published the results of this first phase in 2020 [6]. The first six months of the pandemic itself, however, resulted in an increase in HBE research and activity as indicated by the same sample of architecture firm websites. We, therefore, decided to conduct a post-COVID-19 second phase of the same study in 2021, to discover any new synergies between HBE research and practice at that time.

In both the pre-and post-COVID-19 phases, we analyzed the same sample of 58 architectural design firms. The selection of firms was not limited to any one country. The only inclusion criteria for selecting these firms were for them to have some form of research or design dissemination related to the HBE field.

Our research methodology consists of a systematic content analysis and mapping exercise of peer-reviewed publications, conference proceedings, white papers, and websites created and maintained by professional design firms invested in the HBE field. These sources of information were scanned for scientific research and evidence-based outcomes in design and health. This data was collected and then analyzed for pre- and post-COVID-19 impacts. With the use of an online tagging program, we collected metadata

[1] Klepeis et al. (2001).

annotations from this content from August 2019 through May 2021.

Finally, this study analyses the findings presented from these sources and discusses the potential for increasing the dissemination of future HBE-related design and research work.

4. RESULTS

We published the results of the pre-COVID-19 phase of this study in the year 2020 [6] and they will, therefore, not be presented in much detail here. In this section, we primarily present the post-COVID-19 phase results, and we compare both phases in this section as well as the discussion section that follows (section #5).

A preliminary analysis using the controlled tagging tool as part of the content analysis post-COVID-19 was done first, to check if the 58 design firms collected as part of the sample had at least one piece of evidence of an HBE-related research or design project. The results showed three main tendencies in how design firms feature their expertise in HBE: 1) their architecture and interior design portfolio, 2) expertise of their employees in HBE research fields, and 3) descriptions of HBE research and its connection to any outcomes in the form of actual built projects.

104 statements within their websites and publications of these design firms showed several different ways in which they advertised their architecture practice. Most often, they described built environment solutions with images in their portfolio or highlighted specific HBE interventions in existing and new projects. From the 58 design firms' websites and publications, the content analysis found that ten firms used three types of statements, 24 used two types, and the rest (24) used one type of statement to mention that HBE-related approaches primarily defined their architecture practice. To conceal the identity of these firms, we are not providing any specific examples of their statements here. Other statements in their websites or publications advertised their awareness of the problems related to HBE (only some of which was COVID-19 specific) primarily by citing expertise of the senior partners or their staff, or by promoting their role in projects. Fewer statements referred to other external sources or partnerships with research organizations or universities or others that increased their team expertise for an HBE-related project.

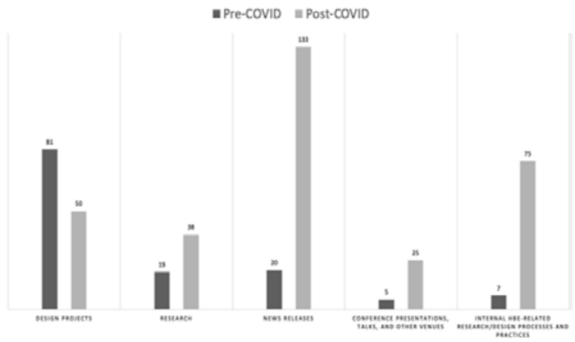
A frequency analysis was then applied to all the statements collected in multiple tagging sessions, to check if any of them could somehow assist in the grouping of firms sharing similar approaches to advertise their HBE-related practice or research processes. The Pearson correlation in Table 1 shows no significant association between problem awareness and proposed solutions by design firms. An association between firms that offer HBE solutions to sources of research (peer-reviewed, white papers, etc.), also appears to be insignificant. Similarly, a correlation between HBE-related problem awareness and any research sources also appears to be insignificant.

Table 1:
Pearson Correlations of HBE-related themes within the post-COVID-19 content analysis. Source: Authors, 2021.

Pearson Correlation		Interpretation
Problem awareness Proposed solution	-0.26	nullable correlation
Proposed solution & Sources	0.00	nullable correlation
Problem awareness & Sources	-0.01	nullable correlation

As expected, the content analysis results showed significant differences in pre-and post-COVID-19 HBE-related research and design activity in the second phase of this study. Figure 1 shows a comparison between the frequency of use of different communication outlets pre- and post-COVID-19. We see a marked increase in the amount of HBE-related research discussions in websites, news releases, conference presentations, other venues, and internal practice processes and procedures related to HBE projects. The only decrease was in the number of actual built projects as result of these processes, but this could be because many of these projects are still in progress (under design or construction).

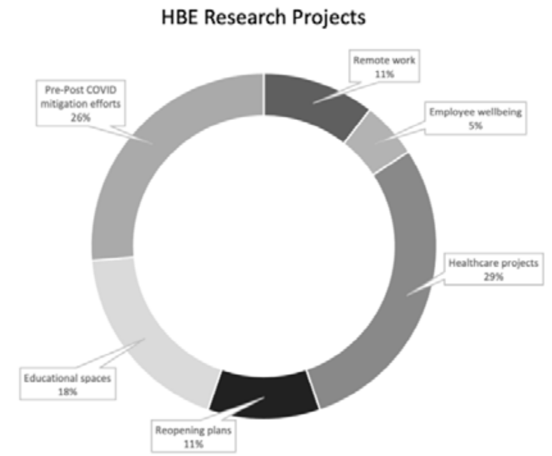
Figure 1: *Frequency of use of the outlets of communication pre- and post-COVID-19 across 58 firms. Source: Authors, 2021.*



Our content analysis also found many research topics and themes related to healthcare spaces, educational spaces, remote work, employee wellbeing, and COVID-19 mitigation. Their distribution is shown in Figure 2. Firms that mentioned designing healthy environments as one of their primary focus areas appeared to have other areas of expertise which also aligned with human-centric and evidence-based approaches to design. While the comparison of pre-and post-COVID-19 results indicate a sharp increase in HBE-related activity, design firms missed opportunities to effectively disseminate their work in scholarly venues such as journal articles, conference presentations, or proceedings on a larger scale.

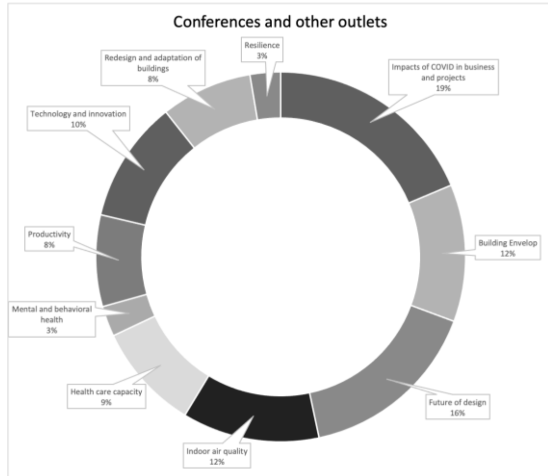
The HBE-related projects showcased in design portfolios post-COVID-19 were more diverse than before. Many projects (29%) were new healthcare projects or expansions, retrofits, or upgrades to existing health care facilities, while new or upgraded non-healthcare buildings were fewer, at 11%. Another 18% or projects were HBE-related upgrades (which included risk-mitigation measures and safety) to education spaces. 26% of projects consisted of pre- or post-COVID-19 mitigation efforts in existing buildings where their specific type was not mentioned. 11% of HBE-related efforts were concerned with remote working which included upgrades to existing technologies, working-from-home guidelines, designing temporary or permanent remote co-working spaces, or research related to health aspects of remote working. A relatively small amount of research discussions (5%) were about employee wellbeing which included design and non-design-related questions (such as exercise, adequate nutrition, outdoor activity, down-time, etc.).

Figure 2: *Frequency analysis of HBE-related research topics post-COVID-19. Source: Authors, 2021.*



8% of all the design firms studied post-COVID-19 proposed new design standards for workplaces and the creation of unconventional workspaces like pavilions, private pods, and outdoor work or dining areas with flexible or permanent partitions. 6% planned to send or sent contributions to incubators for creating collaborative opportunities and partnerships to carry out experimental projects. 6% of the firms were working on the conversion of spaces into emergency care, triage and testing facilities, or indoor or outdoor vaccination sites. Figure 3 shows the distribution of different topics covered by the design firms in conferences, presentations, live sessions in social media, and blogs post-COVID-19. It shows the extent of discussion on the impacts of COVID-19 on businesses and projects (19%), reflections on the future of design post-COVID-19 (16%), analyses, best practices, and lessons learned in the design and construction of the building envelope and indoor air quality (12% each), and contributions to technology and innovation (10%). 38% of HBE-related updates and communications intended for clients and employees on firms' websites included the mention of recommended cleaning and sanitation practices, 31% included health and safety guidelines and updates for protecting their employees, and another 31% included statements on how they would create safer environments for visitors and clients. We assume that these statements and updates, however, kept changing considerably along with new discoveries and changing scientific information related to COVID-19. The data for these results was collected in early 2021 and may therefore, not correctly represent all the current information on these firms' websites.

Figure 3: *Topics addressed by design firms in conferences, presentations, and blogs post-COVID-19. Source: Authors 2021.*



5. DISCUSSION

This study reveals the impact of the COVID-19 on HBE-related research and practice on design firms by studying their online presence and content. Although, it is limited in scope and scale, it highlights useful findings and trends for professional practice as well as future research. Mining online content from websites and other sources was optimal for this study since these venues became crucial sources of information once businesses shifted to telework and were thereafter, forced to rethink how they presented updates and work-related information. The amount of new HBE-related website activity which we found post-COVID-19 as compared to pre-COVID-19, proved this to be true. We also found increase in the showcasing of specialized methods or approaches to HBE projects, degrees of expertise, knowledge, talent, and successful projects or collaborations in the field, by design firms.

This study also found the content analysis method described earlier, to be useful and efficient for finding synergies between HBE research and practice. The pandemic crisis, in this regard, presented an opportunity to study how design firms invested in HBE showcased their project work, their research, how their decision-making was impacted by the ever-changing nature of the pandemic. We also found that the topics of discussion and HBE-related initiatives and processes, closely aligned with much of the COVID-19-related information published in scientific and mainstream media at that time.

The pandemic may have had some negative impact on businesses and operations of design firms, however, from this study, we know that the emergency pushed the design and building construction sector to re-organize and reconsider their priorities. These included not only creating healthy spaces for post-COVID-19 risk mitigation and re-entry, but also keeping their employees safe. Uncertainty about the pandemic and remote work may have also led to financial gains (e.g., saving on energy costs for keeping workplaces operational) and health benefits for employees (such as reduction in commuting stress, spending more time with families, etc.). These issues although related to HBE research and practice, are outside the scope of this study.

We found that discussions on how to prevent future pandemics went beyond sanitization and maintenance measures, to issues such as permanent increases in fresh air supply and improving indoor air quality. Further, we found content on how public spaces could be designed to be healthier with physical and social distancing, providing outdoor spaces, and so on. In this regard, professionals in the HBE field appeared to be forced to rethink and evaluate their existing design approaches.

A considerable number of discussions also focused on healthcare spaces, which were largely impacted by the pandemic. Firms which specialized in healthcare design were challenged to provide quick and effective short-term solutions, however, we found that they also invested in longer-term design thinking and research. Different building typologies in healthcare such as outdoor and indoor vaccination sites, mobile and temporary care units, and makeshift hospitals were designed and built.

The most popular communication outlets used by HBE design firms were updates and posts on their own websites. The curation of the topics helped one understand their priorities, ongoing work processes, their specializations in technology, research expertise, and other related information. The increase in website and other online venues also demonstrates an increase in the need for electronic communication as employees, clients, and other stakeholders in building projects shifted to remote work.

6. CONCLUSION

Pre- and post-pandemic trends and findings in HBE indicate that design practitioners explore different ways to showcase their research and design work along with continuing transformations in the field. Practitioners and firms increasingly refer to scientific literature in HBE, and provide access to their solutions, contributions, sources, and outcomes.

Design firms, however, may require an increase in the scope of their project deliverables to find more synergies in HBE research and practice, which is difficult due to limitations in cost, time, and required expertise. To counter these limitations, there is a need to break down and simplify research processes, form partnerships with other researchers in the field, and market them better as a valuable part of design projects. Importantly, HBE processes and methodologies must be documented and shared effectively among the larger research community to create better synergies in the field.

Design firms, just like other organizations, adapted quickly, and underwent changes in their approaches and processes in HBE from 2019-2021 (and this trend continues as the pandemic wears on). Global epidemics and pandemics may become more frequent, and in response design firms in the HBE field will continue finding new ways to function, optimize their processes, and increase their efficiency. While these firms may have unique areas of expertise and human-centric and evidence-based approaches to design and research, they may be missing opportunities to disseminate this knowledge by not documenting their work in scholarly journal articles, white papers, conference presentations, proceedings, or other suitable venues on a larger scale. These trends, however, may change with the increase in specialization and the areas of expertise of different professionals directly or indirectly connected to the design industry, and interdisciplinary work. HBE must not be considered a specialized field of practice and become a common denominator in all design projects instead. This will also help create healthier built environments, reduce disease transmission, and better prepare our society for the next pandemic.

7. LIMITATIONS OF THIS STUDY

This study is limited in scope and scale. We highly recommend a larger, follow-up study which includes surveys and interviews of design practice leaders, employees at different levels, clients, and other stakeholders. With the ever-changing nature of COVID-19, more comprehensive, follow-up studies may also discover more types of effective HBE research and design methodologies and synergies between them.

ACKNOWLEDGEMENTS

We acknowledge the contribution of the nonprofit organization Hypothes.is in making its controlled tagging technologies available as open access for the topic modeling analysis.

REFERENCES

1. Oppenheim, B., Gallivan, M., Madhav, N. K., Brown, N., Serhiyenko, V., Wolfe, N. D., & Ayscue, P (2019). *Assessing global preparedness for the next pandemic: development and application of an epidemic preparedness index*. BMJ global health, *4*(1), e001157.
2. Crandall, M. (2019). Human-centered design and community engagement. *National Civic Review*, *108*(1), 40-51.
3. Design & Health Research Consortium. (n.d.). Retrieved from https://www.aia.org/resources/78646-design--health-research-consortium
4. Van Aken, J. E., & Romme, A. G. L. (2012). A design science approach to evidence-based management. *The Oxford handbook of evidence-based management*, 43-57.
5. Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., ... & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology, 11*(3), 231-252.
6. Engineer, A. (2020). New synergies between research, education, and practice for health and wellbeing outcomes in the built environment. *EAAE-ARCC International Conference Proceedings*, Valencia, Spain.

One size does not fit all
Questions and insights to develop new occupant-centered well-being and comfort models

PAULINA WEGERTSEDER-MARTINEZ[1]

[1] Departamento Diseño y Teoría de la Arquitectura, Universidad del Bío-Bío, Chile.

ABSTRACT: Current comfort models, within the current standards, cover the needs of the general population, based on a neutral acceptance under static conditions. People seek comfort, and inside a building, this goal drives certain responses or actions (adjusting thermostats, opening windows, turning off lights, etc.) to satisfy their personal needs in a given space and time. Needs and actions are dynamic and vary for each individual, and as a result of this and other reasons, office buildings regulated under optimal comfort criteria, do not fully satisfy the occupants' needs. This article is part of a project that seeks to contribute towards developing a new comfort and well-being model to provide flexibility and adaptability for the environmental conditions of shared office spaces, considering occupant-centered stimuli and dynamic requirements. This section focuses on developing a perception survey, whose sole focus is not just environmental comfort, but rather includes health and well-being criteria that arise from a revision of well-being certifications in buildings, like WELL and Fitwel, and from an interdisciplinary scientific review. The survey shows that it is not enough to just seek satisfaction, as other questions that delve deeper into the criteria show the incoherence of the same user or discrepancies between users of the same space.
KEYWORDS: Survey, Well-being, Comfort Models, Open Plan Offices, Post-occupancy Evaluation Energy, Comfort

1. INTRODUCTION

Office design has prioritized the use of single shared spaces by groups of workers since 1930, when artificial lighting and HVAC systems appeared which, although they allowed extending design layouts, led to the centralization of comfort [1]. Nowadays, we continue using this open plan layout in offices, where different people cohabit under almost the same generalized environmental conditions, even though the requirements, characteristics and/or preferences vary among people. Hence, the need for an architectural design that provides flexibility is needed, but do the comfort models that regulate buildings contain these characteristics in their criteria?

Current comfort models, under the current standards, cover the needs of the general population, based on a neutral acceptance of static conditions (80% satisfied in the case of the Predictive Mean Vote-PMV, and a temperature range that considers the satisfaction of only healthy adults in the case of ASHRAE). People seek comfort, and inside a building, this goal drives given responses or actions (adjusting the thermostat, opening the window, turning off the lights, etc.) to satisfy their personal needs in a given space and time ("right here, right now"). The needs and actions are dynamic and variable for each person, and because of this and other reasons, office buildings regulated and set up by standards that are governed under optimal comfort criteria, do not manage to satisfy the comfort requirements of their occupants [2-4].

Office occupants seek immediate comfort, without considering the positive and/or negative long-term impacts this may have on their health and well-being. For example, recent research has determined the benefits daylight has and how light intensity can affect our circadian cycle, affecting our physical, physiological and/or psychological state for better or for worse [5, 6]. Poor sleep quality can accentuate depression, high blood pressure, and other biological and functional alterations [7]. And it is precisely in office buildings with extensively shared surfaces where these light differences are seen, meaning that some workers are more affected regarding the reception of natural light, making artificial lighting necessary, and thus bringing a higher likelihood of harm for their health, despite having reached the light comfort needed to perform their tasks.

This article is part of a research project that seeks to contribute to the development of a new comfort and well-being model, which provides flexibility and adaptability of the environmental conditions of shared office spaces, considering occupant-centered dynamic requirements and stimuli. In particular, this publication goes further into the goal of developing a perception survey, whose focus is not just on environmental comfort, but rather that includes health and well-being criteria, which arise from a revision of well-being certifications for buildings, such as WELL and Fitwel, and from an interdisciplinary scientific review.

2. MATERIALS AND METHODS
2.1 Survey development and testing

Currently, most of the surveys applied to get to know occupant perception focus on IEQ criteria, with some general satisfaction considerations, but they contain an evaluation that is not holistic enough, i.e., one that includes other health and well-being indicators. The WELL Building Standard® certification system, which appeared in 2014 and which proposes an innovative approach focused on strategies of the well-being of the user, considers surveys with a more comprehensive vision to be applied one year after the certification. However, these are must be paid, and in the 10 approved surveys [8], there are discrepancies in the approaches and priorities, without even presenting the same criteria.

Therefore, the goal is to develop a survey that shows the differences in perception regarding comfort, health, well-being, and productivity, among people in shared and private offices, considering criteria that do not only fall within thermal, light, acoustic, and air quality objectives but rather that represent a comprehensive nature and that analyze the estimation of relationships between variables, revealing the factors that cause said differences between occupants. It is also important that the tool can be applied in air-conditioned buildings under the current standards, and without exclusive considerations of energy efficiency and/or with "green certification".

2.1.1 Definition of the content

To define the area and parameters the survey covers, a state-of-the-art review was made regarding three aspects: scientific articles on comfort, well-being, or health in the built environment surveys; surveys validated and applied for certification systems; and, studies that determine which strategies in office buildings cause dissatisfaction for people, whether in the physical, mental and/or social sphere.

Four main areas have been identified (Table 1), which coincide with the content of other surveys [9-12], but unlike these, its definitions and perceptions have a more holistic nature in a social and economic context that is pertinent to the South American reality, and it does not just consider "tangible" aspects of the building's design, but ones that are empirically related with the well-being of the occupants in office buildings with varied occupation types.

Table 1:
Definition of the survey content

Domain	Item	Sub Item
Occupant Profile		Age, Gender, Type of Work, Type of Shift, Time in the Office, Density of People, Seniority Control options of Indoor Environmental Conditions.
Comfort at Work	Thermal Comfort	Thermal satisfaction when it is hot/cold outside
		Description of the temperature when it is hot/cold outside
		Factors that affect thermal satisfaction
		When the temperature becomes a problem
	Acoustic Comfort	Satisfaction with the noise level
		Factors that affect acoustic satisfaction
	Lighting	Satisfaction with the lighting
		Factors that affect lighting satisfaction
		Daylight
	Indoor Air Quality	IAQ Satisfaction
		Factors that affect IAQ satisfaction
	Workspace	Privacy, safety, cleanliness, external window, layout, interior design
		Factors that affect satisfaction with the workspace
	Ergonomics	Satisfaction with the comfort of the furniture
		Factors that affect satisfaction with the comfort of the furniture
	Services and Design in the Building	General design, Resting Space, Socialization, Safety, Cleanliness, Connectivity, Public Transportation, Interior Design
Health and Wellbeing	Health	Perception of physical and mental health, and physical activity Frequency in which SBS symptoms, mental health, and sleep disorders, are felt. Options to improve physical activity
	Support for personal well-being	The balance between personal life and work, optimism, being close to people, feeling comfortable
	Nature	Type of view Connection with nature
	Nutrition	Drinking water
		Healthy food
Productivity	Personal productivity	Influence of environmental conditions when it is hot/cold outside
		Possibility for development
		Reasons that affect productivity
	Absenteeism Reasons	

One of the hypotheses that allowed defining the criteria that would be included in each domain, was that the people who manifest having control about changing the environmental conditions or use offices that are not shared, tend to feel more satisfied in terms of "comfort in the workplace".

When asking about the personal control of the physical environment which office occupants may or may not have, it is key to connect other positive or negative manifestations of personal satisfaction with the work environment and to start some inquiries and conjectures about implications on health and well-being. [13, 14] indicate that personal control is considered as an important reason for people to "*forgive*" certain weaknesses or poor building performance, and according to [15], people who live in naturally ventilated buildings have the same ability. But this control can be key in affecting the way others feel. Authors such as [16] state that personal decisions to adjust the temperature in an office, directly affect the comfort of other occupants, who may not share the same preferences. On the contrary, here it is suggested that those who have limited or no control of the indoor environment, or who share offices, tend to manifest a lower satisfaction in terms of comfort. The premise that gender differences lead to differences in satisfaction levels of the physical setting, and the interaction with air-conditioning systems [17, 18], is also included.

Regarding the domains of health, well-being, and productivity, here it is suggested that the greatest impact on a better or worse result depends on the occupation of the space, that is to say, whether many people share the office, they have no option to personalize the space, the furniture cannot be adjusted, nature is not seen through the window, and/or the food options are deficient and not very healthy.

2.1.2 Survey development

Each area has different items and related sub-items that are rated in two ways: multiple-choice, and on a 7-level Likert scale. In addition, a general question is added at the end to obtain additional comments about their workplace or the building in general. Although the 7-point scale was kept throughout the survey, the options on the extremes vary depending on the question. For example, in the case of satisfaction, the scale varies from "generally unsatisfied" to "generally satisfied", while, in individual health perception questions, this ranges from "very bad" to "very good". The proposed tool does not just ask generally about satisfaction and personal perceptions, but rather each item has questions that allow knowing why there is more or less satisfaction, why there is a better or worse perceived health, what causes absenteeism, etc. It is for this reason, that questions such as "Which of these factors affect your thermal satisfaction in your workspace when it is cold outside?" were used.

For these answers, the state-of-the-art of the influential factors for low comfort, poor health, or low well-being was revised, both from the bibliography and from domestic studies that detect shortcomings in buildings that determine a lower satisfaction, health issues, absenteeism, among others.

Once the survey was made, the key questions and those not previously validated were chosen to be subjected to an expert review. 10 experts from different countries (Costa Rica, Denmark, Spain, Argentina, the USA, Belgium, and Chile) took part, to address a broader spectrum of socio-cultural realities, despite all of them having lived in Chile for at least 6 months. Starting from this review, adjustments were made to the survey, which included eliminating some answer options and some questions altogether. Another relevant change was differentiating between hot and cold seasons with regards to the comfort questions, and the logical order of some answers.

Once the survey was adjusted, a pilot test was run in a real work context, in an office building with different workspace typologies.

2.1 Implementation of the pilot test

In Chile, each region has 18 Ministerial Secretariats, which are normally found in separate buildings with little built surface considering the number of officials these hold. It is for this reason that the Housing and Urbanism building (Fig. 1, 2) was chosen, located in the city of Concepción (36°46'S latitude and 73°03'W longitude). According to the Köppen classification, Concepción has a Csb2 climate, where temperatures are normally below the acceptable comfort range. Therefore, heating demands predominate almost all year round.

Because of Covid-19, when the survey was applied the occupants were not all present, which is why they were surveyed electronically through their bosses, hence the higher success in the participation [19]. The survey was applied to 75 people, receiving 53 responses.

Figure 1:
Office building chosen as a case study

Figure 2:
One of the offices where the survey was applied

The goal was to validate the application and coherence of the survey designed in this research, as it must allow knowing the personal perception regarding comfort, health, well-being, and productivity of the people in their workspaces, as well as the reasons behind these perceptions, whether these come from the building design, their surroundings, the use of strategies, and personal control, among others.

This allowed suitably defining the main lines of evaluation for the surveys, to get to know the relationships between areas and to understand the influence and dependence between the variables asked about.

3. RESULTS

Most of the people surveyed spent between 76 and 100% of their shift sat at their work station, in shared open-plan offices without partitions, where 90% are less than 2.5m from a window, this despite only 40% stating they have enough daylight to not use artificial lighting. 45% state they can open or close curtains and/or blinds and almost half of them have the option to flip switches to light the entire office, affecting the environmental conditions of others. Despite the relationship between alterations of the circadian rhythm and the use of artificial light, 85% indicate that sleeping problems range from moderate to none.

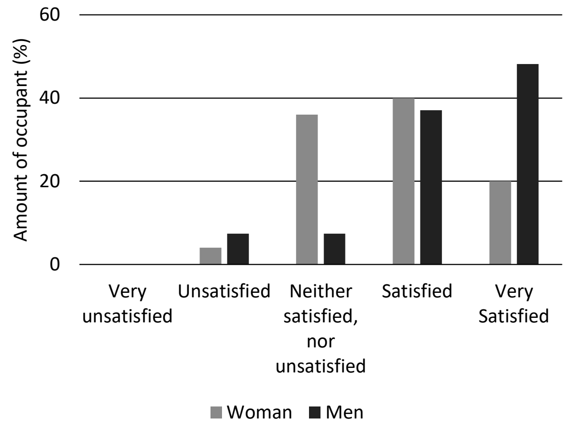
Almost 50% of the people say they are satisfied with the temperature in summer, and 60% in winter. Despite this, they state that the HVAC system does not respond quickly enough, which leads to 1/3 of the answers indicating that temperature is a common issue in the mornings (< 11 am). 60% are not satisfied with the acoustic comfort and most attribute it to outside noise with windows open or closed, along with people talking nearby. Concerning IAQ, 74% are satisfied, which is why the fact that 30% consider that "the freshness varies during the day" may contribute to this perception.

As for personal well-being, most stated that they felt supported, optimistic, close to others, but the trend falls when being asked about "whether they like the building". Feeling down or sad is a symptom for at least 50%, while the same number did not feel happy even one day a week. In terms of health symptoms, headaches and dry eyes were the most common issues. The perception for "nourishment" tends to be poor, as most answered that healthy eating options are outside the building and are costly and that the institution does not provide a space for eating and/or preparing food. Almost 70% can see other buildings and parking lots from their window, and the same percentage felt it was very important to feel a connection with nature. Contradictions are seen regarding ergonomics: 68% are satisfied with the comfort of the furniture, but 40% indicate that the chair is uncomfortable and that they cannot adjust their monitor.

Regarding productivity, most state they often are productive, and that they can do their work correctly, although they say they are distracted by activity nearby and the lack of acoustic privacy. The reasons behind absenteeism are stress, illness, and care for family members.

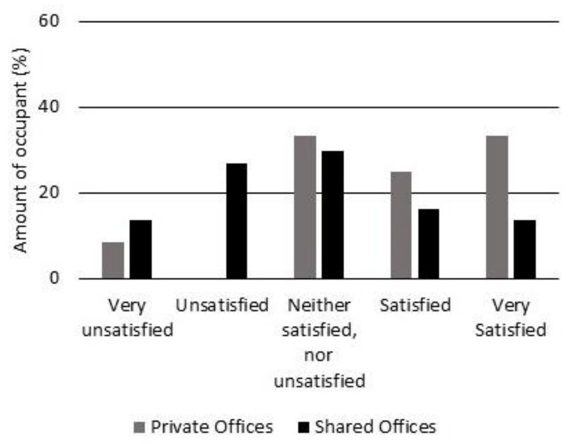
On differentiating by gender, few differences are seen regarding thermal, light, and acoustic satisfaction, unlike what has happened in other research [17, 18]. The same happens in the answers for furniture comfort and the taste of drinking water. Greater differences are seen with IAQ satisfaction, where females are neutral and satisfied, while males are either "satisfied" or "very satisfied" (Fig. 3).

Figure 3:
IAQ satisfaction, differentiated by gender



Although most of the people work in shared offices, on differentiating the type of place, not all the results seen are equal to the general trend. In the acoustic satisfaction aspect, for example, those who were very unsatisfied in shared offices almost triple when compared to people in private offices (Fig. 4).

Figure 4:
Acoustic satisfaction differentiated by shared and private offices



It was seen that some questions could not reveal the degree of control over environmental conditions or the options for this, the reason why this was adjusted and included explicitly in Dimension 1, where they describe their profile and the characteristics of the office. This to conclude, regarding the hypothesis that providing the user with the capacity to control the physical environment, where they can individually choose which indoor environmental parameter to adjust, will have a significant effect on their tolerance regarding comfort, meaning that this and the satisfaction increase, as has been previously stated [20, 21].

4. DISCUSSION OF FINDINGS

The pilot survey was really useful to adjust the questions that must be made for the end goal of the whole study, which considers the survey as just another input. The aim is to complement these answers with the behavior people have upon giving them the option to adjust their personal thermal and lighting conditions in their workplace. It has been seen [15, 22] that people tend to answer surveys in one way, but their actions and/or habits do not always match the theoretical answers. Thus, in this way, the actions that the occupants perform could be compared with their written answers.

The survey was designed to demonstrate that the preferences among people who share an office tend to be diverse, and thus require opportunities that allow personally adjusting their environmental, ergonomic, food conditions, etc. The opportunities to experiment and extend the temporary "excursions" outside the comfort zone, limited as acceptable, for example, allow an increase of comfort, as the occupant can acclimatize on feeling these dynamic temperatures as acceptable and/or pleasant [23].

It is sought to reveal background information that shows that "population"-based thermal comfort models, both the PMV/PPD and Adaptive Comfort, predict a mean response for a group of people, but have a low prediction power at an individual level [24-26]. In addition, knowing the type of work, and the time at the desk allows having a context if there is movement during the day, whose short-term temperature fluctuations affect the thermal comfort of the occupants [27].

Contradictions seen in answers regarding ergonomic aspects, for example, show that the survey allows understanding certain reasons that affect people's health (physical, in this case), and thus go further into changes that can be made to not just reach immediate comfort (here and now) that affects productivity, but that contribute in the mid and long term for their health and well-being.

The questions do not just intend to know satisfaction in different office setups, but allow revealing facts that are not included in other surveys, which end with findings on general performance aspects, but not on actual causes.

4. CONCLUSIONS

This article outlines the need to develop and use occupant consultations tools that do not just cover IEQ criteria, but that consider health and well-being matters. Well-being levels in an office will depend on how harmonious the relationship is between "personal preferences", "design performance" and "productivity". As such, a tool was designed that does not just show the satisfaction in different aspects, but that reveals the positive and negative stimuli that are affecting the comfort, well-being, health, and productivity of people that share spaces designed for a standard person for better or for worse, without intra- and inter-individual considerations.

People are rarely aware of how much they are affected in health terms on acting to benefit immediate comfort. The survey shows that it is not enough to know satisfaction levels, as the other questions are diverse in content about the built environment parameters that affect people, they show incoherence with the same user and uncover discrepancies among users that share the same space.

On seeing the answers obtained, a future action was proposed of making specific interviews, to better understand some situations by focusing on the occupant, being able to include aspects related to medical and work history, among others, and thus, calibrating results to generate new comfort models that do consider people as different and not as an average.

ACKNOWLEDGEMENTS

This work was supported by the Chilean National Scientific and Technology Development Fund (Fondo Nacional de Desarrollo Científico y Tecnológico), FONDECYT, research grant N° 11200667.

REFERENCES

1. MacCormac, R. (1992). The dignity of office. The Architectural Review, 190(1143): p. 76–82.
2. Geng, Y., Ji, W., Wang, Z., Lin, B., and Zhu, Y. (2019). A review of operating performance in green buildings: Energy use, indoor environmental quality and occupant satisfaction. Energy and Buildings, 183: p. 500–514.
3. Lee, J., Wargocki, P., Chan, Y., Chen, L., and Tham, K. (2019). Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings. Indoor Air, 29(1): p. 112–129.
4. Altomonte, S., Schiavon, S., Kent, M., and Brager, G. (2019). Indoor environmental quality and occupant satisfaction in green-certified buildings. Building Research and Information, 47(3): p. 255–274.
5. Aries, M., Aarts, M., and Van Hoof, J. (2015). Daylight and health: A review of the evidence and consequences for the built environment. Lighting Research and Technology, 47(1): p. 6–27.
6. Brainard, G., Hanifin, J., Greeson, J., Byrne, B., Glickman, G., Gerner, E., and Rollag, M. (2001). Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. Journal of Neuroscience, 21(16): p. 6405–6412.
7. Dinges, D. (2006). The state of sleep deprivation: From functional biology to functional consequences. Sleep Medicine Reviews, 10(5): p. 303–305.
8. IWBI. Standard WELL V2. [Online], Available at: https://v2.wellcertified.com/v/en/overview [10 May 2021]
9. Graham, L., Parkinson, T., and Schiavon, S. (2021). Lessons learned from 20 years of CBE's occupant surveys. Buildings and Cities, 2(1): p. 166–184.
10. Giampaoletti, M., Pistore, L., Zapata, G., Pablo, J., and Goycoolea, F. (2020). Monitoring and Post-Occupancy Evaluation of a regenerative indoor environment. In W. Lollini, R.; Pasut (Ed.), RESTORE: Rethinking Sustainability TOwards a Regenerative Economy (pp. 1–49)
11. Candido, C., Kim, J., De Dear, R., and Thomas, L. (2016). BOSSA: A multidimensional post-occupancy evaluation tool. Building Research and Information, 44(2): p. 214–228
12. Bluyssen, P. M., Aries, M., and van Dommelen, P. (2011). Comfort of workers in office buildings: The European HOPE project. Building and Environment, 46(1): p. 280–288
13. Gou, Z., Prasad, D., and Siu-Yu Lau, S. (2013). Are green buildings more satisfactory and comfortable? Habitat International, 39: p. 156–161
14. Brager, G. S., and De Dear, R. J. (1998). Thermal adaptation in the built environment: A literature review. Energy and Buildings, 27(1): p. 83–96.
15. Deuble, M. P., and de Dear, R. J. (2014). Is it hot in here or is it just me? Validating the post-occupancy evaluation. Intelligent Buildings International, 6(2): p. 112–134.
16. Shahzad, S., Calautit, J., Calautit, K., Hughes, B., and Aquino, A. (2018). Advanced personal comfort system (APCS) for the workplace: A review and case study. Energy & Buildings, 173: p. 689–709.
17. Sun, W., Cheong, K., and Melikov, A. K. (2012). Subjective study of thermal acceptability of novel enhanced displacement ventilation system and implication of occupants' personal control. Building and Environment, 57: p. 49–57
18. Kogawa, Y., Nobe, T., and Onga, A. (2007). Practical Investigation of Cool Chair in Warm Offices. Proceedings of Clima 2007 WellBeing Indoors, 2–7
19. Baird, G., and Dykes, C. (2012). The potential for the use of the occupants' comments in the analysis and prediction of building performance. Buildings, 2(1): p. 33–47.
20. Frontczak, M., and Wargocki, P. (2011). Literature survey on how different factors influence human comfort in indoor environments. Building and Environment, 46(4): p. 922–937.
21. Clausen, G., and Wyon, D. P. (2008). The combined effects of many different indoor environmental factors on acceptability and office work performance. HVAC and R Research, 14(1): p. 103–113.
22. Engelen, L., and Held, F. (2019). Understanding the office: Using ecological momentary assessment to measure activities, posture, social interactions, mood, and work performance at the workplace. Buildings, 9(2): p. 54
23. van Marken Lichtenbelt, W., Hanssen, M., Pallubinsky, H., Kingma, B., and Schellen, L. (2017). Healthy excursions outside the thermal comfort zone. Building Research and Information, 45(7): p. 819–827
24. Kim, J., Schiavon, S., and Brager, G. (2018). Personal comfort models – A new paradigm in thermal comfort for occupant-centric environmental control. Building and Environment, 132(January), 114–124.
25. Zhang, H., Arens, E., and Zhai, Y. (2015). A review of the corrective power of personal comfort systems in non-neutral ambient environments. Building and Environment, 91: p. 15–41.
26. Parkinson, T., and De Dear, R. (2015). Thermal pleasure in built environments: Physiology of alliesthesia. Building Research and Information, 43(3): p. 288–301.
27. Vellei, M., and Le Dréau, J. (2019). A novel model for evaluating dynamic thermal comfort under demand response events. Building and Environment, 160(March): 106215.

PLEA 2022 SANTIAGO
Will Cities Survive?

Adapting the workplace to the new reality in Mexico City

DANIEL IBARRA FLORES [1]

[1] Grupo Girault, Mexico City, Mexico.

ABSTRACT: In the context of the pandemic caused by SARS-COV 2 virus, the feasibility to achieve at least 4ACH in a workplace to diminish contagion risk was proven by passive means; despite of it, a hybrid ventilation system was proposed, integrating mechanical injection and passive ventilation, achieving at least 12ACH; in addition passive strategies were integrated such as exposed thermal mass enhancing night flush effectiveness and shading devices were proposed on the façade increasing thermal comfort from 60% to 99.7% eliminating the need for curtains to control glare and un wanted solar radiation, increasing the UDI factor from 58% to 68%.
KEYWORDS: Natural Ventilation, Covid, Passive office, air pollution, comfort

1. INTRODUCTION

To facilitate the safe return to activities due to the pandemic caused by the SARS-COV 2 virus, we have to reshaped the way we conceive our indoor environments, making imperative the adaptation of the workspace into the new reality; to avoid contagions, we must achieve adequate air quality. To guarantee the well-being and health of its occupants, health specialists warn that to decrease the risk of contagions or disease intensity, enclosed spaces must facilitate air renewal and comply with at least the 4 air changes per hour (4 ACH) established in the international standards for working environments.

As an ideal scenario, natural ventilation can be enabled in the working environments to accomplish the ACH desired. However, in Mexico City there are other factors that must be taken under consideration when aspiring to achieve ventilation by passive means, such as noise and poor air quality. Air pollution has been the main reason in the past decades to discourage building owners and tenants of going for natural ventilated spaces.

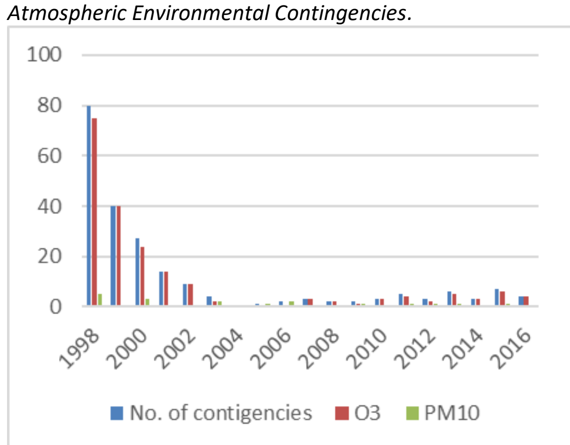
The present analysis begins from the assumption that well-implemented natural ventilation is healthier and more energy-efficient than the use of HAVC systems, which by renewing the air, the filters used are ineffective in containing the virus. Exploring the transformation of an enclosed office building in Mexico City, towards a healthy indoor environment that contemplates not only air renewal, but also the unwanted consequences that natural ventilation could cause in work spaces, such as excessive noise, pollution induction and thermal discomfort.

2. AIR POLLUTION AND VENTILATION

Despite Mexico City mild climate, air pollution has been the main reason for developers and building owners not to opt for natural ventilation to achieve comfort and air renovation in office buildings.

However, data shows that air pollution has been dropping dramatically since the 90´s after the implementation of some environmental policies. The main pollutant that has triggered environmental contingencies for the past 20 years has been O3, suggesting that if natural ventilation wants to be implemented, O3 must be analysed further.

Figure 1:
Atmospheric Environmental Contingencies.

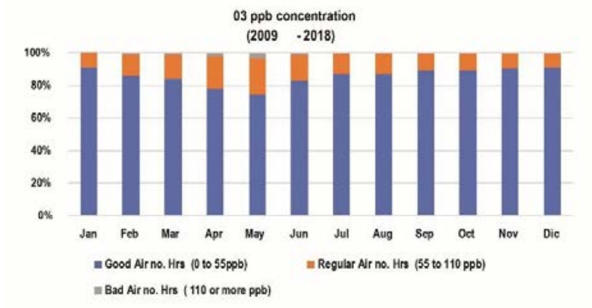


Note: Environmental contingencies record in Mexico City, from 1998 to 2016. [4]

Ozone being the main air pollutant trigger of the atmospheric environmental contingencies in the city was explored further in other to create a natural ventilation schedule which procures safe air quality (O3 below 55ppm) [1].

Data from the past 10 years was gathered and the trend was analysed, as shown on figure 4 good air quality is considered between 0 and 55ppm, regular air quality from 55 to 110ppm and bad when levels of 03exceed 110ppm; figure 6 represent the percentage of time (hours) that the air was classified under each category during the period studied (2009-2018). Data shows how good air quality its more likely for most of the time, "regular" and "bad" air its most likely to happen during the hot and dry season (February – May) decreasing after the rainy season begins.

Figure 2:
O3 PPB Concentration (2009 – 2018).

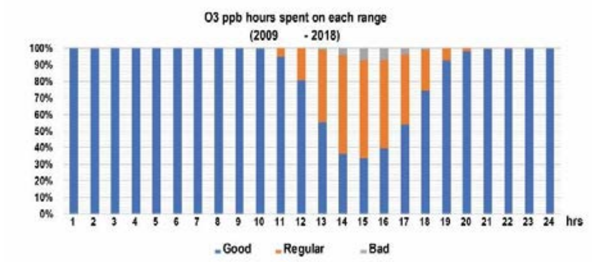


Note: Monthly average percentage of Ozone concentration "ppb" air classification, Good (0-55ppb), Regular (55-110ppb) and Bad (110 or more) Sources: after [4].

O3 distribution tends to be higher during daytime when solar radiation is present, and the air temperature increases. It is lower when relative humidity is higher, usually at night and during the rainy season. It reaches its maximum levels during the hot and dry season when cooling is most needed [4].

However, after analysing the O3ppm hourly during the 10-year period (2009 to 2018) (Fig.3), data shows that when "regular" air quality happens its between 11am and 8pm and "bad" air between 1pm and 4pm, although the probability for the air been classified as good during the same time is higher. This data could help to create an annual natural ventilation schedule for always good air (100%), disabling ventilation from 11am to 8 pm (fig.3). Meaning that night ventilation is a suitable strategy for night flush as ventilation is enabled without compromising the interior air quality.

Figure 3:
O3 ppb hours spent on each range



Note: Monthly average percentage of Ozone concentration "ppb" air classification, Good (0-55ppb), Regular (55-110ppb) and Bad (110 or more) Sources: after [4].

2.1 Ventilation Schedule

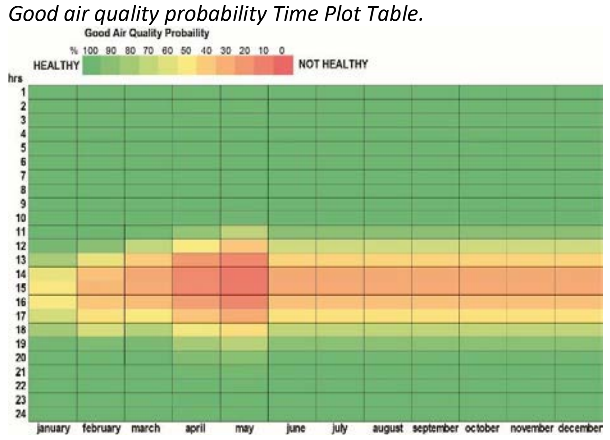
O3 was explored further in other to create a natural ventilation schedule which procures clean and fresh air (O3 below 55ppm) [.1], to counteract the "polluted air" misperception which has encouraged mechanical ventilation and cooling.

Data from the past 10 years was gathered and the trend was analysed in order to create an accurate schedule, the data was divided for each month and a table was created to guide natural ventilation (Table 1). The schedule for 90% or more chances for always "good" air ventilation is described as followed:

- January – February, from: 19 to 12
- March, from: 19 to 11
- April – May: 20 to 10
- June – December: 19 to 11

Data shows how good air quality its more likely for most of the time, "regular" and "bad" air condition its most likely to happen during the hot and dry season (February – May) decreasing after the rainy season begins. Suggesting that it is possible to encourage natural ventilation, if the schedule is respected.

Table 1:
Good air quality probability Time Plot Table.



Note: Ventilation schedule, using a colour scale to illustrate the probability of air complying the good air classification (O3 0-55ppb). Sources: after [4].

As a preliminary conclusion it is recommended to use the table as a guide for the time and period of the year for when its most likely to have regular or good air conditions before ventilating. The previous suggests that it is possible to encourage natural ventilation, if the schedule is respected.

3. DESIGN APLICATION

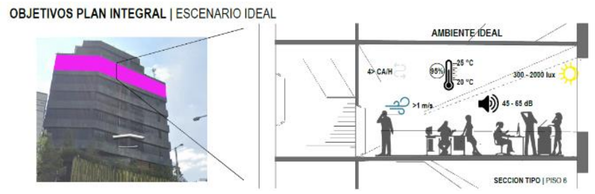
A thermodynamic model was created using Energy Plus and Open Studio with ladybug tools. Simulating the possible natural ventilation strategies that could be applied in the building to achieve the minimum desired air changes per hour (4 ach) to achieve a healthy environment; contemplating the pros and cons of each one of them, considering practical and economic feasibility.

3.1 IDEAL SCENARIO

To achieve an integrated proposal, the effect of the ventilation implemented was evaluated on the thermal and acoustic comfort in in parallel, to stablish a goal for the design proposal an "ideal" work scenario was created (fig. 4) that would consider the following factors:

- Acoustic
  - o Avoid Street and highway noise
- Thermal Comfort
  - o Air Temperature
  - o Radiant temperature
  - o Operative Temperature comfort range (20-25 ° C) depending on the season of the year this range could be modified.
- Air
  - o Health: 4 or more ach
  - o Speed: Not greater than 1.5m / s
  - o Quality: Avoid air pollution (Ozone, PM10, PM2.5)
- Daylight
  - o Between 300 and 2000 lux
- Materials
  - Thermal, acoustic, VOCs free

Figure 4:
Ideal scenario.



Note: Representative section diagram of the ideal scenario within the studied office. Cross section project area.

3.1 Base Case

In order to measure the results of the different strategies to be analysed, the situation of the building was measured and simulated to stablish a base case.

The office building is located at a crossroads, one of which is a highly transited highway; it has 7 floors with approximately 350m2. In terms of ventilation and energy use, it has an enclosed scenario with no natural ventilation of HAVC system; the main construction set consists in concrete slabs with gypsum panels as partitions, carpets and fixed double glancing windows with a window to floor ratio of 50%.

In summary, the current scenario or base case, does not meet the basic conditions of indoor environment quality, only 0.1 ach were achieved, 39% of the time during working hours the comfort range (25 to 26 ° C) was exceeded, useful daylight (UDI) reaches 68% of the year with open shitters, given the incidence of direct solar radiation on the windows due to the building orientation, occupants tend to use the shitters during the morning, reducing UDI to 58%, decibels were measured during working hours testing the acoustics, an adequate range between 45 and 65 was measured this could be attributed to fixed double glass windows and absorbent materials such as carpet.

Figure 5:
Pre-intervention scenario or base case.

Note: Representative diagram of the Base Case or pre-intervention scenario of the office. Cross section project area.

3.2. Natural Ventilation

The first tested strategy in order of relevance was the natural ventilation, just by making some of the windows operable with openings equivalent to 8% of the façade gate, the desired objective of at least 4 ach was achieved, according to the simulations carried out, the previous outcome happens after adapting the windows on the façade intermittently a 40 cm high vent in the lower part of the window; if so, it would be achieved an average from 6.5 to 10.9 ach. This solution creates new problems, as shown in figure 3, after opening a vent towards the outside, air tightness is lost and acoustic levels arises, expecting a decibel increase caused by the noise from the road to at least 80 decibels.

Parallelly as the air inlet faces directly the highway and the street, an increase in pollutants result of combustion is expected, in conjunction with intermittent air speed greater than 1m/s which would cause the office papers to fly away. In contrast the average hours above the maximum comfort range would drop from 39% to 10% approximately; however, the undesired consequences of the previous proposal mean that the occupants would close the windows, nullifying the positive effect of air renewals and the increase in thermal comfort.

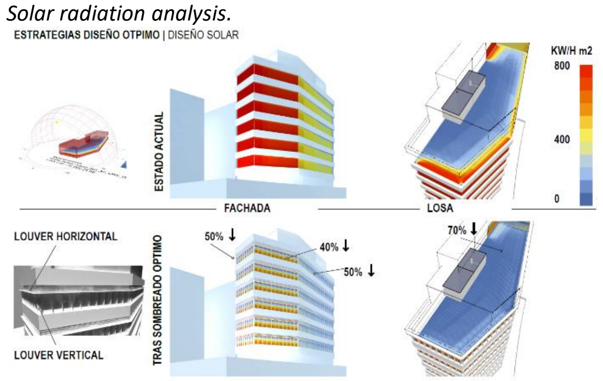
Figure 6:
Window opening natural ventilation scenario

Note: Representative diagram of the desired (air renewal) and unwanted consequences (noise and air pollution) of the operable simple ventilation in the office. Cross section project area.

3.3 Integral Facade

After analyzing some of the parallel consequences of natural ventilation described above, an integral façade was developed to face these negative implications in parallel to achieve viability. The location of the vent was moved to the top of the window to reduce the wind speed on the work surface and take advantage of the thermal advantages of the "stake effect". After this movement, an optimal shading study was carried out to take advantage of the opening of the ventilation as an element in the facade as a shading device, reducing solar radiation in the windows by 40% and 50% depending on the orientation and up to 70% less on the interior of the slab, as can be seen on figure 7.

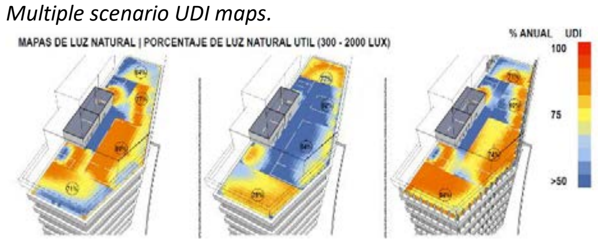
Figure 7:
Solar radiation analysis.



Note: Solar radiation analysis on the facade and interior floor slab, before(above) and after(below) elements of optimal shading.

The effect of shading devices (louvers and lateral fins) on useful natural light was analyzed, finding that the interior shading devices or curtains could be dispensed after achieving an increase and even distribution of Useful Daylight Illuminance (UDI) of around 80% in all the working area, as shown on figure 8.

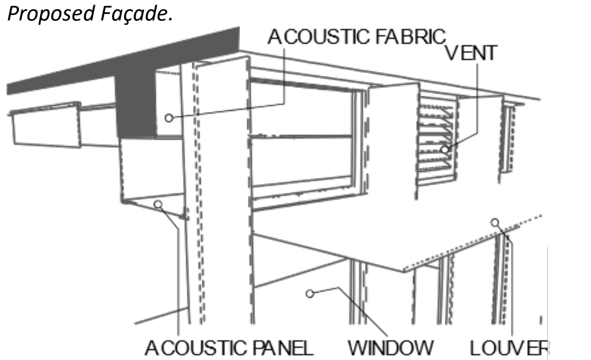
Figure 8:
Multiple scenario UDI maps.



Note: Comparative UDI annual percentage maps for the different working areas on the 6th floor. On the left the map of the base case, in the centre of the base case with closed curtains and on the right the proposed scenario after shading devices on the facade.

The horizontal louver, conceived as a shading element prior to the ventilation, also has an acoustic connotation, it is proposed that it extends 80 centimeters long from the window and has an upward inclination of 30% this with the intention of acting also as an acoustic barrier, the benefit has been tested and measured in residential buildings in Hong Kong, documenting a reduction of up to 10 db. In addition, acoustic panels are recommended on the opening gap to absorb the incoming noise inside immediately after the air vent or inlet. (fig. 9)

Figure 9:
Proposed Façade.



Note: Representative façade section showing the elements proposed for the integral façade.

Finally, in comparison to the previous scenario, the effect of the shading devices on thermal comfort in conjunction with the natural ventilation in the upper part was measured, resulting in a decrease on the overheating percentage of the interior space by 3 and 8% depending on the space. The ach remained between 6.5 and 10.9.

3.4 Integral Design Proposal

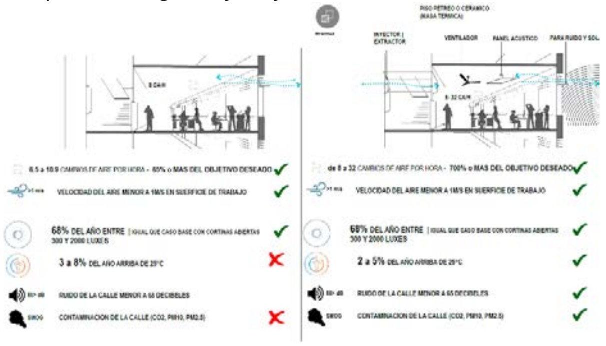
The proposal consists of two possible scenarios, one that would work as passive and the other as active. The passive scenario contemplates the aforementioned, integrating an integral façade which addresses most of the unwanted consequences of natural ventilation, however, by using the front of the building that faces the highway and the street as air inlet, there is still occasional entry of pollutants as the opening is fixed.

The proposal intends to generate an interior environment with positive pressure, in order to convert the vents of the south, east and north façade into air extraction, inducing the west façade that is not exposed to the street or road as a point of air injection by active means using a mechanical injection system incorporating air filters. Thus, a better and more consistent air renovation and quality is expected inside the space; in combination with the replacement of floor materials such as carpet with marble will merge with the thermal mass of the building slab, enhancing the effect of night cooling, increasing the thermal comfort of the space.

As for the operation of the air injection system, it is recommended to follow the ventilation schedule shown on table 1, activating the fan during the pollution picks, when outdoor air quality is classified as bad or regular, mostly between 1 and 4 pm.

Figure 10 shows a comparative scheme of the two final proposed scenarios, in the passive scenario the parameters described in point 2.4 are reached in the proposed scenario, an air renewal of between 8 to 32 CA / h would be achieved, the same levels of useful daylight (68%), a thermal comfort of up to 99.7% would be achieved if a constant speed of 1m / s was achieved during heat peaks, acoustic levels not higher than 65dB and finally an environment without Combustion residue pollutants.

Figure 10:
Comparative diagram of the final scenarios.

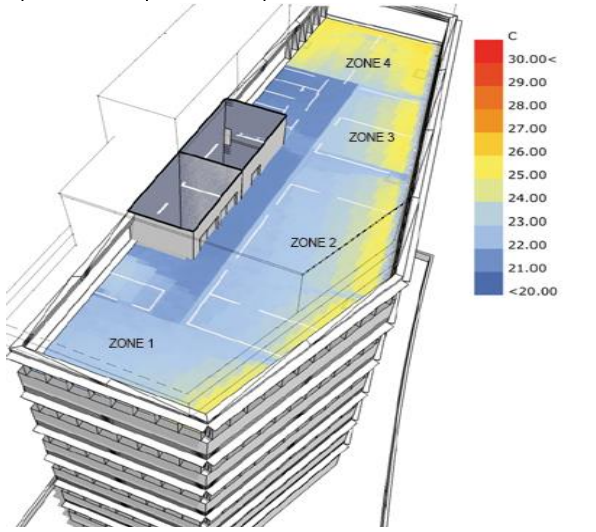


Note: Comparative schematic section between the passive scenario (left) and the proposed final scenario (right). Displaying from top to bottom, air renewal, air velocity, UDI, comfort percentage, noise and air pollution.

3.5 Thermal Comfort

The ideal scenario proved to be within the comfort range for almost the whole year, if the strategies were applied correctly, it is estimated that 99.7% of the year would reach temperatures within the comfort range inside the workspaces, as an active element the air injector that would facilitate night-time cooling and for the extremely hot weeks expected during April and May, an individual desktop fan is suggested to ensure air movement of 1m/s directly over the occupants. (Fig.11)

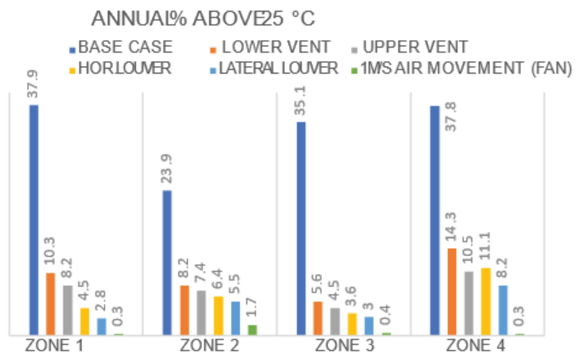
Figure 11:
Operative Temperature map.



Note: Schematic floor plan, mapping expected indoor operative temperature after the integral design proposal.

If so, during a typical week it is estimated 100% of the time within the comfort range, as shown in the thermal comfort map in section and plan in figure 8, a stable and practically uniform temperature is achieved throughout the workspace of 22°C rising to 24°C in areas close to the windows. Figure 12 shows the effect that each of the strategies and design elements had on thermal comfort.

Figure 12:
Annual hours OPT % above 25°C.



Note: Comparative charts, showing the annual hours percent of the operative temperature above 25°C on the analysed zones after implementing the design strategies.

3.6 Materials and General Design Elements

The materials suggested for the interior meet thermal, acoustic and well-being needs, in that they follow cleanliness criteria and the accumulation of viruses or bacteria.

- Change carpets for marble
- Replace the acoustic benefits of the carpets, with acoustic absorption panels on the ceiling, such as those suggested in the section of elements(fig.9)
- Solar control, horizontal and vertical louvers for acoustic rebound purposes and blocking of direct solar radiation.
- Acoustic membrane immediately ventilated.
- Low consumption air injector / extractor.

4. IMPLEMENTATION

The first phase that was implemented of the design proposal was the natural ventilation strategy, enabling fresh air to enter into the office, parallelly the acoustic membrane and panel were installed as an acoustic ventilation box (fig.12). Finally, the carpet floor was removed, exposing the thermal mass of the concrete slab.

Figure 12:
Natural ventilation acoustic box.

Note: Natural ventilation acoustic box installation, enabling fresh air entry while diminishing the exterior excessive noise.

5. POST OCCUPATIONAL EVALUATION

After the first phase was implemented, a post occupational evaluation was performed, measuring the decibel levels inside the office, the air pollution trend and thermal comfort.

Acoustic performance was evaluated measuring during a typical day the decibel levels using simple tools data sowed fluctuating levels, ranging between 55 to 65, some atypical picks of around 80db were detected as due to the heavy traffic on the highway. Users argue that as the carpeting floor was removed, acoustics tend to be worst than before, never the less no discomfort was expressed.

Simple air quality measurements were taken, using "Flow" a datalogger by Plume Labs. Data was gathered for more than 6 months, and no evidence of combustion gases were detected, suggesting that despite the proximity to the highway, air quality was not compromised. On daily basis VOC´s were the most predominant, picking when cleaning products were used. PM10 and PM2.5 diminished after the carpet was removed.

Thermal comfort was evaluated performing a survey to the workspace users, most of them expressed to have experience cold during summer (rainy season), but during the hot season during spring, no overheating was reported, were as before the intervention overheating was constantly reported.

6. CONCLUSION

After applying the strategies described, the feasibility to achieve at least 4ACH in a workplace to diminish contagion risk was proven by passive means; despite of it, a hybrid ventilation system is recommended, integrating mechanical injection and passive ventilation, to achieve at least 12ACH; in addition passive strategies were integrated such as exposed thermal mass enhancing night flush effectiveness and shading devices were proposed on the façade increasing thermal comfort from 60% to 99.7% eliminating the need for curtains to control glare and un wanted solar radiation, increasing the UDI factor from 58% to 68%.

Data is still being gathered and analysed from the post occupational analysis to suggest further improvements.

ACKNOWLEDGEMENTS

The previous analysis and design implementation wouldn't have been possible without the trust and enthusiasm of everyone at Grupo Girault, particularly Felipe Girault, to whom I wish to manifest my gratitude.

REFERENCES

1. Aire.cdmx.gob.mx (2019) Difusión del Gobierno de la Ciudad de México. [online] Available at: http://www.aire.cdmx.gob.mx/descargas/monitoreo/normatividad/NADF-009-AIRE-2017.pdf [Accessed 15 Feb. 2019].
2. Ibarra, D. (2018), Passive Design for Multiple-Use Buildings in Mexico Hot and Dry Climate, MArch Dissertation, Architectural Association School of Architecture, London.
3. Molina, L. (2009). Air quality, weather and climate in Mexico City. WMO, [online] (Bulletin 58), pp.49-51. Available at: https://public.wmo.int/en/bulletin/air-quality-weather-and-climate-mexico-city [Accessed 9 Apr. 2017].
4. Aire.df.gob.mx. (2020) Dirección de Monitoreo Atmosférico. [online] Available at: http://www.aire.df.gob.mx [Accessed 20 Apr. 2020].

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

PLEA 2022 SANTIAGO
Will Cities Survive?

Evaluation of ventilation rates in residential and non-residential spaces during occupancy using carbon dioxide concentrations

IGNACIO CARRASCO[1], CONSTANZA MOLINA[1]

[1]Escuela de Construcción Civil, Pontificia Universidad Católica de Chile, Santiago, Chile

ABSTRACT: Over the last few decades, concerns regarding air quality within buildings have increased, particularly in Europe and the United States. Although it is possible to know the ventilation rate by design, the actual values (during the occupation) usually remain unknown. We measured CO_2 *concentrations in 40 occupied rooms of three types of buildings (residences, workplaces, and classrooms) during the 2021 winter in Santiago de Chile. Two methods were applied to estimate the ventilation rates: the Decay rate and the Steady State. Results were analyzed by group and method to show variability and disparity. Results show a moderate agreement between methods. They also show a significant difference between houses and other building typologies—none of the residential buildings complied with the national or international standard for minimum ventilation rates. Conversely, 78% of workplaces meet the minimum recommendation, and 55% meet the minimum recommendation against COVID-19. Finally, 91% of the evaluated classrooms satisfactorily meet the international standard, but only 9% of them meet the minimum recommendation against COVID-19. This study suggests that an increase in ventilation rates might be required to achieve acceptable indoor air quality and reduce the risk of airborne transmission.*

KEYWORDS: Ventilation, COVID-19, Buildings, CO_2 *concentrations*

1. INTRODUCTION

During the last decades, concern has increased regarding indoor air quality in buildings, particularly in Europe and the United States. Moreover, in March 2020, ventilation rates in working and living environments gained greater importance due to the global pandemic caused by SARS-CoV-2, and were identified as a key factor in reducing the risk of infection to this, and other, diseases that can be transmitted by aerosols.

Very little is known about the indoor air quality in Chilean buildings. It is necessary to state the ventilation rate in rooms at the design stage of a project, but the actual ventilation during occupancy remains generally unknown and unchecked. Some guidance on how much ventilation is needed has been established by national and international technical groups, such as [1-4]. Their requirements for determining ventilation rates typically depend on the number of occupants, the room area, and the building type. A failure to deliver the correct amount of fresh air into the building would risk deteriorating the air quality needed for diluting contaminants, keeping occupants comfortable and healthy, and providing sufficient oxygen for stoichiometric combustion.

Given the current pandemic, and possible implications of this on the future, the need arises to know *what are the ventilation rates in Chilean buildings? Do these ventilation rates comply with current regulations or guidelines?* This paper answers these questions by estimating ventilation rates in buildings that are expected to have the most significant impact on the health of the population due to the time spent in them: (i) residential buildings, (ii) workplaces, and (iii) classrooms.

Other studies have evaluated ventilation rates (VR) in Portugal [5], in USA classrooms [6], and in Serbia [7]. They all show that VRs can be up to 49% below the design rate.

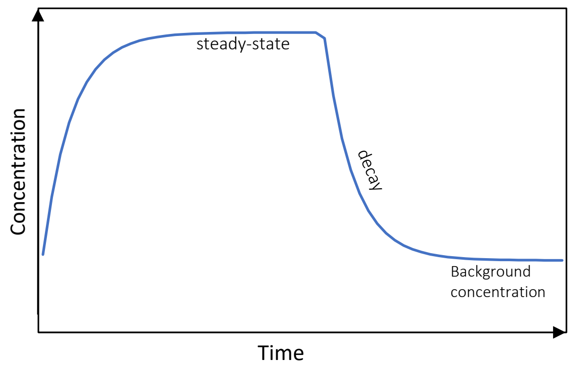
The indoor CO_2 concentration has been used as an indicator of per capita ventilation for many years [8]. It is worth noting that CO2 concentrations are not used to control indoor air quality but rather as an indicator of compliance with a required ventilation rate. This study measured CO_2 concentrations in 40 naturally ventilated buildings (20 residences, 9 workplaces, and 11 classrooms) located in Santiago de Chile during the 2021 winter season and when used under SARS-CoV-2 restrictions designed to limit transmission.

2. THEORY

Methods for calculating ventilation rates

The CO_2 concentration in an occupied room, given steady conditions, increases above the ambient concentration to an upper *steady-state* concentration. When the occupants leave the room, the CO_2 concentration decays back to the ambient concentration, which is also assumed to be steady; see Figure 1. The time taken to reach both steady-state concentrations is a function of the space volume. A mass balance equation is used to estimate the ventilation rates using measured CO2 concentrations. This is applied in two situations: (i) during the *steady-state* phase, after the mass of the tracer gas generated in the room has balanced with the mass coming into and leaving the room, and the concentrations reach the maximum, and (ii) during the *decay* phase, once the sources have been eliminated and the concentration starts to decrease [6].

Figure 1:
Typical tracer gas concentrations over time with steady-state and decay phases.



2.1 Steady-State.

A ventilation rate can be estimated from the steady state CO_2 concentration; see Figure 1. People continuously emit carbon dioxide into a room at a rate that is dependent on their sex, age, body mass, and activity. These rates are generally assumed to apply to an entire population, which increases uncertainty in them [8]. The effect of this variability on the predictions has been explored previously in [9], showing that mean emission rates can vary by 20% between demographics, especially when the occupants are children. Nevertheless, this study does not account for these uncertainties and uses representative values when needed.

A mass balance equation is used to estimate ventilation rates of a room by the Steady State method:

$$Q_o\left[\frac{m^3}{h}\right] = \frac{G\left[\frac{mg}{h}\right]}{(C_{in,ss} - C_{out})[mg/m^3]} \qquad (1)$$

where, Q_o is the outdoor airflow rate that includes ventilation and infiltration, G is the sum of $\boldsymbol{CO_2}$ generation rates of the occupants, $C_{(in,ss)}$ is the Steady State indoor CO_2 concentration, and C_{out} is the outdoor CO_2 concentration. This method assumes that the sole source of CO_2 is from the occupants, and that any air entering from adjoining spaces has a CO_2 concentration equal to the ambient concentration.

The CO_2 generation rate (G) of a person is determined following [10]:

$$G = (RQ \times BMR \times Met \times 0.000569) \times 3600\left[\frac{L}{s}\right] \qquad (2)$$

where, *RQ* is the ratio of the volumetric rate at which CO_2 is produced to the rate at which oxygen is consumed, known as the *respiratory quotient*, and is assumed to be 0.85 [10], *BMR* is the basal metabolic rate of the person, the essential energy a person requires to sustain life, determined following the Harris-Benedict's equation [11] that depends on body height and mass, and *Met* is the dimensionless metabolic rate that describes the ratio of a person's energy demand required to complete a specific physical activity relative to their BMR.

CO_2 concentrations are generally given in standards in units of parts per million (ppm) (µL of CO_2 per L of air), so they are converted to a mass ratio assuming 1.94 mg/m^3 per ppm, where

$$(C_{in,ss} - C_{out})[ppm] \times 1,94\left[\frac{mg}{m^3}/ppm\right] = (C_{in,ss} - C_{out})\left[\frac{mg}{m^3}\right] \qquad (3)$$

where, $C_{in,ss}$-C_{out} (ppm) is the difference between indoor and outdoor concentrations, known as the *excess* concentration, at Steady-State conditions. Finally, the ventilation rate is normalized by the number of occupants, resulting in airflow *per capita* (in L/s/p or m^3/s per person).

2.2 Decay Method

The ventilation rate can be estimated from the decay of CO_2; see Figure 1.

$$C(t) = (C_0 - C_r)e^{-at} + C_r \qquad (4)$$

$$a = -\frac{1}{t}\,ln\left(\frac{C_t - C_r}{C_0 - C_r}\right) \qquad (5)$$

where, *C(t)* [ppm] is the concentration at time t[h]; C_0 is the initial concentration (at t=0); C_r is the concentration of the replaced air; and *a* is the ventilation rate in air changes per hour (h^{-1}), or ACH. Finally, ACH is converted to a volume flow rate with units of L/s and L/s per person.

3. METHODS

3.1. Characterization of ventilation rates

We carried out *in-situ* measurements to characterize ventilation rates using *Aranet4* sensors. These sensors measure and record up to two weeks of CO_2 concentrations (± 50 ppm), relative humidity (± 3%), air temperature (± 0,4°C), and atmospheric pressure (± 0,001 atm). Here, the sensor was set to record mean averaged data every 2 min.

The decay and the steady-state methods were applied to estimate the ventilation rates using equations (1) to (5). The method was chosen according to the room conditions, and its occupancy status. Measurements were carried out during and after occupation in 40 different rooms in three types of buildings (see Section 1). Data on occupancy times, number of people, room dimensions, and people's weight and heights were collected for each case. In the residences, the monitor was placed in the bedrooms during sleeping and left to measure after waking, when possible.

The decay method requires the time-resolved data of indoor concentrations measured in the rooms; see right-hand side of Figure 1. The best linear fit to the logarithm of the difference between indoor and outdoor concentration over time was obtained for each case. The slope of this fitted line corresponds to the mean ventilation rates over that period. The goodness of fitness of the data was evaluated and considered satisfactory for a coefficient of determination ($\boldsymbol{R^2}$) greater than 0.8, indicating a *robust* association between the model and the empirical data, following the recommendation of [12].

Results were compared against ASHRAE 62 standard of 7 L/s per person, the ASHRAE's recommendation of 20L/s per person or more to minimize SARS-CoV-2 infections, and the minimum of 0.5 h^{-1} suggested by [13].

Finally, the impact of excluding the furniture volume from the air volume on the results was tested to find whether there is a significant difference, and so should be part of the protocol.

3.2. Statistical analyses

3.2.1. Comparison between building typologies

Data are summarized by building type (residential, workplaces, and classrooms) using descriptive statistics to compare and test variability between and within these groups.

First, the Shapiro-Wilk test is applied to test the normality of each dataset, the integrity of the measured data, and to choose the appropriate statistical test. For normal distributions, the means are compared using the Student's t-test to determine if there is a significant difference between them. The Mann-Whitney non-parametric test is applied for those that differ from normality.

The magnitude of the difference between groups, known as the effect size, is analyzed using Cohen's *d*, and classified following [12]: (i) ≤0.41 is *small*, (ii) ≤1.15 is *moderate* or (iii) ≤2.7 is *high*.

3.2.2. Comparison between methods

A similar analysis is carried out to determine the difference between the two methods. First, a Shapiro-Wilk test is applied to each dataset to test normality. The means are then compared using the *Student's t*-test to determine if a significant difference between them exists or the medians are compared using the Mann-Whitney test when distributions are not normally distributed.

The strength of the association, or the magnitude of the effect, is determined following [12] and using Pearson's estimate for comparing two or more variables. Accordingly, a *small*, *moderate,* or *strong* association is determined for a maximum value of 0.2, 0.5, or 0.8 for Pearson's *r*, respectively.

4. RESULTS AND DISCUSSION

4.1 Ventilation rates

Table 1 summarizes the ventilation rates obtained during the campaign. In all cases using the decay method R^2 values were larger than 0.8. The results show great variability in the three types of buildings, reflecting their physical characteristics and occupancies. In addition, the results obtained from these typologies vary significantly in their mean value (μ), and in their variance, indicated by coefficients of variation (Cv) of 42% for residential buildings, compared to 108% for workplaces, and 51% for classrooms.

4.2 Comparison between building types

The results also show a significant difference between ventilation rates in residences and both workplaces and between residences and classrooms, U=4, ($p < .05$); see Figure 2. Conversely, it is not possible to find a significant difference between workplaces and classrooms (p = 0.079). Despite this, the magnitude of the effect shows a *small* difference between workplaces and classrooms (d = 0.59) and between residences and workplaces (Cohen's *d* of 0.89), and a *moderate* difference between residences and classrooms (d = 1.79). It should be noted that the occupancy in residences was for one or two persons at the measuring time.

Figure 2:
Ventilation rates per capita (L/s/p) by building typology (both methods).

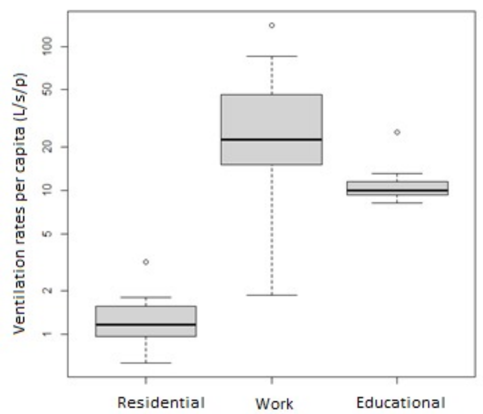


Table 1:
Ventilation rates per person (L/s/p) determined the decay and steady-state methods and by building typologies.

	Residential	Working spaces	Classrooms
n	20	9	11
Minimum	0.63	1.88	1.60
Percentile 5%, $\boldsymbol{P_5}$	0.75	2.56	4.03
Median, $\boldsymbol{M_{ed}}$	1.17	22.56	16.36
Mean, μ	1.31	41.73	14.93
95% percentile, $\boldsymbol{P_{95}}$	1.87	118.82	24.19
Maximum	3.17	140.90	25.48
Standard deviation, σ	0.55	45.19	7.62
Coefficient of variance, $\boldsymbol{C_v}$ [nd]	0.42	1.08	0.51

Note: [nd]: non-dimensional.

Table 2 shows the results obtained using the decay method. The population mean of ACH for residencesis estimated to be between 0.18 and 0.29 h^{-1}, 2.6 to 4.48 h^{-1} for workplaces, and 2.39 to 3.97 h^{-1} for classrooms, with 90% certainty; see 90% C.I in Table 2. It is worth mentioning that these ventilation rates were only measured after occupation, and with windows and doors closed. Thus, they can be considered representative of the infiltration rate as there was no ventilation.

Table 2:
Ventilation rates as air changes per hour ACH (h^{-1}) by the decay method.

	Residential	Working spaces	Classrooms
n	12	9	11
Minimum	0.06	0.18	0.36
Percentile 5%, $\boldsymbol{P_5}$	0.09	0.21	0.92
Median, $\boldsymbol{M_{ed}}$	0.22	1.81	3.31
Mean, μ	0.24	3.54	3.18
95% percentile, $\boldsymbol{P_{95}}$	0.51	9.90	5.77
Maximum	0.69	11.27	7.49
Standard deviation, σ	0.17	3.78	1.80
Coefficient of variance, $\boldsymbol{C_v}$ [nd]	0.69	1.07	0.57
Confidence interval, (90%)CI	0,24 ± 24%	3,54 ± 28%	3,18 ± 25%

Only one of the residential rooms met the recommended minimum ventilation rates of 0.5 h^{-1} and 7 L/s per person. Although occupant behavior was not included in the analyses, it is acknowledged that the human factor may play a significant role in keeping this parameter under healthy and acceptable levels [14]. This is because the campaign was carried out during the winter, and so occupants may have preferred to keep windows closed to save energy and/or preserve their thermal comfort. Future data on occupant behavior and their understanding of, and interaction with, ventilation systems is needed to fill these knowledge gaps.

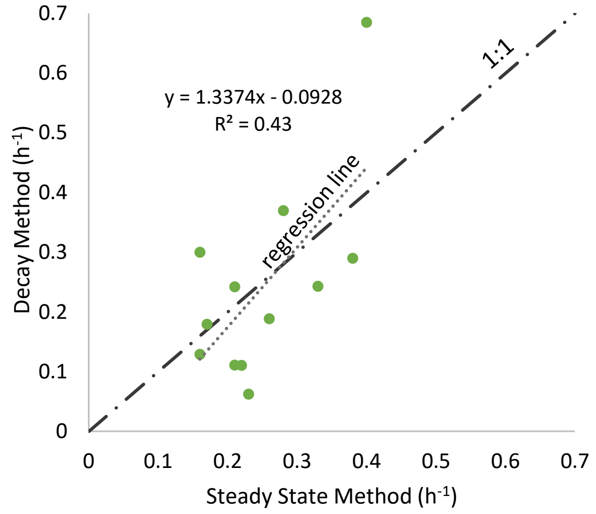
Better compliance with the ASHRAE standard is observed in workplaces and classrooms, where 78% and 91% are >7 L/s/p, respectively. This could be influenced by the health recommendations issued by local authorities to reduce the risk of infection. Here, occupants may have acted to reduce transmission risk at the expense of their thermal comfort. However, only a small number of rooms (9%) met the recommended 20 L/s per person to reduce the spread of SARS-CoV-2. Data on occupant behavior and their understanding of, and interaction with, ventilation systems outside of the pandemic is required to understand if this is true.

4.3 Comparison between methods

To apply both ventilation estimation methods to the same room, the concentrations must have reached the upper steady-state when occupied, and then the room must be unoccupied for the remainder of the measuring period. These conditions were observed in 12 of 40 cases, and exclusively in residences. The coefficient of determination ($\boldsymbol{R^2}$ = 0.43) shows a *moderate* difference, according to Ferguson's thresholds (2009) [12]; see Figure 3. This disagreement might reflect the random variability of the parameter –the natural variation over time since the tests were carried out at different times– and epistemic uncertainty due to the applied methods. Here, the uncertainty in the emission rate (see Equation 1) will have significantly affected the estimate of the ventilation rate using the steady state method. Data on the left-hand side of the 1:1 agreement line indicate higher values using the decay method than the steady-state. In addition, the results using these two methods show a significant discrepancy in the mean value (μ); and variance, indicated by a $\boldsymbol{C_v}$, of at least 33% for the steady-state method, and 69% for the decay.

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

Figure 3:
Steady-state vs decay method, including the 1:1 agreement line and regression line (n=12).



Finally, furniture volume varied between 5 and 10% of the room volume in residences; see Table 3. The impact of excluding furniture volume from the total air of these types of buildings and rooms was tested, but the results did not show a significant difference (p-value > .05 and Cohen's *d* = 0.18). Thus, including the furniture volume in the calculation would not affect the results significantly. Since the furniture to room volume ratio was found to be higher in residences than in any other typology, the impact on the other typologies is expected to be less significant.

Table N°3:
Furniture and room volume in residences (m^3)

	Furniture volume m³	Room volume m³	Air volume m³
n	20	20	20
Minimum	1.46	14.42	12.94
Percentile 5%, P_5	1.48	16.39	14.69
Median, M_{ed}	2.39	24.99	22.45
Mean, µ	2.25	26.15	23.90
95% percentile, P_{95}	2.86	37.07	35.34
Maximum	3.37	50.21	47.53
Standard deviation, σ	0.50	7.71	7.55
Coefficient of variance, C_v [nd]	0.22	0.29	0.32

Although this study provides empirical evidence of current ventilation performance in Chilean buildings, more information is needed to better inform future design in a highly unregulated built environment.

Given the importance and impact of this parameter on a population's health, preparing our buildings with resilient ventilation is pressing. Moreover, well-managed ventilation could have positive impacts on energy consumption, health, and billing costs related to air conditioning. Thus, this study can be used to inform new regulations and commissioning, disseminate, and raise awareness of ventilation, using conditions, and buildings management.

Finally, more studies related to ventilation rates and their drivers are needed. A greater number of studies and data would allow a better understanding of the variability of this parameter, and its uncertainty could be reduced. Continuous testing to ensure compliance with the standards at the operational stage would prevent consequences that are potentially significant, and will affect the health of the population. This applies not only during a pandemic but also at all other times.

5. CONCLUSIONS

This study collected information on ventilation rates in three types of rooms by measuring CO_2 concentrations. The measuring campaign was carried out in 40 occupied rooms of three building types (residential, workplaces, and classrooms) located in Santiago de Chile in wintertime. The decay and steady-state methods were applied depending on the rooms' use conditions.

Results showed great variability in VR between the three types of buildings. The airflow for houses (n=20) was Me = 1.17 (90% CI [0.75 - 1.87] L/s/p), for workplaces (n=9) a Me = 22.56 (90% CI [2.56 – 118.82] L/s/p), and Me = 9.68 (90% CI [4.89 – 19.29] L/s/p) for classrooms. 0%, 78%, and 91% of the residential, work, and classroom facilities met the national or international ASHRAE standard for minimum ventilation rates, respectively. This suggests that, in normal conditions, most of the existing stock could need additional ventilation to achieve acceptable indoor air quality. Low VRs could have been influenced by weather and use conditions during the measuring period, insufficient room volume, or an excessive number of people.

The comparison between types of buildings showed a significant difference between residential rooms and the other types ($p < .05$). However, it was not possible to find a significant difference between workplaces and classrooms ($p = 0.079$). Despite this, the magnitude of the effect showed that the three typologies have a *small* to *moderate* difference (0.59 – 0.89). Finally, a *moderate* correlation was obtained between both methods ($\boldsymbol{R^2}$= 0.43).

Although data remains limited for Chilean buildings, these results can be used in future measurement campaigns and building design, and the uncertainties can be incorporated into simulation and intervention studies.

REFERENCES

1. National Institute for Standardization. (2013). Ventilation. Acceptable indoor air quality. Requirements (INN Chilean Standard No. 3308). Santiago, Chile
2. National Institute for Standardization. (2014). Ventilation. Acceptable indoor air quality on buildings low-income residential height. Requirements (INN Chilean Standard No. 3309). Santiago, Chile
3. American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2019). Ventilation for Acceptable Indoor Air Quality (ASHRAE Standard 62.1).
4. American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2016). Ventilation and Acceptable Indoor Air Quality in Residential Buildings (ASHRAE Standard 62.2).
5. Asadi, E., Costa, J. J., & Gameiro da Silva, M. (2011). Indoor air quality audit implementation in a hotel building in Portugal. *Building and Environment*, 46(8), 1617–1623. https://doi.org/10.1016/j.buildenv.2011.01.027
6. Hänninen, O. (2013). Novel second-degree solution to single zone mass-balance equation improves the use of build-up data in estimating ventilation rates in classrooms. *Journal of Chemical Health and Safety*, 20(2), 14–19. https://doi.org/10.1016/j.jchas.2012.12.001
7. Turanjanin, V., Vučićević, B., Jovanović, M., Mirkov, N., & Lazović, I. (2014). Indoor CO2 measurements in Serbian schools and ventilation rate calculation. *Energy*, *77*, 290-296.
8. Persily, A., & de Jonge, L. (2017). Carbon dioxide generation rates for building occupants. *Indoor Air*, *27*(5), 868–879. https://doi.org/10.1111/ina.12383
9. Molina, C., & Jones, B., Persily, A. (2020). Investigating Uncertainty in the Relationship between Indoor Steady-State CO2 Concentrations and Ventilation Rates. *AIVC 2021 Conference*, *Proceedings*
10. Persily, A., & de Jonge, L. (2017). Carbon dioxide generation rates for building occupants. Indoor Air, 27(5), 868–879. https://doi.org/10.1111/ina.12383
11. Shimer, D. A., Jenkins, P. L., Hui, S. P., & Adams, W. C. (1995). 132 Measurement of breathing rate and volume in routinely performed daily activities. *Epidemiology*, *6*(2), S30.
12. Ferguson, C. J. (2009). An effect size primer: A guide for clinicians and researchers. *Professional Psychology, Research and Practice*, 40(5), 532–538. https://doi.org/10.1037/a0015808
13. Dimitroulopoulou, C. (2012). Ventilation in European dwellings: A review. *Building and Environment*, 47, 109–125. https://doi.org/10.1016/j.buildenv.2011.07.016
14. D'Oca, S., & Hong, T. (2014). A data-mining approach to discover patterns of window opening and closing behavior in offices. *Building and Environment*, *82*, 726-739.
15. Calì, D., Andersen, R. K., Müller, D., & Olesen, B. W. (2016). Analysis of occupants' behavior related to the use of windows in German households. *Building and Environment*, *103*, 54-69.

Optimized design for a smart office indoor environment for mitigating electromagnetic radiation pollution

Future cities

RESHNA RAVEENDRAN[1] AND KHEIRA ANISSA TABET AOUL [1]

[1] Architectural Engineering Department, College of Engineering, United Arab Emirates University, UAE

ABSTRACT: 5G smart buildings indicate the next transformational phase in the built environment and deploying numerous Internet of Things (IoT) and smart devices that are connected wirelessly, may produce unintended health problems for their occupants. Research and strategies in this direction are rare, and thus this paper aims to explore a potential design layout for a small office space taking into account Electromagnetic Radiation (EMR). The two main design aspects addressed in this simulation paper are network connectivity and building materials in relation to their shielding effectiveness. The simulations were performed using Computer Simulation Technology (CST) for two different frequencies, 2.45 and 6 GHz for three building materials: glass, concrete and wood. All building materials' shielding effectiveness increased with frequency as high frequency scatters more. Glass increased radiation inside the space due to back reflection, as indicated by their negative value of shielding effectiveness while concrete and wood blocked incoming radiation at both tested frequencies. Among the three building materials tested, wood is suggested to provide safe interior spaces for occupants to shield themselves from high-frequency indoor radiation. The study also recommends separating permanent and temporary occupancy interior areas based on network connectivity with suitable materials.

KEYWORDS: Smart Buildings, 5G, Health and Wellbeing, Electromagnetic Radiation, Computer Simulation Technology

1. INTRODUCTION

The future of cities is tied to the growth in smart buildings and IoT. Though the benefits are numerous from energy efficiency, promoting productivity and domotics assistance to dwellers [1]. The threats from these future smart buildings and smart cities are equally important and they can range from e-waste, radiation from IoT and smart devices with high frequency and excess CO2 from datacentres [2]. Radiation from wireless devices and IoT is a source of a health concern as research-based evidence suggests that a myriad of illnesses can arise from continuous exposure [3]. There are mainly two categories of EMR pollution exposure that can occur in an indoor environment; one from Extremely Low Frequency (ELF) used by numerous home appliances, such as refrigerators, computers, hairdryers and the other from high-frequency radio , microwaves emitted by cellular antennas, cordless phones, Wi-Fi routers, baby monitors and IoT devices [4]. ELF is found to cause leukaemia, stress on the immune and nervous systems, dizziness, insomnia, headaches, digestive and circulatory problems [5][6]. Radio and microwaves are also found to cause adverse health effects such as tumors, cancers, decrease in white blood and red blood cells [7][8][9]. The adverse health effects from 5G (1 GHz-300 GHz), millimeter waves (from 30 GHz) are found to be several times worse than that of ELF, radio and microwaves [10][11][12].

Smart buildings connect numerous numbers of IoT devices and sensors to a cloud processor to send collected data for analysis and to make decisions about building functions. Thus, a typical smart building, envisioned to use 5G and 6G, i.e., up to 300 GHz will generate a continuous radiation with potential impacts on its occupants.

One of the commonly recommended solutions is to provide hybrid connectivity, using wired and wireless connections as per the space layout requirements [13]. However, this area is less explored, thereby lacks suitable information regarding the mitigation of wireless radiation.

In this paper, two design features are explored, one being possible design layouts for an office building to reduce radiation based on positioning of network connectivity. The second is the interior building materials that must be carefully selected to provide good shielding effectiveness (SE) from the wireless to the wired zones, lest radiation penetrates the wired (radiation-free zone).

Three dominant building materials were tested in this study using CST simulation: Glass, concrete and wood, for two different frequencies, 2.45 GHz and 6 GHz.

2. LITERATURE REVIEW

In 2011, International Agency for Research on Cancer (IARC) of World Health Organization (WHO) declared radio frequency radiation from 30 KHz – 300 GHz as possibly carcinogenic (Group '2B') [14][15]. The radiation exposure guidelines followed by the International commission on Non-ionising Radiation Protection (ICNIRP) [16] and Federal Communications Commission (FCC), however considers radiation from radio frequency to have acute effects and those limited to heating of tissues [17]. Scientists believe the millimeter frequency to cause biological problems like cardiovascular problems, chromatin (DNA complex), hormonal changes. High frequency waves are also found to absorb water easily and cause eye problems even without heating effects, which is more dangerous [18]. Based on these research findings, several countries such as the Netherlands, Switzerland, Australia have banned 5G [19] until conclusive research findings about the safety of implementing it is guaranteed. On the contrary, there are research studies that indicate microwave radiation or those radiation which are non-ionic do not cause any health issues from the usage of mobile phone or from cellular base stations [20][21]. Some researchers also reported that there is no correlation between cancer and EMF [22][23]. However, research on this topic still remains inconclusive to understand if these types of radiation are harmful to humans or not.

There are only a few studies done in the domain of buildings and radiation and none about smart buildings in particular. However, in their study, Vizi & Vandenbosch (2015), highlighted the potential shielding effect that building material(s) and shape(s) could impose on external EMF, but the study did not consider any wireless antenna source. Instead they simulated the space by irradiating with a plane wave of 1 GHz [24]. Wahba et al., (2021) simulated in CST the power density variation and influence of different roof shapes and concluded that roof shapes significantly influence EMR dissipation inside a building [25]. However, both of these studies used a plane wave excitation and not a real-source antenna.

Moreover, building materials have natural electromagnetic properties that vary with frequency [26]. Thus, the dissipation of EMR inside smart buildings with wireless smart and IoT devices will produce different radiation patterns based on different building materials and frequencies. Hence, this paper aims to explore different zoning arrangements possible to reduce radiation and to evaluate the shielding effectiveness of the selected three building materials.

3. METHODOLOGY

The study used a simulation-based approach. Cisco packet tracer was employed to understand the main two design solutions that can be applied to smart buildings in mitigating EMR from various sources like smartphones, IoT devices and routers. The first design element was construed by network modelling to create different layouts possible in a smart office. These network layouts help differentiate between wired zone (green colour) and wireless zone (beige colour) in Figure 1. CST software was used to perform simulations to determine the shielding effectiveness of building materials.

The following equation (1) calculated shielding effectiveness (SE),

$$SE = 20\ log\frac{[E_1]}{[E_2]} \qquad (1)$$

Where, E1 and E2 are the estimated electric field intensities with no shielding material and with shielding material, respectively at the same point or plane. The same equation can be applied for H-field as well.

The simulations were carried out for two frequencies, 2.45 GHz (4G) and 6 GHz (5G). Validation for the reliability of CST was also conducted before carrying out simulations in an actual concrete room.

3.1 Hybrid Design Layouts

The hybrid design layouts depict how an office space (discussed in this study) can be zoned appropriately to contain (control? limit?) radiation from wireless devices within that area. Therefore, zoning would allow (force?) the radiation not to transmit to other building areas. Two different options for hybrid design layout for zoning are provided. The first option (Fig. 1) has a separate network connection to all spaces, except for the reception region. It has been designed so that people who visit the office space alone need to use wireless internet on their smart phone or tablet.

The second design alternative is to provide zoning for the meeting room, so that transient occupants or visitors in the office can use wireless internet for their discussion (Fig. 2).

Further, both designs can be optimized if eco-routers are used wherever wireless internet connection is provided, for instance, in the reception area to mitigate radiation. Eco-routers are routers that produce 90% less radiation than conventional routers [27]. The visitors using the meeting room in design 2, can be provided with RJ-

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

45 ethernet cable connection that is available for smart phones and laptops.

Figure 1:
Hybrid design layout 1

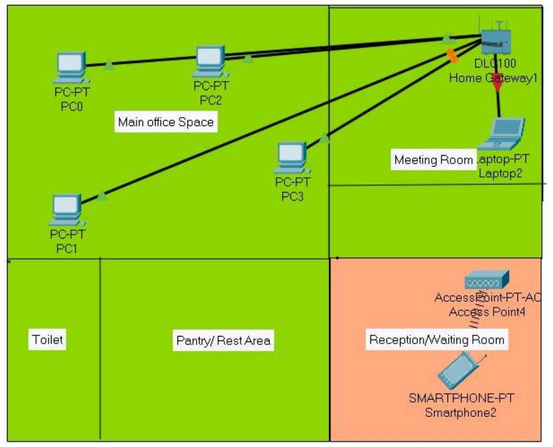
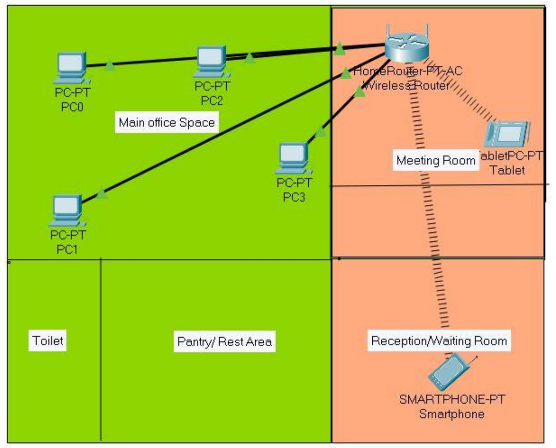


Figure 2:
Hybrid design layout 2



The next part of the study will examine the influence of building materials in reducing the EMR generated in the wireless zone to wired zone, using the first design layout.

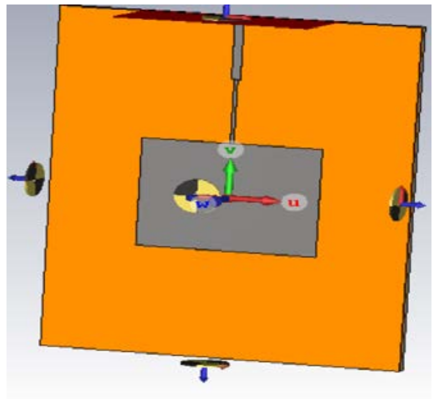
3.2 CST simulation

The purpose of the simulation is to evaluate the shielding effectiveness of building materials in the reception area (wireless zone) to the wired zone. Moreover, the SE will also help to understand the role of building materials in mitigating the EMR generated indoors. For the design layout in Figure 1, a 3D model was initially created in Sweet Home 3D, which was later imported to CST (Fig. 3).

Figure 3:
3D model of office space in Sweet Home

Wireless excitation for simulation testing was provided by importing field sources of an antenna for the needed frequency. The antenna was separately simulated in CST before extracting the field sources. Figure 4, shows the patch antenna used for exciting the office model.

Figure 4:
Patch Antenna used for wireless excitation



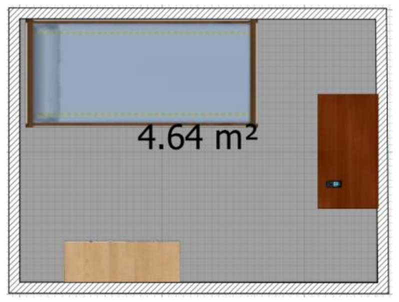
Finally, building materials were reassigned to match the operating wireless frequency. The CST model with antenna field source were simulated for different frequencies.

3.3 Validation

Validation was conducted to verify the result of real measurements and CST simulation. Figure 6 shows the room plan and the smartphone device used to check the generated EMF using wintact WT3121 instrument.

The electric and magnetic field measured at 15 cm from the device was 26 V/m and 0.05 A/m, and the electric and magnetic field measured using CST were 27.769 V/m and 0.068 A/m respectively.

Figure 5:
Plan of real room where EMR measurements were taken



4. RESULTS AND DISCUSSIONS

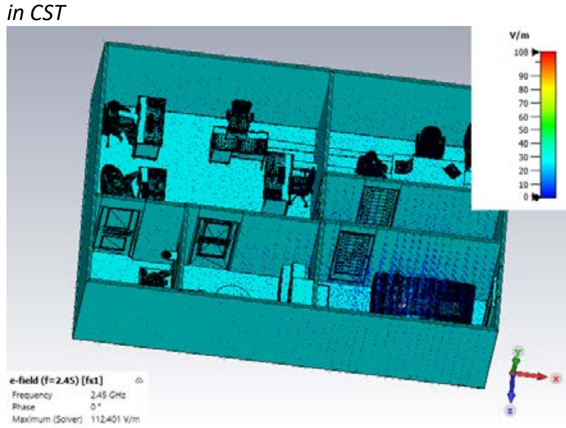
In order to calculate the shielding effectiveness, electric and magnetic fields were calculated at the same plane (30 cm from the reception area wall). Measurements were taken from simulation with and without the shielding material for the simulation model. E-field computed from CST without shielding material was 5.085 V/m at 2.45 GHz and 34.778 V/m at 6 GHz.

Similarly, H-field without shielding material was found to be 0.011 A/m at 2.45 GHz and 0.045 A/m at 6 GHz. Table 1 recorded the shielding effectiveness of the three building materials for E-field and H-field using equation 1. Simulated E-field distribution for material wood at 2.45 GHz is shown in Figure 6.

Table 1: Tabulations of shielding effectiveness

Frequency (GHz)	Building Material	Shielding Effectiveness of E-field (dB)	Shielding Effectiveness of H-field (dB)
2.45	Glass	-1.043	-2.094
2.45	Concrete	1.472	1.743
2.45	Wood	2.277	1.743
6	Glass	2.383	1.938
6	Concrete	4.284	4.121
6	Wood	17.142	19.084

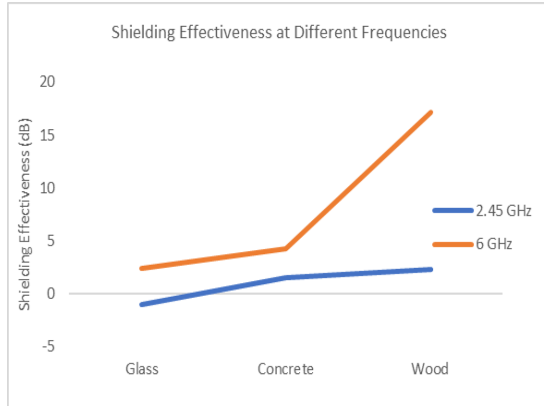
Figure 6:
E-field distribution of building material wood at 2.45 GHz in CST



As frequency increased from 2.45 GHz to 6 GHz, the shielding effectiveness of E-field improved considerably. All values were positive, especially for glass, whose SE changed from negative to a positive value (Fig. 7). The reason can be attributed to the fact that glass is known to reflect and create multiple reflections inside the space more than concrete or wood. This in turn caused the radiation to increase in the reception area instead of reducing it.

Concrete and glass showed almost the same SE at 2.45 GHz but differed at 6 GHz, as wood's SE increased to 17.142 dB from 2.277 dB (Table 1). This explains that as frequency increases, it scatters more and thus, building materials' shielding capability increases regardless of the material. A similar trend was observed for the SE of H-field.

Figure 7:
Graphical representation of SE of materials at 2.45 and 6 GHz



Concrete and wood can be chosen as the building materials which can reduce radiation at 2.45 GHz rather than glass. At 6 GHz, all materials showed positive SE value, but, overall, wood proved to be the best material regarding shielding capacity as it attenuates the radiation both inside and outside the reception area.

5. CONCLUSION

The study evaluated an office space for mitigating EMR through hybrid zoning and selecting appropriate building materials. The hybrid zoning of the office space was done using Cisco packet tracer, while the shielding capability of building materials was performed through CST simulation. The study recommends separating permanent and temporary occupancy interior areas based on network connectivity with suitable materials. Wired connectivity can be provided for permanent workstations with employees. Wireless connectivity with eco-routers can be designed for common areas such as reception, waiting room, a pantry that are open to temporary and infrequent occupancy rates.

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

Among the three building materials tested, wood is recommended to provide safe interior spaces for occupants to shield themselves from high-frequency indoor radiation.

ACKNOWLEDGEMENTS

This research was funded by United Arab Emirates University, Grant Number, 31R102.

REFERENCES

[1] E. I. Batov, "The distinctive features of 'smart' buildings," *Procedia Eng.*, vol. 111, pp. 103–107, 2015.

[2] R. Raveendran and K. A. Tabet Aoul, "A Meta-Integrative Qualitative Study on the Hidden Threats of Smart Buildings/Cities and Their Associated Impacts on Humans and the Environment," *Buildings*, vol. 11, no. 6, p. 251, 2021.

[3] D. Nowak and K. Radon, "Electromagnetic pollution (electrosmog)--potential hazards of our electromagnetic future," *MMW Fortschr. Med.*, vol. 146, no. 9, pp. 38–40, 2004.

[4] B. A. Meyers, *Pemf-the Fifth Element of Health: Learn Why Pulsed Electromagnetic Field (Pemf) Therapy Supercharges Your Health Like Nothing Else!* BalboaPress, 2013.

[5] C. D'Angelo, E. Costantini, M. A. Kamal, and M. Reale, "Experimental model for ELF-EMF exposure: Concern for human health," *Saudi J. Biol. Sci.*, vol. 22, no. 1, pp. 75–84, 2015.

[6] L. Kheifets and R. Shimkhada, "Childhood leukemia and EMF: review of the epidemiologic evidence," *Bioelectromagnetics*, vol. 26, no. S7, pp. S51–S59, 2005.

[7] A. B. Miller *et al.*, "Risks to health and well-being from radio-frequency radiation emitted by cell phones and other wireless devices," *Front. Public Heal.*, vol. 7, p. 223, 2019.

[8] M. Feychting, A. Ahlbom, and L. Kheifets, "EMF and health," *Annu. Rev. Public Heal.*, vol. 26, pp. 165–189, 2005.

[9] J. Breckenkamp, G. Berg, and M. Blettner, "Biological effects on human health due to radiofrequency/microwave exposure: a synopsis of cohort studies," *Radiat. Environ. Biophys.*, vol. 42, no. 3, pp. 141–154, 2003.

[10] A. Hirata, S.-I. Matsuyama, and T. Shiozawa, "Temperature rises in the human eye exposed to EM waves in the frequency range 0.6-6 GHz," *IEEE Trans. Electromagn. Compat.*, vol. 42, no. 4, pp. 386–393, 2000.

[11] S. Singh and N. Kapoor, "Health Implications of Electromagnetic Fields, Mechanisms of Action, and Research Needs," *Adv. Biol.*, vol. 2014, p. 198609, 2014, doi: 10.1155/2014/198609.

[12] D. H. Gultekin and P. H. Siegel, "Absorption of 5G radiation in brain tissue as a function of frequency, power and time," *IEEE Access*, vol. 8, pp. 115593–115612, 2020.

[13] F. M. Clegg *et al.*, "Building science and radiofrequency radiation: What makes smart and healthy buildings," *Build. Environ.*, vol. 176, p. 106324, 2020, doi: https://doi.org/10.1016/j.buildenv.2019.106324.

[14] I. W. G. on the E. of C. R. to Humans, "Non-ionizing radiation, Part 2: Radiofrequency electromagnetic fields.," *IARC Monogr. Eval. Carcinog. risks to humans*, vol. 102, no. PT 2, p. 1, 2013.

[15] L. Hardell, "World Health Organization, radiofrequency radiation and health-a hard nut to crack," *Int. J. Oncol.*, vol. 51, no. 2, pp. 405–413, 2017.

[16] I. C. on N.-I. R. Protection, "ICNIRP statement on the 'Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz),'" *Health Phys.*, vol. 97, no. 3, pp. 257–258, 2009.

[17] "RF Safety FAQ | Federal Communications Commission." https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/faq/rf-safety#Q24 (accessed Aug. 23, 2020).

[18] M. Kojima *et al.*, "Ocular Effects of Exposure to 40, 75, and 95 GHz Millimeter Waves," *J. Infrared, Millimeter, Terahertz Waves*, vol. 39, no. 9, pp. 912–925, 2018.

[19] K. Chamberlin and M. Roberge, "Final Report of the Commission to Study The Environmental and Health Effects of Evolving 5G Technology."

[20] A. Stewart, J. N. Rao, J. D. Middleton, P. Pearmain, and T. Evans, "Mobile telecommunications and health: report of an investigation into an alleged cancer cluster in Sandwell, West Midlands," *Perspect. Public Health*, vol. 132, no. 6, pp. 299–304, 2012.

[21] V. S. Benson *et al.*, "Mobile phone use and risk of brain neoplasms and other cancers: prospective study," *Int. J. Epidemiol.*, vol. 42, no. 3, pp. 792–802, 2013.

[22] J. E. Moulder, K. R. Foster, L. S. Erdreich, and J. P. McNamee, "Mobile phones, mobile phone base stations and cancer: a review," *Int. J. Radiat. Biol.*, vol. 81, no. 3, pp. 189–203, 2005.

[23] P. Elliott *et al.*, "Mobile phone base stations and early childhood cancers: case-control study," *Bmj*, vol. 340, 2010.

[24] G. N. Vizi and G. A. E. Vandenbosch, "Building materials and electromagnetic radiation: the role of material and shape," *J. Build. Eng.*, vol. 5, pp. 96–103, 2016.

[25] A. S. Wahba, A. Elboushi, Y. M. El-Sherbiny, and M. El-Shazly, "Electromagnetic energy in buildings: analysis of the effect of roof shape and treated materials," *J. Build. Perform. Simul.*, vol. 14, no. 5, pp. 536–553, 2021.

[26] D. Ferreira, I. Cuiñas, R. F. S. Caldeirinha, and T. R. Fernandes, "A review on the electromagnetic characterisation of building materials at micro-and millimetre wave frequencies," in *The 8th European Conference on Antennas and Propagation (EuCAP 2014)*, 2014, pp. 145–149.

[27] "JRS Eco Wireless Routers – JRS Eco Wireless." https://www.jrseco.com/pcat/low-radiation-wifi-routers-jrs-eco-wifi/ (accessed Jul. 07, 2021).

Regenerating urban surfaces to achieve healthy and resilient neighbourhoods

A case study of Trento, Italy

ANNA CODEMO[1], SARA FAVARGIOTTI[1], ROSSANO ALBATICI[1]

[1] University of Trento, Department of Civil Environmental and Mechanical Engineering, Via Mesiano 77, 38123 Trento, Italy

ABSTRACT: Climate adaptation and mitigation are becoming a priority in urban planning practices and design. To effectively promote healthy and liveable conditions, an integrated approach is foreseen, balancing energy requirements, urban health and climate resilience. The transformation of urban surfaces, such as roofs, facades and open spaces, has a key role in this process. Indeed, they can contribute to producing renewable energy, reducing energy consumption, providing sustainable water management, and reducing outdoor temperature. Urban design plays an essential role in defining the types of materials and colors, ensuring an effective integration of different functions. This paper aims to provide design solutions for envelopes and open spaces to regenerate the existing built environment. First, a workflow is assessed defining the required services of the areas and the possible types of interventions. Finally, a set of solutions is proposed according to the type of surfaces and buildings. The application of the proposed approach has been tested in Trento, Italy, in a mixed-use neighbourhood. The suggested actions, based on the combination of nature-based, renewable energy sources and energy efficient technologies could constitute a guideline for practitioners and decision-makers to effectively retrofit urban areas.
KEYWORDS: climate adaptation, mitigation, regeneration, urban design, multifunctional solutions

1. INTRODUCTION

As highlighted in the Paris Agreement, cities constitute key hubs of actions to address sustainable development. Climate adaptation and mitigation are becoming a priority in urban planning and design practices. To ensure healthy and liveable conditions, an integrated approach is foreseen to effectively balance energy requirements, urban health, and climate resilience. However, the implementation of climate resilient and low carbon interventions is still slow [1], due to for example lack of adaptive and novel planning tools and scarce capacity to coordinate multiple scales and sectors [2]. Moreover, while new areas and buildings are driven by sustainability regulations, the most critical challenge consists of the transformation of the existing heritage [3]. In this context, to achieve healthy and resilient urban areas, several challenges need to be tackled: integrating adaptative and mitigative requirements in the urban planning tools, in order to facilitate the implementation [4]; promoting a balance between adaptation and mitigation actions, to intervene efficiently in the built environment [5]; facilitating the transformation of the built environment compared to new constructions, to avoid land consumption and to regenerate the existing building stock [6].

Considering this framework, the present study focuses on the need to shift towards multifunctional solutions and to prioritise the transformation of the existing heritage to new constructions. Thus, it provides design solutions for buildings and open spaces to achieve low energy, adaptive and healthy regeneration interventions, based on the combination of Nature-based (NbS), Renewable Energy Sources (RES)-based and energy efficient technologies solutions. To contribute to the creation of a multiscale and multifunctional approach, the specific objectives of the paper are (i) the definition of a preliminary catalogue of solutions for urban transformations, and (ii) the experimentation of sets of solutions in a case study.

2. CLIMATE SENSITIVE REGENERATION APPROACH

Current practices lack a systemic approach capable of integrating several functions and challenges, and prevent regeneration processes able to tackle simultaneously several challenges. This study relies on the procedural framework, the performances and the functions of the built environment developed in previous studies [7], aiming to delineate a guidance for design practices. This method is developed through three steps (Fig. 1): characterization of the area, definition of the required performances and identification of possible systems of interventions. The approach is meant to offer a guideline to regenerate neighbourhoods, as well as to propose design guidelines for open spaces and buildings according to typologies and morphology.

The proposed framework is based on the integration of climate-related challenges. Specifically, it combines the objectives and the required performances to simultaneously achieve temperature regulation, sustainable water management, energy sustainability, and health and wellbeing.

Considering the interactions between urban climate and the built environment, the process guides through the change of urban components' key parameters (e.g. morphology, geometry, materials), impacting on energy use, outdoor comfort, wellbeing and water management. Specifically, a system of interventions is set to modify the built environment starting from tridimensional parameters, affecting ventilation, solar radiation [8], to buildings' envelopes and open spaces through permeability, albedo, evapotranspiration [8].

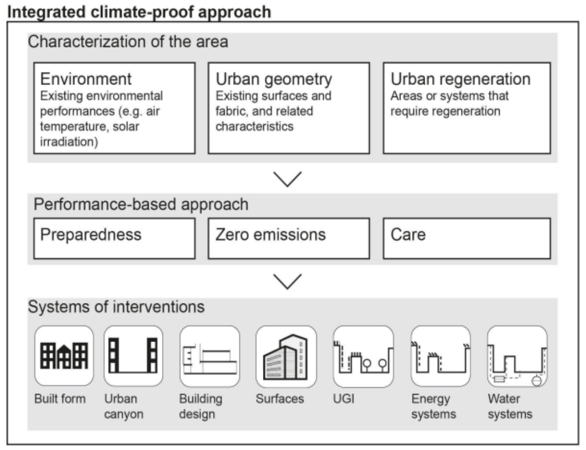


Figure 1: Proposed workflow for climate sensitive regeneration.

As the aim of the research is to consider transformations of the existing built environment, the proposed solutions will focus on the transformation of the existing urban surfaces, such as open spaces and buildings, rather than on the morphology of urban fabric. The question addressed in this paper is how to transform the urban surfaces to achieve climate-related performances.

3. CATALOGUE OF SOLUTIONS

The present paragraph focuses on the delineation of a catalogue of solutions for surfaces, to facilitate the implementation of the integrated climate-proof approach. Recent scientific literature highlights the importance of designing urban surfaces considering the impacts that they can have on climate change. For example, recent studies suggest how to transform roofs in order to provide multiple functions [e.g. 9], or to combine urban surfaces with green infrastructure [e.g. 10]. Despite the attention that urban surfaces have been receiving, the common approaches to their exploitation are mainly sectorial. For example, they focus on single solutions [e.g. 11] or on single purposes, such as mitigation [e.g. 12]. Some recent studies investigate scenarios combining adaptation strategies to future climate and mitigation techniques [e.g. 13.], or to combine different challenges related to buildings' energy performances [e.g. 14]. However, such studies focus on the relationship between energy performances and outdoor temperatures, excluding the impacts of solutions on water management.

The catalogue of solutions proposed in this study aims to overcome such limitations, by highlighting which solutions are available and which climate-related benefits they provide, including regenerative, adaptive concepts. Hence, the suggested solutions consider the urban components as a diaphragm, giving attention to the twofold effects of urban components on the indoor and the outdoor environment.

3.1 Methodology

The inventory of solutions is based on the following steps: classification of urban surfaces, literature review on possible solutions, categorization of solutions, identification of synergies and conflicts between climate-related challenges. According to the analysed literature, the selected solutions are suitable for urban areas and provide multiple benefits. The aim of the literature review is to select types of solutions, to describe where they can be applied, and to specify their direct and indirect benefits.

3.2 Classification of surfaces

The types of urban surfaces available for transformations are both on ground and buildings' envelopes (Fig. 2). Ground surfaces include linear elements (e.g. streets) and open spaces (e.g. parking lots), while buildings' surfaces are divided between roofs, facades and additional tridimensional elements.

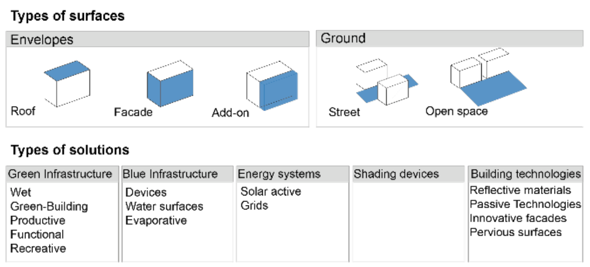


Figure 2: Types of surfaces.

3.2 Collection and categorization of solutions

A comprehensive literature review has been conducted, reviewing existing catalogues of solutions, research articles on single solutions, and research articles comparing different solutions.

The collected solutions have been categorized as follows: Urban Green Infrastructure, Blue Infrastructure, Energy Systems, Shading devices, Building technologies (Fig.2). Each category is further divided in sub-categories, according to the type of solution.

Urban Green Infrastructure (UGI)

UGI provides many ecosystem services (e.g. balancing water flows, providing thermal comfort), contributing to ecosystem resilience and bio-physical, social, psychological benefits [15]. It is an infrastructure of built systems and green spaces, including large-scale elements such as wetlands, forests, parks, and small-scale elements such as green roofs and green facades.

Blue Infrastructure (BI)

BI provides benefits to sustainable water management as well as to cooling, through evaporation. It includes: natural water surfaces, such as rivers and lakes; artificial ones, such as canals; techniques like spaying and water curtains, which can be applied to ground surfaces as well as to buildings [16].

Energy systems (ES)

ES include systems in urban areas that can generate energy locally produced from RES, to meet energy requirements (heating, cooling, electricity, hot water). Clean energy in built-up areas is mostly produced by active solar systems, applied in buildings' surfaces or on-ground, as well as by grid systems that connect multiple buildings.

Shading devices (S)

S include solutions to protect from direct solar radiation, to adapt to the increase of temperature and to reduce the buildings' energy needs. Shading devices solutions can be applied to buildings surfaces, as well as to open spaces.

Building Technologies (BIT)

BIT refer to the adaptive technologies, which rely on passive design to improve building energy efficiency and, indirectly, outdoor thermal regulation. These solutions include the techniques applied to buildings' envelopes to encourage natural ventilation and maximize direct solar gains.

3.3 Integrating solutions in the urban surfaces

In this paragraph, a collection of solutions is presented to highlight their functions and to provide a reference to integrate them in the urban components.

The results have been schematized in tables, to provide a simple and comprehensive result. The schemes are meant to offer guidance in choosing how to transform the built environment for practitioners and decision makers.

Table 2:
Types of solutions to implement on buildings' envelopes

Type	Device	Category	Synergies
Roof	Green roofs	UGI	T,WM,E,HW
	Cool roofs	BIT	T,E
	Wet roofs	UGI	T,WM,E,HW
	Ventilated roofs	BIT	E
	Solar active PV	ES	E
	Solar thermal panels	ES	E
Facade	Thermal insulation	BIT	E
	Green walls	UGI	T,WM,E,HW
	Cool walls	BIT	T,E
	Trombe wall	BIT	E
	Glass with solar control	BIT	E
	Adaptive skins	BIT	E
	Sunshade	S	E
	Phase Changing Materials	BIT	E
	Climate facades	BIT	T,E,HW
	Ventilated facades	BIT	E
	Double skin facades	BIT	E
	Natural ventilation	BIT	E
	Night cooling	BIT	E
	BIPV	ES	E
	Solar panels	ES	E
Add-on	Productive façade systems	UGI	T,E,HW
	Vertical farming	UGI	T,WM,E,HW
	Wintergardens	BIT	E,HW

Note: Categories: UGI – Urban Green Infrastructure, ES – Energy systems, BIT – Building and Infrastructure Technologies; Synergies: T – Temperature regulation, WM – Water Management, E – Energy Sustainability, HW – Health and wellbeing.

To frame the contribution of urban surfaces to the climate-related challenges, their benefits are divided according to the scheme proposed in Fig. 1: Temperature Regulation (TR), Sustainable Water Management (WM), Energy Sustainability (ES) and Health and Wellbeing (HW).

In the following paragraph, we focus on the solutions that can be applied to envelopes and open spaces.

Rethinking building skins

Two main categories of solutions can be distinguished for envelopes (Tab. 2): technologies relying on passive design, that improve energy efficiency of the building, and active technologies producing energy from renewable energy sources.

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

The functions of the buildings' envelopes related to the above-mentioned climate related challenges are as follows [e.g. 17, 18]:

- Facilitating natural ventilation to reduce energy consumptions for air conditioning (e.g. through double skin facades);
- Increasing direct solar gain to reduce energy consumptions for heating (e.g. through solar greenhouse, regenerative PCM-facades, double skins facades);
- Controlling heat transmission to reduce energy losses (e.g. through insulation and green roofs);
- Increasing solar reflectance to reduce energy consumptions for air conditioning (e.g. through cool roofs and cool facades);
- Locally producing energy from RES (e.g. through photovoltaic panels and thermal solar);
- Collecting and reusing rainwater to reduce runoff (e.g. with using green and wet roofs).

Table3:
Types of green walls

Green walls	
Ground based	With self-climbing plants With climbing trees
Plant-trough based	Wall based lant troughs Ground based plant troughs
Wall-bound	Wall based with plant-troughs modules Wall-bound systems (Living Walls)

The presented catalogue of solutions is not exhaustive, and it is meant as a tool that could be constantly updated. Moreover, several mentioned solutions are general, and can be further categorized, according to the specific technologies, as in the case of the green facades, described in Tab. 3.

Integrating nature in open spaces

The integration of nature in open spaces contributes to several benefits: improving health and wellbeing of people, creating more comfortable outdoor areas, managing urban water in a sustainable way, as well as indirectly reducing buildings' energy consumptions.

The climate-related functions of the open spaces integrated with UGI and BI are as follows [e.g. 19, 20, 21]:

- Facilitating ventilation, to reduce air temperature;
- Increasing evapotranspiration, to reduce surface and air temperature as well as to manage rainwater;
- Improving soil infiltration to temporarily retain water and reduce runoff;
- Maintaining groundwater levels, preventing low river flows in summer and reducing the amount of wastewater.

Table 4:
Types of NbS to implement in open spaces

Type	Device	Category	Synergies
Street	Drain ditches	UGI	T,WM,E*,H
	Gutters	UGI	WM, T*
	Infiltration strips	UGI	T, WM, HW
	Channels	BI	T, WM, HW
	Green barriers	UGI	T, E, HW
	Bioswales	UGI	T, WM, HW
	Trees in streets	UGI	T, WM,E, HW
Open space	Green surfaces	UGI	T,WM,E*,HW
	Pervious pavements	BIT	T, WM, E*
	Cool pavements	BIT	T, WM, E*
	Urban forests	UGI	T,WM,E,HW
	Rain gardens	UGI	T,WM,E*,HW
	Pocket gardens	UGI	T,WM*,E*,HW
	Flowerbeds	UGI	T, WM, HW
	Private edible gardens	UGI	T,WM,E,HW
	Community gardens	UGI	T,WM,E*,HW
	Community edible gardens	UGI	T,WM,E*,HW
	Trees in open spaces	UGI	T,WM,E,HW
	Trees in parkings	UGI	T,WM,E,HW
	Trees in parks	UGI	T,WM,E,HW
	Bioretention areas	UGI	T,WM,E*,HW
	Bioretention basins	UGI	T,WM,E*,HW
	Wet areas	UGI	T,WM,E*,HW
	Water surfaces	BI	T, E, HW
	Lamination	BI	T, WM, E*
	Fitodepuration	UGI	T,WM,E*,HW

Note: Categories: UGI – Urban Green Infrastructure, BI – Blue Infrastructure, ES – Energy systems, BIT – Building and Infrastructure Technologies; Synergies: T – Temperature regulation, WM – Water Management, E – Energy Sustainability, HW – Health and wellbeing.

Moreover, the use of Sustainable Urban Drainage Systems (SUDS) improves water quality, by reducing the amount of contaminants, enhances biodiversity and provides valuable habitats and urban quality features [26].

4. APPLICATION IN A MIXED-USE NEIGHBORHOOD

The application of the catalogue has been tested in Trento, an Alpine city in the North of Italy. A mixed-use neighbourhood has been chosen, mainly characterized by isolated buildings with large impervious open spaces, leading to urban heat island effect and stormwater management challenges (Fig.3).

Figure 3: Case study: mixed-use neighbourhood in the North of Trento, Italy, and selected areas for the application of the sets of solutions.

A set of solutions has been applied to the case study, experimenting with integrated solutions to address different challenges. Coherently with paragraph 3.3, in this paper we report examples of combinations for envelopes and open spaces. According to the characteristics of the area, the chosen open space is a parking lot, while the envelope belongs to an office building east-west oriented.

4.1 Rethinking building skins

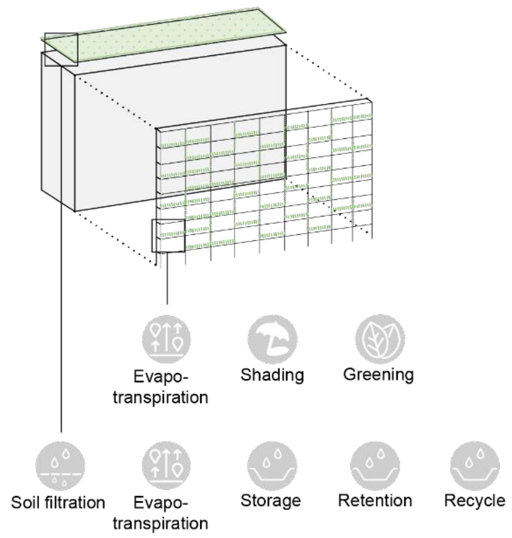


Figure 4: Proposed set of solutions for an office building: creation of a second skin to protect from summer overheating and green roof with PV panels to improve the building's energy performance.

The approach developed for the selected building is to rethink the second skin to address excessive overheating in summer. A green second skin is proposed in the south facade to control solar radiation and to improve the façade's quality, with a ground-based system with plant troughs and solar shading.

Moreover, a green roof is introduced to improve the building energy behaviour and to mitigate the UHI effect, combined with solar photovoltaic panels, partially covering the energy demand of the building.

4.2 Integrating nature in open spaces

The selected neighbourhood contains many flat paved surfaces - mainly used for parking - which lead to UHI effect and stormwater management issues. The main aim, by using NbS, is to provide urban cooling and to control the rainwater in the source (by using green roofs and pervious surfaces) and in the site (by introducing rain ditches). Thus, the proposed solutions aim to increase permeability and shaded areas, to effectively reduce runoff and reduce surface temperature. Moreover, by introducing NbS the quality of the area can improve.

Two scenarios have been proposed: the former integrates drain ditches and trees in the parking lot, preserving the number of parking spots; the latter reduces the number of spots, to increase the green surfaces and to create a more pleasant area.

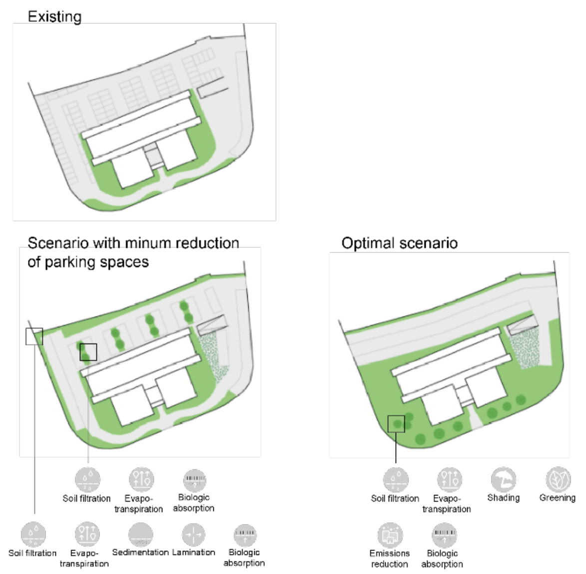


Figure 5: Two scenarios of application of NbS in a parking lot: the first one introduces drain ditches to collect rainwater, the second one is an optimized version that improves temperature regulation and the quality of the area.

5. CONCLUSION

The main purpose of the study is to strengthen the role of urban surfaces to develop guidelines achieving multiple functions for climate resilience and sustainability. The outcome is the experimentation of a method to support decision makers and practitioners in designing and implementing interventions combining climate adaptation and mitigation with regenerative actions. The multi-function and multi-scale proposed approach aims to guide socio-ecological transition and could represent an effective asset for urban transformations responding to the climate-related challenges.

Future developments of the study will include the experimentation of other typical typologies in the urban environment of Trento, to extend the proposed guidelines. Furthermore, the evaluation of the environmental performances of the proposed solutions is expected to understand their effectiveness.

ACKNOWLEDGEMENTS

The research received support from the "Trento Urban Transformation" project (founded by the Municipality of Trento and the University of Trento) and PEARLS (project that received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 778039).

REFERENCES

1. Olazabal, M., & Ruiz De Gopegui, M. (2021). Adaptation planning in large cities is unlikely to be effective. Landscape and Urban Planning, 206, 103974. https://doi.org/https://doi.org/10.1016/j.landurbplan.2020.103974
2. Magni, F., Litt, G., & Carraretto, G. (2021). Metropolitan Cities supporting local adaptation processes. The case of the Metropolitan City of Venice. TeMA - Journal of Land Use, Mobility and Environment, 14(2), 125–144.
3. Giorgi, S., Lavagna, M. and C. A. (2020). Circular Economy and Regeneration of Building Stock: Policy Improvements, Stakeholder Networking and Life Cycle Tools. In S. and L. C. and Z. A. della Torre Stefano and Cattaneo (Ed.), Regeneration of the Built Environment from a Circular Economy Perspective (pp. 291–301). Springer International Publishing. https://doi.org/10.1007/978-3-030-33256-3_27
4. Hurlimann, A., Moosavi, S., & Browne, G. R. (2021). Urban planning policy must do more to integrate climate change adaptation and mitigation actions. Land Use Policy, 101, 105188. https://doi.org/https://doi.org/10.1016/j.landusepol.2020.105188
5. Joint Programming Initiative Urban Europe (2019). Strategic Research and Innovation Agenda, SRIA 2.0. https://jpi-urbaneurope.eu/app/uploads/2019/02/SRIA2.0.pdf [accessed 08.06.20]
6. Ricci, M. & Favargiotti, S. (2019). Trento Leaf Plan. Cinque sfide per il metabolismo urbano. EcoWebTown ournal of Sustainable Design, 19
7. Codemo, A., Favargiotti, S. & Albatici, R. (2022). Climate sensitive urban regeneration: experimenting an adaptive and zero-energy approach in Trento, Italy. Proceedings of EcoCity (under review)
8. Raven, J., Stone, B., Mills, G., Towers, J., Katzschner, L., Leone, M., Gaborit, P., Georgescu, M., & Hariri, M. (2018). Urban planning and design. Cambridge University Press.
9. Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K. Y., & Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. In BioScience (Vol. 57, Issue 10, pp. 823–833). https://doi.org/10.1641/B571005
10. Vera, E., Cameron, B. and D. P. and G. D. and M. G. and P. U. (2017). Nature-Based Solutions and Buildings – The Power of Surfaces to Help Cities Adapt to Climate Change and to Deliver Biodiversity. In H. and S. J. and B. A. Kabisch Nadja and Korn (Ed.), Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice (pp. 159–183). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_10
11. Pisello, A. L. (2017). State of the art on the development of cool coatings for buildings and cities. In Solar Energy (Vol. 144, pp. 660–680). Elsevier Ltd. https://doi.org/10.1016/j.solener.2017.01.068
12. Taleghani, M. (2018). Outdoor thermal comfort by different heat mitigation strategies- A review. Renewable and Sustainable Energy Reviews, 81(P2), 2011–2018. https://EconPapers.repec.org/RePEc:eee:rensus:v:81:y:2018:i:p2:p:2011-2018
13. Garshasbi, S., Haddad, S., Paolini, R., Santamouris, M., Papangelis, G., Dandou, A., Methymaki, G., Portalakis, P., & Tombrou, M. (2020). Urban mitigation and building adaptation to minimize the future cooling energy needs. Solar Energy, 204, 708–719. https://doi.org/10.1016/j.solener.2020.04.089
14. Natanian, J., & Auer, T. (2020). Beyond nearly zero energy urban design: A holistic microclimatic energy and environmental quality evaluation workflow. Sustainable Cities and Society, 56. https://doi.org/10.1016/j.scs.2020.102094
15. Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A. G., Mittal, N., Feliu, E., & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. Journal of Environmental Management, 146, 107–115. https://doi.org/10.1016/j.jenvman.2014.07.025
16. Croce, S., & Vettorato, D. (2021). Urban surface uses for climate resilient and sustainable cities: A catalogue of solutions. Sustainable Cities and Society, 75. https://doi.org/10.1016/j.scs.2021.103313
17. D'Olimpio, D. (2017). Il retrofitting energetico e bioclimatico nella riqualificazione edilizia. Tecnologie e soluzioni tecniche per il miglioramento della prestazione energetico-ambientale degli edifici, Legislazione tecnica
18. Lollini, R., Pasut, W. et al (2020). Regenerative technologies for the indoor environment: Inspirational guidelines for practitioners. COST Action, CA16114 RESTORE, Working Group Four Report.
19. Charlesworth, S. M. (2010). A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, 1(3), 165–180. https://doi.org/10.2166/wcc.2010.035
20. Woods Ballard, B. (Bridget), & Construction Industry Research and Information Association (2015). The SuDS manual. CIRIA.
21. Charlesworth, S.M. and Booth C. A. (eds.) (2017). Sustainable Surface Water Management: a Handbook for SUDS, Wiley Blackwell, Oxford.

PLEA STGO 2022
WILL CITIES SURVIVE? ARCHITECTURE FOR HEALTH AND WELL-BEING

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 02
16:30 — 18:00

CHAIR
GILLES FLAMANT

PAPERS
1123 / 1124 / 1218 / 1639 / 1202 / 1524

25TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA 2022 SANTIAGO
Will Cities Survive?

Eco-cooler for vulnerable communities

A low-tech passive cooling vernacular approach for hot arid climates

MARWA DABAIEH[1], MONICA MICHEL ZACHARIA [2], MEDHAT KAZEM [3]

[1]Malmo University, Malmo, Sweden
[2]EID Studio, Cairo, Egypt

Abstract: With the gradual rise in the Earth's temperature, the number of people suffering from extreme heat waves, especially in hot climates is also increasing. A hands-on experimental passive cooling system made from traditional Shisha clay funnels for the hot and dry Egyptian climate is tested in an urban living lab for proof of concept. Several clay funnels were investigated and tested for their performance for cooling in terms of size and form. The clay funnels were first measured and simulated for their efficiency in accelerating air flow inside residential units and their ability to enhance the air velocity if combined with cross ventilation strategies. Computational Fluid Dynamics (CFD) simulations were conducted in ANSYS Fluent to understand the airflow behaviour inside simulated test shoe boxes designed to resemble living rooms. A standard k-ε turbulence model for single and multi-unit' configurations was used, followed by the application of experimental test cells for the cooling system and monitoring to test thermal performance. The simulation results showed significant enhancement in air flow and air speed inside the test room compared to conventional windows, while the monitored test cells showed an average reduction in indoor temperature of 5 degrees and an average humidity reduction of 40 %. Further monitoring is needed to test other alternatives of the eco-cooler funnel design and improve overall performance.

KEYWORDS: Passive cooling, clay funnels, CDF, living labs, vernacular thinking, urban poor

1. INTRODUCTION

With global climate change, we are now facing an uptick in extreme heat events(Hulme, 2022). More areas worldwide will likely be affected by extreme heat waves more often while other areas will experience more severe heat for longer periods of time. These events will increase mortality rates due to heat stroke, draught and other negative consequences of extreme and prolonged heat on health and wellbeing. Typical hot arid climates are charactered by hot mornings and rather cool nights. In the past, vernacular approaches using cool night flushes helped to reduce high morning temperatures by cooling buildings at night and trapping cool air inside until at least noon. However, recent trends show increases in the number of hot summer nights per year, which means less cooling occurs at night.

Air-conditioning systems in residential units are now being installed in mild climates and even in cold climates to cope with summer heat waves. Air-conditioning systems are not only energy abusive, but they also contribute to increases in outdoor temperatures, further exacerbating climate change. Apart from the negative side of using active mechanical air conditioning systems, air-conditioning increases indoor comfort. Yet it is restricted to those who can afford to buy and pay the energy bills. This privilege does not apply to the majority of urban poor populations who live in poor conditions and can't afford such luxury. Home-makers, children, people with disabilities, and retirees are examples of population demographics who stay at home most mornings, often suffering from indoor heat stress during summer months. At night, the majority of the population who cannot afford mechanical air conditioning often suffers not only due to the heat, but compounded by the sleep deprivation it causes.

These vulnerable communities are the main beneficiaries of the outcomes of this study. The main point of this study is to offer a low-tech cooling system that can be installed easily and function like a "plug and play" system. The system can be assembled in less than 2 hours. Users can buy the eco-cooler pieces and install them themselves based on the size of their homes. The main and sole materials of the eco-cooler is clay.

This study was conducted in Cairo, Egypt, where there is a hot arid climate and60 % of the population lives under poor conditions, in informal areas. The research team has been working on using 'cone shaped' clay units to accelerate air-movement inside indoor spaces and reduce air-temperature. Clay has thermal properties that offer a natural regulator for heat transmission from outdoors to indoors. This lag-time in heat transmission is improved when the walls of residential units are not only made of clay, but also thick. After several experimental trials with clay cone shaped cooling units, Shisha funnels available in traditional Egyptian markets (see figure (1&2)) were tested. Using an existing good available in most markets for an affordable price (I EGP= 0.001 USD) will help make the eco-cooler accessible to most families.

The eco-cooler was monitored during June and July of 2021 and 2022. The results are promising in terms of reducing the humidity and air temperature of indoor spaces. The experimental work for the eco-cooler unit was done in an urban living lab on a roof top of one of the residential buildings in Cairo. The idea has potential for further applications in similar climatic contexts.

2. METHODOLOGY

The study followed an experimental urban living lab methodological approach using several tools and techniques.

2.1 Experimental simulation

The first step of the study was to conduct an experimental simulation using several shapes and forms of cone units (Shisha funnels) as a base for the eco-cooler. This step was based on our understanding for the rule of thumb of aerodynamics for cone shapes and the thermal properties of clay. Test simulations included an investigation of the efficiency of different forms. We tested 10 different shapes and sizes of Shisha funnels that were available in Egyptian markets. The funnels were drawn in 2D and 3D so as to use real-life measurements in computer simulations. After running Computational Fluid Dynamics (CFD) simulations, two shapes were selected for further analysis as test cells in an urban living lab context on the roof top of a residential building in Cairo.

2.1.1 CFD simulation

The Computational Fluid Dynamics (CFD) software package ANSYS FLUENT 2019 R3 was used in this study to simulate the airflow performance for different shisha funnel units. Two-dimensional geometry was drawn for both solid and fluid domains. The SIMPLE algorithm was applied for the pressure–velocity coupling in the segregated solver. A second order upwind scheme was adopted for the discretization of the governing equations. A standard k-ε turbulence model was applied to model the transport of turbulent kinetic energy, which is one of the most effective methods for natural ventilation simulations (Hughes et al, 2012). Uniform inlet velocity for the boundary condition was assumed to be 3.37m/s (the average wind speed in Cairo according to the weather data files.)

A 60x70 cm shoe box was modelled to resemble a living room with 21.5x30.5 cm (width x height) windows. In the shoe box, 4 Shisha funnels were tested for both single and cross ventilation techniques, as shown in figure 1. The window size was selected to be ⅓ the size of the façade to resemble typical residential units in Cairo. Figure 2 shows the shoe box computational domain, with dimensions of 17x7m for width and height, respectively.

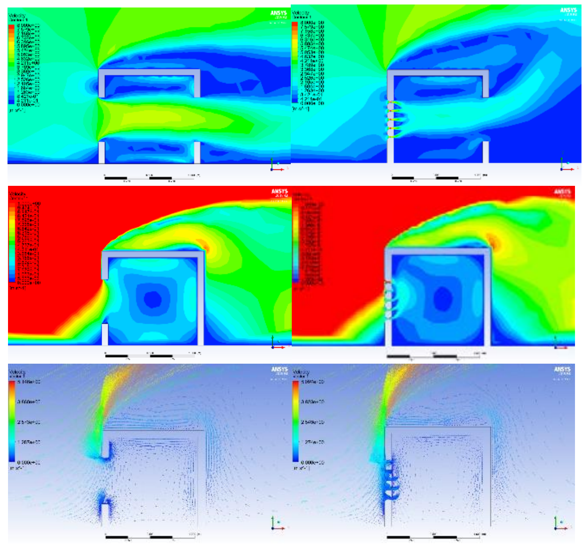


Figure 1: Single side and cross ventilation investigation in a 1x1 m shoe box room.

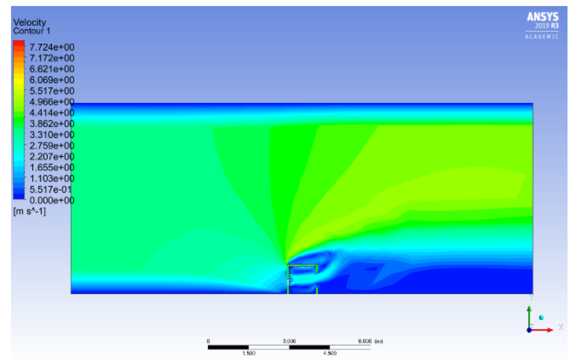


Figure 2: The computational domain

2.2 Test cells in urban living lab

3 test cubes (60*60*60 cm) were constructed on a roof top of a residential building in Cairo. The materials used in the text cubes are red bricks for the wall and

reinforced concrete for the ceilings. They resemble conventional construction techniques used in informal residential areas in Cairo. The eco-cooler was installed in two of the test cubes. One was installed using a single Shisha layer (7 cm thick) and another was installed using a double Shisha layer (14 cm thickness), measuring 20 cm in high and 20 cm wide. One test cube was left without an eco-cooler as a control case. Figure 3 shows the test cells after constructing and implementing the eco-cooler. Figure (4) shows the final outcome of the test cells with the two different designs of the eco-cooler.

Figure 3: The construction process of the eco-cooler during the proof-of-concept test cells using 8 and 16 funnels.

Figure 4: The eco-cooler after completing the drying process and before monitoring started.

2.3 Monitoring and evaporative cooling

The monitoring was carried out using the computer software Easy Logger. Ten minute intervals were monitored over the course of 7 days – from August 8 to August 15, 2021. The loggers were places in the three test cells (two containing eco-coolers and one control case). Outdoor temperature was also measured to compare between the temperature of the indoor test cells and the outdoor one. The loggers were placed in the center of the test cells for the indoor monitoring while the outdoor temperature was measured through a local weather station. The loggers and the weather station were calibrated. Figure 5 shows the test cells and the loggers during monitoring.

The text cubes were monitored from August 8-15, 2021 to test the efficiency of the eco-cooler pilot trial. Indoor temperature and humidity were monitored together with outdoor temperature and humidity. Figure 5 shows the loggers inside the test cells.

Figure 5: The loggers inside the test cells during monitoring.

After the complete construction of the eco-cooler and after the complete drying process of the clay mortar (to ensure that there was no internal humidity in the clay funnels or the mortar), monitoring started. A water sprinkling system was added for evaporative cooling. The water sprinklers were automated to spray water on the clay funnels 3 times a day for one minute each time between 8:00 PM and 09:00 PM. Figure 6 shows the eco-cooler after water sprinkling.

Figure 6: The test cells in the evening after the water sprinkling for evaporative cooling.

3. RESULTS AND DISCUSSION

3.1 Simulation outcomes

The CFD simulation for the 60x70cm shoe box room showed the velocity contours of the vertical plane inside 4 different test cells for cross ventilation. One scenario was tested for a typical case using a conventional window and the three others were tested using the Shisha funnels in different configurations. These 4 different test cells were used to compare the performance of different Shisha funnel configurations.

The results of the simulation showed that using Shisha funnels on both sides of the shoe box created the most uniform air distribution (Figure 7d). In terms of the placement of Shisha funnels, when 4 Shisha units were used as inlets and one as an outlet, the least air distribution was achieved (Figure 7b). When one side was used with 4 Shisha funnels and the other side was left open, the air distribution was better than resulted from the configuration shown in Figure 7a, but worse (lower speed) than the configuration shown in Figure 7d. The configuration shown in Figure 7a demonstrated the highest air velocity in the center of the room, but non-uniform air distribution, compared to the configurations shown in Figures 7c and 7d.

When one side was used with 4 Shisha funnels, as shown in figures 7c and 7d, it accelerated the air velocity in the upper level of the box compared to the fully open window show in figure 7a. Although the configurations shown in 7c and 7d achieved better air distribution in the whole room, 7a achieved the highest air velocity and distribution in the lower part of the room. While these preliminary results show that Shisha funnels do not seem to increase the air velocity inside the room compared to the fully open window, their shape shows promise in helping redistribute and orient airflow inside rooms, especially in cases where airflow is not perpendicular to the front of the room.

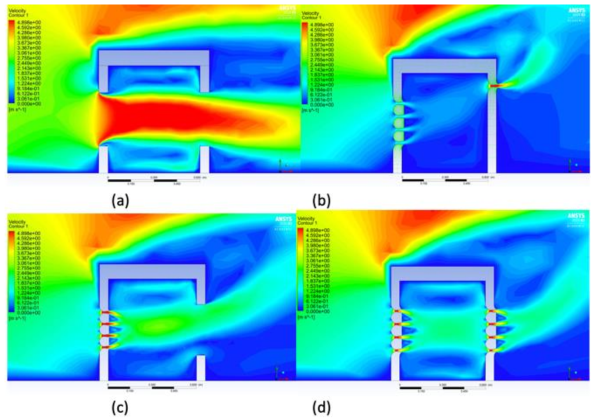


Figure 7 shows the final simulation outcome

While the shape of the clay funnel minimizes the amount of air that passes through the external wall and inside the shoe box, it maximizes the air velocity inside the clay funnel and gives a better air distribution in the whole space. Moreover, the characteristics of the clay material show high potential to reduce the air temperature in living rooms using evaporative cooling. Accordingly, the internal diameter of the clay funnel could be optimized in further research to maximize the amount of air that enters the room by cooling the air that passes through the clay material.

3.2 Monitoring outcomes

Monitoring showed a difference between the performance of the eco-cooler when dry and when wet using evaporative cooling. That is compared to the performance of the control case and the outdoor temperature. After sprinkling water on the funnels to test the evaporative cooling of the two eco-cooler cases, monitoring results showed a 4 degree difference (for the 9 nozzles) and 4.5 degree difference (for the 13 nozzles) in indoor air temperature compared to the control case. The control case was 0.5 degrees higher compared to the outdoor temperature. The temperature difference diminished as the nozzles were dried, reaching a difference of only 2 degrees and 2.5 degrees compared to the base case, respectively. These results can be interpreted to mean that the evaporative cooling was effective in helping reduce the air temperature inside the test cells. More monitoring for the impact of water sprinkling is needed over a longer period of time in order to more accurately measure the evaporative cooling effects of the wet shisha funnels.

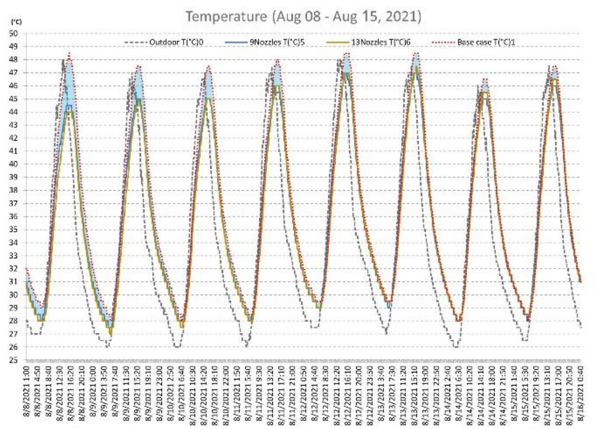


Figure 8. Monitoring outcomes, showing the temperature difference between the two test cells with clay nozzles, the control case, and the outdoor temperature.

Figure 9: Short video demonstrating the proof-of-concept construction process

4.CONCLUSION

This study used vernacular low tech and passive cooling concepts to design and implement a pilot eco-cooler using Shisha funnels for Cairo's hot arid climate. The experimental study and monitoring results were promising in terms of reducing the indoor temperature by 4.5 degrees. More trials will be conducted to improve the performance of the eco-cooler and reduce the indoor temperature to 24 degrees as an average indoor comfort range in Cairo and similar climates.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help of the residential building owner for giving us the opportunity to conduct the experiment on their roof top.

REFERENCES

1. Koch-Nielsen, H. (2002). Stay cool: a design guide for the built environment in hot climates. James & James.
2. Dabaieh, M., & Elbably, A. (2015). Ventilated Trombe wall as a passive solar heating and cooling retrofitting approach; a low-tech design for off-grid settlements in semi-arid climates. Solar Energy, 122. https://doi.org/10.1016/j.solener.2015.10.005
3. Fathy, H (1986) Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates, Published for United Nations University by the University of Chicago Press, Chicago, 1986.
4. Givoni, B. (1994). Passive Low Energy Cooling of Buildings. John Wiley {&} Sons.
5.Hughes, B.R., Calautit, J.K. and Ghani, S.A., 2012. The development of commercial wind towers for natural ventilation: A review. Applied energy, 92, pp.606-627.

PLEA 2022 SANTIAGO

Will Cities Survive?

Z-free home

A circular practice

MARWA DABAIEH [1], ILIA IARKOV, [2] KASPER RODIL [3]

[1]Malmo University, Malmo, Sweden
[2]Lund University, Lund, Sweden
[3] Aalborg University, Denmark

ABSTRACT: The need for affordable housing require more compact living conditions. With the rising impacts of climate change, a new way of thinking is needed to develop more resilient and climate responsive ways of living. In response, the idea of a 'Z free home' was born. The 'Z free home' is a tiny mobile house equipped with passive and eco-cycle systems that achieves 9 zero targets. The main design and construction concept is based on circularity and a return to nature life cycle principles. In this paper, the design concept, building modelling, and simulation for the Z free home design proposal is evaluated. The project is ongoing, and it aims at a full-scale physical prototype as a proof of concept for the 9 zero targets. This paper describes the design phase and will show the next steps planned for the proof of concept i.e., the 1:1 house model. The project is designed for the cold Swedish climate, but could be more widely applicable, both in other mild climates as well as hot climates.
KEYWORDS: Z free home, Eco-cycle, Passive design, 9Z

1. INTRODUCTION AND STATE OF THE ART

Scarce global resources and the mounting climate crisis are among the greatest challenges mankind faces today. There is a growing recognition that there is no planet B and that addressing the issues of climate change, biodiversity loss, mass extinction and environmental damage and pollution may be the principal challenges of our time (Hes & Du Plessis, 2015). Buildings and construction together account for more than 36% of global final energy use and 39% of energy-related carbon dioxide (CO_2) emissions (IEA, 2021). In recent years, the building sector has been moving steadily towards energy and resource efficiency, yet still not enough has been done to offset the rising energy demands of the building and construction industry. Over the next 40 years, the world expects to build 230 billion square metres in new construction (UN, 2021). That is the equivalent of adding a city the size of Paris to the planet every single week and a city the size of New York City every month.

Traditionally, in order to solve housing shortages, mass building using industrial materials is the quickest and easiest solution. A building's impact on the environment typically comes as a low priority. Fortunately, many opportunities exist to deploy energy-efficient and low-carbon solutions for buildings and construction (Dabaieh,2017). However, such ideas are not yet mainstream in the building market, especially within the residential sector. The UN's Sustainable Development Goals are giving new purpose to businesses, their buildings, and how they are designed, constructed, and used (French& Kotzé, 2018). Ambitious action is needed without delay to avoid locking in long-lived, inefficient building assets for decades to come (Lopes et al.,2017).

In this paper, an experimental living lab study is discussed as a pilot project for the design of a circular home. The study followed methodological steps to achieve 9 zero targets following circular design principles. While the study is ongoing, this paper reports on the results of what has been achieved so far. The house was designed for a Swedish climate, specifically for Lund, in southern Sweden. However, the methodological approach is possible to follow in different climatic and geographical contexts.

2. THE Z- FREE HOME DESIGN CONCEPT

The Z free home is a high-risk, high-gain eco-cycle home that exemplifies a return to nature design solution. The house will be designed and built using bio-based fibres that are sometimes disregarded as agriculture waste. The home is powered by renewable energy sources and aims to save 40% of energy consumption compared to current energy efficient buildings in Sweden. No mechanical systems will be used for heating, cooling or ventilation.

The building will be based on natural zero energy solutions that function year-round and produce more energy than the building consumes. The house will offset all its carbon emissions, if any, and aim to reach a negative carbon footprint. When it is time to demolish the building, all the main building components can be re-used as building materials, food for animals, or as biofuel. If the materials are not recuperated, they can rot as compost and return to nature. All organic waste and wastewater will be recycled and reused again, leaving zero waste behind. The design is simple, and all the eco-cycle systems will function as plug and play solutions.

The project is challenging – constructing the house in only 5 days with the help of 7 volunteers in a do-it-yourself (DIY) fashion, using only screwdrivers. In this way, the house is a unique challenge – it requires zero outside energy inputs, generates zero building material waste, produces zero carbon dioxide emissions, requires zero material costs, bears zero transportation impacts, creates zero operational waste, and requires zero labour costs (if you build it yourself). Finally, it has zero impact on the environment when the building is demolished.

3. METHODOLOGY

The project follows four main methodological steps. However, this paper will only present the outcome of the accomplished parts of the first and second phases as the third and fourth phases are not yet completed. The 4 phases are:

1. Design and design development phase:

This phase starts with a literature review and 10 intensive structured interviews with technical experts in the field of green systems. The literature review and interviews formed the basis of the architectural design phase for the innovative passive and eco-cycle systems. After the technical design phase, successive runs of building simulations were conducted using building energy modelling as a decision support tool for the passive and the eco-cycle systems design. Towards the end of this phase, two participatory and transdisciplinary workshops were carried out with technical experts, municipality personnel, a designer, representatives from the green construction building sector and local homeowners representing the non-technical home occupants. Virtual Reality (VR) interactive tools were used in these workshops to help the participants understand the passive and eco-cycle systems inside the house. The outcome of the workshop was meant to assist in enhancing the eco-cycle systems and add user-friendly detailing in the design of some of the features that were not accepted by the technical experts or homeowners.

2. Technical calculations and simulation:

A more advanced modelling and computational fluid dynamics simulation was carried out with the help of numerical calculations for energy use, heating and cooling loads, CO_2 emissions and renewable energy power generation. In addition to calculations and simulation for life cycle assessment (LCA) and life cost analysis (LCC). After that, lab experiments on building materials will be carried out to test the proposed materials to be used in the construction of the house. Tests such as water and fire resistance, compression, tension strength and structural stability were conducted. Many design iterations are expected in this phase after the simulation. A re-design and re-assessment will be done to verify the efficiency of the proposed systems after the LCA and LCC calculations.

At this stage of the project, the evaluation of the primary energy needs, and visual comfort of the Z-free home was measured with the ClimateStudio simulation software. The outdoor climate conditions were taken from the Climate OneBilding database (One Building, 2022) for Malmö (Sweden), with information from 2004 through 2018. The values of the domestic hot water and internal equipment loads were not calculated at this stage, and instead were taken from the requirement of the Swedish National Board of Housing, Building and Planning's constitution (BFS) 2017:6 BEN 2 (Boverkets författningssamling, 2017) for residential construction, providing values of 20 kWh/m^{2}y for domestic hot water and 30 kWh/m^{2}y for household needs. In future stages, these values might be re-evaluated and reduced.

One of the aims of this stage of the project is the evaluation of primary energy demands for heating and cooling and a comparison of those values against the requirements of BEN 2 (Boverkets författningssamling, 2017), Swedish environmental buildings standard 'Miljöbyggnad' (SGBC, 2021a), and German Passive House Institute standards (Passivhaus, 2021). According to aforementioned standards, primary energy use for heating and cooling should not exceed 15 kWh/m^{2}y after the implementation of passive measures, and total energy use intensity of the passive house should be below 75 kWh/m^{2}y. Indoor temperature was also considered, with the inclusion of FEBY18 standard requirements (Feby 18, 2019). For Sweden, this standard defines overheating as an indoor temperature above 26°C between April and September. Typically the number of hours when temperature is above 26°C should not exceed 10% of the whole number of hours in this period.

Electricity produced through solar panels was also calculated at this stage. The simulation included specific monocrystalline solar modules - model CS3K-300MS, which maintain a 20 % nominal efficiency. The inverter used for the photovoltaic installation was Solar Power YS YS-3000TL, 240 V. The system covers a total of 16 m^2 of the roof.

3. Proof of concept phase

The aim of this phase is testing the proposed low impact building envelope using natural materials (clay and plant-based materials like straw, reeds, wood, kenaf and jute) together with the passive eco-cycle systems in real life. A prototype of the test cells will be built in a laboratory environment to reduce the performance gap between the building performance simulation calculation and the real building performance. It will also allow for necessary design rectifications to be made before the full-scale house prototype is implemented. The proposed passive systems, a Trombe wall and a green wall, will be tested in the solar simulator lab. They will be simulated again together with earth pipes in the wind tunnel simulator lab to test the efficiency of passive heating and cooling with natural ventilation and natural air purification systems. Test cells are also important in order to estimate the efficiency expected from eco-cycle systems such as the composting toilet and the biogas stove. They can also be used for water heating. A demonstration test hybrid renewable energy system (PV and domestic wind turbine) without batteries will also be tested in both the solar lab and the wind lab. This is to ensure a net plus energy production in connection to the passive heating and cooling systems. The same tests will be conducted for the earth fridge and the low-tech waterless machines. In parallel to this phase, the researchers will prepare a detailed inventory for the test cells from a cradle-to-cradle life cycle perspective. The payback time for the systems and the whole buildings will also be calculated.

4- DIY construction in an urban living lab

The building construction stages for a physical full house model (20 m^2) with the eco-cycle and passive systems as a proof of concept is planned in DIY fashion. The house will be built in the experimental urban living lab area in Lund. The duration of construction is expected to take between 5 and 7 working days with the help of 7 volunteers. However, poor weather conditions could delay the construction process. Construction is to be carried out using participatory do-it-yourself (DIY) methods. Architecture and building construction students together with students at vocational schools will be the main target groups as volunteers. In this phase, pre-occupancy structure safety site tests will be carried out together with water leakage and indoor air infiltration tests. Finally, test occupancy time will be measured as part of a post-occupancy evaluation.

4. RESULTS

4.1 Literature outcomes

The literature search helped ground this study. It helped the researchers understand whether similar research on passive and eco-cycle building design has been conducted using circular design concepts. The target sources were journal articles, books, and technical reports from research projects, architecture, construction companies, and investment companies. The outcome of the literature search could be summarised in a gap between academia and practice when it comes to testing and experimenting zero emission building and circular buildings. The search also showed that the majority of circular buildings end up as pilot projects, but do not make it in common practice. There is a lack of application of eco-cycle systems in an integrated manner with passive systems and circular design principles. There are no homogeneous design protocols that can combine all three objectives – passive house, circular design principles, and at the same time equipped with eco-cycle systems.

4.2 Design proposal

The house design process resulted in a compact living house prototype – a place that contains the main necessities for a tiny house equipped with daily conveniences. Several passive systems are used to cover the needs for heating, cooling, natural ventilation, and daylight. A hybrid Trombe wall and green wall are used for passive heating and for indoor air purification. An Earth Air Heat Exchanger (EAHE) which takes advantage of both open and closed air cycles, is used for passive heating, passive cooling, and natural ventilation. A skylight is integrated in the roof design for adequate daylight, which is always a challenge in Scandinavian climates. Eco-cycle systems are show in Figures (1,2&3).

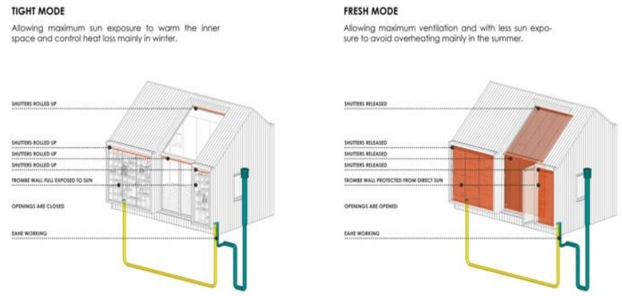


Figure 1: EAHE for passive cooling and heating used both for fresh and tight mode.

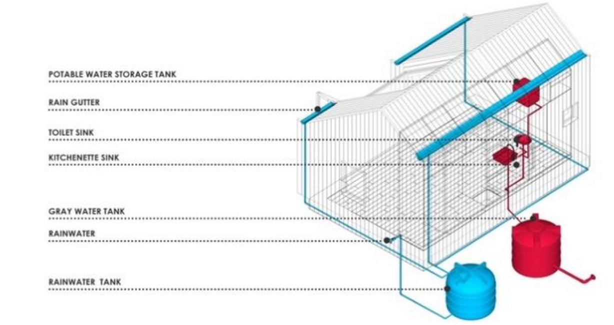


Figure 2: Waste management systems for recycling and reuse of grey and black water in addition to rainwater harvesting.

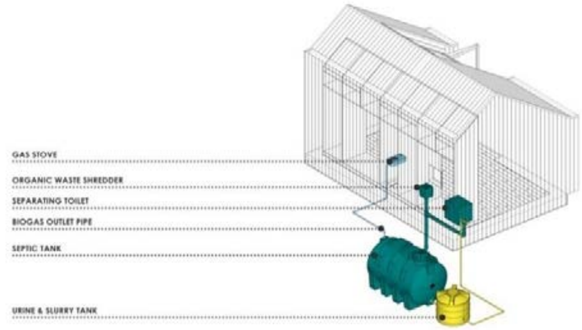


Figure 3: Waste management system for biofuel.

The house has flexible folded furniture together with a built-in kitchen and bathroom. The kitchen is equipped with a stove, refrigerator, and a biogas composting system as fuel for the stove. The bathroom has a toilet that separates solid waste as compost or biofuel for hot water. The kitchen also has an organic composter where organic waste from the bathroom can be mixed to produce biofuel for cooking and to heat water. The grey water from both the bathroom and the kitchen is filtered and reused for household cleaning and for irrigating non-edible crops in the green wall. Figure (4) shows the integrated hybrid green wall and the Trombe wall together with folded furniture.

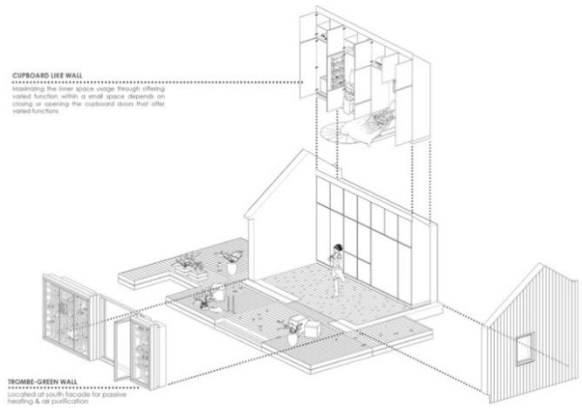


Figure 4: Axonometric of the house showing the folded furniture design, integrated Trombe wall and the green wall passive systems.

The folded furniture helps in maximising the use of the space. It also gives a flexible layout so that the tiny house can be used for office space during the day, if needed. If guests are invited, the folded bedroom creates extra space. Figures 5, 6 and 7 show the interior layout of the house.

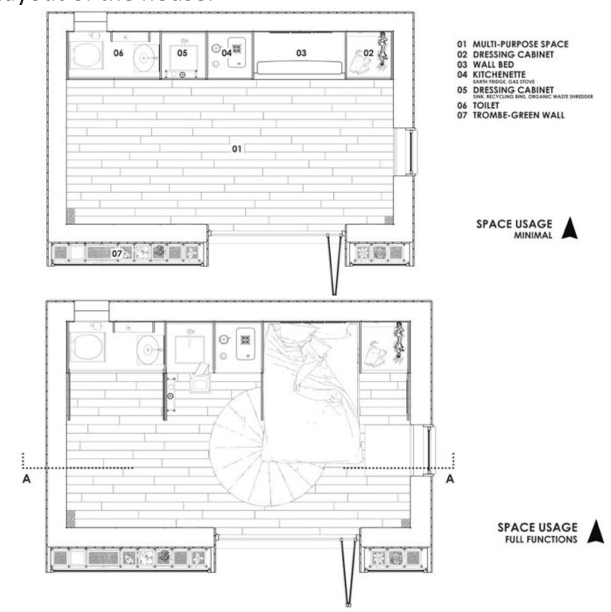


Figure 5: House plan. The top plan shows folded mode, and the lower plan shows the unfolded mode.

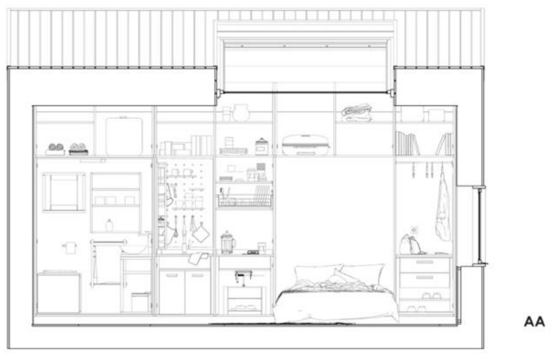


Figure 6: Cross section of the house showing the different interior foldable facilities.

Figure 7: The south elevation showing the hybrid Trombe wall and the green wall together with the skylight.

4.3 Interviews and VR participatory workshop

The interviews with expert designers were very informative in the design of the passive systems. Interviewees raised their concerns about how the eco-cycle and passive systems function. The architects who were interviewed are considered specialists in green building design. One used the EAHE as a geothermal system for passive heating and one used the Trombe wall for passive heating. Thus, the shallow EAHE used in the Z free home was a new application for them as it is for passive heating, ventilation, and air purification. Was also new for the interviewees the use of Trombe wall, which is integrated with the green wall and used for heating, cooling, and air filtration. Some of the concerns raised for the passive systems were related to the mould formation in EAHE and the efficiency of the passive systems. The numerical calculations and the outcome of the simulation were used to support the discussion and show the expected efficiency of the passive and eco-cycle systems. Only one expert architect had previously worked with eco-cycle systems, and he has tested many of the approaches proposed in the Z free home, such as the composting toilet. The rest of the architects shared doubts on how the waste management works and the efficiency of the systems for biogas production and the heating of water. The outcome of the interviews was helpful to adjustment the design of the house.

The participatory VR workshop with laymen participants representing potential homeowners was informative. The participants were able to understand the mechanism of operating the various passive systems using VR tools. For example, they gave their feedback on how easy or how difficult it was to open the green wall or the earth refrigerator. They were also able to provide feedback on the folded furniture and how they perceived the space in terms of size and functionality. The outcome of the workshop and feedback from the participants was helpful to adjust the design for the passive and the eco-cycle systems. Figures 8 & 9 show the VR experiment.

Figure 8: Testing the Eco-cycle systems in VR- Photo credits MED 8 at Aalborg University.

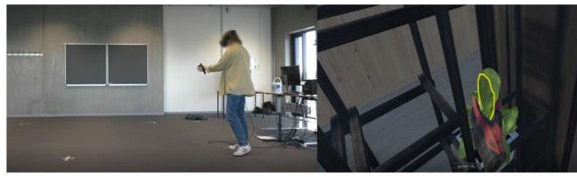


Figure 9: Testing the Hybrid Trombe wall and the green wall in VR. The left side shows a VR participant interacting from an in-room view. The right side shows the participant interacting inside VR.

4.4 Simulation results

The outcome of the building simulation for heating loads, cooling loads and energy production was useful to optimise the efficiency of the passive systems for the reduction of heating and cooling demands together with optimising active the renewable systems. Based on the simulation, the building requires approximately 13 kWh/m^{2}y of primary energy to cover the cooling demand and approximately 10 kWh/m^{2}y of primary energy to cover the heating demand. Both values were calculated with the consideration of EAHE. Paired with the energy use intensity of approximately 73 kWh/m^{2}y, the evaluated house satisfies the passive house standard. The skylight proved to be detrimental for the summer period, due to the significant overheating and visual glare problems it caused. However, the cooling and heating system fixed this problem, as demonstrated in figure 10. The total energy use for different house functionalities was 1467 kWh, while the electricity production from solar panels was 3452 kWh, which is more than the calculated energy consumption. Therefore, the house will perform as an energy positive house. The daylight factor was within the standard range, except in the zone under the skylight, as demonstrated in figure 11. The spatial disturbing glare simulation showed a significant number of views with intolerable glare as demonstrated in figure 12. Venetian blinds were installed to remove the glare in the most extreme cases. For the natural ventilation simulation, the EAHE was sufficient to provide the adequate air intake for fresh air needed given the small size of the house.

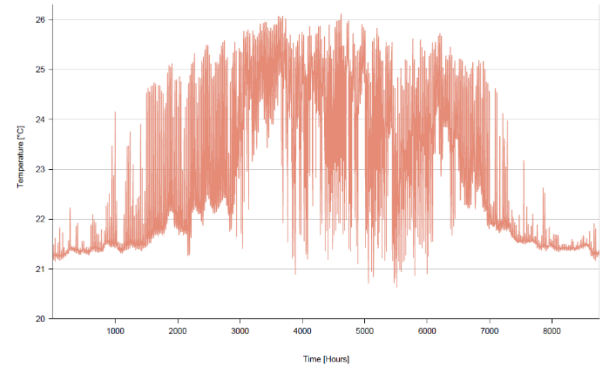


Figure 10: Temperature distribution within the Z-free home on an hourly basis.

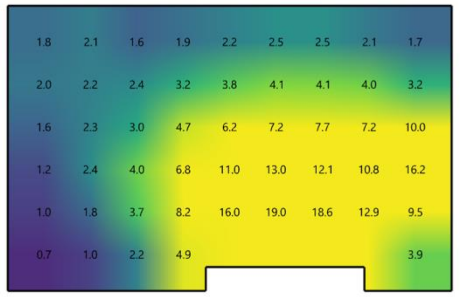


Figure 11: Daylight factor in the Z-free home.

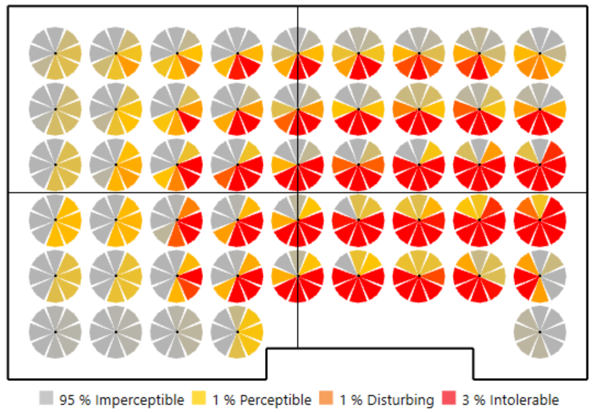


Figure 12: Spatial disturbing glare in the Z-free home on an annual basis.

5 Discussion

The Z free house as pilot for combining eco-cycle systems with passive means through circular design is a high gain project given all the challenges it is trying to overcome. From the phases finished so far, one can say that the design details for passive and eco-cycle systems and aspects in the house are the main reason for its efficiency and performance to achieve the zero energy, zero emission, zero waste and zero carbon. The rest of the zeros will be verified after finalising the rest of the methodological phases. The involvement of architects and engineers was important to improve the design details and achieve better performance. The involvement of laymen users in the VR workshop gave more confidence for the design technicalities and use. Many concepts in the Z free house are not common in normal residential units, so it was important to employ a user-centred design approach. The simulation phase as a design support tool was important to make several optimizations. For example, blinds was introduced over the skylight to reduce glare and overheating over summer.

There are still challenges ahead, particularly in relation to fire proofing, water resistance and construction detailing. Once the construction of the house is complete and the building envelope is tested, a complete life cycle assessment and life cost analysis will be conducted to review the final performance of the house and the pay back time.

6 Conclusion

This paper details the outcomes of the first two phases of the Z free home research project, showing the design and the different participatory approaches with expert interviews and VR workshops with laymen participants. The project is a high gain project as preliminary outcomes show that the house performs better than standard energy efficient residential buildings according to Swedish standards. Yet it is also a high-risk project, since the performance of passive and eco-cycle system in real life can differ than simulation. As this project is ongoing, it is still hard to conclude its final performance outcomes; however, the preliminary results are promising. The full-scale final proof of concept will demonstrate all final study outcomes and the real performance in the real climate in Lund, Sweden.

Acknowledgment

The author would like to thank research assistant Mohamed ElBangy, Med 6&8 students at AAU for the VR workshop and acknowledge Crafoord for the research grant.

References

1. Dabaieh, M. (2017). Minus carbon & plus energy: a design home kit. (1st edition). Malmö: Malmö university press.
2.Feifer, Lone., Imperadori, Marco., Salvalai, Graziano., Brambilla, Arianna. & Brunone, Federic, 2018. Active House: Smart Nearly Zero Energy Buildings. Cham: Springer International Publishing.
3. French, D. & Kotzé, L.J. (red.) (2018). Sustainable Development Goals: law, theory and implementation. Cheltenham, Glos: Edward Elgar Publishing.
4. Hes, D. & Du Plessis, C.(2015). Designing for hope: pathways to regenerative sustainability. New York: Routledge.
5. IEA. (2021). World Energy Outlook 2021 : Part of the World Energy Outlook. International Energy Agency, 386. https://www.iea.org/reports/world-energy-outlook-2021
6. United Nations. (2021). Global Status report for Buildings and Construction 2021. United Nations Environment Programme. https://globalabc.org/resources/publications/2021-global-status-report-buildings-and-construction
7. One Building. (11 4 2022). ClimateOneBuilding. Retrieved from ClimateOneBuilding
8. Boverkets författningssamling. (26 June 2017). Boverkets föreskrifter om ändring av verkets föreskrifter och allmänna råd. Retrieved from Boverkets författningssamling: https://rinfo.boverket.se/BEN/PDF/BFS2017-6-BEN-2.pdf
9. SGBC. (2021a). SGBC: Miljöbyggnad. Retrieved from SGBC: https://www.sgbc.se/certifiering/miljobyggnad/ [2021-12-08]
10. Passivhaus. (5 December 2021). Retrieved from International Passive House Conference 2023: www.passivhaustagung.de
11. Feby 18. (2019). Byggnadskrav.Retrieved from Forum för Energieffektivt Byggande: https://www.feby.se/files/2019-01/byggnadskrav.pdf

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Natural ventilation for indoor air quality in schools regarding thermal comfort during the winter season in Chile

MARTIN ORDENES[1], GILLES FLAMANT[2]

[1] Universidad Federal de Santa Catarina,
[2] Centro de Desarrollo Urbano Sustentable, Pontificia Universidad Católica de Chile, Santiago, Chile

ABSTRACT: From the AChEE technical report published in 2012, to achieve thermal comfort and energy performance in educational buildings, this present research work aims to be an additional contribution to explore the potential of natural ventilation for indoor air quality in classroom during the winter season in Chile. The same classroom modeled in the AChEE report is used to evaluate through EnergyPlus simulations the impact of different natural ventilation strategies on the indoor temperatures and CO_2 concentration. Results show the importance to consider the close association between thermal comfort and CO_2 concentration level, especially for climates with extreme cold conditions in winter. Indoor air quality cannot be seen as an independent parameter to explore natural ventilation as an option for classroom air renovation in these colder situations. For Santiago it is possible to propose a periodic natural ventilation strategy with brief moments of window opening since CO_2 concentration declines quickly and the local climate offers a propitious scenario in terms of wind availability and moderate temperatures during the winter season. For cities like Concepción and Punta Arenas, with more severe winter climate, this strategy would no longer be adequate.
KEYWORDS: Natural ventilation, Thermal comfort, Indoor Air Quality, Educational building simulation.

1. INTRODUCTION

In 2012 the Chilean Agency for Energy Efficiency (AChEE, in Spanish) published a technical report to establish envelope project guidelines all over the country in order to achieve thermal comfort and energy performance in educational buildings [1]. It shows, through simulations, the importance of ventilation for comfort and thermal loads. Despite the concern with indoor air quality (IAQ), no contaminant modelling was included in the report and a constant ventilation rate was used for all cases, which implies a mechanical ventilation system. Thus, this work aims to contribute with this effort by exploring the potential of natural ventilation in a representative classroom to control CO_2 concentration conditions for the academic calendar under the climatic conditions of different southern Chilean cities. This scenario presents an important challenge during the winter season: How and in which extent can we use natural ventilation to provide adequate fresh air conditions without cold draughts during teaching hours?

2. INDOOR AIR CONDITIONS IN CLASSROOM

A concern about IAQ for our children's health and its impact on learning environment is not something new. Even before the pandemic situation imposed by COVID-19, there is evidence that reduced respiratory disease effects and reduced student absence are associated with increased fresh air supply rates and low CO_2 concentration [2], even though adequate temperature and humidity conditions were observed [3]. For classroom spaces using natural ventilation, a CO_2 concentration target level up to 1000 or 1500 ppm can be established as a daily average limit during the occupied period, considering the variability of wind driving forces [4]. However, some studies reported nearly 40% to 60% of the occupied time CO_2 concentration exceeding 1000ppm and occasionally reaching a maximum concentration of 3000 to 5000ppm, mainly in winter season [5 – 7].

2.1 Schools in Chile

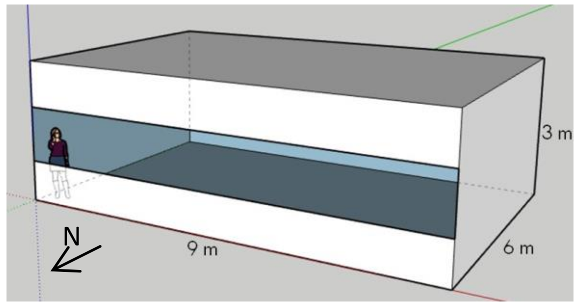
The AChEE report [1] highlights CO_2 concentration as the main internal contaminant in Chilean schools due to a high density occupation from students and moderate opportunities to use natural ventilation to improve air quality in many cities since an annual average wind speed of 2,0m/s is registered. Main suggestion is to use the stack effect in the winter season by high openings close to the ceiling.

However, there is experimental measurement in schools during a regular academic year evidencing inadequate internal conditions in primary schools of Santiago and Punta Arenas with very low indoor temperatures during the winter season (70% of the time below 17°C) and CO_2 concentration easily higher than 1000ppm during teaching hours [1, 9 - 10].

3. SIMULATION METHOD FOR SCHOOLS

The same classroom modeled in the AChEE report [1] is used to evaluate the impact of different natural ventilation strategies on the indoor temperatures and CO_2 concentration. According to this report, a 54 m^2 classroom is common for public school establishments in the Ministry of Education national plan. Thus, a representative model with 6 x 9 x 3m dimensions with adiabatic walls except for the northern façade was considered. Such façade is a 200mm concrete wall with an external thermal insulation and a double glazing system for a window of WWR 34% (Figure 1).

Figure 1:
Classroom model used in EnergyPlus.



Occupation period follows the academic calendar in Chile: 1st semester from 03/01 to 07/15 and 2nd semester from 08/01 to 12/10. Classes, Monday to Friday from 8am to 4pm with an hour lunch break at 12am. Internal heat gain is due to artificial lighting system (11W/m^2), electric equipment (6W/m^2) and people considering 1 adult teacher (108W) and 45 children students (66W each), as it was modeled in the AChEE report [1].

The simulation software used is the latest version of EnergyPlus (V9.5.0). To model the CO_2 concentration in the classroom, the Zone Contaminant Source and Sink object was used, considering an external CO_2 concentration of 400ppm and an internal generation of $3{,}82 \cdot 10^{-8}$ m^3/s for each unit (in W) of metabolism. To model natural ventilation, the Zone Ventilation Object called Wind and Stack Open Area was used, this algorithm for natural ventilation considers both wind driven forces and thermal stack effect from climatic data. Weather files used for Santiago (33°South), Concepción (36°South) and Punta Arenas (53°South) are TMYx2004-2018 data [11].

Although thermal comfort depends on operative temperature, windows control is due to air temperature above 20°C considering that the mean radiant temperature can be lower than 20°C, due to heat losses in winter conditions. Even if there is evidence from Chilean students to adapt in a wide range of indoor temperatures [9], opening for natural ventilation is controlled by a narrower range of indoor temperatures (20°C – 25°C) in order to preserve children's health and to guarantee a proper environment for concentration and learning. This same purpose is used to establish a CO_2 concentration limit of 1000ppm, since higher indoor concentrations of CO_2 impairs attention span and increases concentration loss and tiredness.

Preliminary simulation results with no ventilation strategy (only a 1,5 ACH infiltration), showed a daily average CO_2 concentration of 1800ppm and a peak CO_2 value above 2200ppm every school day. Without any ventilation, a maximum of 15 students can be admitted in class in order to keep CO_2 concentration under 1000ppm.

Thus, three strategies (ST) for natural ventilation are explored for public schools of Chile: (ST1_Comf_Vent) Thermal comfort oriented natural ventilation where window opening is controlled automatically to preserve internal temperature between 20°C and 25°C; (ST2_ExtraBreak_Vent) ST1_Conf_Vent plus an extra ventilation mandatory for 15 minutes between classes (class break); (ST3_WindOrient_Vent) ST2_ExtraBreak_Vent but rotating the classroom to face the more frequent wind direction in winter, i.e. south for Santiago and Concepción and west for Punta Arenas. No HVAC is considered in any strategy.

4. RESULTS

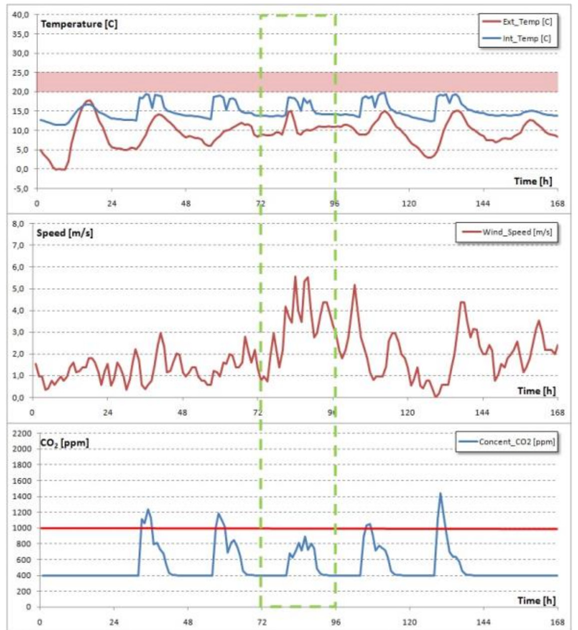
Outputs from EnergyPlus simulations are analysed on a week base scale, mainly for temperature, wind conditions, ventilation rate and CO_2 concentration for the winter season.

To illustrate a common behaviour found from results, Figure 2 shows the third week of August in Santiago for the thermal comfort oriented ventilation (ST1_Comf_Vent). In these graphs, red series indicate outdoor conditions and blue series indicate conditions inside the classroom.

From the first graph it is possible to observe that this ventilation strategy keeps the indoor temperature close to the lower level of thermal comfort (20°C). This is because internal heat increases indoor temperature above 20°C and then the window opens to let in the cold outside wind. This would be the maximum ventilation rate we can get when thermal comfort is the main priority. However, from the third graph it is possible to observe that this strategy is not enough to guarantee IAQ, since 4 out of 5 days in this week the internal CO_2 concentration is above 1000ppm. Only on Wednesday all the academic period is below the CO_2 concentration limit due to a combination of a more pleasant outdoor temperature and a higher wind speed, as it is highlighted in the green square. In total, this week showed a 63% of the occupied hours below 1000ppm.

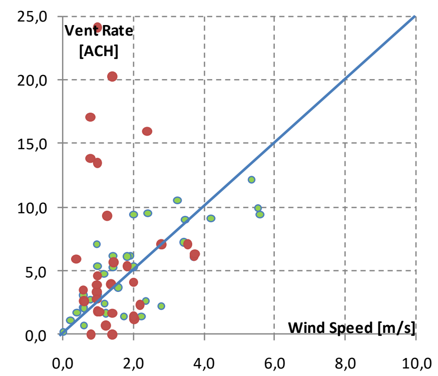
Another common result found in most simulations is that the highest CO_2 concentration levels occur on the first teaching hours of each day. Because it is the moment of the day with the lowest outdoor temperature, the window remains closed most of the time.

Figure 2:
Temperature, wind speed and CO_2 conditions for comfort oriented ventilation ST1 in Santiago.



Additionally, it was observed from this first ventilation strategy tested that it is not possible to establish a direct association between wind speed and ventilation rate (Figure 3). This correlation would be helpful to estimate the air renovation in a similar classroom from an outside anemometer data.

Figure 3:
Wind speed and ventilation rate for comfort oriented ventilation ST1 in Santiago.



The green series in Figure 3 shows the data for the same week as for Figure 2 and it can be observed a quite direct correlation between these two parameters. However, the week before (red series) shows no association and even higher ventilation rates can be observed for low wind speed. This is because the outdoor air temperature is closer to lower comfort limit (20°C) allowing the window to remain open for a longer period of time.

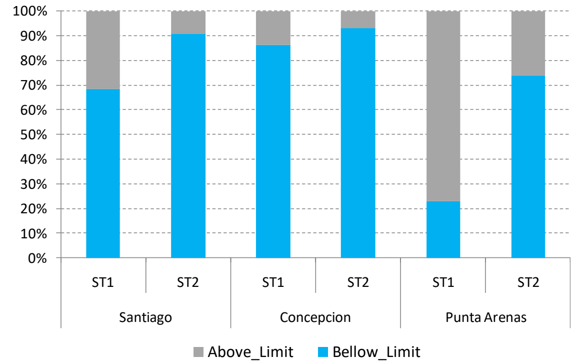
Thus, it is not possible to establish a general simple rule for schools where "the more wind, the better ventilation". When thermal comfort is a key aspect in the cold season, other parameters matter like outdoor and indoor air temperature and wind direction.

4.1 Windows open during class break

For the winter season, it is important to do a detail analysis to better understand the impact of natural ventilation on thermal comfort and indoor air quality in schools.

Figure 4 shows the impact of ventilating for 15 minutes between classes, by comparing the CO_2 concentration for ventilation strategies ST1_Comf_Vent and ST2_ExtraBreak_Vent.

Figure 4:
Percentage of occupied hours with CO_2 above and below limit for ventilation strategies ST1 and ST2.

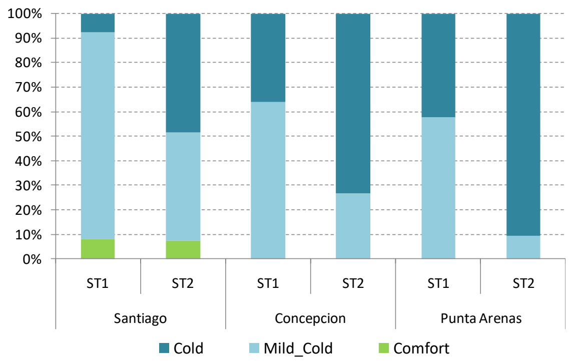


These results show how this brief period of window opening can significantly improve the IAQ in classrooms, especially in the coldest city (Punta Arenas) where a thermal comfort oriented ventilation strategy (ST1) keeps the window closed and lead to a 77% of the occupied hours with a CO_2 concentration above 1000ppm. In this case, ST2 seems to invert the IAQ situation and shows an acceptable CO_2 condition for 74% of the teaching hours in winter.

However, this 15 minutes ventilation imposed before classes will let the cold outdoor air inside the classroom and reduce the indoor temperature despite the internal heat generated from people and equipment. This can lead to increase the discomfort sensation in students as it is shown in Figure 5.

As it was shown earlier in Figure 2, the comfort oriented ventilation strategy (ST1) keeps the indoor temperature slightly below the lower comfort limit and all these hours should compute as a cold condition and contribute to thermal discomfort. In order to better understand the thermal impact of the 15 minutes ventilation strategy, this result was subdivided in "Mild_Cold" sensation when 18°C ≤ Int_Temp < 20°C and "Cold" sensation when Int_Temp < 18°C.

Figure 5:
Percentage of thermal comfort during occupied hours for ventilation strategies ST1 and ST2.



Santiago is the only city where thermal comfort can be achieved for 8% of the class hours during the winter season without any heating system and the 15 minutes ventilation strategy between classes doesn't change very much this percentage. However, the thermal discomfort is accentuated by having almost half of the time with a cold condition inside the classroom. For Concepción and Punta Arenas, ST2_ExtraBreak_Vent significantly increases the cold situation in the classroom. In Punta Arenas this brief period of ventilation can lead to a very cold condition almost all winter, causing not only a thermal discomfort situation but probably serious respiratory disease and learning problems in students.

4.2 Solar orientation versus wind orientation

The base model presented in Figure 1 has the only window oriented to north. This is convenient for cold regions in the southern hemisphere to take advantage of the solar radiation to heat internal spaces. But since the ventilation strategy during break times leads to the opening of the window for a short period of time it is interesting to explore if this strategy can be improved rotating the classroom and orienting the window to the most frequent wind direction in the winter period, i.e. facing south for Santiago and Concepción and west for Punta Arenas.

Table 1 presents the percentage of occupied hours in August with the acceptable CO_2 level (concentration below 1000ppm), comparing a solar oriented classroom (with higher solar heat gains) (ST2) and a wind oriented classroom (with a higher potential for ventilation rate) (ST3).

For both orientations it can be observed a slight variation of percentage from week to week without a clear tendency or behaviour. This variation is expected since wind conditions can be very random.

Table 1:
Percentage of occupied hours in August with acceptable CO_2 conditions for ventilation strategies ST2 and ST3.

		1st week	2dn week	3rd week	4th week
		%			
Santiago	Solar Oriented	88,6	91,4	88,6	85,7
	Wind Oriented	82,9	80,0	82,9	68,6
Concepción	Solar Oriented	77,1	97,1	97,1	94,3
	Wind Oriented	65,7	88,6	88,6	91,4
Punta Arenas	Solar Oriented	68,6	80,0	68,6	74,3
	Wind Oriented	68,6	74,3	68,6	71,4

However, it can be seen from Table 1 a clear tendency to reduce the percentage of acceptable CO_2 concentration when the classroom is rotated to chase the best wind condition. This aggravation in the IAQ of the classroom can be explained by a lower indoor temperature because less solar heat gain is admitted and the window remains closed for a longer period of time each week as it is shown in Table 2.

Table 2:
Total of time (in hours) of the occupied period with closed windows for ventilation strategies ST2 and ST3.

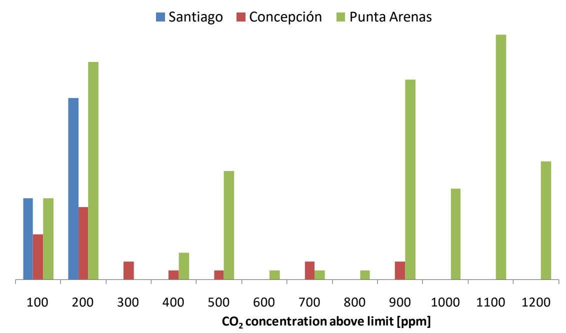
		1st week	2dn week	3rd week	4th week
		Time [h]			
Santiago	Solar Oriented	1,0	2,0	1,0	1,0
	Wind Oriented	3,0	4,0	3,0	5,0
Concepción	Solar Oriented	3,0	0,0	0,0	1,0
	Wind Oriented	4,0	4,0	3,0	3,0
Punta Arenas	Solar Oriented	10,0	7,0	10,0	8,0
	Wind Oriented	10,0	9,0	10,0	10,0

4.3 Final diagnosis for comfort oriented ventilation

Since strategies of opening for 15 min (ST2) and wind oriented ventilation (ST3) had degraded significantly the thermal comfort in winter and could expose students to extreme cold conditions, a more detailed analysis is performed in order to observe the scope of natural ventilation oriented for thermal comfort (ST1) can have to maintain acceptable CO_2 conditions in the classroom.

Figure 6 shows the frequency of occurrence for the CO_2 concentration above the acceptable limit (1000ppm) for the three cities. It is evident that for climates with a moderated winter season, like Santiago and Concepción, a ventilation strategy oriented to preserve thermal comfort of students can present CO_2 concentration levels slightly above the recommended limit (100 ~200 ppm). On the other hand, an extreme winter season as in Punta Arenas, presents an important challenge since indoor air temperatures are always below 20°C and CO_2 concentration can frequently double the recommended limit.

Figure 6:
Frequency of occurrence for CO_2 concentration above limit (ST1)



5. CONCLUSION

From the AChEE published in 2012, to achieve thermal comfort and energy performance in educational buildings, this research work aims to be an additional contribution to explore the potential of natural ventilation for indoor air quality in classroom during the winter season and thus, caring about learning and health of our young students in public schools.

Observing results in general, it is important to highlight the close association between thermal comfort and CO_2 concentration level, especially for climates with extreme cold conditions in winter. Indoor air quality cannot be seen as an independent parameter to explore natural ventilation as an option for classroom air renovation in these colder situations. This partial approach could lead to expose students to very cold conditions in class and undesirable cognitive and health consequences.

From the tendency observed in ventilation strategies simulations, it is possible to propose for Santiago a periodic natural ventilation strategy with brief moments of window opening (ST2_ExtraBreak_Vent) since CO_2 concentration declines quickly and the local climate offers a propitious scenario in terms of wind availability and moderate outdoor temperatures during the winter season. The city of Concepción has a similar climate condition as Santiago; however, ST2_ExtraBreak_Vent can cause an increase on discomfort cold hours. For Punta Arenas, with more severe winter climate, this strategy would no longer be adequate because it emphasizes the cold air condition inside the classroom and could, eventually, create learning and respiratory problems in students. For these colder climates, thermal comfort should be considered as a priority in the control of the window opening and privilege solar orientation for the architectural project. In these cases, indoor air quality should be treated as a concern for fresh air renovation rate as part of a HVAC system performance.

ACKNOWLEDGEMENTS

This research work was accomplished as part of the International Academic Exchange Programm (PRINT) with the financial support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) from Brazil, trough the financial code 001. We also thank the support from the project ANID/FONDAP/15110020 (CEDEUS), Chile.

REFERENCES

1. AChEE – Agencia Chilena de Eficiencia Energética, (2012). Guía de Eficiencia Energética para Establecimientos Educacionales. Santiago, Chile. 356 pp.
2. Fisk, W., (2017). The ventilation problem in schools: literature review. Indoor Air Journal, 27: p. 1039–1051.
3. Johnson D., Lynch, R., Floyd, E., Wang J., and Bartels J (2018). Indoor air quality in classrooms: Environmental measures and effective ventilation rate modelling in urban elementary schools. Building and Environment, 136: p. 185-197.
4. Education and Skills Funding Agency. (2018). Building Bulletin 101: Guidelines on ventilation, thermal comfort and indoor air quality in schools.
5.Cai, C., Sun, Z., Weschler, L., Li, T., Xu, W., Zhang, Y. (2021). Indoor air quality in schools in Beijing: Field tests, problems and recommendations. Building and Environment, 205.
6. Gabriel, M., Paciência, I., Felgueiras, F., Rufo, J., Mendes, F., Mourão, M., Moreira, A., Fernandes, E. (2021). Environmental quality in primary schools and related health effects in children. An overview of assessments conducted in the Northern Portugal. Energy and Buildings, 111305.
7. Wang, X., Yang, L., Gao, S., Zhao, S., Zhai, Y. (2021). Thermal comfort in naturally ventilated university classrooms: A seasonal field study in Xi'an, China. Energy and Buildings, 247.
8. ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers (2022). ASHRAE Position Document on Indoor Carbon Dioxide. [Online], Available: https://www.ashrae.org/about/position-documents [16 March 2022]
9. Trebilcock, M., Soto-Muñoz,J., Yañez, M., Figueroa-San Martin, R. (2017). The right to comfort: A field study on adaptive thermal comfort in free-running primary schools in Chile. Building and Environment, 114: p. 455-469.
10. Laboratorio de Arquitectura – LABARQ (2012). Auditoría energética y de condiciones de confort en establecimientos educacionales: Zona centro interior (Peñalolén) y zona sur (Punta Arenas). Pontificia Universidad Católica de Chile. 160 pp.
11. Lawrie, L., Drury C. (2019). Development of Global Typical Meteorological Years (TMYx). [Online], Available: https://climate.onebuilding.org/ [16 August 2021].

PLEA SANTIAGO 2022
Will Cities Survive?

Communicating Carbon

Visualising embodied carbon results for data lead design decisions

NEWMARCH, EMILY RUTH[1]; DONN, MICHAEL[1]; TWOSE, SIMON[1]; SHORT, FIONA[3]; DOWDELL, DAVID[2]

[1] Victoria University of Wellington, New Zealand
[2] Building Research Association of New Zealand
[3] Warren and Mahoney, New Zealand

ABSTRACT: This paper reviews the effectiveness of methods of communication for embodied carbon in buildings. 272 visualisations were extracted from 10 different LCA tools available to designers. The visualisations were categorised into goals for designers to focus the sample size. The groups of visualisations were presented to a group of senior architects to provide feedback on their understanding of the information. This feedback was used as a starting point to develop a dashboard and visualisation to ensure embodied carbon information about a project can be effectively communicated and understood to enable meaningful action. This paper is a contribution from a research project embedded in the production processes of an architecture design firm.
KEYWORDS: Embodied Carbon, Designers, Data Visualisations, Life-cycle assessment

1. INTRODUCTION

Globally there is an increasing need to calculate and mitigate the carbon emissions from buildings. Many countries have committed to 2°C of warming limit in the 2015 Paris Agreement[1]. In 2018, the IPCC suggested that it is critical to stay below a 1.5°C limit [2]. To remain below these limits, it is essential to address emissions of carbon dioxide and other greenhouse gases that contribute to climate change. Globally, buildings contribute 39% of carbon dioxide emissions [3]. Of these emissions, 28% are reported as caused by operational carbon and 11% by embodied carbon [3]. With efforts to lower energy consumption and transition national grids to renewable sources, operational carbon emissions will reduce and likely lead to embodied carbon representing a much larger proportion of the carbon impact if left unaddressed [4].

1.1 EMBODIED CARBON

Embodied carbon is the emissions used to produce, construct, maintain, and deconstruct buildings. Embodied carbon is calculated as part of a Life Cycle Assessment (LCA), which reports on multiple environmental impacts from buildings. A LCA breaks down a building's life cycle into modules that are outlined in EN15978 [5]. To simplify the process, data that is input into the LCA is sourced from Environmental Product Declarations (EPD) or databases that represent industry averages for common materials. Embodied carbon data is typically recorded as Global Warming Potential (GWP_{100}) and considers emissions from fossil fuel consumption and biogenic carbon storage and emissions [6].

1.2 THE NEED FOR VISUALISATIONS

Whilst guidelines and templates for producing full LCA results exist, they are targeted at LCA experts [7], [8]. Currently there are no guidelines for the interpretation of LCA results that address a wider group of stakeholders [9], including designers who will use the results to inform decisions. The effect is LCA results are perceived as complex and difficult to interpret [10], [11]. To inform design decisions, it is critical that results from an LCA, including embodied carbon, are interpreted effectively[9]. Further, the format of the results must be understandable by multiple stakeholders to encourage interaction and collaboration in the exchange of relevant information [12]. For effective interpretation of results, visualisations can provide the necessary support to inform design decisions [9]. The use of visualisations to improve the interpretation of LCA results has been widely discussed in the literature [13]–[15]. Whilst visualisation is recognised as useful to support interpretation of the results, there is limited research developing the type of visualisations for building LCA results [9].

As part of an LCA, a building's carbon emissions are necessary to understand among all stakeholders interested in remaining within the 1.5°C limit. Developing visualisations for building energy performance has been widely documented for decades [16], [17], in turn making the interpretation of operational carbon easier. Embodied carbon is an emerging area and has far fewer studies developing visualisations of the results. Of the studies that do exist, there is heavy emphasis on the EN15978 modules through Sankey diagrams [18], [19], and the cost of embodied carbon through Marginal Abatement Cost Curves MACC [20]. Both approaches focus on singular visualisation styles and require specialist involvement. As a result, wider stakeholder involvement is excluded, making it difficult to use the results in decision making.

2. METHOD

The research for this paper has been undertaken in collaboration with an architectural practice in New Zealand and is targeted at using an academic understanding of the field to benefit real projects. The method consists of four parts. The first part defined the goals for key stakeholders at different design stages for embodied carbon (through LCA). The second part reviewed graphs for visualising embodied carbon from LCA tools against the goals to classify the different visualisation methods. In the third part architects were asked for feedback on the visualisations for their effectiveness in identifying carbon hotspots and interpretability to stakeholders. Finally, the fourth part developed a visualisation strategy for effective communication of embodied carbon.

3. RESULTS

This section is broken down into four parts to match the steps in the method section. It was identified that whilst the issue of communication effects a wide range of stakeholders, strategies for what works best will be different for each group. The research project that feed into this paper was in close contact with senior architects, who have provided feedback for effective communication of results that can lead to more data lead design decisions.

3.1 GOALS FOR DESIGNERS

The following is a list of key goals for designers to benefit from the interpretation of LCA results.

1. Benchmarking
   Understanding the buildings results in context of benchmarks is important to scale the performance of the building. Gaining an understanding of scale is especially important if the building is aiming to meet a limit benchmark set by a regulatory authority or a target benchmark allowing it to gain certification for demonstrate high performance. Benchmarks like these will be part of project briefs and will be the first item to establish the project's success at a high level.
2. Building Element Contribution
   To focus a project team consisting of many consultants, understanding what part of the building is contributing the highest amount of embodied carbon is beneficial to focusing team meetings.
3. Building Material Contribution
   Drawing attention to high embodied carbon building materials can allow a project team to begin to explore alternative lower carbon options.
4. Comparative Study
   Evaluating the embodied carbon benefits of different options can help inform decisions at different scales from whole building composition, to different building element options, to alternative materials.
5. Financial Cost of Carbon
   Value engineering is a frequent part of many design processes. Understanding the financial cost of carbon in context of a project can help stakeholders understand if the building is good value for money.
6. Data Quality
   As an emerging area, not all projects have Environmental Product Declarations (EPD). Due to this generic data can be used to supplement data when none is available. Understanding how much supplementary data is required is useful to gauging the precision of the results.
7. Emissions per Life Cycle Stage
   EN 15978 outlines several key stages in a buildings life cycle where embodied carbon emissions can occur. At a basic level, understand the difference between what emissions will be caused upfront or today verse future emissions during the use and end of life stages. For a design team being able to distinguish the difference allows them to track the success of different reduction strategies. For example, using low carbon materials compared to longer lasting materials.

3.2 REPORTING EMBODIED CARBON

3.2.1 Sample Size

Currently there are many tools being realised rapidly. To explore a range of different visualisations for embodied carbon a sample of ten tools from three different producers was selected. The sample selected aimed to cover both early and detailed design LCA tools.

Table 1: LCA tool sample size

Producer	Tool
One Click LCA	LCA for Green Star
One Click LCA	Life Cycle Carbon - Global
One Click LCA	Net Zero Carbon Tool
One Click LCA	Carbon Designer
One Click LCA	Revit Plug-in LCA tool
One Click LCA	LCA Planetary

Etool	EtoolLCD
BRANZ	LCA Play
BRANZ	LCA Quick

From the sample of tools a total of 272 data visualisations were extracted from the results of a LCA. Some of these tools had additional reporting features that couldn't be accessed and it is recognised that the true number of visualisations available is larger. Across the sample size the visualisations came from 17 different graph types. Figure 1 illustrates the hierarchy of graph types present in the sample.

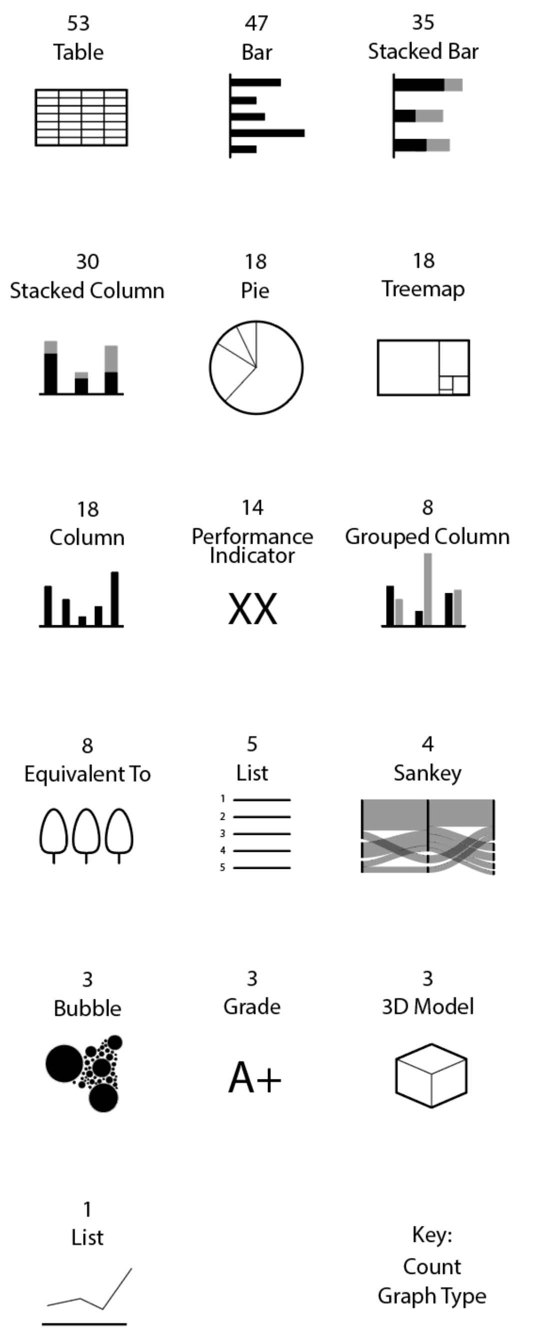


Figure 1: Sample of graph types from LCA tools

The initial overview of the sample of graph types shows that tables most commonly appear on result pages for LCA tools. While a table cannot be understood at a glance they were often present to precisely document the exact results calculated.

Stacked bar and column graphs also appeared frequently as they have the benefit of being able to add a third string of information onto a graph. However, more information can require more time to interpret and make identifying any issues or opportunities from the results harder.

3.2.2 Categorising graphs by goals

All graphs presented in LCA tools were included in the sample size to show the range of information a designer would be presented with. Figure 2 shows the proportion of the graphs the related to the goals for designers outlined in section 3.1. Any graph that didn't show information on carbon was excluded. Many graphs had a clear connection to the goal. In some cases, this was less clear and graphs were included to allow a designer to determine their effectiveness. For example, there were a range of graphs that presented the carbon equivalent version of the results. As this could be a form of benchmark through an attempt to scale the results, the graphs were categorised against that goal.

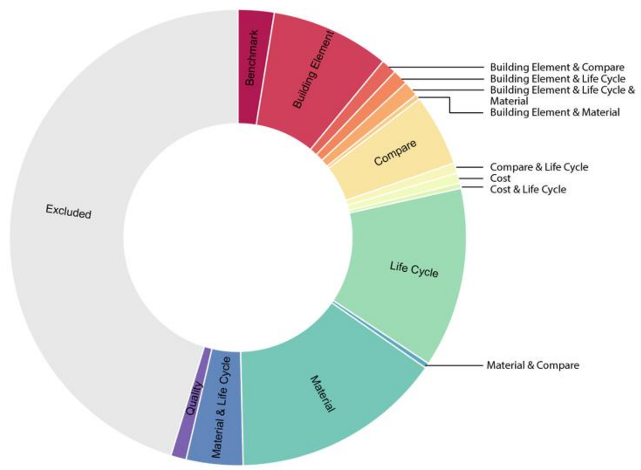


Figure 2: Sample size categorised into goals

Whilst there were a few graphs that represented multiple goals, most graphs only presented the goal against carbon emissions. For example, a bar graph showing the emissions from different life cycle stages. However, under each category there is a lot of diversity in the graph types used with no clear pattern or dominate type used.

3.3 FEEDBACK FROM SENIOR ARCHITECTS

To understand what graph was easiest to understand a sample of three senior architects within the practice were asked to complete a survey followed with a meeting to discuss their feedback. Figures 5-11 document their feedback across the different goals for designers.

At a glance the results show the participants had mixed results in many of the goal categories. The only goals were there was 100% agreement was for the building element and material breakdown where they all voted for a 3D model. Out of a sample size of 272 different graphs in the full sample only 2 were 3D models. The 3D models have a colour projected only the building to highlight good (green) and bad (red) elements or materials. These graphs were only available in the Revit Plugin tool produced by One Click LCA.

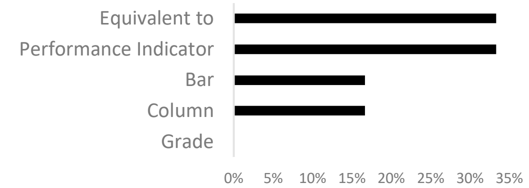


Figure 3: Benchmark against a carbon goal

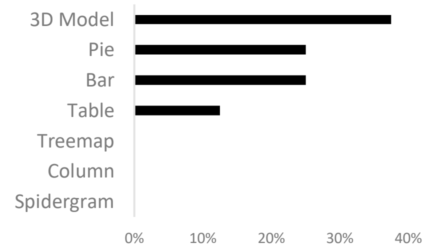


Figure 4: Analyse building elements

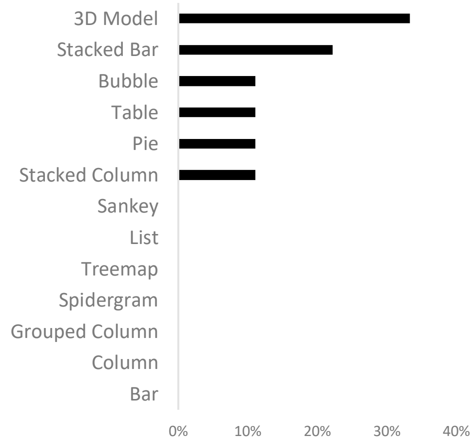


Figure 5: Analyse building materials

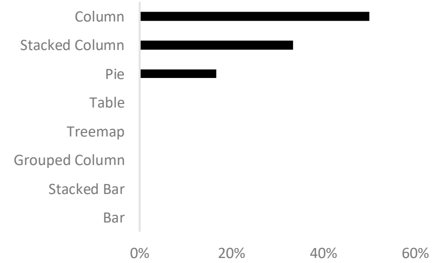


Figure 6: Analyse life cycle stages

Figure 7: Analyse costs

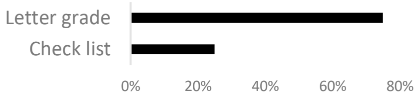


Figure 8: Gauge material data quality

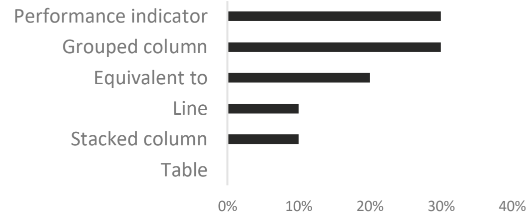


Figure 9: Compare different options

3.3.1 Breaking down a building

There was 100% agreement by participants on how a building should be broken up in elements and how materials should be categorised. In most tools the list can be created by downloading the results and grouping data to conform to the list below. The only tool that produced the participant's favourite building element breakdown was Carbon Designer, a tool by One Click LCA. The breakdown appeared only intermittently when the interim results were being review before being sent to the main tool platform.

Table 2: Preferred breakdowns

Building Element	Material Breakdown
Foundation	Material Type Example
Cleanliness layer	CLT
Ground Slabs	LVL
Floor Slabs	Precast Concrete
Columns	In-situ Concrete
Beams	Reinforcing Steel
Load bearing internal walls	Membrane
Balconies	Glass
Staircases	Aluminium Mullion
Underground walls	
External walls	
Cladding	
Windows	
External doors	
Roof slab	
Roofs	
Internal Walls	
Floor Finishes	
Ceiling Finishes	

3.4 DASHBOARD

Based on the feedback from senior architects a proposed strategy for a communicating embodied carbon was developed (fig 12). Hierarchy has been given to the 3D model to connect the results back to the project specific conditions. If the dashboard was presented on an interactive digital platform the difference between building and material carbon intensity could be toggled in-between.

Supporting information that provides detail about the results surrounds the 3D model to provide designers the opportunity to gain a deeper understanding. From discussions with the surveyed senior architects, being able to gauge at a glance what the key information is from each visualisation was critical. Having a clear and simple purpose per visualisation makes them easier to communicate to stakeholders who may have less knowledge of embodied carbon and how to make informed decisions from the information.

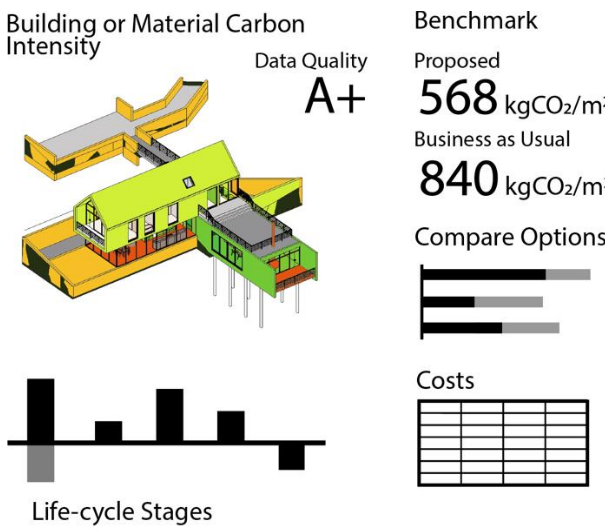


Figure 12: Embodied Carbon Dashboard

3.4 3D MODEL v DRAWING

Beyond simply projecting the results through colour onto a 3D model in Revit the paper pursued the potential of this technique to become an architectural drawing. Figure 13 illustrates the potential to combine the coloured projection of the results from the One Click LCA Revit Plugin with the ability to easily create an exploded axonometric drawing in Revit. This visualisation serves the goal to analyse the results per building element. By exploding the different building elements, the embodied carbon performance of each element can be quickly understood.

Exploding the diagram also allows design decisions to focus on a specific element, for example the substructure and foundations which are highlighted orange and red indicating a high carbon intensity in these elements. To further develop this diagram from being purely qualitative, a list with the quantities of carbon corresponding to each building element could be added. Doing so would also allow for other types of embodied carbon to be communicated, including biogenic carbon or recycled content in the selected building materials.

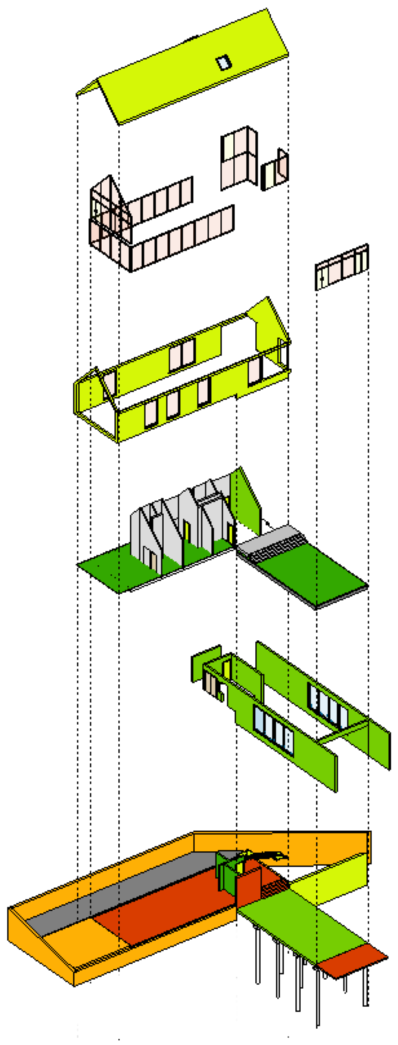


Figure 13: Embodied carbon exploded axonometric drawing

4. CONCLUSION

The urgency for action to remain below the 1.5°C of global warming limit is well recognised by many architects and stakeholder groups. As national grids turn towards renewable sources and low energy technologies become more readily available, the need to reduce embodied carbon emissions increases. Therefore, there is a high importance of making embodied carbon results understandable for decision makers during the design of buildings. This paper presents an overview of current visualisation techniques categorised against key goals to be used as a starting point.

Unlike the design of products, most buildings are unique due to a combination of different variables including site conditions and brief requirements. This means that each design is approached differently with a diverse combination of stakeholders involved in decision making. Nevertheless, tasks requiring a design process are often repeated to form the backbone of architectural design services. An outline of the goals for embodied carbon along this process emphasised the need for visualisations to match the scale of decisions being made.

The review of embodied carbon visualisations from 10 LCA tools identified the large number of visualisations that are competing for a designer's attention. The terminology used within the visualisations were targeted at LCA experts with an understanding of the calculation method outlined in EN15978.

The feedback from senior architects on the visualisation methods demonstrated the need for a visual connection back to the design. Distilling a project into graphs, whilst good for comparisons, can make the results difficult to understand. The feedback highlighted the success of visualisations that connected embodied carbon emissions with the project specific characteristics. Notably the most successful visualisations were coloured projections of results on a 3D model. These visualisations show the value of a qualitative element in the communication of quantitative information. For designers to make informed decisions the results from an LCA need to be understood quickly in a meaningful way.

ACKNOWLEDGEMENTS

To be added to the final version of the paper.

5. REFERENCES

[1] United Nations, 'PARIS AGREEMENT', 2015.
[2] IPCC, 'Global Warming of 1.5 ºC', Special Report, 2018.
[3] B. Lebot, 'Global Status Report 2017', p. 48, 2017.
[4] LETI, 'LETI Climate Emergency Design Guide', London Energy Transformation Initiative, London, United Kingdom, Jan. 2020.
[5] BSI, 'Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method'. The British Standards Institution, 2012.
[6] ISO, 'Environmental labels and declarations — Type III environmental declarations — Principles and procedures'. International Organization for Standardization, 2006.
[7] S. Joshi, C. Bayer, M. Gamble, and R. Gentry, 'AIA Guide to Building Life Cycle Assessment in Practice', *Am. Inst. Archit.*, p. 14, 2010.
[8] Joint Research Centre (European Commission) *et al.*, *Guide for interpreting life cycle assessment result*. LU: Publications Office of the European Union, 2016.
[9] B. Kiss *et al.*, 'Review of visualising LCA results in the design process of buildings', *Build. Environ.*, vol. 190, p. 107530, Mar. 2021
[10] G. M. Zanghelini, E. Cherubini, and S. R. Soares, 'How Multi-Criteria Decision Analysis (MCDA) is aiding Life Cycle Assessment (LCA) in results interpretation', *J. Clean. Prod.*, vol. 172, pp. 609–622, Jan. 2018
[11] P. T. Lekkas, 'Life Cycle Assessment (LCA) in Business. An overview on drivers, applications, issues and future perspectives.', Apr. 28, 2013.
[12] C. Baldassarri, F. Mathieux, F. Ardente, C. Wehmann, and K. Deese, 'Integration of environmental aspects into R&D inter-organizational projects management: application of a life cycle-based method to the development of innovative windows', *J. Clean. Prod.*, vol. 112, pp. 3388–3401, Jan. 2016
[13] A. Braune, C. Ruiz Durán, and J. Gartner, 'Life cycle assessments—a guide on using the LCA', Technical report, German Sustainable Building Council. DGNB GUIDE April, 2018.
[14] E. Gutierrez, B. Adenso-Diaz, S. Lozano, and Y. Barba-Gutierrez, 'Visualisation of LCA environmental impacts of electrical and electronic products using multidimensional scaling', *Int. J. Prod. Lifecycle Manag.*, vol. 4, no. 1–3, pp. 166–185, 2009.
[15] M. Röck, A. Hollberg, G. Habert, and A. Passer, 'LCA and BIM: Visualization of environmental potentials in building construction at early design stages', *Build. Environ.*, vol. 140, pp. 153–161, Aug. 2018, doi: 10.1016/j.buildenv.2018.05.006.
[16] G. Baird, H. R. Bruhns, M. R. Donn, and N. P. Isaacs, 'Application of the Exo-Endo Model to the Measurement of Building Energy Performance', *Perform. Build. Serv. Facil.*, Jan. 1990,
[17] T. Gerrish, K. Ruikar, M. Cook, M. Johnson, M. Phillip, and C. Lowry, 'BIM application to building energy performance visualisation and management: Challenges and potential', *Energy Build.*, vol. 144, pp. 218–228, Jun. 2017,
[18] F. Pomponi and A. Moncaster, 'A Method for Visualising Embodied and Whole Life Carbon of Buildings', in *Building Information Modelling, Building Performance, Design and Smart Construction*, M. Dastbaz, C. Gorse, and A. Moncaster, Eds. Cham: Springer International Publishing, 2017
[19] F. Pomponi and A. Moncaster, 'Benefits and challenges of visualising embodied and whole life carbon of buildings', presented at the International Conference on Sustainable Ecological Engineering Design for Society, Leeds Beckett University, UK, 2016.
[20] M. Robati, P. Oldfield, A. A. Nezhad, D. G. Carmichael, and A. Kuru, 'Carbon value engineering: A framework for integrating embodied carbon and cost reduction strategies in building design', *Build. Environ.*, vol. 192, p. 107620, Apr. 2021

PLEA SANTIAGO 2022
Will Cities Survive?

Energy demand reduction in two case studies based on the same residential studio:

Mediterranean and Hot Climates

ALQADI, SHIREEN BADER[1 2]; ELNOKALY, AMIRA[2]; KAFAFI, AHMAD [3]; IRFAYIEH, WALA[3]

[1]Birzeit University
[2]University of Lincoln
[3]Palestine Polytechnic University

ABSTRACT: This paper studies the effectiveness of natural stone as a thermal mass in two different climates: the Mediterranean and hot climates (Jerusalem, Riyadh) were taken as case studies. Stone was added to the conventional wall layers of a simple residential studio in the chosen zones of each climate. The simulation was performed using Design Builder software to assess the annual energy demand and the level of comfort in each case. The simulation has shown that using natural stone as a thermal mass has reduced energy demand in the Mediterranean climate by 7% and 9% in Hot climates. The indoor temperature increased in winter and decreased in summer in the two climatic regions. Results have shown that the best place and thickness of the natural stone in the wall in the Mediterranean and the Hot climates are at 20cm external layer (cladding).
KEYWORDS: Building Envelope, Natural Stone, Indoor Environmental Quality (IEQ), thermal mass

1. INTRODUCTION

The world is facing tremendous challenges due to climate change which is changing the energy consumption patterns in buildings. The building envelope is what separates the indoor from the outdoor environments of a building, and has a significant role in moderating variations in the outdoor weather conditions (Mohamed etal. 2021; Mohammad and Shea,2013), where the heat transfer loss in building envelopes accounting 60%–80% of the total heat transfer loss (Meng et al., 2015). Hence, improving the performance of the building envelope can play a major role in optimising energy consumption in buildings. This paper studies the efficacy of natural stone as a thermal mass in three different climates: temperate (Mediterranean), hot and oceanic temperate (Jerusalem and Riyadh) were taken as case studies. Stone was added as cladding to the conventional wall layers of a simple residential studio in each climatic zone. The simulation was performed using Design Builder software to assess the annual energy consumption and the level of user internal comfort in each case.

2. THERMAL MASS

The use of thermal mass in the building envelope could provide a potential solution to the challenges of thermal comfort requirements and high energy consumption in cooling and heating.(Reilly& Kinnane,2017) Thermal mass is the ability of a material to absorb and store heat energy. (GreenSpec, 2004). The envelope with thermal mass needs to absorb a lot of heat energy before the temperature on the surface of the envelope changes (Nowoświat and Pokorska-Silva, 2017). The larger the thermal mass, the more heat energy can be stored during off-peak periods and partly recovered during peak periods (Johra et al., 2019). A high thermal mass material is not generally a good thermal insulator (YourHome, 2013). Therefore, the appropriate use of thermal mass throughout the building envelope can reduce energy usage in residential buildings by maintaining a comfortable internal temperature (Reilly and Kinnane, 2017).

Thermal mass reduces the energy usage in residential buildings by sustaining a comfortable internal temperature with no heating or cooling in certain climatic conditions and to minimize energy demand and create a sustainable future thermal mass in buildings needs to be utilized (Katherine et al., 2007) and create a 40% savings in total cooling costs in certain areas Braun et al (2001).

Thermal mass if used well, can cut down and delay peak temperature during daytime, which will result in a significant reduction in the size of the cooling system, and during night hours, high thermal mass will absorb and store enough ‘‘cooling energy’’, which will slow down the heating process during the day Cheng et al. (2005). The construction materials of high thermal mass significantly keep the indoor environment within the human thermal comfort zone, especially during summer. Thus, the energy required for maintaining the thermal comfort of the room is greatly reduced (Sharaf et al., 2020). The type and location of the thermal mass in the building envelope and its relation with the other components of it define its performance and impact on the indoor building environment.

Natural stone and marble are considered one of the main materials employed in the building and construction sector (Abu Hanieh et al., 2013). As natural stone is a material with high energy efficiency (Kumar, 2015) natural stone application has been considered traditionally as low energy demanding materials (Ozkahraman and Bolatturk, 2006). Natural stone has thermal mass; it can absorb, store, and release the sun’s heat energy (“Natural Stone| Vesta Marble and Granite,” 2020). Moreover, the stone and marble industry is one of the main economic resources in most of the Middle Eastern and Mediterranean countries, especially in Palestine (The International Trade Centre (ITC), 2018). This sector contributes widely to the local production, exports and employment capacity (Abu Hanieh et al., 2013). According to the Palestinian Central Bureau of Statistics (PCBS), it is one of Palestine's top exporting industries, with exports reaching $214m in value in 2017, accounting for 20 percent of all Palestinian exports (Ihsheish and Falah, 2018).

3. METHOD

Using DesignBuilder software a model of a simple residential studio (8*10 m) with 3 m height has been simulated in two different climates: Jerusalem in Palestine as a Mediterranean climate zone and Riyadh, Saudi Arabia as a Hot Desert climate (Figure 1). The base case models were developed using the conventional building materials and methods in each case. The characteristics of the external walls (base case) in Jerusalem and Riyadh are presented in tables 1 and 2 respectively.

Figure 1:
Studio floor plan

The conventional wall layers in each climatic zone have been tested and recorded as Base-Cases **and the suggested scenarios were compared to them**

For each case, two simulations were performed in which the first the HVAC was off (to compare the internal temperature) then the HVAC was on to compare the energy demand for each case. The results have been tested in typical summer and winter weeks.

Table 1: External wall thermal characteristics used in Jerusalem (Base case)

	Stone 5cm	Concrete 13 cm	Polyurethane 3cm	Concrete blocks 7cm	Plaster 2cm
Conductivi-ty(W/mK)	1.1	1.0	0.038	0.7	0.25
Density (kg/m3)	2500	2000	15	1400	1500
Specific heat capacity (kJ/kg.K)	0.84	0.75	1.1	0.8	0.9
U value (W/m2K)	0.8				

Table 2: External wall thermal characteristics used in Riyadh (Base case)

	Plaster 1.5cm	Polystyrene 9 cm	Concrete blocks 20 cm	Plaster 1.5cm
Conductivi-ty	0.25	0.038	0.7	0.25
Density (kg/m3)	1500	15	1400	1500
Specific heat capacity (kJ/kg.K)	0.9	1.1	0.75	0.9
U value (W/m2k)	0.36			

The thermal mass for each scenario in both cases was calculated. The different scenarios and thermal mass for each exterior wall are seen in tables 3 and 4. Palestinian stone was used in different thicknesses as internal or external cladding.

Table 3: External wall thermal mass for each scenario for Jerusalem case

Stone thickness	Inner	Outer	Thermal mass (J/m2K) of the external walls
5cm (base case)		*	246.5
10 cm		*	288
15 cm		*	330
20 cm		*	375.5
10 cm		*	292

with air gap			
10 cm	*		330
15 cm	*		372.5

Table 3: External wall thermal mass for each scenario for Riyadh case

Stone thickness	Inner	Outer	Thermal mass (J/m2K) of the external walls
1.5 cm morter (base case)		*	252
10 cm		*	336.7
15 cm		*	546.7
20 cm		*	651.7
10 cm with air gap		*	239.2
10 cm	*		336.7
15 cm	*		546.7

4. RESULTS

Figure 2 shows the indoor temperature as the results of the simulations for the different scenarios in Jerusalem Case. The results show that using thermal mass can decrease the indoor thermal temperature by almost one degree compared to the conventional wall section (conventional method) during summer. It is also clear from Figure 6 that there is no big discrepancy between the cases when using stone with a thickness that is equal to or more than 10 cm either internally or externally so that the indoor temperature reached almost 27.5 ºC, except for the cases 10 cm of inner stone and 10 cm of outer stone which were slightly higher. Using the thermal mass increased the indoor temperature during winter in all the cases by 1- 1,5 degrees. The best cases during winter were 20 cm of external stone or 10 cm with an air gap which reached an increase of 1.5 degrees. Using this type of cladding can decrease the energy demand by around 7%.

Figure 2:
Indoor temperature (C°) in the different scenarios in Jerusalem

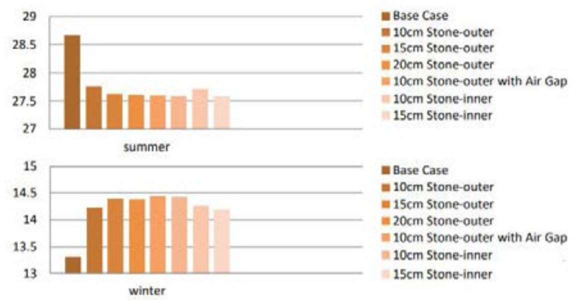
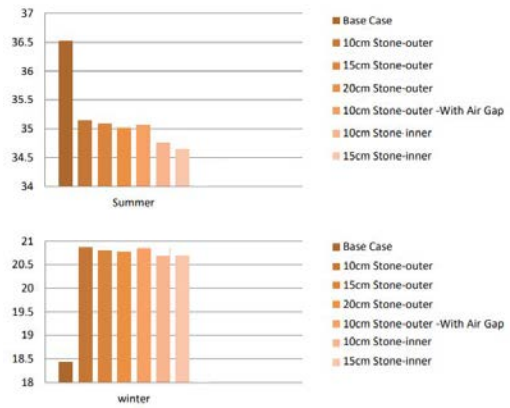


Figure 3 shows the indoor temperature as the results of simulation for the different scenarios in the Riyadh Case. The results show that using thermal mass can decrease the indoor thermal temperature by 1- 1.8 degrees Celsius in summer compared to the conventional wall section. It is also clear from Figure 3 that adding thermal mass has increased the indoor temperature by 2.5- 2.8 degrees Celsius during winter. There is no big discrepancy between the cases when using stone as cladding. The highest indoor temperature was when 20 cm of stone was added as external cladding. Using this type of cladding can decrease the energy demand by 9%.

Figure 3:
Indoor temperature (C°) in the different scenarios



5. Discussion

Based on consumption during January 2020, energy consumption in Palestine varies between 285 kWh in Gaza to 482 kWh in the central West Bank (PCBS,2021). The residential sector was responsible for 45 % of Energy use in the Middle East in 2018 (MEETMED, 2020). Lack of electricity and the high cost of imported electric power are the main factors in the low Palestinian consumption of electric power. many households living in fuel poverty, cannot afford their heating bills because their homes have no or poor insulation (Al Qadi, et.al, 2018). On the other hand, the demand for cooling energy is increasing due to climate change, increase of the users' expectations and extreme climatic conditions in the Middle East (Namdar et. al, 2021). It is becoming today of utmost importance to think of alternative methods and tools to retrofit existing building stocks to be able to reduce energy use in buildings (Mona, 2021; Al Qadi, et al,2022). The only way forward is to keep on running more simulations through an iterative approach of optimisation and then run more simulations (Al Qadi et al, 2021). It is only through several times of iterations, calibrations, sensitivity analysis and optimisation that new knowledge is created. It is only through this iterative process of optimisation that we have confidence in the information created and closing the loop and communicating the results with a higher percentage of confidence.

6. CONCLUSION

Modelling and computer simulation have shown that using Palestinian natural stone as a thermal mass will reduce energy demand in the Mediterranean climate by 7% and by 9% in Hot climate. Indoor temperature will increase in winter in the Mediterranean climates by 1◦C and 2.3◦C in Hot climates. While in summer it will decrease by 1◦C in the Mediterranean climate, by 1.5 ◦C in Hot climate. Results have shown that the best place and thickness of the natural stone in the wall in the Mediterranean climate is 20cm external layer and for the hot climate 15cm inner layer.

REFERENCES

- Abu Hanieh, A., Abdelall, S., Hasan, A., 2013. Sustainable Development of Stone and Marble Sector in Palestine. Journal of Cleaner Production.
- Al Qadi,S. , Sodagar,B.,Elnokaly, Calibrating building thermal simulation model using indoor environmental measurements , ",A, Zero Energy Mass Custom Home 2021International Conference, 26 - 28 October 2021
- Al Qadi,S. , Sodagar,B.,Elnokaly,A.,Estimating the energy used for cooling in the Palestinian houses, the case of Hebron , , 16th International Conference on Energy Sustainability , (11-13 July, 2022) (submitted).
- Al Qadi,S. , Sodagar,B.,Elnokaly,A., Estimating the energy used for heating in the Palestinian houses, the case of Hebron , , Journal of Cleaner production, June, 2018
- Amos-Abanyie S., Akuffo F. O., Kutin-Sanwu V. (2013) Effects of Thermal Mass, Window Size, and Night-Time Ventilation on Peak Indoor Air Temperature in the Warm-Humid Climate of Ghana S. Amos-Abanyie, The Scientific World Journal, 2013(1)
- Braun, J., Montgomery, K., & Chaturvedi, N. (2001). Evaluating the Performance of Building Thermal Mass Control Strategies. HVAC&R Research, 7(4), 403–428.
- Camuffo, D., 2019. Temperature: A Key Variable in Conservation and Thermal Comfort, in: Microclimate for Cultural Heritage. Elsevier, pp. 15–42.
- Cheng, V., Ng, E., & Givoni, B. (2005). Effect of envelope colour and thermal mass on indoor temperatures in hot humid climate. Solar Energy, 78(4), 528–534. Construction Materials & Local Market Survey in Palestinian Territories (2002), energy codes for buildings
- GreenSpec: Thermal Performance: Thermal Mass in Buildings, 2004. URL http://www.greenspec.co.uk/building-design/thermal-mass/ (accessed 11.12.20).
- Ihsheish, M. and Falah, B., 2018. Regulating and Improving the Competitiveness of the Stone & Marble Industry: Challenges and Required Interventions. Palestine Economic Policy Research Institute (MAS), Palestine.
- Johra, H., Heiselberg, P., Dréau, J.L., 2019. Influence of envelope, structural thermal mass and indoor content on the building heating energy flexibility. Energy and Buildings 183, 325–339.
- Kumar, A., 2015. Overview of Natural Stones as an Energy Efficient and Climate Responsive Material Choice for Green Buildings. pp. 27–35.
- Ma, P., & Wang, L.-S. (2012). Effective heat capacity of interior planar thermal mass (iPTM) subject to periodic heating and cooling. Energy and Buildings, 47, 44–52.
- Meetmed, country report on energy efficiency and renewable energy investment climate, Palestinain Terretories, 2020, p19.
- Meng, X., Yan, B., Gao, Y., Wang, J., Zhang, W., Long, E., 2015. Factors affecting the in situ measurement accuracy of the wall heat transfer coefficient using the heat flow meter method. Energy and Buildings 86, 754–765.
- Mohammed, A.M. , Elnokaly, A., Aly, A. M. Empirical investigation to explore potential gains from the amalgamation of phase changing materials (PCMs) and wood shavings, Energy and Built Environment, 2 (3) (2021), pp. 315-326
- Mohammad, S., Shea, A., 2013. Performance Evaluation of Modern Building Thermal Envelope Designs in the Semi-Arid Continental Climate of Tehran. Buildings 3, 674–688.
- Mona. S, Juaidi, A, Abdallah, R., Albatayneh,A, Dutournie,P, Jeguirim, M, (2021), Towards Sustainable Energy Retrofitting, a Simulation for Potential Energy Use Reduction in Residential Buildings in Palestine, Energies, 14, 3876
- Natural Stone Floor Tiles | | Vesta Marble and Granite, 2020 URL https://vestamarble.com/choosing-the-right-stone-for-your-floor/ (accessed 11.24.20).
- Nowoświat, A., Pokorska-Silva, I., 2017. The Influence of Thermal Mass on the Cooling off Process of Buildings. Period. Polytech. Civil Eng.
- Passive Cooling using Thermal Mass, 2020. GCCA. URL https://gccassociation.org/passive-cooling-using-thermal-mass/ (accessed 11.24.20).
- Reilly, A., Kinnane, O., 2017. The impact of thermal mass on building energy consumption. Applied Energy 198, 108–121.
- Rodrigues, E., Fernandes, M.S., Gaspar, A.R., Gomes, Á., Costa, J.J., 2019. Thermal transmittance effect on energy consumption of Mediterranean buildings with different thermal mass. Applied Energy 252, 2019.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

- Sharaf F., Zampieri P. (2020) The impact of thermal mass on building energy consumption: A case study in Al Mafraq city in Jordan, Cogent Engineering, 7(1)
- Stevens, V., Kotol, M., Grunau, B., & Craven, C. (2016). The Effect of Thermal Mass on Annual Heat Load and Thermal Comfort in Cold Climate Construction. Journal of Cold Regions Engineering.
- The International Trade Centre (ITC), 2018, national export strategy stone and marble. sector export strategy 2014-2018, the state of Palestine.
- Zhang, T., Tan, Y., Yang, H., Zhang, X., 2016. The application of air layers in building envelopes: A review. Applied Energy 165, 707–734

Seasonal cooling/ heating effect produced by courtyards with different aspect ratio in tropical climates

IVAN JULIO APOLONIO CALLEJAS [1], EDUARDO KRÜGER [2], LETICIA MENDES DO AMARANTES [1], FERNANDA APARECIDA SANTANA DOS SANTOS [1], DEBORAH TORRES DA SILVA [1]

[1] Departamento de Arquitetura e Urbanismo, Universidade Federal do Mato Grosso
[2] Departamento de Construção Civil, Universidade Tecnológica Federal do Paraná

ABSTRACT: There is substantial knowledge on the thermal potential of the courtyards in microclimate amelioration in arid and Mediterranean climates. However, in tropical regions, studies on that are still scarce and strongly required, especially in South America. This study aims to evaluate the seasonal cooling/ heating effects provided by courtyards with different morphologies in a tropical region. It was conducted in two buildings, located in the mid-western region of Brazil, with different aspect ratio (height/width). Shading and insolation indices were compared to the courtyard thermal performance evaluated by the thermal gap between outdoor and courtyard air temperature monitored during hot-dry and hot-wet seasons. The cases studied indicated that a courtyard with a low aspect ratio is only able to provide cooling effect during nighttime. In turn, courtyards with high aspect ratios, due to the lower average insolation received and higher shading provided by its inner envelope, can be advantageous during daytime. In seasonal terms, a courtyard with a low aspect ratio provides more beneficial cooling effects during the hot-dry period during nighttime. On the other hand, the courtyard with a high aspect ratio provides a cooling effect during the whole year, with marked thermal attenuation during the hot-wet season.
KEYWORDS: Urban Climate, Thermal Gap, Microclimate Impact, Thermal Performance.

1. INTRODUCTION

Extreme temperatures are becoming more frequent in both cold and hot climate zones due to climate change [1], which reinforce the need to pay more attention to the urban microclimate. Outdoor urban environments are affected not only by the regional and local climate components but also by urban form and building density. The latter can be linked to urban architectural design which influences microclimate due to urban geometry, textures, and layout/ geometry of buildings, streets, and squares [2]. In this regard, due to its capacity to act as buffer space outside buildings, the transitional space provided by the courtyard as an architectural element has been indicated as a passive design strategy as it acts as a "microclimate modifier" due to its ability to provide milder environments [3].

The courtyard is characterized by an open space, delimited by buildings on its perimeter that provides a transition space between indoors and outdoors. It provides ventilation, daylighting, and shading to the surrounding environments and can perform several functions in the built environment, such as acting as a space for socialization and leisure [4]. The scientific literature indicates that this architectural strategy is capable to regulate its thermal exchanges with the outside environment through proper design, which is achieved by considering the environmental exposure factors such as solar access, shading, wind permeability, building orientation, layout/configuration, shape/aspect ratio, building materials, among others [5].

In addition, the void created in the urban fabric by the use of courtyard morphology reduces the city built-up area, which is particularly important in warm climates, such as those located in tropical regions. As a result, courtyards have been suggested to be a mitigation strategy against the effects of the urban heat island phenomenon, due to the more favourable microclimate generated in their interior, with the potential to mitigate the effects of global warming [6]. According to Diz-Mellado et al. [7], the higher the external temperatures, the better thermal regulators courtyards become, achieving a temperature difference with the outside of over 17 °C on very hot days in warm cities.

The cooling effect provided by this vernacular architecture has been quantified in diverse climate zones worldwide, ranging from hot arid [5], Mediterranean [7], tropical [8], to colder European climates [9], through fields measurement and thermal simulations. These studies state that physical aspects of courtyards such as layout, orientation, and aspect ratio

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

(AR, a ratio between the height and width of the inner courtyards), among others, are key factors that affect the effectiveness of a courtyard to provide cooling effects. In turn, the climate-tempering ability of the courtyards is usually investigated in specific periods of the year, frequently during summer-time conditions. Few studies have yet attempted to analyse the seasonal effectiveness of the courtyard in microclimate amelioration [8,10,11], particularly through field measurements.

Taking into consideration the fact that courtyards in tropical areas should optimally promote shading and ventilation to their users [4], the present paper evaluates cooling/ heating effects provided by two courtyards with different aspect ratios located in a central region of Brazil, with marked under hot-dry and hot-wet seasons.

2. MATERIALS AND METHOD

2.1 Study Location

The study was carried out in two buildings located in a mid-sized city, with tropical savannah climate (Köppen's Aw). Local climate is characterized by a hot and humid season, between October and April), and a hot and dry season, between May and September [12].

Both buildings are located in Cuiabá city, capital of Mato Grosso/ Brazil. The first one is in the downtown area (at 15°36'31.07"S, 56° 6'12.79"W), built in the early 19th century, featuring neoclassical style with two-storey buildings in the perimeter and two rectangular courtyards oriented according to a NE-SW axis. Courtyard dimensions are 13.7m x 10m with a mean height of 11.8m, which yields an aspect ratio AR= 1.14 (Fig. 1a). The second courtyard is located in the south-eastern region of the city (at 15°35'53.13"S, 56° 5'46.95"W), with a single storeyed building in the perimeter, and built in 1831, with its architecture designed following a historic eclectic style and having an almost square shallow central courtyard aligned to a NE-SW axis, with dimensions of 75.2m x 64.3m and a mean height of 7.0m, yielding an aspect ratio AR= 0.11 (Fig. 1b).

(a) (b)

Figure 1:
Illustration of the courtyards at (a) city centre [13] and (b) south-eastern region [14].

The study is justified considering the function of courtyards of regulating thermal behaviour [15], with heat drain and heat source possibilities. The first condition is observed in intermediate and narrow courtyards (AR>1.0), where walls and ground surfaces of well-shaded courtyards are often at a lower temperature than outside, except at times when solar angles are elevated, and the courtyard is exposed to solar radiation. The second condition can be observed in shallow courtyards with low aspect ratios (AR<0.3) as enclosing walls and ground surface accumulate heat when exposed to the sun, leading to increased air temperatures compared to outside during daytime.

2.2 Monitoring Campaigns

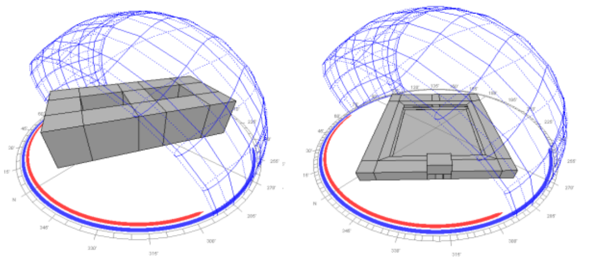
Monitoring in the courtyards was from June 2019 to May 2020, during the hot-dry and the hot-humid periods, which allowed us to characterize and quantify their cooling potential. Air temperatures were recorded inside the courtyard using sensors properly calibrated and solar-shielded and located in the centre of each courtyard. "Outdoor" temperatures and wind velocity were also recorded by a meteorological station located at the rooftop of enclosing buildings (Fig. 2).

(a) (b)

Figure 2:
Sensors location inside the courtyard and at the rooftop of the buildings with (a) AR =1.18 and (b) AR=0.11.

2.3 Data Analysis of courtyards

Shading and Insolation indices were used to represent the courtyards' performance. The first index represents the average percentage of the total courtyard's surface area that is shaded (ranging between 0-1), and the second index gives the average level of insolation (calculated considering direct and diffuse radiation) received by the 3D surface area (surrounding walls and ground surface) exposed to the sun inside the courtyard, measured in Wh/m². The Ecotect Analysis software [16] was utilized to simulate and obtain a quantitative measure of shading and insolation on the 3D surfaces area of each courtyard (Fig. 3).



(a) (b)

Figure 3:
Simplified 3D model of courtyards with (a) AR=1.18 and (b) AR=0.11 (Font: Ecotect Software building modelling)

The percentage of shading on the four inner façades and ground surface was estimated for the time frame from 6 am to 6 pm. The average hourly shading index for the 3D surface area inside the courtyard was calculated using Equation (1):

$$\mathbf{I_{shade}} = \frac{\sum_{i=1}^{n}(\mathbf{AS_i \cdot HPS_i})}{\sum_{1}^{n}\mathbf{AS_i}} \qquad (1)$$

where AS_i - area of each surface *i* of the courtyard;
HPS_i - hourly percentage of shadow on that surface.

The incident solar radiation received by each surface (Wh/m²) weighted by the percentage of the courtyard surface area hit by radiation was utilized to measure the average hourly insolation index received by the courtyard as a whole, according to Equation (2):

$$\mathbf{I_{isolation}} = \frac{\sum_{i=1}^{n}(\mathbf{SRI_i \cdot HPRS_i \cdot AS_i})}{\sum_{1}^{n}\mathbf{AS_i}} \qquad (2)$$

where SRI_i - solar radiation intensity on each surface *i* of the courtyard;
$HPRS_i$ - hourly percentage area of solar radiation received by surfaces *i* of the courtyard;
AS_i - area of surface *i* of the courtyard.
The daily shading and insolation indices were later computed as monthly average values.

2.4 Passive Cooling/ Heating indexes

The thermal gradient (ΔT) or gap between outdoor (OT) and courtyard air temperature (CT) for any time of the day was evaluated according to Equation (1):

$$\Delta T = OT - CT \qquad (1)$$

The positive and negative temperature differences represent cooling and heat effect, respectively, inside the courtyard.

The thermal difference was evaluated by the cooling and heating effects inside the courtyards. These values were later calculated as monthly averages, giving an indicator that represents the monthly thermal cooling and heating effect of each courtyard.

3. RESULTS AND DISCUSSION

The annual course of the average monthly $I_{insolation}$ and I_{shade} indices in the inner envelope of courtyards throughout the year can be visualized in Figure 4. When the solar angle is lowest (winter solstice), it is possible to notice that the insolation intensities in the courtyards are at lower levels with a higher level of shading. However, for higher solar angles (from the spring equinox to summer solstice), a rise in the $I_{insolation}$ and a corresponding reduction in the I_{shade} are observed.

The $I_{insolation}$ indicated that insolation intensities are more pronounced in the wide-open courtyard (AR=0.11) than in the more constrained one (AR=1.16). The I_{shade} has the opposite behaviour in relation to $I_{insolation}$ for both courtyards. As a consequence, the insolation intensities are on average 168% higher and shading protection 38% lower in the courtyard with the low aspect ratio (AR=0.11). Notice that $I_{insolation}$ and I_{shade} are maximum and minimum, respectively, during the wet season (from October to April) which can reduce even more the courtyards' thermal performance during this period.

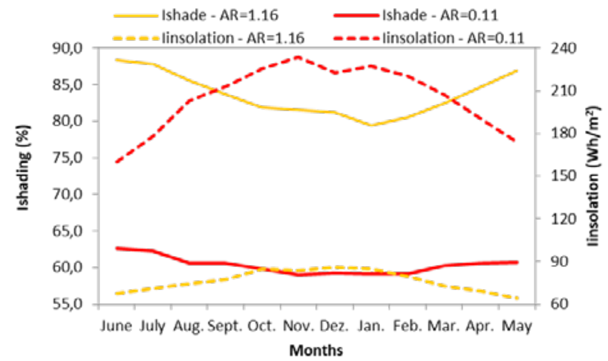
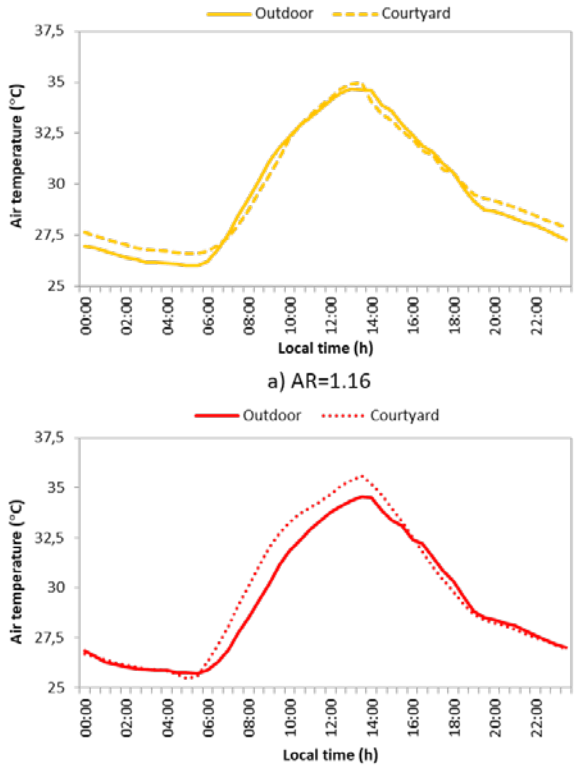


Figure 4:
Monthly average shading and insolation indices of both courtyards.

November exemplifies the typical behaviour of the air temperature in both courtyards for a period with the highest level of insolation and lowest shading provided by the envelopes of the courtyards (Figure 5). It is possible to notice that the cooling and heating trends are not the same in the two courtyards. Cooling occurs when thermal conditions in the courtyard are milder than concurrent conditions measured at the rooftop weather station, while heating is characterized by the opposite behaviour. The overheating inside courtyards has been reported in other studies and regions [17,18], with the form factor attributed as the main performance parameter, since it controls solar radiation and shading throughout the day

In the courtyard with a high aspect ratio (AR=1.16), the heating effect is only noticed when solar angles can reach the inner envelope of the courtyard (in the narrow window between 10 am to about 1 pm) and during night-time, when radiative losses to the sky are reduced due to the outgoing long-wave radiation trapping, resulted from the more obstructed sky dome (Fig. 5a). In these cases, the difference between courtyard and rooftop temperature (ΔT) is on average -0.5°C, with a peak value of -0.7°C. Outside these hours, the courtyard is capable to block direct solar radiation gains during most of the day. ΔT analysis indicates a slight passive cooling effect inside the courtyard with average values of +0.3°C and a peak of +0.7°C.

In turn, the courtyard with low aspect ratio (AR=0.11) has a higher solar exposure throughout the day that leads to increased solar heat gains, raising air temperatures (Fig. 5b). The overheating effect is on average -1.4°C and peak value of -2.5°C. This condition is only modified in the late afternoon when direct solar gains decrease and shading takes place in the courtyard, providing a cooling effect. The courtyard remains 0.4°C cooler than at the rooftop station during nighttime with a peak value of 1.3°C due to its unconstrained environment expressed by its high sky view factor, which allows radiative losses to the sky.



a) AR=1.16

b) AR=0.11

Figure 5:
Monthly average daily course of courtyard and rooftop air temperature during monitoring in November 2019.

The tempering effect observed in both courtyards is consistent with those simulated by Rojas et al. [15] using a CFD model of courtyards with simplified shapes, i.e., courtyard with a high aspect ratio (AR=1.16) acting as a heat drain while the one with a low aspect ratio (AR=0.11) would act as a heat source due to its unshaded walls and ground surface. The average and maximum values quantified in the tropical region are quite lower than those observed in the Mediterranean where passive cooling is more substantial, with average attenuation of 4.4 °C in courtyards with similar morphologies [3]. This might be associated with the nocturnal radiative cooling resulting from the difference between atmospheric and terrestrial longwave radiation, which is more pronounced in the Mediterranean region than in the tropical region [4].

The average monthly cooling/heating effect evaluated considering the typical behaviour previously described is shown in Figure 6 and Table 1. Due to its capacity of providing shade and controlling isolation, the courtyard with a high aspect ratio is capable of moderating outside temperature, providing a steady cooling effect throughout the year, with a slight increase in the wet season (October to April) compared to the dry season (May to September). The tempering capacity is more pronounced during the wet season, despite the reduction in the I_{shade} and the raise in the $I_{insolation}$. In turn, the heating effect verified during nighttime and for periods with high solar angles during daytime shows little change throughout seasons.

Table 1:
Average cooling and heating effect quantified for the courtyards in the seasons.

Aspect Ratio	AR=0.11		AR=1.16	
Season	Cooling	Heating	Cooling	Heating
Hot-dry	0,88	-0,28	0,63	-0,73
Hot-wet	0,38	-0,74	0,70	-0,58

On the other hand, the courtyard with a low aspect ratio presents a different pattern as it tends to accumulate heat when exposed to the sun, becoming a heat source during daytime. A heating effect is most pronounced during the wet season In July and August, the heating effect is almost null, as these months are characterized by a hot-dry period and have frequent cold fronts that can make the courtyard cooler than the outside environment [4].

To further explain the patterns observed in both courtyards in the interplay between shading and insolation, humidity certainly plays a role. During the dry season, the lower insolation and higher shading help to balance the input energy fluxes, mainly driven by the solar radiation, reducing the sensible fluxes exchanges and heat stored inside the courtyards' inner envelopes due to the lower temperature than outside. As a result, the climate-responsive capacity of this strategy is enhanced, raising the cooling effect in the courtyard with a high aspect ratio and reducing the heating effect in those with a low aspect ratio.

During the wet season, despite the rise in insolation and reduction in shading, the progressive rise in latent heat fluxes exchanges inside the courtyard due to rainfall intensification in the region from November to February helps counterbalance the sensible fluxes exchanges while the water availability in the construction materials reduces the heat stored inside the mass of the courtyard walls [19]. Notice that in this period, the cooling effect in the courtyard with a high aspect ratio is the highest during daytime and the heating effect is reduced mainly in the night period. In turn, the rainfall elevation in the region from November reduces the heating effect in daytime although it also reduces the cooling effect during nighttime inside the courtyard with low aspect ratio.

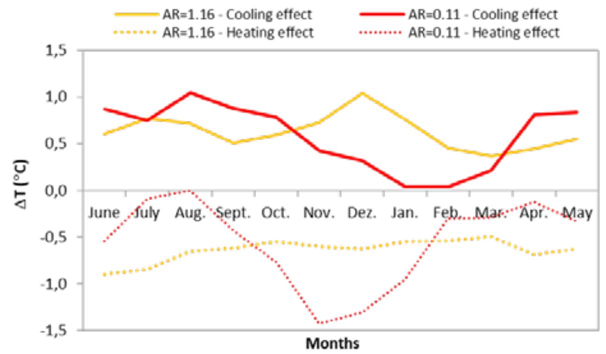


Figure 6:
(a) Average monthly shading index and (b) average monthly cooling/ heating effect quantified in each courtyard.

Based on the results we can state that the main disadvantage of applying the courtyard strategy in building design in the tropics is concerning the heating effect. Because of the morphological characteristics of the courtyard with higher AR, with a more restricted possibility to warm up the inner envelope and similar restrictions to dissipate the long-wave radiation, the heating effect is little impacted by the solar position. In contrast, due to its inability to control incoming solar radiation and provide shading, aggravation in overheating is observed in the shallow courtyard for higher solar angles and the opposite is verified when the sun is more declined to the northern hemisphere, i.e., with overheating attenuation. Therefore, an adequate thermal study must be conducted to define the courtyard's proportions during the design phase.

4. CONCLUSION

The findings confirm the thermal benefits of courtyards since these architectural resources provide a passive cooling effect in tropical regions. The interplay between shading and insolation plays a role in the courtyards' thermal performance. The aspect ratio factor (the proportion between height and width) is a key factor to be considered in the design phase as well as the building function and usage condition.

Deep courtyards are recommended where the primary use is during daytime, especially those with commercial and institutional function, due to their capacity to block solar radiation and to provide shading during most of the day, resulting in a cooling effect in these transition spaces. However, due to the long-wave radiation trapping and the heat stored inside the mass of the courtyard walls, overheating is observed at nighttime, which could hinder its use during the night, and also affect the thermal performance of the surrounding indoor environments of the enclosing building. Commercial and institutional buildings are usually not in use during the night, however, in the case of residential buildings, it is suggested that a thermal-energy performance analysis is carried out in order to decide the feasibility of using this transition space.

Shallow courtyards should have their usage preferably set for the late afternoon and during nighttime, due to the cooling effect observed in these environments. The lack of protection against solar radiation makes these courtyards excessively overheated during daytime. Unless complementary strategies are designed for such as vegetated niches, shaded areas among others, the shallow courtyard design should be avoided due to the high levels of radiation present in the tropics. Despite that, at night, the cooling effect observed in the field measurements points to a favourable thermal performance of the adjacent environments, therefore becoming interesting solutions for residential buildings.

In seasonal terms, the courtyard with a high aspect ratio can provide a cooling effect during the whole year, especially during the hot-wet season where attenuation reaches its peak and the heating effect is reduced by its minimal. In turn, the courtyard with a low aspect ratio is more beneficial in the hot-dry season since the cooling effect, only observed during nighttime, is greater in this period and the heating effect during daytime is reduced to minimal intensities inside the inner envelope.

ACKNOWLEDGEMENTS

The authors would like to thank the State Department of Culture, Sport and Leisure of the State of Mato Grosso /Brazil and Social Service for Commerce of Mato Grosso (SESC) for authorizing this research. This work was financially supported by the Federal University of Mato Grosso/ Brazil (CNPq funding) and the Research Support Foundation of Mato Grosso, Brazil (FAPEMAT N.0534180/2016).

REFERENCES

1.Intergovernmental Panel on Climate Change (2018). Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. https://www.ipcc.ch/sr15/

2. Berghauser Pont, M. Y.; Haupt, P. A. (2009). Space, density and urban form. Thesis. 303p. Technische Universiteit Delft, Netherlands.

3. Rivera-Gómez, C., Diz-Mellado, E., Galán-Marín, C., López-Cabeza, V. (2019). Tempering potential-based evaluation of the courtyard microclimate as a combined function of aspect ratio and outdoor temperature, Sustainable Cities and Society, 51: p. 101740.

4. Callejas, I. J. A; Durante, L. C.; Diz-Mellado, E.; Galán-Marín, C. (2020). Thermal Sensation in Courtyards: Potentialities as a Passive Strategy in Tropical Climates. Sustainability, 12: p. 6135.

5. Soflaei, F., Shokouhian, M., Abraveshdar, H., Alipour, A., (2017). The impact of courtyard design variants on shading performance in hot- arid climates of Iran, Energy and Buildings, 143: p. 71-83.

6. Zamani, Z., Heidari, S., Hanachi, P., (2018). Reviewing the thermal and microclimatic function of courtyards. Renewable and Sustainable Energy Reviews, 93: p. 580-595.

7. Diz-Mellado, E., López-Cabeza, V. P., Rivera-Gómez, C., Galán-Marín, C, .Rojas-Fernández, J., Nikolopoulou, M. (2021) Extending the adaptive thermal comfort models for courtyards, Building and Environment, 203: p. 108094.

8. Rodríguez-Algeciras, J., Tablada, A., Chaos-Years, M., De la Paz, G., Matzarakis, A., (2018). Influence of aspect ratio and orientation on large courtyard thermal conditions in the historical centre of Camagüey-Cuba. Renewable Energy, 125: p. 840-856.

9. Taleghani, M., Tenpierik, M., & van den Dobbelsteen, A. (2014b). Indoor thermal comfort in urban courtyard block dwellings in the Netherlands. Building and Environment, 82: p. 566–579.

10. Martinelli, L., & Matzarakis, A. (2017). Influence of height/width proportions on the thermal comfort of courtyard typology for Italian climate zones. Sustainable Cities and Society, 29: p. 97–106.

11. Akbari, H., Cherati, S. M., Monazam, N. H., Noguchi, M. (2021). Effect of courtyards' geometrical parameters on climate adaptability and shading performance in hot-arid climate of Yazd (Iran), Sustainable Energy Technologies and Assessments, 48: p. 101594.

12. Callejas, I. J. A., Biudes, M. S., Machado, N. G., Durante, L. C., Lobo, F. A. (2019). Patterns of Energy Exchange for Tropical Urban and Rural Ecosystems Located in Brazil Central. J. Urban Environ. Eng., 13: p. 69–79.

13.Lacerda, L.B. (2018). Patrimônio Histórico-cultural de Mato Grosso; Entrelinhas: Cuiabá, Brazil.

14. RD news. Available online: https://www.rdnews.com.br/galeria_embeds_full.php?id=390#ad-image-5 (accessed on 16 Marc 2022).

15. Rojas, J.M.; Galán-Marín, C.; Fernández-Nieto, E.D. (2012). Parametric Study of Thermodynamics in the Mediterranean Courtyard as a Tool for the Design of Eco-Efficient Buildings. Energies, 5:2381-2403.

16. AUTODESK. Autodesk Ecotect Analysis: Sustainable Building Design Sofware. 2016.

17. Forouzandeh, A. (2018). Numerical modeling validation for the microclimate thermal condition of semi-closed courtyard spaces between buildings. Sustain. Cities Soc., 36: p. 327–345.

18. Cantón, M.A.; Ganem, C.; Barea, G.; Llano, J.F. (2014). Courtyards as a passive strategy in semi dry areas. Assessment of summer energy and thermal conditions in a refurbished school building. Renew. Energy, 69: p. 437–446.

19. Callejas, I. J. A.; Nogueira, M. C. J. A.; Biudes, M. S.; Durante, L. C. (2016). Seasonal Variation of Surface Energy Balance of a Central Brazil City. Mercator, 15: p. 85–106.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 02
16:30 — 18:00

CHAIR
GILLES FLAMANT

PAPERS
1598 / 1637 / 1587 / 1302

26TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

The thermal performance of Lacaton & Vassal's winter gardens

Revisiting three case studies

ALONSO CANDAU, RAFAEL[1] COLLO, FLORENCIA[1] DAMBRON, OLIVIER[1]

[1] Atmos Lab

ABSTRACT: For the past 30 years, Lacaton & Vassal have been working with winter gardens and greenhouses, inserting a new type of space in buildings, as a mean for climate control and adaptability. Their articulation and technical specifications have been improved and systematised across the years. This research project in collaboration with the architects seeks a precise understanding of the winter gardens' behaviour to further improve and adapt them. It shows that the winter gardens are as smart passive systems that can save energy, create more enjoyable spaces that are bright, adaptable, and comfortable across the seasons and ultimately, they provide well-being and joy to their occupants. Conclusions are drawn from information provided by the architects, interviews, observations, temperature monitoring, and environmental simulations.
KEYWORDS: Lacaton & Vassal, winter gardens, environmental transformations, low energy housing

1. INTRODUCTION

Winter gardens and conservatories have been relegated from the environmental design agenda, as configurations did not seem to bring much benefit to the parent building, and they presented a higher risk in summer than a benefit in winter. Nowadays, massive amounts of insulation seem to be the only way to improve the thermal performance of a building.

However, for the past 30 years, the French practice Lacaton & Vassal have been working with winter gardens and greenhouses in a novel way, inserting a new type of space in buildings, whether residential, office or else, as a mean for climate control, free space and adaptability. They have appropriated the technology of agricultural greenhouses, engineered to work with the sun, wind and light, and of which indoor conditions are controlled with the use of geotextiles, adapted structures and nets. They have domesticated these elements to work with climate in human-occupied buildings. Their residential schemes spread across France, but new projects are being built in Switzerland and Germany.

The work of Lacaton & Vassal is particularly relevant for their strong philosophy and influence in the international architectural scene: their oeuvre is published worldwide (1,2,3), they teach in leading schools and were recently awarded the EU Mies Van Der Rohe prize 2019 (4) and the Pritzker price 2021 (5).

Their winter garden systems are a smart, passive, and adaptable design solution that can be implemented in temperate climates with warm season. This research project in collaboration with the architects seeks a precise understanding of the winter gardens' behaviour to further improve and adapt them. This paper will focus on three residential schemes in France. Conclusions are drawn from information provided by the architects, interviews, observations, temperature monitoring, and environmental simulations.

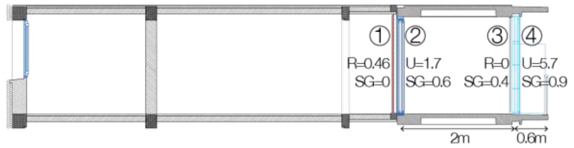
Figure 1:
Exterior and interior view of a winter garden

2. THE WINTER GARDENS

Winter gardens are used as building envelopes and "free-space": somewhere people can choose how to use, when to occupy and how to furnish (Figure 1). The architects expose their philosophy in Actitud (2017): they base their designs on doing more with less, and therefore economic savings: agricultural greenhouses offer large while inexpensive envelopes, considerably cheaper than those of traditional buildings.

"From the moment you can offer double or triple the space (for the same price), houses can function in a non-uniform way: some areas are insulated and heated whereas some others are not, and these spaces can be combined". Lacaton & Vassal explain that winter gardens can be comfortable most of the year, depending on temperature, sun and rain. Their aim is to "take advantage of outdoor conditions, domesticate them, manage them and transform them: the opposite attitude from an insulated space that defends itself from climate". Whilst their indoor spaces are generous, winter gardens become the space of freedom, where people are liberated from pre-sets, the space where the user is given freedom of choice.

Figure 2:
Composition of winter garden system

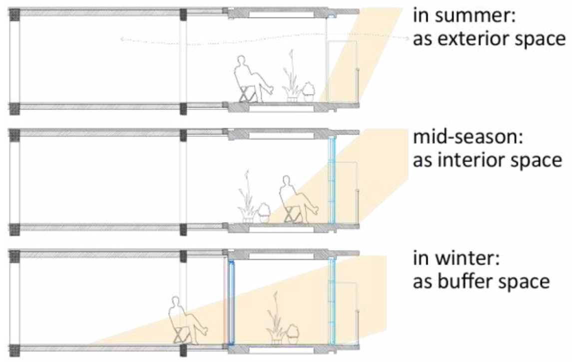


The articulation of the winter gardens has been improved and systematised across the years. They are composed of 4 adaptable layers that ensure an optimal performance throughout the year. From the inside out, the first layer is a thermal curtain (R=0.46m²K/W) that insulates the living areas at night, protects from the sun in the hottest hours. The second layer is the limit of the heated envelope. It is a double glazing with minimum U-value, maximum light and solar transmission. The last layer is the outer glazing, which is single and often permeable to air through slits. In front of it, a permeable geotextile screen controls solar access or privacy. Its opening ratio is project specific depending on orientation and climate. 2/3 glazing panels are always operable to maximise air flow. The interior surfaces of the winter garden are exposed concrete to take advantage of its thermal mass. A small balcony helps to control the highest sun and is also used for fire prevention purposes. Figure 2 shows the different elements of the system with their U or R value and the Solar Heat Gain Coefficient. The careful design of each element guarantees that users consider the space as a buffer in winter instead of a heated area. The ease of operability ensures that occupants use every element regularly.

The environmental benefits that these systems offer are numerous, both for the parent building and for the inhabitants: they act as buffer spaces, regulating thermodynamic exchanges with outdoors and allowing users to take advantage of the climate through its adaptive features. They mitigate heat loss thank to the insulation provided by the air and by the extra layer, but unlike that of an insulation product, they allow in maximum solar gains and daylight and preserve the surrounding views and contact with nature. Regarding airflow, winter gardens reduce infiltration towards the parent building by reducing wind pressure on the façade. Also, the incoming air from the winter garden is pre-heated which is more hygienic and healthier than through mechanical systems. A small opening during the cold period enables the renewal of fresh air. Regarding acoustics, winter gardens can halve incoming noise.

The use and function of the winter gardens vary with the seasons (Figure 3). In winter, when both layers are closed, they function as buffer spaces. In summer, when the external layer is opened, the system becomes a deeper balcony shading the interior from the high sun and functions as a protected outdoor space. During the mid-season, gentle temperatures inside allow the occupants to leave the internal layer open and use the area as an extension of the indoor space.

Figure 3:
Use of the winter garden across the seasons



3. THE CASE STUDIES

This paper presents the work carried out in three of their residential schemes. Plans, sections, images and climate data of each cas and city are summarised in Table 1:

-"Cité Manifeste", in Mulhouse (2005) featuring row houses. It was one of their first buildings. Units are organised by pairs, in two levels.

-"Logements étudiants & sociaux, Ourcq-Jaurès", in Paris (2014). Newly built, inside the urban tissue.

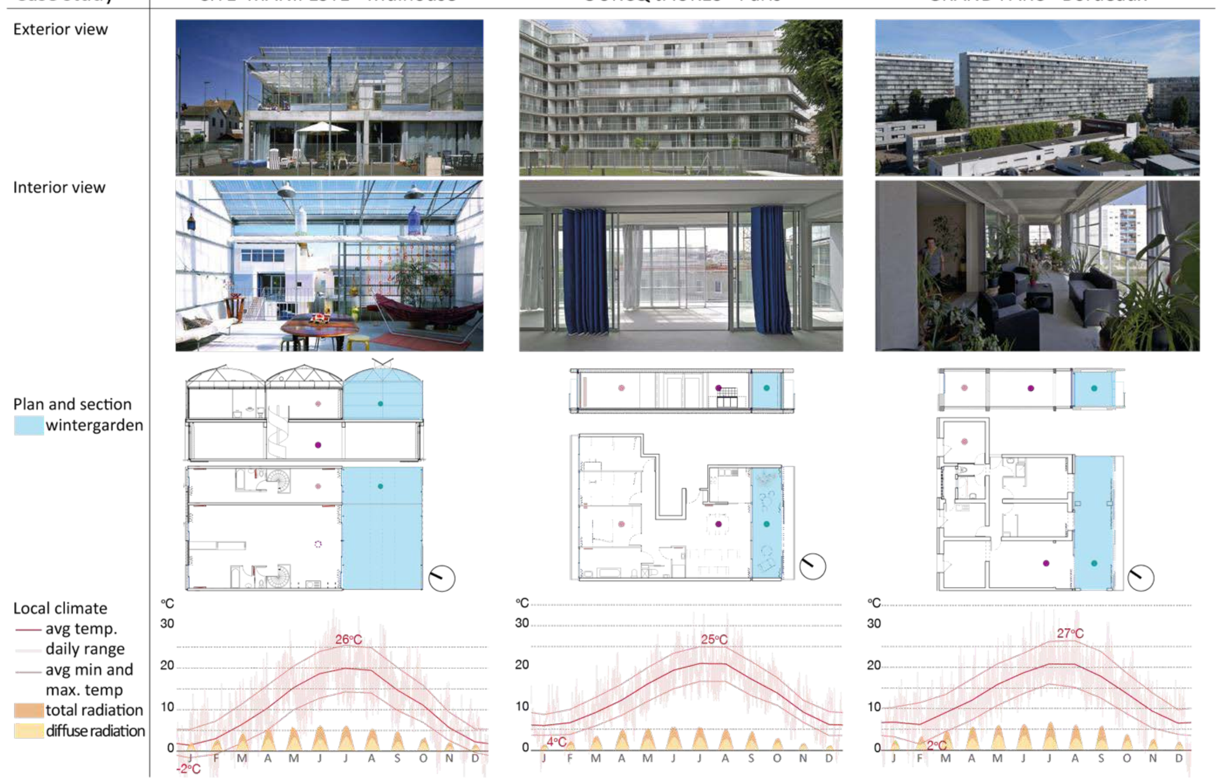
-"Transformation de 530 logements au Grand Parc" in Bordeaux (2016), a refurbishment of a typical 60-70's building where winter gardens were added.

The 3 climates are classified as Cfb in the Koppen Geiger classification, Temperate Oceanic with all month's average temperature below 22°C and warm summers. Mulhouse is closer to a Cold climate and has lower averages in winter. Bordeaux is lower in latitude and has the warmest summers.

4. METHODOLOGY

Fieldwork was carried out in the three buildings. It consisted of interviews to occupants of 10 units to learn from their impression of the space and

Table 1:
Case studies and corresponding climate

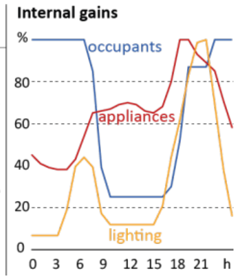


elements; and leaving temperature dataloggers to study the thermal behaviour. The case studies were assessed using environmental design principles and analysis tools.

Weather data were obtained from Meteonorm 7.0. Thermal models were simulated in Energy Plus and calibrated with measurements and interviews. Building inputs were provided by the architects. When available, internal gains and setpoints were set according to the French regulation RT 2012. Schedules and other inputs (unavailable in the regulations) were set according to EN 15251. Table 2 shows a summary of inputs.

Table 2:
Input summary

Material specifications	MH/OU/BO	Internal gains	
U_{walls}	0.3/-/0.2	Total occupants	3
U_{floor}	1.2/-/-	Appliances W/m²	
U_{roof}	0.2/-/-	Livingroom	3.5
U_{window}	4.4/1.1/1.7	Kitchen	10
$SHGC_{window}$	0.4/0.6/0.5	Rest	0
VLT_{window}	0.4/0.6/0.8	Lights W/m²	
U_{wg}	5.7	Living/Kitchen	5.0
$SHGC_{wg}$	0.9/0.7/0.9	Bedrooms	2.5
VLT_{wg}	0.9/0.9/0.9	Rest	0
		Fresh air m³/person·h	30



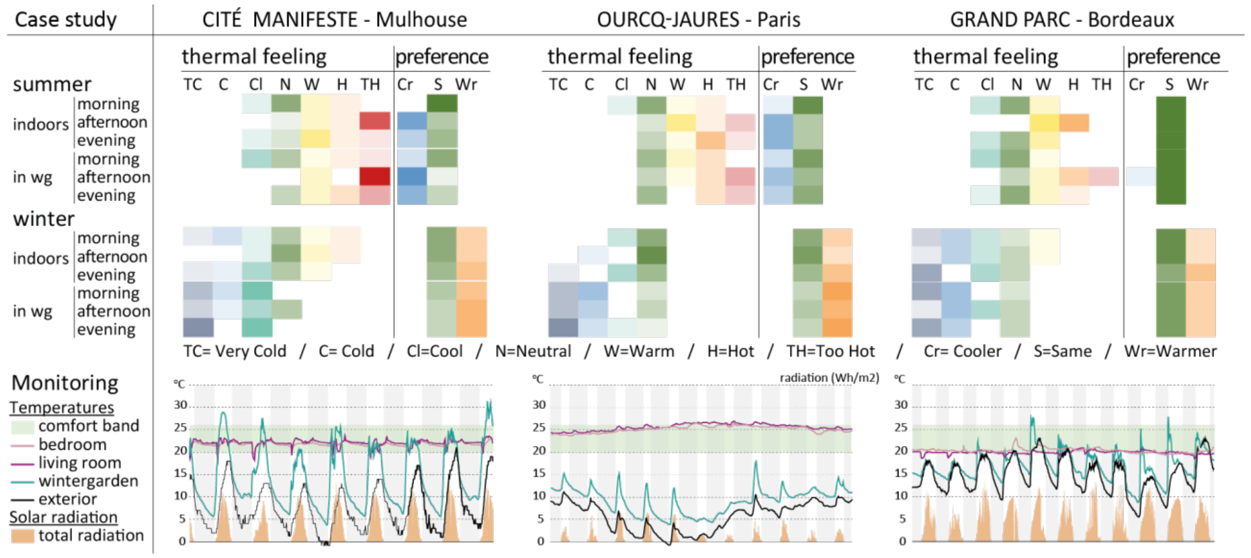
For the calibration, exterior temperature was introduced from the measurements. Solar radiation, wind speed and direction were extracted from nearby weather stations. Simulated free-running zone operative temperatures were evaluated against the adaptive comfort zone based on EN 15251 (cat. II).

5. DESIGN FEATURES

Most of the dwellings designed by Lacaton & Vassal are exposed in at least two orientations to allow for cross-ventilation. Living areas are systematically oriented to the south or south-east, depending on the plot, to take advantage of the warming sun. Winter gardens always follow living areas and therefore receive the sun during the morning and eventually early afternoon all year round. Bedrooms are located towards the north or northwest quadrants. In between the spaces there are none or minimal divisions to allow the air to flow, doors are often sliding to foster it. Access to the units is always from the core, so that winter gardens remain private spaces of the occupants, far from the look of strangers.

All the winter gardens are composed of the elements previously mentioned. The case of Cité Manifeste is particular, as the greenhouse's roof is exposed. It has a horizontal shading and an automated roof opening (it opens when wg_{temp}>21°C). Ourcq-Jaures and Grand Parc are typical floors of larger buildings.

Table 3:
Fieldwork results



6. FIELDWORK RESULTS

Feedback from 30 interviews is summarised below:

-100% of the interviewees reported using windows and curtains to adjust their thermal comfort

-None of the interviewees reported having an extra heating device in the winter garden

-80% use interior curtains to protect from the sun or too much cold

-83% use exterior curtains to prevent from heat, light or for privacy issues

-Ourcq-Jaures was the case where occupants use the least the adaptive elements

-most of the interviewees reported opening the intermediate window "as soon as it is nice"

Also, dataloggers were left in all three cases during a week in the living room, one bedroom, winter garden and the immediate exterior (see Table 2 for locations). Table 3 shows results from thermal sensation feedback inside the unit and in the winter garden together with temperature monitoring.

In all cases, people reported being very satisfied with their thermal environment, especially in winter as there are barely any complaints. However, some points are to be noted: In Mulhouse, most of the interviewees consider that the house, but specially the winter garden are too hot during summer afternoons. This is due to the excessive exposure of the greenhouse roof. Notably, the architects did not plan any vertical shading in the winter garden, but all occupants placed a form of shading in the exposed glazing. In Ourcq-Jaures, occupants considered that bedrooms are too hot during summer evenings. The north-west orientation of the bedrooms without any exterior shading device penalises the performance. In Grand Parc, the satisfaction is remarkable as nobody reported preference for cooler temperatures in summer in any of the spaces, even the climate is the hotter. This is due to the high amount of thermal inertia in the structure and walls of the building controlling peaks.

Measurements were taken during winter (except for Grand Parc, where it was already spring), and heating was used in the three cases.

In Mulhouse, thermostats are individual, and easy to monitor by the users. The occupant had it set at 22º. She opens all the windows during the morning to ventilate, which is reflected by a drop in the temperature of 2-3°C. Otherwise, interior temperature remains relatively stable around the target.

In Ourcq-Jaures, heating is centralised. Users can regulate each radiator, but without a clear view on the temperature. This results in a setpoint that is too high, around 25°C. Furthermore, when outdoor temperature drops below 0°C, the building manager increases temperature to 26.5°C. The centralised system did not help for the occupants to regulate their own temperature, as they do not seem to be aware of that possibility. This also explains the poorer use of the adaptive features.

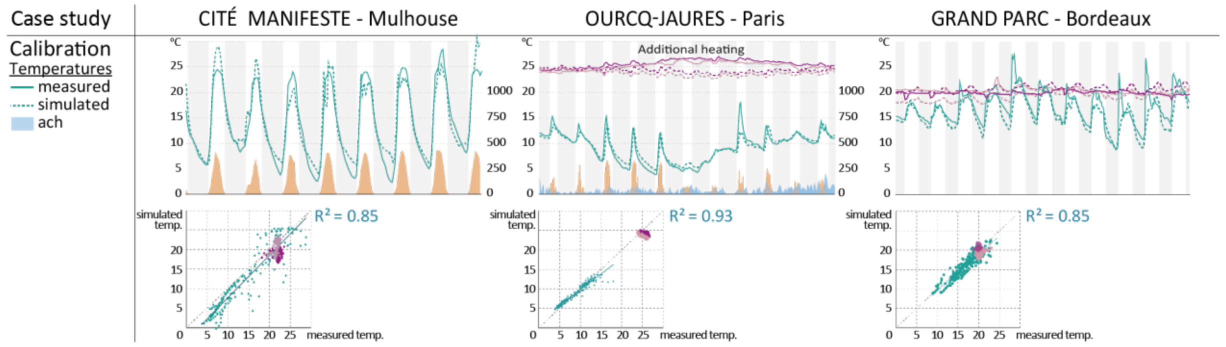
In Grand Parc, the thermostat is individually regulated. In the studied unit, it was set at 20°C. Winter garden doors were left open during the day. Indoor temperatures are very stable around the target. If the winter garden had been closed, the buffer effect would have been enough to maintain the same temperatures passively.

In general, the winter garden proves to be effective as a buffer space:

-In Mulhouse, its temperature is always above outdoors by 2-4º at night and 7-13º during daytime (all days were sunny). The shading was always on.

-In Ourcq-Jaures, its temperature is 2-8°C higher than outdoors. In sunny days, temperature rises fast and reaches differences of 6-8°C, which is particularly effective for very cold sunny days. The

Table 4:
Thermal model calibration



effect of the inertia is clear: after 3 sunny days, and during a cloudy one, the temperature difference is still at 4°C. In the second cloudy day, it drops to 2°C. This means that during cloudy days, the winter garden still acts an effective buffer space.

-In Grand Parc, as the windows were open during the day, the buffer effect is less clear. During night-time, the difference with outdoor temperature is 3-4ºC.

Fieldwork results proved that occupants indeed use the elements to control their environment. Winter gardens are effective as buffer spaces during winter, and enjoyable during the mid-season and summer. Only Mulhouse overheats due to the roof exposure.

7. CALIBRATION OF THE THERMAL MODELS

Fieldwork results were used to calibrate the thermal models, notably the winter gardens, as all other spaces were using heating. Key parameters to calibrate were amount of thermal inertia and infiltration air changes, to follow reality as close as possible. Table 4 shows the results of the calibration of the three cases.

Indoor simulated temperatures follow closely the measured ones, with an average difference of 1ºC and a maximum difference of 3ºC. Winter garden temperatures match more closely than internal spaces, as their temperature depends more on envelope and material properties than indoors - where cooking or number of people at any given time influence temperature. Regression analysis of the scatter plots showing measured against simulated temperature reveal a correspondence of 0.85-0.93 which is fairly accurate.

8. ANALYTIC WORK AND RESULTS

For the winter garden operation, fieldwork results were interpreted as follows:

-Interior doors open "as soon as it is nice". The input is translated as: if t_{wg}>20.5°C and t_{int}>20°C, or if t_{int}>24°C

-Exterior doors open entirely during summer and if t_{wg}>26°C and t_{ext}< t_{wg}

-Thermal curtains are activated at night-time during the mid-season and winter

-Solar curtains are activated when incident radiation > 100W and during night-time in summer for privacy.

Thermal simulations in passive mode were used to understand the behaviour across the year. Results match the objectives of the architects:

-During summer days, temperature inside the winter garden follows outdoors and can even fall below during peak time for the two cases of the buildings where the roof is concrete. The space is therefore better than a comfortable outdoor space. In Mulhouse, temperature follows outdoors, but with with some 7°C more.

-During the mid-season, the temperature of the winter garden reaches the comfort band most of the days, especially when it is sunny. The space can therefore be used as an extra indoor space.

-During winter, the temperature difference with outdoors validates its functioning as buffer spaces: For the cases of Ourcq-Jaures and Grand Parc, temperature differences reach 3-8°C both during day and night-time, depending on the sun and thermal inertia. For Mulhouse, temperature difference at night is lower due to the large exposure of the winter garden envelope and lack of thermal inertia. During daytime, difference can be 5-15°C, depending on the sun.

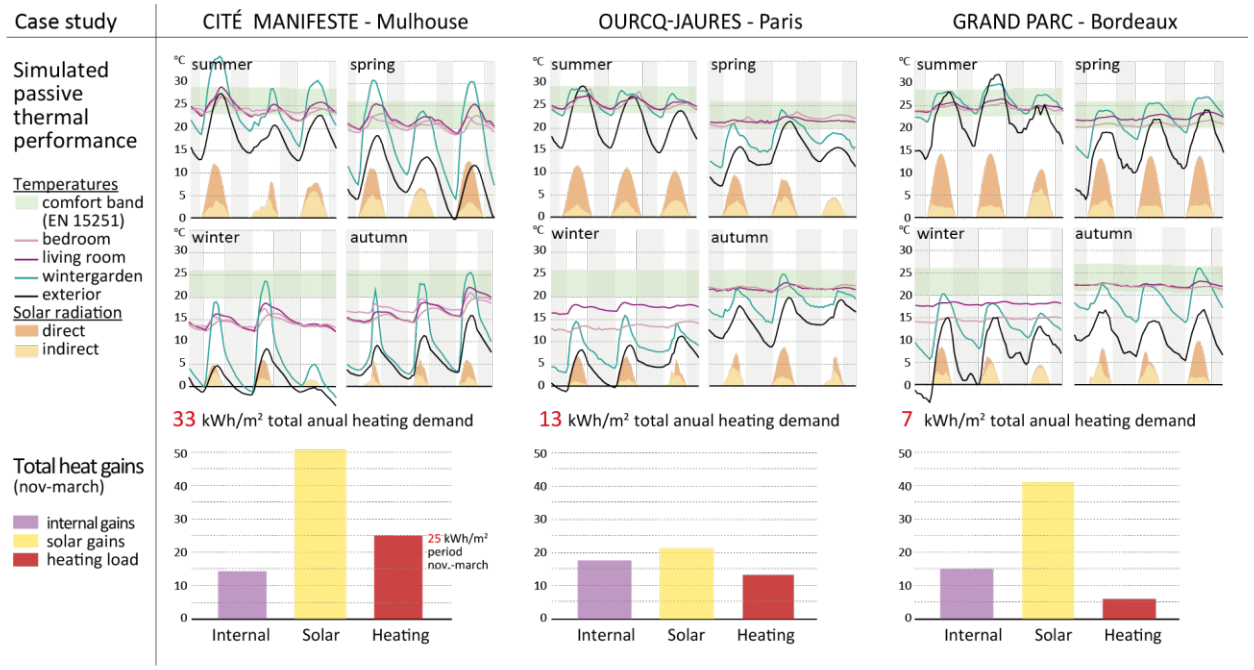
Indoors, temperatures remain stable and inside the comfort band most of the year. During the coldest months, all the units require heating.

With regards to energy demand, Grand Parc and Ourcq-Jaures require very little heating (> 15 kWh/m²). However, Mulhouse's demand is higher (33 kWh/m²). It is relevant to remind that this climate is also the coldest one.

During peak days, the winter garden is particularly efficient. First, because the thermal inertia keeps temperatures higher and second, because those days are sunny: the sun heats the space and the buffer effect is enhanced. This helps to reduce the peak load.

Looking at the internal gains of the entire house during the heating period, it is clear that the largest contribution to rise the temperature inside is the sun, which is a more reliable and sustainable source than relying on internal gains or heating.

Table 5:
Results of analytic work



9. DISCUSSION

Lacaton & Vassal's buildings are designed consistently following bioclimatic principles. The adaptive features are maximised as many layers can be activated according to environmental conditions and user's will. The units are bright due to the large windows, and winter gardens do not prevent the units from being properly daylit.

From the two studied typologies, the winter garden with the opaque roof works consistently better as the balance of exposed surface and thermal inertia is better calibrated. With the exposed roof, interior spaces overheat considerably in summer.

Simulations demonstrated that the winter garden can be an asset throughout the year: In winter, temperature differences with outdoor validates its functioning as a buffer space, and heating demand is low even with a fully glazed envelope. Although the sun is not intense, it still represents a net heat gain. In summer, the different shadings, thermal inertia, and cross ventilation work effectively as temperatures remain and below outdoors during peak times. During the mid-season, gentle temperatures inside allow the occupants to use the area as an extension of indoors.

An adequate operability of the elements is key to regulate interior temperature properly, and most of the users seem to be doing it intuitively:

- In winter, both glazing layers should be kept closed and solar curtains open. Thermal curtains should be closed at night.

- During summer, all the layers should be open to evacuate heat and allow proper ventilation. Both curtains can be deployed to control the sun and privacy.

- During the mid-season, the operability of the elements depends on the sun and temperature. In general, especially during sunny days, doors towards the winter garden can be left open as the temperature should be comfortable as indoors. Thermal curtains closed at night help to maintain temperatures.

Individual regulation of the heating system is a key condition for the system to work properly and save energy: if the users are not aware, they use less the adaptive features, setpoints are higher, and the overall energy consumption is higher.

10. CONCLUSIONS

All in all, Lacaton & Vassal´s winter gardens act as smart passive systems that can save energy, create more enjoyable spaces that are bright, adaptable, and comfortable across the seasons and ultimately, they provide well-being and joy to their occupants. This type of configuration proves that the concept of the winter garden still has a lot to offer.

ACKNOWLEDGEMENTS

Th authors would like to thank Lacaton & Vassal for facilitating the research and for the long discussions; ETH Zurich who has partially funded the research; and the occupiers who kindly allowed us to leave the dataloggers and provided us with the relevant data.

REFERENCES

1. https://www.lacatonvassal.com/publications.php
2. El Croquis, (2015) "Lacaton & Vassal 1993 2015 - Post media horizon", El Croquis 177/178.
3. Architecture + Urbanism (2012) Lacaton & Vassal, A+U 498
4. https://miesarch.com/work/3889
5. https://www.pritzkerprize.com/
6. Lacaton, A. and Vassal J.P. (2017). Actitud. Gustavo Gili

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA SANTIAGO 2022
Will Cities Survive?

Energy performance simulation in a residential building in Santiago

Impact of passive design considerations, building envelope features, ventilation strategies and energy systems

MARIO MELANO[1] JOSEFINA ECHAIZ[1] GILLES FLAMANT[1] FRANCOIS SIMON[1] CESAR OSORIO[1] JAVIER RIVERA[1] WALDO BUSTAMANTE[1] ANGELICA FIGUEROA[2]

[1] Pontificia Universidad Católica de Chile
[2] Ministerio de Vivienda y Urbanismo (MINVU)

ABSTRACT: Buildings and the construction industry in general are contributors to the current climate crisis in the form of energy consumption and CO_2 emissions. Passive solar design, envelope material composition, ventilation strategies and energy systems are key aspects in mitigating that contribution. This paper provides indications on the influence of these considerations on the energy performance of a residential building located in Ciudad Parque Bicentenario (Cerrillos, Santiago), a new urbanisation project developed by the State considering sustainability criterion. InSight® and Revit® are used to determine the building typology and shape that maximise passive solar gains. DesignBuilder® is used to determine the heating demand and the risk of overheating, considering different envelope thermal insulation levels, air permeability levels and ventilation strategies. Primary energy consumption and CO_2 equivalent emissions are estimated for different energy system scenarios, including solar thermal and photovoltaic options. Results show that the heating demand can be reduced by over 80% when considering highly efficient building measures, compared to that obtained with the current Building Thermal Regulation. Air-source heat-pump is found to be an attractive solution if used only in heating mode, while the solar thermal energy system can achieve a saving of 86% in domestic hot water energy consumption.
KEYWORDS: Passive design, Envelope thermal insulation, Ventilation, Energy performance, Energy Systems

1. INTRODUCTION

Current models of urban development take few things into consideration other than economic gain, which leads to a never-ending expansion of cities in the form of disconnected, overcrowded and highly resource consuming buildings [1]. Chilean national objectives aim for all new residential constructions to be net-zero energy by 2050 [2], but the actual energy code for buildings does not incentivise them to achieve high energy performance [3]. One initiative of the Ministry of Housing and Urban Planning (MINVU) is the development of Ciudad Parque Bicentenario (CPB), a new urbanisation project that considers better quality standards than those defined in the actual urban planning regulations. Located in the city of Santiago, CPB aims to reclaim a 250-hectare abandoned space and develop from scratch an integrated and sustainable urban area formed by low cost social housing with access to services, public transportation and outdoor areas. The project is currently under construction, with the core element *Parque Cerrillos*, a 50-hectare park, already completed alongside some public and residential buildings. It is the first time that MINVU is planning this type of initiative, as part of a national policy. Thus far, high-quality social housing projects were only implemented by municipalities [4].

The present study aims to determine the requirements related to building design and services for the construction of an energy efficient building on a specific terrain in CPB, *Plot B5* (Figure 1), which will follow this new model of social housing with subsidised rent. The analysis focuses on the urban, architectural and technical strategies to ensure that the future building is as energetically efficient as possible. This study aims to contribute to the MINVU policy for the construction of energy efficient social housing.

Figure 1:
Location of Plot B5 in CPB (white coloured area)

2. GOALS AND METHODOLOGY

The general goal of this paper is to present guidelines and tools to design energy efficient housing, from the macro-scale of location and sun exposure, to passive architectural design and material choices, all the way to energy systems. Precise information and metrics are provided for the case of *Plot B5* in CPB, but the methods used in the investigation may also be useful for any other building, working as a sort of energy efficient building project manual.

In order to achieve this goal, the study was subdivided into three steps: (1) Location and Solar Access, (2) Energy Performance Simulations, and (3) Energy Systems. Each step takes information from the previous one to obtain specific data. The methodology for each section goes as follows:

2.1 Location and Solar Access

- Analysis of the context of Plot *B5*: relationship with nearby public spaces and buildings, annual solar path and shadows that the built environment causes on the plot (Revit® [5]), and plot constructability capacity according to regulatory restrictions.
- Analysis of solar radiation on main facades during winter, through a series of different volumetric iterations (InSight® [6] - Revit® [5]).
- Select the orientation and shape that maximise the passive solar gains of the future buildings.

2.2 Energy Performance Simulations

- Establish inputs for simulations (composition of building envelope, air permeability and ventilation, internal heat gains, activity schedule, etc.) considering several different scenarios to compare, including the thermal insulation regulation required in Santiago's current Thermal Regulation.
- Performance simulation (Design Builder® [7] – EnergyPlus™ [8]) during the winter to determine the heating demand, and during the summer period to evaluate the risk of overheating.

2.3 Energy Systems

- Analysis of heating, domestic hot water (DHW) and electricity demands.
- Analysis of the efficiency of different systems for heating generation (electric radiator, air- and ground-source heat-pumps, natural gas boiler) and distribution (water radiators, underfloor heating). Determination of the potential of solar systems (photovoltaic, thermal). Different energy system scenarios are established.
- Comparison of primary energy consumption and CO_2 equivalent (CO_2-eq) emissions of the different energy scenarios.

3. ANALYSIS AND RESULTS

3.1 Location and solar access

To conduct the first section of the Location and Solar Access Study, a 3D model of the existing built environment was prepared using Revit®, and a simulation of the projected shadows for both the summer and winter solstices was performed. It was concluded that the surrounding built environment does not produce significant shadows on *Plot B5*, so the main concern of a future project relies on the shadows the buildings may produce upon themselves. Considering the surroundings, the plot has the possibility of good views, and could articulate the excellent adjoining public spaces. It was also found that the hypothetical buildings in plot B5 should use the maximum permitted height in order to maximise passive solar gains in winter.

For that purpose, 16 different volumetric iterations of different basic building types were modelled in Revit. Solar radiation incidence (kWh/m²) on the main facades during the winter period (06/21 – 09/20) was simulated for each iteration using Autodesk InSight®. The criteria used to compare iterations was the percentage of facade area that receive less than 100 kWh/m² during the winter. Therefore, the iterations that achieve the lowest percentages are considered to be optimal. The results of the simulations (Table 1) showed that the buildings should conform to a "bar" or block typology, and that they should be oriented towards the east-west, in order to maximise solar gains during the winter and avoid south facing facades.

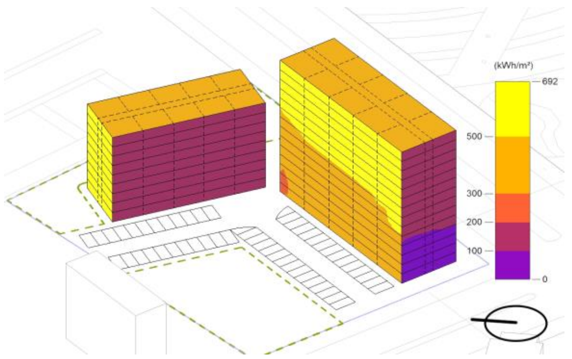
Table 1:
Volumetric iterations of the incidence of solar radiation on facades during winter

Iteration n°	Description of building typology	% of facade area under 100 kWh/m² during winter
01	5 square towers, evenly distributed	2.4%
02	2 bars, centred on plot, east-west facades	15.0%
03	2 bars, centred on plot, north-south facades	50.0%
04	4 bars and a tower, evenly distributed on the plot	6.5%
05	4 bars and a tower, alongside perimeter of the plot	12.5%
06	3 bars on perimeter + a tower on the centre of the plot	14.0%
07	1 thin bar parallel to north boundary + 1 thick bar parallel to east property line	27.9%

08	1 thin bar aligned to north boundary w/ 50° rotation + 1 thick bar parallel to east property line	0.0%
09	1 thick bar aligned to north boundary w/ 50° rotation + 1 thick bar parallel to east property line	0.0%
10	1 thin bar parallel to south boundary + 1 thick bar parallel to east property line	9.4%
11	2 thin bars aligned to north and south boundaries w/ 50° rotation + 1 thick bar parallel to east property line	1.5%
12	2 thin bars parallel to north and south boundaries + 1 thick bar parallel to east property line	15.4%
13	2 thin bars aligned to north and south property lines w/ 50° rotation	1.6%
14	2 towers centred on the plot + 1 thick bar parallel to east property line	1.0%
15	1 thin bar aligned to north boundary w/ 50° rotation + 1 thick bar parallel to east property line + 1 tower on south-west corner	1.0%
16	1 thin bar parallel to south boundary + 1 thick bar parallel to west property line	8.7%

The findings showed that the ideal building type should be two bars, with one volume aligned to the north property line and rotated (~50°), and the other aligned to the east property line (Figure 2). The distribution and layout of one- and two-bedroom apartments were also determined using the current housing market in Santiago as reference. All one-bedroom apartments are located in the north block while all two-bedroom apartments are located in the east block.

Figure 2:
Ideal building type and disposition for Plot B5
Note: the colours indicate the amount of solar radiation received by the facades during the winter period.



3.2 Energy Performance Simulations

The selected buildings and apartments were used for the Energy Performance simulations. The simulations were carried out with the EnergyPlus engine using the DesignBuilder interface, in order to determine the heating demand and the risk of overheating for the apartments in a typical year for the climate of Santiago. Four apartments for each façade of both buildings were examined, that is, 16 apartments in total. Units on the top floor below the roof and on the penultimate floor, units in the centre of the blocks and units in the corner of the blocks were considered in order to cover different orientations and sun exposures. Four scenarios considering different envelope standards and ventilation strategies were evaluated (Table 2):

Table 2:
Energy Efficiency scenarios for simulations

#	Scenario	Description
CASE RT	Current Thermal Regulation (RT)	Thermal insulation levels correspond to those of the current Thermal Regulation. High rate of air infiltration. No ventilation system.
CASE 0	New RT	Thermal insulation and air permeability correspond to those of the Thermal Regulation update proposal sent for simplified consultation in August 2020. Simple flow ventilation system.
CASE 1	New RT_2	Thermal insulation and air permeability Identical to CASE 0. Double flow ventilation system with heat recovery.
CASE 2	Low Consumption	Improved envelope insulation and air permeability standards. Double flow ventilation system with heat recovery.

The specific inputs for the simulation of each scenario are described in Table 3 and Table 4. The results are shown in Figure 3 and Figure 4.

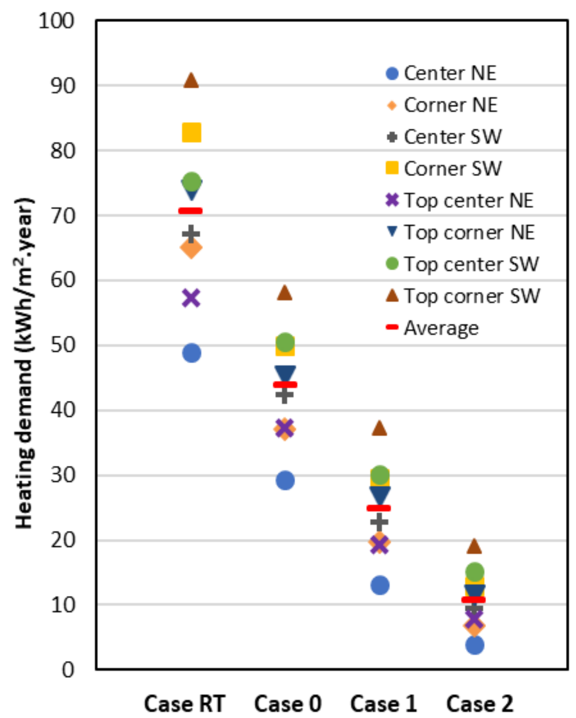
Table 3:
Thermal Transmittance of building envelope elements

		CASE RT	CASE 0	CASE 1	CASE 2
Walls	U (W/m^2K)	1.81	0.75	0.75	0.42
	Insulation thickness (mm)	10	40	40	80
Roof	U (W/m^2K)	0.43	0.39	0.39	0.33
	Insulation thickness (mm)	80	90	90	110
Windows	Glass (W/m^2K)	5.8	2.89	2.89	2.69
	Frames (W/m^2K)	5.88	2.2	2.2	2.2

Table 4:
Ventilation Inputs by scenario

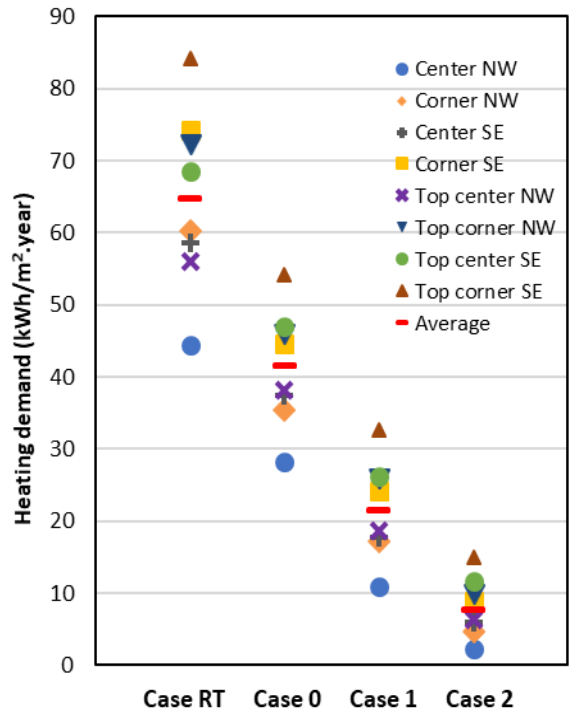
		CASE RT	CASE 0	CASE 1	CASE 2
Infiltration	Air change per hour (ACH)	1.5	0.5	0.5	0.2
Mechanical ventilation	Air change per hour (ACH)		0.97	0.97	0.97
	Heat recovery ventilation (Y/N)	NO	NO	YES	YES

Figure 3:
Heating demand for the one-bedroom apartments



Results indicate that it is possible to achieve an 82% to 85% reduction in the annual heating demand when implementing higher thermal insulation levels, lower air permeability and mechanical ventilation with heat recovery (Case 2) instead of those defined in the actual Building Thermal Regulations (Case RT), with a heating demand lower than 15 kWh/m² per year for most of the apartments under analysis.

Figure 4:
Heating demand for the two-bedroom apartments



With regards to the risk of overheating during summer, the use of solar protections proved to be essential in order to maintain an acceptable indoor thermal comfort. Results showed that thermal comfort can be ensured in the living room during occupation hours with the use of interior shades, combined with intensive ventilation through window openings during the coldest hours of the day. The living room balcony, as an overhang, also contributes to reducing solar gains in summer. The use of exterior shades on the bedroom windows is necessary to maintain a comfortable indoor temperature during the night. The use of intensive night-time ventilation through window openings is also recommended in bedrooms to reach thermal comfort.

3.3 Energy systems

A series of different energy system scenarios (Table 5) for the production of heating and domestic hot water (DHW) were compared through estimates of annual primary energy consumption per square metre (kWh/m^2.year) and CO_2 equivalent emissions ($kgCO_2/m^2$.year) for both apartment types. The study assumes the overall efficiencies presented for each system in Table 6. The study also estimates the performance of a Solar

PLEA STGO 2022

WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Thermal System (STS) for DHW production and a Photovoltaic Panel System (PVS) for electricity generation using the Solar Explorer tool [9].

Table 5:
Energy system scenarios

Scenario	Types of generation and distribution
S1	- Heating: electric radiators in every room of each apartment - DHW: collective electric accumulators
S2	- Heating: air-to-air heat-pump - DHW: collective electric accumulators
S3	- Heating: ground-to-water heat-pump + underfloor heating system - DHW: collective electric accumulators
S4	- Heating: natural gas condensation boiler + water radiators - DHW: natural gas boiler + collective accumulators
STS & PVS	100% of roof Surface occupied by STS (60%) y PVS (40%)

Table 6:
Energy system overall efficiencies

Scenario	Heating	DHW	Electricity
S1	1.00	0.77	1.00
S2	2.50	0.77	1.00
S3	3.50	0.77	1.00
S4	0.90	0.69	1.00

The following results are divided by apartment type. The primary energy consumption is evaluated considering an heating demand of 20 and 40 kWh/m^2.yr, corresponding approximately to case 0 and case 1 of section 3.2. The energy demand for DHW production is estimated to 28 and 34 kWh/m^2.yr for the one- and two-bedroom apartments respectively. The electricity demand is evaluated to represent 41 kWh/m^2.yr considering average usage for cooking and other domestic equipment. The primary energy conversion factors for each fuel are presented in Table 7, along with the CO_2 equivalent emission factors. Results are shown in the following Figure 5 and Figure 6.

Table 7:
Primary energy conversion and CO_2-eq emission factors

Fuel type	Primary energy conversion factor	CO_2-eq emission factor
Electricity	1.9 [10]	0.4398 [11]
Gas Natural	1.1 [10]	0.2277 [12, 13]

Figure 5:
Primary energy consumption and energy-related CO_2 emissions (heating + DHW + electricity) comparison for the one-bedroom apartment

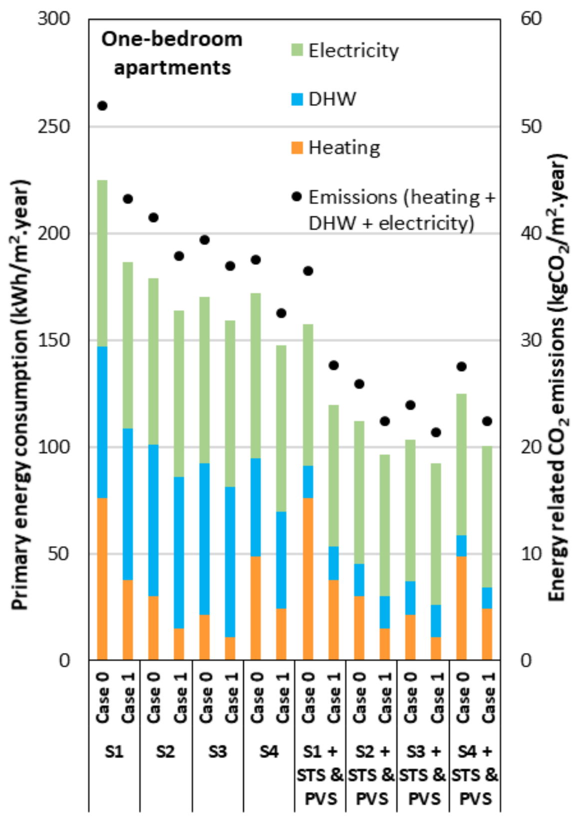
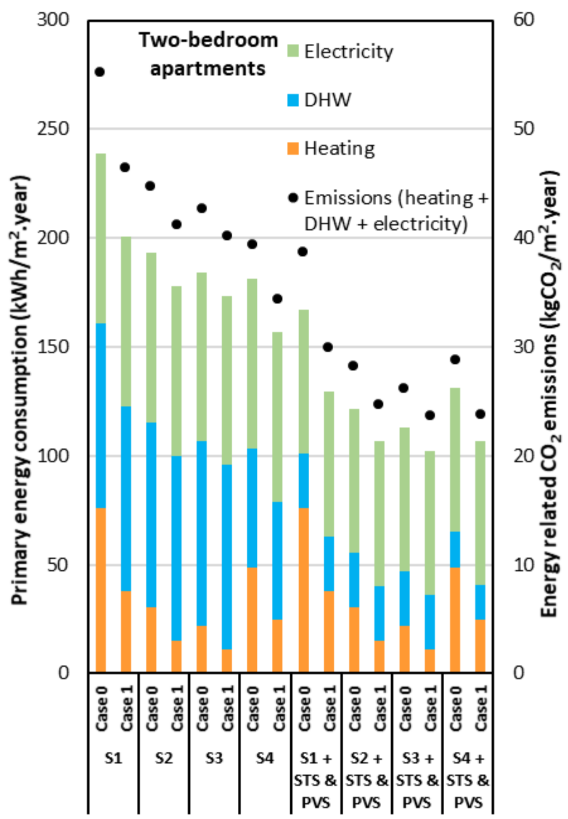


Figure 6:
Primary energy consumption and energy-related CO_2 emissions (heating + DHW + electricity) comparison for the two-bedroom apartments



The Energy Systems analysis results show that it is not possible to reach net-zero energy consumption, the limiting factor being the space available for solar panel installation. The STS, occupying 60% of the roof area, allows a saving of 86% in DHW energy consumption, while the PVS, occupying the other 40%, can save 15% of the consumption of electricity. The most sustainable solution is found to be the ground-source heat-pump with hydraulic underfloor heating (S3) with both solar systems. This has the lowest primary energy consumption and CO_2 emissions of the selected options, but it implies contemplating various supplementary works in the construction project. The air-source heat-pump (S2) is found to be an attractive solution in terms of CO_2 emissions and installation cost. However, its implementation could produce a rebound effect in terms of energy consumption and CO_2 emissions as building occupants would certainly also use it in cooling mode, instead of adopting passive strategies (solar protection devices and ventilation through window openings. The electric radiator solution (S1) is the most economically sound installation option, but the least sustainable in terms of primary energy consumption and CO_2 emissions. However, this solution would probably be the most convenient when the heating demand is low. The gas condensing boiler solution (S4) appears to be a good compromise between installation cost and operating CO_2 emissions, but it contributes to increasing the country's energy dependence on importing fossil fuels, rendering it the least sustainable option.

4. CONCLUSION

The study describes how an apartment building in Santiago can achieve low energy consumption, by the use of appropriate passive design considerations, features of the building envelope (i.e. materials and air infiltration), ventilation strategies and energy systems. Results show that a reduction of the yearly heating demand of over 80% may be achieved when considering highly efficient building measures, compared to that obtained with the current Building Thermal Regulation.

These results are specific to the climate conditions of Santiago. Given the diversity of climates in Chile, other technical requirements should be determined to reproduce similar high energy performance construction projects in other Chilean locations. Besides, an in-depth economic analysis of the different measures is necessary to validate the feasibility of their implementation, according to the monetary restrictions of such social housing and state funded projects. Finally, climatic data that reflect future climate changes should be used to simulate the heating demand and the risk of overheating in the future. The scenarios introduced in the study show the influence of the different key factors on the building operating energy consumption and CO_2 emissions. Such information can be useful in the design process of new buildings or in building retrofits, as it can help decision makers in developing more sustainable buildings.

ACKNOWLEDGEMENTS
This work was supported in Chile by the project ANID/FONDAP/15110020 (CEDEUS).

REFERENCES

[1] Bustamante, W., Chateau, F., Rasse, A. and Schmitt, C., (2019) Hitos críticos en proyectos de regeneración de edificios de vivienda social. In: *SIIU*. Santiago, Chile, September 4-5.
[2] Ministry of Energy, (2022) Transición Energética de Chile - Política Energética Nacional. Santiago.
[3] Bustamante, W., Cepeda, R., Encinas, F., Martínez, P. and Rozas, Y., 2009. Guía de diseño para la eficiencia energética en la vivienda social. Santiago: MINVU.
[4] González Fuentes, C., (2020) Diseño de un modelo replicable de subsidio habitacional de arriendo público y gestión local (Dissertation). UVM.
[5] Autodesk Revit, V. Architecture/Structure/MEP, (2020) California, Autodesk Inc. software.
[6] Autodesk InSight, Version 2020 (2020) California, Autodesk Inc. software ltd.
[7] Design Builder, Version 6.0, (2018) Gloucestershire, Design Builder software ltd.
[8] EnergyPlus, Version 9.5.0 (2021) California, EnergyPlus software ltd.
[9] Molina, A., Falvey, M. and Rondanelli, R., (2017) A solar radiation database for Chile. *Scientific reports*, 7(1): p. 1-11.
[10] MINVU (2019) Curso Evaluadores Energéticos. Sistema de calificación energética vivienda v2.0.
[11] CNE (2020) Factores de Emisión SEN. Comisión Nacional de Energía - Energía Abierta. Santiago.
[12] Forster, P., Ramaswamy, V., Artaxo, P., et al., (2007) Changes in Atmospheric Constituents and in Radiative Forcing. In: Solomon et al. (eds.) Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
[13] Gómez, D.R., Watterson, J.D., Americano, B.B., et al., (2006) Chapter 2: Stationary Combustion. In: Eggleston et al. (eds.) Volume 2: Energy of 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Program. Hayama: IGES.

PLEA SANTIAGO 2022
Will Cities Survive?

Analysis of Building Energy Performance with DSSC BIPV Window According to Lighting Control Method

NAM HYEON KIM[1] JI YEON HYUN[1] BO RANG PARK[1] EUN JI CHOI[1] JIN WOO MOON[1]

[1] Chung-Ang University, Republic of Korea (South Korea)

ABSTRACT: The Purpose of this study is to analyze the cooling, heating, lighting energy consumption, and solar cell generation performance of buildings with DSSC BIPV windows by applying various lighting control methods. Using computer simulations, three types of windows were compared: Low-E, DSSC-R and DSSC-Y. As a result, the DSSC windows showed a higher energy consumption than the Low-E window due to its low VLT value despite its own power production, and all three window types showed the lowest energy consumption in the Linear/Off control method. Based on this study, continuous research on improving VLT and Solar Cell's self-generation efficiency should be conducted in order to increase the utilization of DSSC BIPV windows.
KEYWORDS: DSSC, BIPV, Building Energy, Lighting Control

1. INTRODUCTION

Full-scale zero-energy building systems are actively being implemented, and local government bodies are being increasingly involved in the adoption of measures such as employing building-integrated photovoltaic (BIPV) support systems to realize energy savings in domestic buildings and reduce greenhouse gas emissions. Most buildings utilizing BIPVs include public, business, and educational facilities, where the window-to-wall ratios (WWRs) are typically high. Thus, transparent solar cells can replace windows. Among these, dye-sensitized solar cells (DSSCs) are next-generation devices with outstanding features, such as semi-transparency, a variety of color realization options, and adjustable transparency, and they can be applied to window-type BIPVs.

DSSCs offer the advantages of low unit prices, simple fabrication, and power generation under poor lighting conditions [1]. For this reason, research on DSSC is being conducted in various ways, such as product development, power generation performance, building application plan, etc. However, lighting energy utilization may increase owing to the reduction in solar gain because these cells typically have dark tints to improve power generation efficiency. Increased lighting energy usage can be disadvantageous for the overall building energy consumption. Thus, the power generation and building energy performances must be considered to develop DSSC BIPVs applicable to windows. Notably, improvement in visible light transmittance (VLT) performance is directly related to power generation performance, which poses a technical limitation. Consequently, nergy consumption based on indoor lighting control methods must be analyzed.

This study aims to evaluate the cooling, heating, and lighting energy consumption, as well as solar-cell power generation performances in buildings under various lighting control methods utilizing DSSC BIPV windows. Further, a more energy-efficient lighting control method is proposed to increase the applicability of DSSC BIPV windows as construction materials.

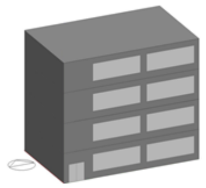
2. MODELING INPUT DATA ANALYSIS

This study analyzes heating, cooling, and lighting energy consumption according to the lighting control method when applying the DSSC BIPV window in office buildings in Seoul climate. It is intended to analyze the total energy consumption according to the power generation performance of the DSSC BIPV window at the currently developed level and further present power generation performance standards for energy reduction.

2.1 Modeling of the target building

An office building with four south-facing stories located in Seoul was modeled using DesignBuilder (Version 6.1.7.007) for energy performance analysis of the building (Table 1). DesignBuilder [2] is an integrated building energy analysis program that includes the baseline conditions of LEED (Leadership in Energy and Environmental Design) and ASHRAE 90.1 and can analyze building energy usage via EnergyPlus. The heat flow rate (U-value) and HVAC system of the building were selected from previous studies and by applying building energy-saving design standards [3]. Further, standard annual weather data in Seoul were used. Seoul is the capital of the Republic of Korea and is located at 37 degrees north. It is an area corresponding to No. 4 (temperature atmosphere) in the eight climate zones separated by IECC and ASHRAE Standards.

Table 1:
Simulation model settings.

Modeling Image		
Building Information	Total Floor area	640 m²
	Number of Floors	4F
	Floor Heights	3.5 m
Exterior window	WWR / Size	40% / 5.6 m × 2 m (8AE)
Lighting	Office-10.2 W/m², Core-2 W/m²	
Dimming	Office-400 Lux, Core-200 Lux	
Internal heat	Occupant	0.161 person/m²
	Office Equipment	11.8 W/m²
Construction (U-Value)	External walls	0.240 W/m²K
	Roof	0.150 W/m²K
	Ground Floors	0.290 W/m²K
Systems	Heating/Cooling setpoint temperature	Fan Coil Unit (4-pipe) 20 °C / 26 °C
Schedule	Heating	Jan 01-Feb 28, Nov 01–Dec 31
	Cooling	Mar 01–Sep 30

2.2 Setting the window type

Three types of window characteristics were selected from DesignBuilder glass data based on International Glazing Data Base and used to analyze the window characteristics (Table 2). The Low-E window has a double-layered glass and consists of transparent glass (6 mm), air layer (12 mm), and coated low-e glass (6 mm). The DSSC windows consist of transparent glass (3 mm), air layer (12.55 mm), DSSC cell (4.4 mm), air layer (12.55 mm), and transparent glass (3 mm). Compared to the Low-E window, the DSSC windows show high insulation performances due to its thick air layer. But the solar heat gain coefficient (SHGC) and VLT are much lower than the Low-E window due to the dark tint of the DSSC Cell and the glass thickness.

The results of the KS L 2415 NFRC 300:2017 test methods from Korea Conformity Laboratories were used to characterize the thermal and optical properties of the DSSC BIPV windows. According to the test report results, Low-E window was used as reference model for performance evaluation on two DSSC Cell types: DSSC-R (red) and DSSC-Y (yellow).

The TiO_2 thickness of DSSC-R and DSSC-Y was 8 µm, and the U-value was 5.77 W/m₂K. The solar heat gain coefficients (SHGCs) of DSSC-R and DSSC-Y were 0.41 and 0.42, VLTs were 6% and 16.1%, and power generation efficiencies were 2.99% and 0.72%, respectively (Table 3).

Table 2
DSSC BIPV Window type.

Type	Glazing Layer (No. thickness)	U-Value [W/m²K]	SHGC	VLT [%]
Low-E	Clr6+Air12+Low-E6 (3e)	1.540	0.490	59.0
DSSC-R	Clr3+Air12.55+DSSC4.4 (Red)+Air12.55+Clr3	1.082	0.426	4.9
DSSC-Y	Clr3+Air12.55+DSSC4.4 (Yellow)+Air12.55+Clr3	1.078	0.436	13.0

Table 3
Physical properties of DSSC Cell.

Type	DSSC-R	DSSC-Y
TiO_2 Thickness [µm]	8	8
U-Value [W/m²K]	5.77	5.77
SHGC	0.41	0.42
SC	0.47	0.48
VLT [%]	6.0	16.1
Inside/Outside Visible Reflectance [%]	9.1/9.4	9.0/8.1
Solar Transmittance [%]	19.2	20.8
Inside/Outside Solar Reflectance [%]	11.2/11.3	10.8/10.3
Infrared Transmittance [%]	20.3	21.3
Inside/Outside transmittance [%]	16.3/16.0	16.0/15.8
Emissivity	0.89	0.89
Powe Generation Efficiency [%]	2.99	0.72

2.3 Lighting control method

The lighting density of the work space was set at 10.2 W/m² and the corridor was set at 2 W/m², and the lighting schedule was set to use lighting energy only during work hours. Dimming control was implemented to adjust the amount of 400lux according to the standard for indoor illumination of business facilities [4].

Three types of lighting control method available in DesignBuilder were considered: linear/off, linear, and stepped (Table 4). Two lighting control sensors were installed 2.8 m and 5.6 m from the window based on the work surface height of 0.75 m. The lighting consumption proportion for these two sensors was set to 50/50.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Table 4
Lighting control techniques in DesignBuilder.

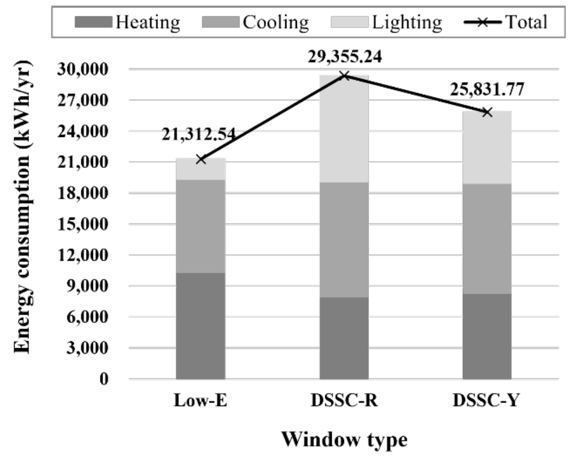
Type	Method
Linear/Off	Sequential dimming and turning off control upon reaching the set value
Linear	Lighting consumption is adjusted sequentially based on illuminance
Stepped	Lighting on/off method according to natural light at step 10

3. SIMULATION RESULT ANALYSIS

3.1. Energy consumption according to window type

Figure 1 shows the building cooling, heating, and lighting energy consumption according to the window type when applying the linear/off method. The total energy consumption, including the energy consumption of heating and cooling lighting, was the highest (29,355.24 kWh) in buildings with DSSC-R windows. Buildings with DSSC-Y consumed 25,831.77 kWh, and buildings with Low-E windows consumed 21,312.54 kWh. Under the linear/off lighting control method, buildings with Low-E windows consumed the least total energy.

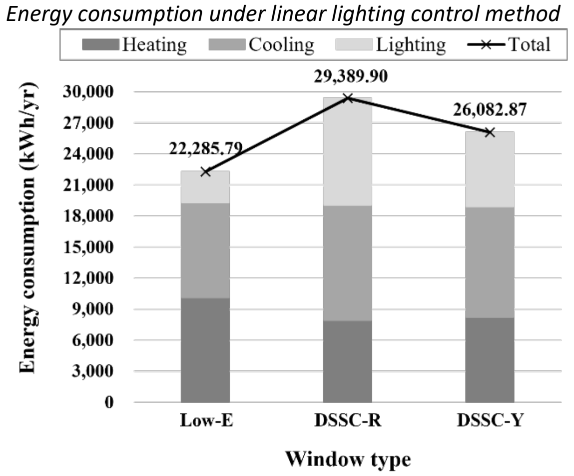
Figure 1:
Energy consumption according to linear/off lighting control method



The cooling energy consumption of buildings to which DSSC-R and DSSC-Y were applied was 11,176.94 kWh and 10,645.92 kWh, respectively, which increased by 2,150.82 kWh and 1,619.79 kWh compared to the reference model. Heating energy consumption was the highest in buildings with Low-E windows, consuming 10,326.17 kWh, and buildings with DSSC-R and DSSC-Y windows consumed 2,391.05 kWh and 2,006.81 kWh, respectively—with that of DSSC-R being its lowest heating energy consumption. Lighting energy consumption was the lowest at 1,960.24 kWh in buildings with Low-E windows. Buildings with DSSC-R and DSSC-Y consumed 10,243.19 kWh and 6,866.50 kWh, up 8,282.94 kWh and 4,906.25 kWh, respectively, compared to the reference model: the highest lighting energy consumption was in buildings with DSSC-R.

Figure 2 shows the energy consumption of building cooling and heating lighting according to the window type when applying the linear method. The total energy consumption of buildings, including the energy consumption for heating and cooling lighting, was highest at 29,389.90 kWh in buildings with DSSC-R windows. Buildings with DSSC-Y consumed 26,082.87 kWh, and buildings with Low-E windows consumed 22,285.79 kWh of energy. Under the linear lighting control method, buildings with Low-E windows consumed the least energy in total.

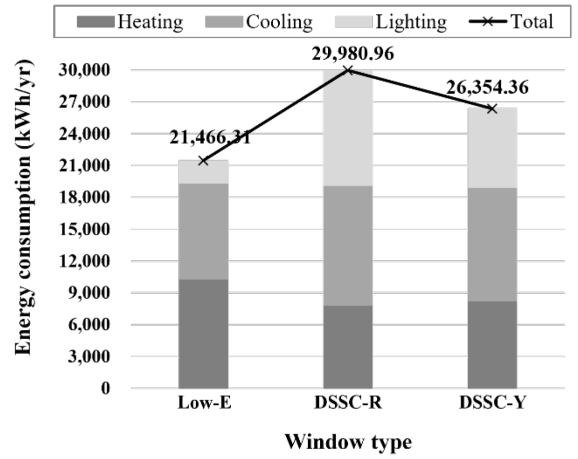
Figure 2:
Energy consumption under linear lighting control method



The cooling energy consumption in buildings with DSSC-R and DSSC-Y was 11,177.20 kWh and 10,672.49 kWh, respectively, which increased by 1,987.86 kWh and 1,483.15 kWh compared to the reference model. Heating energy consumption was the highest at 10,122.47 kWh in buildings with Low-E windows, and buildings with DSSC-R windows and DSSC-Y consumed the least amount of heating energy at 7,903.06 kWh and 8,239.06 kWh, respectively, down 2,219.41 kWh and 1883.41 kWh from the reference model. Lighting energy consumption was the lowest at 2,973.98 kWh in buildings with Low-E windows. Buildings with DSSC-R and DSSC-Y consumed 10,309.64 kWh and 7,171.32 kWh, up 7,335.66 kWh and 4,197.34 kWh, respectively, compared to the reference model, with the highest lighting energy consumption occurring in buildings with DSSC-R.

Figure 3 shows the energy consumption for building cooling and heating lighting according to window type when applying the stepped method. The total energy consumption, including the energy consumption for heating and cooling lighting, was the highest at 29,980.96 kWh in buildings with DSSC-R windows. Buildings with DSSC-Y consumed 26,354.36 kWh, and buildings with Low-E windows consumed 21,466.31 kWh. Under the stepped lighting control method, buildings with Low-E windows consumed the least energy in total.

Figure 3:
Energy consumption under the stepped lighting control method



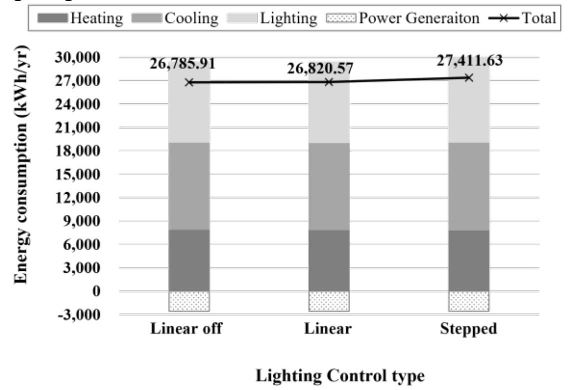
The cooling energy consumption in buildings with DSSC-R and DSSC-Y was 11,294.99 kWh and 10,723.63 kWh, respectively, which increased by 2,255.48 kWh and 1,684.12 kWh compared to the reference model. Heating energy consumption was the highest at 10,283.70 kWh in buildings with Low-E windows. Further, buildings with DSSC-R windows and DSSC-Y consumed 7,984.32 kWh and 8,231.58 kWh, down 2,442.39 kWh and 2,052.12 kWh from the reference model respectively. Lighting energy consumption was the lowest at 2,143.09 kWh in buildings with Low-E windows. Buildings with DSSC-R and DSSC-Y consumed 10,844.66 kWh and 7,399.14 kWh, up 8,701.56 kWh and 5,256.05 kWh, respectively, compared to the reference model, indicating the highest lighting energy consumption in buildings with DSSC-R.

3.2. DSSC Cell Power Generation

Because the DSSC BIPV window can generate its own power from solar energy, it has better energy savings than the Low-E window. The annual power output of DSSC-R and DSSC-Y were 2,569.33 kWh and 637.90 kWh, respectively. The generated energy was equally produced according to the power generation efficiency of the solar cell itself regardless of the lighting control method.

As shown in Figure 4, the total energy consumption of the building considering the power generation of DSSC-R under the three lighting control methods was 26,785.91 kWh, 26,820.57 kWh, and 27,411.63 kWh for the linear/off method, linear method, and stepped method, respectively.

Figure 4:
Total energy consumption of DSSC-R window under the lighting control method



As shown in Figure 5, the actual energy consumption of the building considering the power generation of DSSC-Y under the three lighting control methods was 25,193.87 kWh, 25,444.97 kWh, and 25,716.46 kWh under the linear/off method, linear method, and stepped method, respectively.

Figure 5:
Total energy consumption of DSSC-R window under the lighting control method

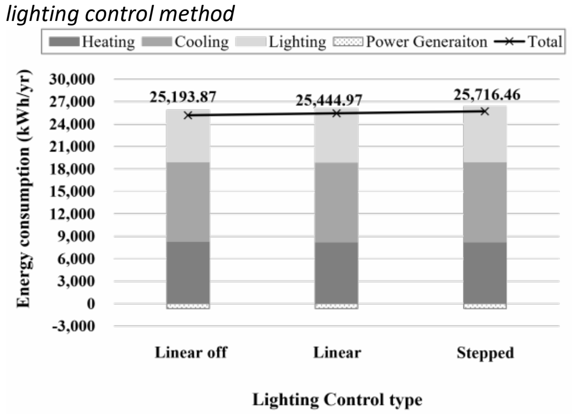


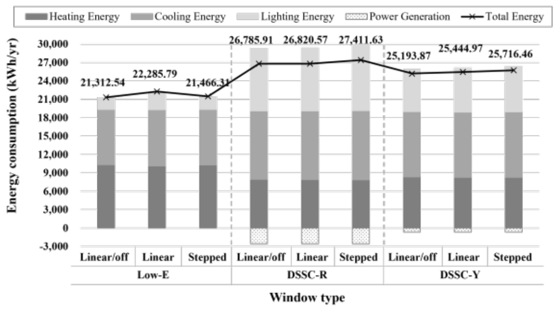
Figure 1 shows the cooling/heating/lighting energy consumption results of the building according to the window type for the three lighting control methods. Regardless of the method used, the total energy consumed reduced in the order of DSSC-R>DSSC-Y>Low-E according to window type. Because the VLT of a DSSC window is significantly lower than that of the Low-E window, the increased energy consumption is attributed to increases in indoor lighting energy to meet the indoor illuminance criteria.

Regarding the DSSC-R method, the annual energy consumption decreased in the order of linear/off (29,355.24 kWh), linear (29,389.90 kWh), and stepped (29,980.96 kWh). Similarly, for the DSSC-Y, the annual energy consumption decreased in the order of linear/off (25,831.77 kWh), linear (26,082.87 kWh), and stepped (26354.36 kWh). For the Low-E method, the annual energy consumption decreased in the order of linear/off (21,312.54 kWh), linear (22,285.79 kWh), and stepped (21,466.31 kWh).

3.3. Discussion

Figure 6 shows the comprehensive results of building energy consumption according to window type under the three lighting control methods. Regardless of the lighting control method, the total energy consumption of buildings according to the window type was high in the order of DSSC-R, DSSC-Y, and Low-E. The main reason for the increase in energy consumption was the increase in lighting energy. The VLT value of the DSSC window was significantly lower than that of the Low-E window, thus natural light flowing into the room decreased. Accordingly, the amount of artificial lighting used to meet the indoor illumination standard increased. In addition, because the increase in the use of artificial lighting increases the indoor heating load, the cooling energy consumption increased compared to the reference model, but the heating energy consumption decreased.

Figure 6:
Annual energy consumption according to window type.



The least annual energy consumption for the DSSC-R was 29,355.24 kWh under the linear method, followed by 29,389.90 kWh under the linear method, and 29,980.96 kWh under the stepped method. For the DSSC-Y, the least annual energy consumption was 25,831.77 kWh when the linear/off method was applied, followed by 26,082.87 kWh under the linear method, and 26,354.36 kWh under the stepped method. For the Low-E lighting control method, the lowest annual energy consumption was 21,312.54 kWh when the linear/off method was used, followed by 22,285.79 kWh for the linear method, and 21,466.31 kWh for the stepped method. The simulation results confirmed that all three types of windows have the highest energy consumption efficiency under the linear/off method.

The annual power outputs of DSSC-R and DSSC-Y were 2,569.33 kWh and 637.90 kWh, respectively, which were produced equally according to the power generation efficiency of the solar cell itself regardless of the lighting control method. In the stepped method with the highest energy consumption, the energy produced by DSSC-R and DSSC-Y reduced annual energy consumption by 9.4% and 2.5%, respectively, but it contributed less to energy reduction due to insufficient power generation efficiency relative to the increased energy consumption. Comparing the linear/off method with the lowest energy consumption in buildings with DSSC BIPV and the linear method with the highest energy consumption for the Low-E window, the difference in energy consumption between DSSC-R and the reference model was 4,500.12 kWh. It was confirmed that DSSC-Y has lower power generation efficiency than DSSC-R, but it consumes less lighting energy; thus, the difference in energy consumption from the reference model is smaller.

4. CONCLUSION

This study analyzes energy consumption under 3 different lighting control methods for a building with DSSC BIPV windows. The results indicate that DSSC BIPV windows consume more energy than Low-E windows owing to low VLTs. The annual energy consumption of DSSC-R and DSSC-Y based on lighting control methods increased in the order of linear/off<linear<stepped. For the Low-E window, the annual energy consumed increased in the order linear/off<stepped<linear, indicating that the energy consumed by all three windows were lowest under the linear/off method. The energies produced by the DSSCs were insufficient for reducing the total energy consumed owing to poor power generation efficiency relative to the increase in energy consumption. Further investigations should be conducted on enhancing the self-power generation efficiencies of solar cells based on the results of this study, including improving DSSC VLTs and exploring appropriate lighting control methods to increase the usability of DSSC BIPV windows.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (NRF-2020M3F8A2099381).

REFERENCES

1.Kim, J.B., Y.G. Lee, P.R. Lee, and M.J. Go, (2017). Dye-sensitized solar cell technology and future prospects. *Korea Photovoltaic Society*, 3(1): p. 25-32.

2. https://designbuilder.co.uk/

3. Kim, N.H., J.Y. Hyun, E.J. Choi, H.U. Cho, and J.W. Moon, (2021). Application and energy performance analysis on the DSSC BIPV windows to office buildings. *Korea Institute of Ecological Architecture and Environment*, 21(1): p. 84-85.

4. IESNA, 2002. The IESNA Lighting Handbook, 9th edition, courtesy of the Illuminating Engineering Society of North America.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA 2022 SANTIAGO
Will Cities Survive?

Evaluation of standards for office buildings to optimize thermal comfort under free running

Case of Concepción, Chile

NAVARRO-ORTIZ, MATIAS[1]; MATTER-JOFRE, HELENA[1]; SALAZAR-VERA, CAROLINA[1]; SARAVIA-MONSALVES, IGNACIO[1]

[1] Department of Building Science, University of Bio Bio, Chile

ABSTRACT: Both the thermal transmittance of the envelope and the natural ventilation affect comfort levels inside office buildings. This research looks to review the current thermal standards for buildings in Chile, evaluating whether they allow maximizing time in comfort in free-running office buildings, fostering a lower energy consumption. Using a simulation in the DesignBuilder software, the thermal behavior of a 100 m² building located in the city of Concepción, Chile, under scenarios with and without sunlight blocking, is evaluated under the 7 different standards found in the Chilean regulations, using the ASHRAE 55-2007 adaptive thermal comfort model. Later, the thermal behavior of 4 of these representative standards is assessed, including ventilation calculated with 50% window opening. The results show that the most restrictive thermal transmittance value does not necessarily guarantee higher comfort percentages, and thus, a lower energy consumption, as the building tends to overheat in summer and, as a result, have a higher energy consumption for cooling, while scheduled natural ventilation maximizes comfort times under free-running in a climate such as that of Concepción.
KEYWORDS: Office building, Thermal transmittance, Thermal envelope; Adaptive comfort; Natural ventilation

1. INTRODUCTION

Improving the thermal properties of buildings is key to reduce energy consumption is key to comply with the commitments of the 2015 Paris Agreement and the UN's Sustainable Development Goals, with buildings being responsible for 36% of the energy used and 39% of energy-related CO_2 emissions [1]. Hence, it is key that countries guarantee an acceptable energy performance of buildings through their regulations [2]. In 2018, 73 countries had obligatory or voluntary building codes [1]. However, it must be considered that in many of these, including Chile, not all uses have to comply with thermal standards. In fact, in Chile, this is only required for residential use and for public buildings designed and built by the Housing and Urbanism Ministry (MINVU) and the Public Works Ministry (MOP). According to Chile's Energy Policy for 2050, 100% of new buildings at this date, must follow OECD standards, with control systems and smart energy management [3]. For this reason, it is important to work on implementing thermal strategies in order to limit energy use in all building types.

In Chile, the thermal standard is mainly based on establishing transmittance values to envelope elements, regulated by climate zones. The first regulation for this, implemented in 2006, is found in the General Urbanism and Construction Ordinance (OGUC, in Spanish), which regulates the envelope of residential buildings [4]. Different standards and certifications have been added later which provide new reference values for the thermal requirements. In this way, the Standardized Terms of Reference (TDRe, in Spanish) were developed in 2011, with Energy Efficiency and Environmental Comfort parameters for MOP works and design tenders [5]; the Environmental Decontamination Plan (PDA, in Spanish) [6], an environmental management tool to reduce the presence of contaminants in saturated areas, introduced in some areas from 2010; the update of Chilean Standard, NCh 1079 in 2019 [7], which regulates transmittance values considering the 9 thermal zones in the country; certifications like the Sustainable Building Certification (CES, in Spanish) [8], present since 2014.

Regarding the implementation of standards to regulate the thermal transmittance of the envelope (U value), the results of a research project based on the simulation of the NCh 1079/2008 standard (values updated in 2019) for different climate zones, concludes that the higher energy demand in the country is from heating, due to the low transmittance value requirement [2], and that the energy used by buildings is mainly determined by the thermo-physical properties of the envelope [9].

For the Concepción climate, with broad temperature ranges between summer and winter, a more demanding transmittance value could lead to indoor overheating issues in summer. This is why natural ventilation conditions, one of the most effective cooling strategies, need to be evaluated, considering an energy consumption reduction of between 30% and 40% compared to buildings with mechanical ventilation [10], apart from giving occupants a comfortable thermal condition and a healthy indoor environment [11]. Previous studies made using simulations have managed to determine the effectiveness of natural ventilation, establishing that, with strategies like nighttime cooling by ventilation, even a significant thickening of the insulation does not have any impact on the length of hours of discomfort [12]. On the other hand, on broadening building operation temperatures by between 1°C and 3°C, there would be a significant energy saving with a lower cost than with ventilation systems, maintaining the indoor thermal comfort levels of the occupants [13]. In this regard, the incorporation of Adaptive Comfort Standards (ACS) in ASHRAE 55 allows having warmer indoor temperatures for buildings with natural ventilation during summer, producing, through the combination of the indoor space environment and personal factors, acceptable thermal environmental conditions for 80% or more of the occupants, defining "acceptable" as the satisfaction associated with "slightly warm", "neual", and "slightly cool" thermal sensations [14].

The goal of this research is to evaluate the influence that the thermal standards of the envelope, and the ventilation levels, have on the percentage of acceptability of adaptive thermal comfort at 80%.

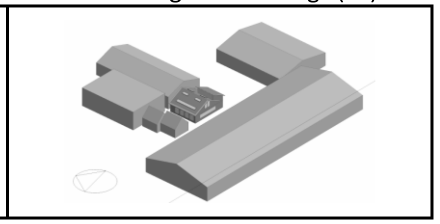
2. METHODOLOGY

An open plan 100 m² building was taken as a reference to perform this study (considering that this is a limited surface to perform the study and that it can have a complete architectural set up for an office building, including a meeting room, kitchenette, and restrooms). This was done to focus the research solely on the elements of the envelope, avoiding the influence of interior partitions on the results. A compact volume of 10x10m was projected (to foster energy saving), with a gable roof (typical of rainy zones in Chile), and a maximum ridge height of 6 meters (average height for buildings with 1 to 2 floors).

2 case studies were put forward considering the conditioning factors of the building's surroundings:

- Analysis scenario including the surroundings (IS): Theoretical volume considering north and west sunlight blocking, using 2-level volume, at a distance of 1.5m and 3m, respectively.
- Analysis scenario excluding surroundings (ES).

IS: Theoretical volume including surroundings



ES: Theoretical volume excluding surroundings

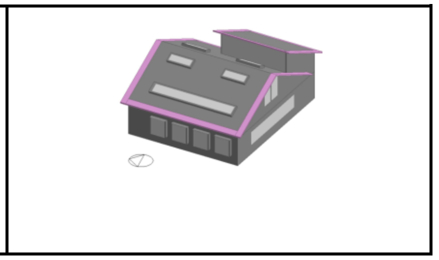


Figure 1: 3D model including (IS) and excluding (ES) surroundings, used in the DesignBuilder software simulations.

Simulations were made using the DesignBuilder program, considering the climate file of the city of Concepción, Chile (Maritime Mediterranean according to the Köppen- Geiger classification). The use of heating and cooling is excluded, and mechanical and natural ventilation is used under a mixed-mode system. With regard to the occupation load, this was set for a period of 1 year, with daytime use of 1,920 hours (8 hours of work a day, 5 days a week, 12 months a year).

A minimum ventilation flow of 0.3 l/s x m² and 2.5 l/s x person was used for the IS and EW cases with scheduled ventilation (as per the ASHRAE 55-2017 standard, Table 6-1: Minimum ventilation ratios in breathing zones for office spaces). A second analysis is proposed considered 50% window opening, to determine the variations of the thermal comfort acceptability percentage.

To analyze thermal acceptability, the ASHRAE 55 thermal comfort model was used with an acceptability range of 80% in free running.

An equipment load of 4.5w/m², metabolic conditions defined as "light office work" with a metabolic rate of 123w/person and a CO_2 generation rate of $3.82x10^{-8}$, are considered for the programmed internal loads, while, a power level of 9.9 w/m² is considered for lighting loads.

The operating temperatures of the premises and the mean weighted operation temperature per hour were obtained with the simulations, from which the adaptive comfort was assessed using the ASHRAE 55 standard. This generated 5 hour ranges: hours with cold temperatures, under the lower 80% acceptability limit; slightly cool hours, between the lower limits of 80% and 90%; comfort hours, within the 90% acceptability; slightly warm hours, between 80% and the upper 90%; and hot hours, over the upper 80%. With these ranges established, the hours of one year were classified, thus establishing the percentage of occupation hours in a comfort situation at 80%, corresponding to the total hours in a 90% total comfort situation, the slightly cool, and the slightly warm. Then, analyzing the total comfort percentages by standard, an adaptation was made by scheduling the calculated ventilation, to check the variation of comfort percentages for given standards under free-running, on including strategies like opening windows in summer.

2.1 Comparison of Standards in the Chilean norm to check adaptive thermal comfort percentages.

Table 1. Thermal standards in the Chilean Standard for residential and public buildings.

Standards	Roof U (w/m²K)	Wall U (w/m²K)	Window U (w/m²K)	SHGC	Light transmission
Concepción PDA	0.33	0.60	*1.2 – 4.4	0.580	0.744
Temuco PDA	0.28	0.45	*1.2 – 4.4	0.580	0.744
Coyhaique PDA	0.25	0.35	*1.2- 4.0	0.580	0.744
OGUC zone 4	0.38	1.70	2.4 – 3.6	0.580	0.744
TDRe	0.40	0.60	1.9 – 3.5	0.580	0.744
CES	0.70	2.90	3.0	0.580	0.744
NCh 1079/2019	0.33	0.45	2.4 – 3.6	0.580	0.744

* The U values are set following the maximum window percentages by orientation

The thermal standards described in Table 1 were used to check the percentages of hours of thermal comfort in free running under the Excluding Surroundings (ES) and Including Surroundings (IS) analysis scenarios. These correspond to the U values (roof, walls, and windows, disregarding the thermal transmittance of the floor in contact with the ground) found in the different Chilean standards that focus on reducing energy consumption (OGUC, TDRe, NCh 1079/2019, CES, PDA), which are mainly required for residential buildings, along with buildings put out for tender by MINVU and MOP (these values were used as there is not a specific standard for private office buildings). The transmittance values are those established for the Concepción thermal zone. However, options for more southernly thermal zones (Temuco PDA and Coyhaique PDA) have been simulated to evaluate thermal behavior using more restrictive U values.

2.2 Simulation using calculated ventilation.

Once the thermal acceptability percentages obtained on simulating the aforementioned transmittance standards are analyzed, a second simulation is made, that seeks to maximize total comfort, reducing heat discomfort by including calculated ventilation. Regarding the opening, a 50% percentage is calculated, estimating, for example, the use of sliding windows (considering the types of main windows and the opening size ranges CIBSE 2005 Table 3.2). For the simulation, the decision was made to choose 4 of the standards presented, considering the following criteria:

- Concepción PDA: Transmittance values in line with the study zone, higher heat discomfort percentages than the other PDA evaluated (which indicates that the total comfort percentages can be improved by incorporating natural ventilation).
- TDRe: Transmittance values in line with the study zone (similar to Concepción PDA). This has lower heat discomfort levels, as well as being a standard that is currently applied for MINVU built office buildings.
- NCh 1079/2019: High transmittance requirements (updated recently in 2019), low total comfort percentages, high heat discomfort percentages.
- CES: Low transmittance requirements (very similar to OGUC), low total comfort percentages, similar heat and cold discomfort percentages.

3. RESULTS

3.1 Simulation with the Standards in the Chilean Norm and results of adaptive thermal comfort percentages

Table 2 presents the results of the adaptative thermal comfort comparison between the different thermal transmittance standards used in Chile. The values in Table 2 show that the highest comfort ranges are achieved by applying the Concepción PDA, Temuco PDA, and especially, the Coyhaique PDA standards, both the IS and the ES case. However, none of the standards analyzed reach a total comfort percentage above 80% under free-running. The results of the Coyhaique PDA standard show total comfort levels that are the closest to 80% (IS=60.9% and ES=55.5%).

Table 2: Percentage of acceptability of adaptive thermal comfort at 80%, ASHRAE 55-2007 with scheduled ventilation (2.5 l/s x person + 0.3 l/s x m²).

Standard	Surroundings	Cold %	Slightly cool %	Comfort % (90%)	Slightly warm %	Hot %	Total comfort % (80%)
Concepción PDA	IS	9.1	5.5	39.1	9.7	36.6	54.3
	ES	5.2	4.6	33.7	9.5	46.9	47.9
Temuco PDA	IS	12.5	7.0	45.0	8.6	26.9	60.6
	ES	8.8	4.9	42.7	8.5	35.1	56.1
Coyhaique PDA	IS	7.9	5.6	46.4	8.9	31.2	60.9
	ES	4.4	4.5	41.3	9.7	40.1	55.5
OGUC Z4	IS	25.6	7.0	37.4	5.8	24.1	50.2
	ES	18.4	5.1	36.2	6.4	33.9	47.7
TDRe	IS	18.3	7.9	41.4	7.7	24.7	57.0
	ES	13.3	5.7	40.5	8.1	32.4	54.3
CES	IS	31.3	7.0	29.5	4.4	27.8	40.9
	ES	23.9	5.7	28.0	4.4	38.1	38.0
NCH 1079/2019	IS	7.7	4.2	26.7	7.2	54.2	38.1
	NS	4.2	2.8	20.5	5.1	67.4	28.4

The results obtained for Temuco PDA (IS=60.6% and ES=56.1%) and Concepción PDA (IS=54.3% and ES=47.9%) are quite close to those obtained under the Coyhaique PDA standard, but with a considerably lower demand in the transmittance values.

Certain more demanding standards for thermal transmittance values, such as NCh 1079/2019, have lower total comfort ranges compared to less demanding standards. In this case, the fall of total comfort is mainly due to the heat discomfort levels (IS=54.2% and ES=67.4%). However, these have much lower cold discomfort percentages (IS=7.7%, ES=4.2%).

The total comfort results of the TDRe standard (IS=57.0% and ES=54.3%) reflect comfort percentages that are slightly higher than those of Concepción PDA, even considering that the transmittance requirement is lower in the wall covering, with heat discomfort percentages of IS=24.7% and ES=32.4%, and for cold of IS=18.3% and ES=13.3%.

The results of applying the OGUC and CES standards have lower total comfort ranges, with the cold and hot discomfort levels pretty even, which is why it is complicated to improve conditions without altering the envelope's requirement.

Figure 2 shows a graphical comparison of the operating temperatures of the different standards used for the simulation.

In general, the weighted mean temperature is between 20°C and 25°C for most of the standards simulated.

It is seen that, on applying the PDA standards (Concepción, Temuco, and Coyhaique), the operational temperatures remain within the ranges of approximately 12°C and 34°C, with Concepción PDA having the highest operating temperatures for both the IS and ES scenarios.

The highest temperature variation ranges are represented by the CES (7°C-36°C), NCh 1079/2019 (12°C-41°C), and OGUC (10°C-35°C) standards.

The operational temperature ranges of the TDRe standard are similar to those of Concepción PDA. However, under the ES scenario, the temperature reaches levels that are slightly higher in the PDA's case (due to the higher transmittance requirement and, as a result, higher overheating in the scenario without sunlight blocking).

Regarding the weighted mean temperature, in the case of the 3 PDA standards analyzed, under IS scenarios, this is between 22°C and 24°C. Under ES scenarios, a slight rise in the mean temperature is seen, due to overheating in summer, with the same situation occurring in the TDRe results.

In the case of the NCh 1079/2019 standard, with a higher requirement in the thermal transmittance values, the average temperatures rise 25°C and 27°C, for the IS and ES scenarios, respectively.

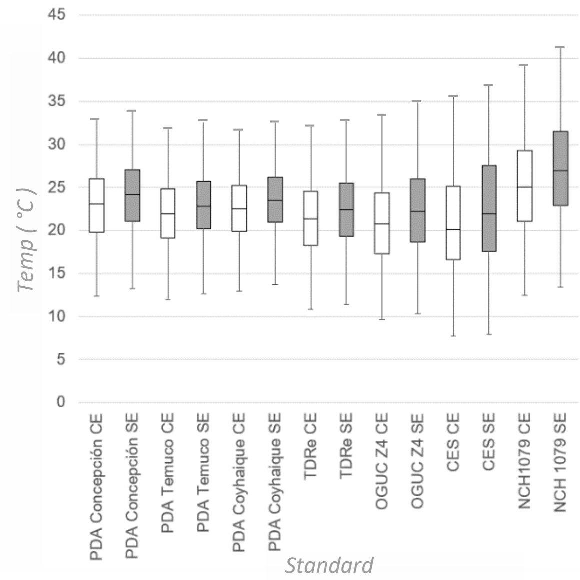


Figure 2: Operating temperatures.

3.2 Case simulation using calculated ventilation

On simulating the Concepción PDA, TDRe, NCh1079/2019, and CES standards with calculated ventilation, the results show there is a significant difference with the previous comfort ranges.

Table 3 presents the results of the adaptive thermal comfort comparison for the different thermal transmittance standards used in Chile, incorporating calculated ventilation with 50% window opening.

Table 3. Adaptive thermal comfort acceptability percentages at 80%, ASHRAE 55-2007. Improved case with ventilation flows calculated with 50% window opening.

Standard	Surrounding	Cold %	Slightly cool %	Comfort % (90%)	Slightly warm %	Hot %	Total comfort % (80%)
Concepción PDA	IS	8.9	5.5	74.6	7.2	3.8	87.3
	ES	8.7	4.5	67.2	9.9	9.8	81.5
TDRe	IS	16.5	7.2	66.6	6.4	3.4	80.2
	ES	14.2	6.5	66.5	8.0	4.7	81.0
CES	IS	26.4	6.7	46.8	8.3	11.7	61.9
	ES	22.6	5.1	42.8	10.9	18.6	58.7
NCH 1079/ 2019	IS	10.4	3.7	59.5	10.2	16.3	73.3
	ES	8.9	3.3	51.9	12.8	23.0	68.1

On revising the results of Table 3, it can be established that, both the PDA and TDRe standards, reach levels above 80% of total comfort in a building with natural ventilation in the city of Concepción.

Regarding more restrictive transmittance values, such as in NCh1079/2019, ranges above 80% total comfort are not reached, due to the high indoor overheating, which is reflected in the heat discomfort percentage (IS=16.3% and ES=23.0%).

For the less restrictive envelope transmittance values, as in the CES, ranges above 80% total comfort are not reached due to the cold discomfort (IS=26.4%

and ES=22.6%) and hot discomfort (IS=16.3% and ES=23.0%) percentages.

Figure 3 presents a graphical comparison of the operating temperatures of the 4 standards analyzed under free-running with ventilation calculated using 50% window opening.

It is seen that the lowest operating temperature variations are given by the Concepción PDA standard. With regard to TDRe under the IS scenario, a higher percentage of cold hours is seen. This is the result of sunlight blocking alongside less demanding transmittance values. As for the temperatures seen under the NCh 1079/2019 standard, although the average mean temperatures are similar to those seen for Concepción PDA, in summer it can have temperatures over 30°C.

Regarding the temperatures observed under the CES standard, although comfort ranges rise under natural ventilation, the operational temperature ranges are too broad due to the low transmittance value requirements.

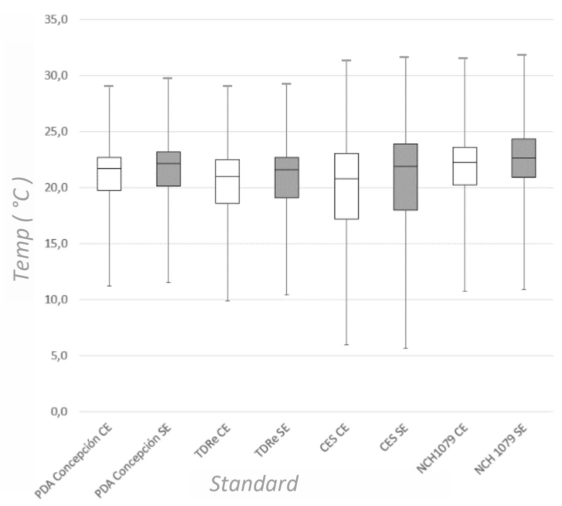


Figure 3: Operating temperatures with calculated ventilation.

4. CONCLUSION

4.1 Application of standards

The standards implemented by Chile for energy saving in buildings, have mainly been focused on thermal transmittance values, improving conditions in winter months, where the heating requirement is more demanding, but disregarding thermal comfort in summer.

According to the results of the different standards analyzed, which have higher demands for the U value, lower cold discomfort levels will be obtained in winter. However, in summer, these standards have high heat discomfort percentages, due to indoor overheating. On the contrary, a low U value requirement will obtain higher comfort ranges in summer as a result of its higher thermal loss capacity through the envelope and, for the same reason, high discomfort levels in winter. As a result, none of the standards presented in the first paragraph manage to reach total comfort ranges of 80% under free-running, as they do not include optimal cooling strategies to maintain indoor comfort levels in summer.

The results of the simulation including surroundings show a reduction of overheating in the summer months, giving higher comfort ranges than the simulations excluding surroundings. This is important when considering the design of an office building, as it can mean that a higher number of north and west-facing windows increases indoor overheating in summer.

4.2 Incorporation of calculated ventilation

Given the climatic conditions of Concepción in summer, time in comfort can be maximized by incorporating natural ventilation strategies, regulating overheating through the insulation of the thermal envelope. However, on facing very demanding transmittance values, opening windows when these are occupied does not generate the necessary cooling, which is why it can be concluded that, unlike what has been suggested by other research [2][9], more restrictive thermal transmittance values do not always achieve higher comfort and energy saving percentages, since, to reach comfort ranges above 80% in summer, HVAC systems are needed to regulate heat discomfort, which means that, to reach the operation of a building under free-running in template maritime climates, there must be a balance between thermal transmittance values and natural ventilation regulation.

DISCUSSION

Through this research, it is seen that some of the current standards for other purpose buildings, may be suitable to improve the thermal comfort conditions of free-running office buildings in Concepción. This article allows opening up the discussion on the possible standards to implement for the thermal envelope of office buildings in Chile to contribute to energy saving, as well as to standardize the implementation of natural ventilation strategies and not just thermal transmittance values, since, as has been concluded in this research, a lower thermal transmittance value does not ensure higher comfort percentages and, therefore, a lower energy consumption.

This study has been made in a given zone in the south of Chile, where for over 60% of the year, winds exceed 9 m/s (information obtained using the Weather Tool software), which is why it is necessary to study adaptive comfort under free-running with natural ventilation in other climatic areas of Chile, to establish whether the strategy outlined is effectively replicable in other areas. In this regard, it is important to discuss the operation and window size in office buildings, through which comfort ranges could be improved depending on the climatic zone where the building is located.

ACKNOWLEDGEMENTS

We would like to extend our gratitude to the teaching staff of the Masters of Sustainable Habitat and Energy Efficiency at the University of Bio Bio in Chile, especially to the researchers Alexis Pérez Fargallo Ph.D., and Laura Marin Restrepo Ph.D., for their contribution, discussions, and review of this paper.

REFERENCES

1. International Energy Agency. (2019). *2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings, and construction sector. International Energy Agency and the United Nations Environment Programme*.
2. Bienvenido-Huertas, D., Oliveira, M., Rubio-Bellido, C., & Marín, D. (2019). A comparative analysis of the international regulation of thermal properties in building envelope. *Sustainability (Switzerland)*, *11*(20). https://doi.org/10.3390/su11205574
3. Ministerio de Energía. (2014). Energía 2050 Política Energética de Chile. *Ministerio de Energía Gobierno de Chile*. Retrieved from http://eae.mma.gob.cl/uploads/D03_Politica_Energetica_de__Chile_2050_Anteproyecto2.pdf
4. Urbanismo, M. D. E. V. Y. (2021). Decreto 192, (2005), 1–7.
5. CITEC-UBB, DECON-UC, & Dirección de Arquitectura, M. de O. P. (2015). Términos de Referencia Estandarizados con Parámetros de Eficiencia Energética y Confort Ambiental, para licitaciones de Diseño y Obras de la Dirección de Arquitectura, según Zonas Geográficas del País y Según Tipología de Edificios _ Versión 2. *Según Zonas Geográficas del País y Según Tipologías de Edificaciones*, *10*, 289.
6. Norma, T., Medidas, E., & La, C. (2013). Biblioteca del Congreso Nacional de Chile - www.leychile.cl - documento generado el 04-Jun-2013. *Lagos R. Mensaje de S.E. el Presidente de la República con el cual se envió al Congreso el proyecto de ley que establece un Régimen de Garantías en Salud. Presidencia; May 22, 2022. Available at http//.www.bcn. cl/histley/19966/index_html [Consul*.
7. Chilena, N. (2019). NCh 1079.
8. Instituto de la Construcción. (2014). *Certificación Edificio Sustentable. Manual Evaluación y Calificación 1*. Retrieved from http://www.certificacionsustentable.cl/documentos_sitio/27310_Manual1_Evaluacion&Calificacion_v1.1_2014.05.28.pdf
9. Oral, G. K., & Yilmaz, Z. (2002). The limit U values for building envelope related to building form in temperate and cold climatic zones. *Building and Environment*, *37*(11), 1173–1180. https://doi.org/10.1016/S0360-1323(01)00102-0
10. Kolokotroni, M., & Aronis, A. (1999). Cooling-energy reduction in air-conditioned offices by using night ventilation. *Applied Energy*, *63*(4), 241–253. https://doi.org/10.1016/S0306-2619(99)00031-8
11. Liping, W., & Hien, W. N. (2007). Applying natural ventilation for thermal comfort in residential buildings in Singapore. *Architectural Science Review*, *50*(3), 224–233. https://doi.org/10.3763/asre.2007.5028
12. Kisilewicz, T. (2019). On the role of external walls in the reduction of energy demand and the mitigation of human thermal discomfort. *Sustainability (Switzerland)*, *11*(4), 1–20. https://doi.org/10.3390/su11041061
13. Albatayneh, A., Jaradat, M., Alkhatib, M. B., Abdallah, R., Juaidi, A., & Manzano-Agugliaro, F. (2021). The significance of the adaptive thermal comfort practice over the structure retrofits to sustain indoor thermal comfort. *Energies*, *14*(10). https://doi.org/10.3390/en14102946
14. De Dear, R. J., & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy and Buildings*, *34*(6), 549–561. https://doi.org/101016/S0378-7788(02)00005-1

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE BUILDINGS AND TECHNOLOGY

DAY 02
16:30 — 18:00

CHAIR
MASSIMO PALME

PAPERS
1140 / 1109 / 1544 / 1394

27TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Passive Displacement Coil Unit (PDCU) system and thermal comfort performance evaluation

STEVE KARDINAL JUSUF[1], NEO POH HONG[2], GEORGE NG[3], SOH YONG LOKE[1]

[1] Engineering Cluster, Singapore Institute of Technology, Singapore
[2] Shinhan Tech-Engineering Pte Ltd, Singapore
[3] MET Engineering Pte Ltd, Singapore

ABSTRACT: This study was conducted to assess the effectiveness of Passive Displacement (PD) systems based on the perspective of thermal comfort experienced by the occupants. The objective of the study was to measure and validate the thermal comfort performance of three different designs of passive displacement cooling equipment through objective measurements of dry bulb temperature, air velocity and humidity measurements across different heights and locations within the space. The average values were then used to compute the Predicted Mean Vote (PMV) Index, which an index that predicts the mean value of the votes of a large group of persons on the seven-point thermal sensation scale. Concluding from the analysis of the accumulated data, Design B is the optimal choice that fulfils the thermal requirements in accordance with guidelines. While, Design A has shown to have the huge potential for large-scale cooling applications due to the significantly higher cooling capacity and feasibility of operating at higher setpoint temperatures for the supplied chilled water
KEYWORDS: Passive Displacement Coil, PDCU System, Thermal Comfort, Performance Evaluation,

1. INTRODUCTION

Passive Displacement Cooling (PDC) is an innovative air-cooled distribution system which relies on the principle of natural convection of heat transfer without a need for mechanical fans to deliver chilled air to the end user.

This system cools the space at high level (ceiling) installations where the cooled and heavier air sinks down in the space and moves horizontally above-ground level to the heat sources in the room which may include equipment, furniture, and occupants. These heat sources then heat up the air and cause it to rise and be drawn back to the cooling coil at the ceiling level. This repetitive cycle induces air circulation in the space resulting in improved thermal comfort levels for the occupants [1].

1.1 Research objective

The study seeks to measure and validate the thermal comfort performance of three different designs of Passive Displacement Cooling equipment through objective measurements of dry bulb temperature, air velocity and humidity measurements across different heights and locations within the space.

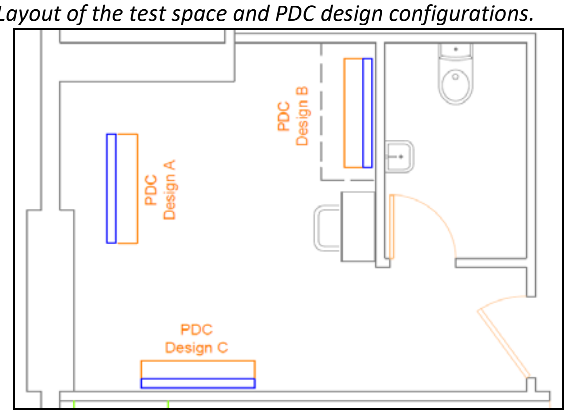
1.2 Research methodology

The experimentation and study were conducted throughout a duration of two weeks within a mock-up of a small, enclosed room with an ensuite bathroom inside a warehouse. The total surface area amounts to 18m^2 with a floor-to-ceiling height of 3m.

All lighting fixtures in the room were kept operational throughout the experiment to serve as internal heat loads for the space.

The room does not have walls that are exposed to outdoor environment and/or direct solar radiation. The spaces adjacent to the room are unused non-air conditioned and not affected directly to outdoor environment either. Therefore, the heat gain to the room is minimal, except a minimum amount of air infiltration from the gap under the room entrance door. This has the purpose to keep the room within the same boundary conditions when the performance of different PDC design configurations were compared.

Figure 1:
Layout of the test space and PDC design configurations.



Each of the three PDC design configuration in the room is designed with a dedicated set of chilled water supply and return piping. The chilled water for the experiment is supplied by an air-cooled portable condenser unit with a cooling capacity of 7.6kW at a supply temperature of 7°C.

1.3 PDC design configurations

The different configurations of the PDC system consists of variations in the coil quantity and fall duct design. Figure 2 illustrates the distinct nature of each configuration.

Figure 2:
PDC system of three different design configurations.

Design A features a dual coil configuration with a cooling capacity of 1.8kW that is ceiling mounted with a fall duct is installed at the outlet of the PDC system to serve as an extension of the system. Designs B and C feature a single coil configuration with a cooling capacity of 0.9kW. The former is installed at the ceiling level in a corner of the room and flushed with the adjacent wall with the outlet of the supplied air located at the ground level, while the latter is located at the mid-wall in another corner of the room and features an extended fall duct of 55cm in length parallel to the adjacent wall.

1.4 Boundary conditions

The experiment consisted of six different scenarios, each with a running duration of nine hours, and two different boundary conditions to be validated. The first round consisted of three scenarios conducted at a room temperature setpoint of 18°C to test the limit of the PDC system's cooling capability at the lowest operable setpoint temperature. The remaining three scenarios were conducted at the optimum room temperature setpoint of 23°C in accordance with local guidelines for day-to-day operating conditions.

Table 1:
Summary of scenarios and boundary conditions of the experiment.

PDC Design Configurations	Boundary Conditions	
Design A (Double Coil Ceiling Mounted)	Room Setpoint: 18°C • With human load • Without human load	Room Setpoint: 23°C • With human load • Without human load
Design B (Single Coil floor outlet)	Room Setpoint: 18°C • With human load • Without human load	Room Setpoint: 23°C • With human load • Without human load
Design C (Single Coil Mid wall outlet)	Room Setpoint: 18°C • With human load • Without human load	Room Setpoint: 23°C • With human load • Without human load

Table 1 summarizes the scenarios and conditions of the experiment.

The human load was represented by a 25-year-old female with an outfit of T-shirt, jacket and long jeans situated in front of a working desk next to the toilet. Light desk activity was carried out with a laptop in a seated position.

In addition, prior to the start of each scenario, the room door was left open for a duration of 12 hours to allow purging and reset of room conditions to the neutral before the commencement of data collection during the daytime, between 0900HRS and 1800HRS.

1.5 Measurement sensors

Sensors measuring the measured dry bulb temperature, relative humidity, air velocity, mean radiant temperature were deployed uniformly across the space to form the PMV equation which is critical in determining thermal comfort of the occupants in an objective measurement setting. Figure 3 shows the overview of the deployed sensors and Figure 4 shows the legend of the indicated symbols.

Figure 3:
Overview of the deployed sensors in the room

Figure 4:
Legend of the indicated symbols in the overview

1.5.1 Thermal stratification measurement

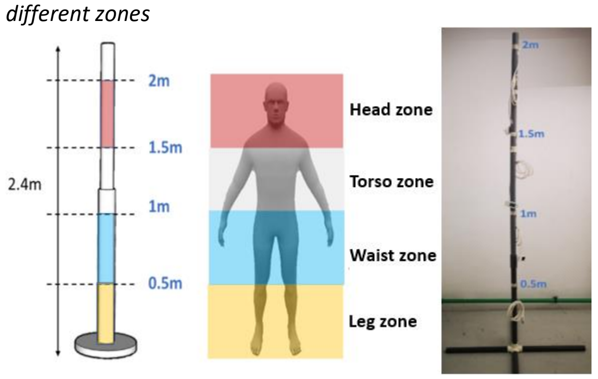
A total of five stratification stands, 2.4m in height, were constructed out of PVC pipes to serve as column support for room temperature, relative humidity, and air velocity sensors.

On each stratification stand is four bi-functional (temperature and relative humidity) sensors installed in 0.5m intervals.

The purpose of this sensor arrangement is to allow understanding of the temperature stratification in the space vertically that is experienced by a typical occupant in a standing position, on different zones of the body. Due to the natural convection theory of air movement, the space at the higher heights from the ground would be warmer than that of lower heights.

The air velocity sensors were installed at the height of 1.5m on Stands 1, 3 and 5 to detect the movement of air at the breathable zone of an occupant at a standing position. Figure 5 shows the setup of a stratification stand and its representation of different zones of an occupant's body.

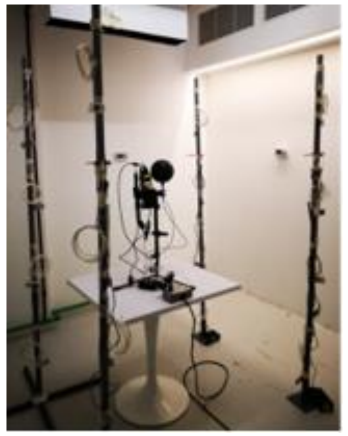
Figure 5:
Typical setup of a stratification stand and representation of different zones



1.5.2 Mean radiant temperature measurement

A multi-functional climate measuring instrument was setup in the centre of the room at a height of 1.5m to primarily measure the mean radiant temperature, relative humidity, and air velocity. Figure 6 shows the setup overview of the instruments and stands within the room.

Figure 6:
Overview of the setup of instruments and stands within the room



1.5.3 Weather data measurement

A bi-functional measurement probe was installed at the exterior of the experimentation premises to measure the dry bulb temperature and relative humidity of the outdoors. The purpose was to determine the significance of the impact of weather conditions on the chilled water supply of the PDCU.

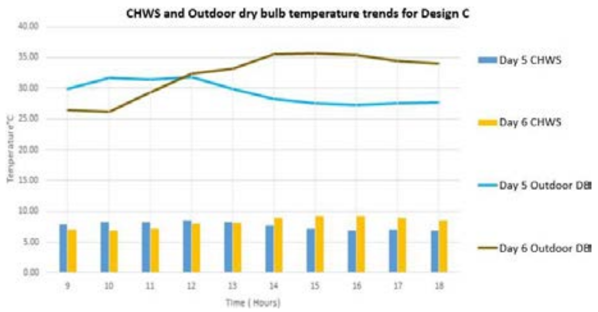
2. RESULTS AND DISCUSSION

This section discusses and analyses the recorded data throughout all six of the experiment scenarios that was carried out at the room temperature setpoints of 18°C and 23°C respectively. Feedback by a participant on the thermal comfort of the room has also been analysed as data for subjective analysis.

2.1 Chilled Water Supply (CHWS) Temperature

According to the trends of the data collected based on the CHWS and outdoor dry bulb temperatures, it is observed that there was significant co-relation between them. The CHWS temperature of the PDCU fluctuates in a similar pattern with that of the outdoor dry bulb (DB) temperature. This trend is especially stark for the dual coil configuration of Design C.

Figure 7:
CHWS temperature trending of Design C with the corresponding outdoor dry bulb temperature



From the chart (Figure 7), the outdoor DB temperature was of a decreasing trend from 1200HRS to 1500HRS of Day 5. In relation, the CHWS temperature of Design C reacted with a similar decreasing trend.

On the other hand, the outdoor DB temperature of Day 6 showed an increasing trend from 1000HRS to 1400HRS. The CHWS temperature followed the same trend throughout the same span of time.

2.2 Room temperature setpoint of 18°C

The purpose of a setpoint of 18°C was to test the limit of the PDC system's cooling capability at the lowest operable setpoint temperature.

The presence of a human load in the room was observed to be an insignificant factor affecting the overall heat load of the space. The recorded data shown the differences to be approximately 1% in margin and negligible.

2.2.1 Temperature distribution of the space at 1.5m

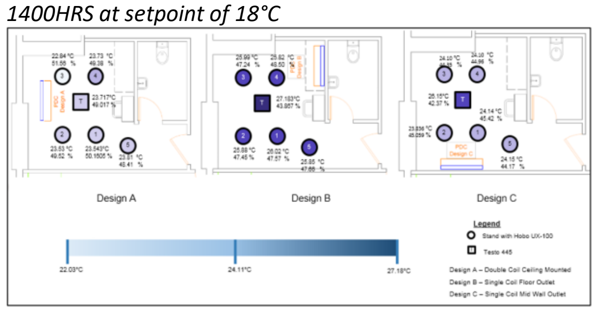
The temperature distribution of the space was analysed at a standardized height of 1.5m from the ground based on the boundary conditions to develop understanding of the temperature flow pattern within the space at different time intervals throughout the day.

Generally, throughout the day, Design A was able to lower the temperature of the room at the greatest extent, averaging at a value of 23.5°C during the hottest period of the day in the early afternoon.

Design B, averaging at a value of 25.9°C in the same period, was observed to be the least effective in lowering the room temperature. Design C measured a median average distributed temperature of 24°C.

Figure 8 shows the temperature and RH distribution (with the scale and legend) in the presence of a human load for each of the designs at a time of 1400HRS, in the hottest period of a day.

Figure 8:
Temperature and RH distribution for all three designs at 1400HRS at setpoint of 18°C



These differences in temperatures have shown that the configuration and positioning of the PDCU can significantly affect the system cooling capability.

Variation of the recorded %RH distribution within the room was shown to be low and contained at 5%. All three designs were able to keep levels at below 50% with Design C slightly more effective in terms of latent cooling.

2.2.2 Temperature and RH stratification of the room

Throughout the experiment, it has been observed that the room temperature and RH are of a near-inversely linear relationship along the different height intervals of measurement of the stratification stands.

Corresponding with the results of the temperature distribution in the space at the height of 1.5m, Design A was observed to generate a temperature stratification of the smallest and lowest average range of 22°C at 0.5m to 23.5°C at 2m. In relation, the RH stratification was also at the smallest average range of 51% at 0.5m to 47% at 2m. Figure 9 shows the temperature and RH stratification of Design A based on the five stands.

Design B generated the steepest as well as largest temperature and RH stratification with an average range of 22.7°C and 52% at 0.5m to 26.1°C and 45% at 2m respectively. Figure 10 shows the charts for temperature and RH stratification of Design B.

Design C generated a median temperature and RH stratification with an average range of 21.7°C and 48% at 0.5m to 24.5°C and 43% at 2m respectively. Figure 11 shows the charts for temperature and RH stratification of Design C.

Figure 9:
Temperature and RH stratification of Design A at setpoint of 18°C

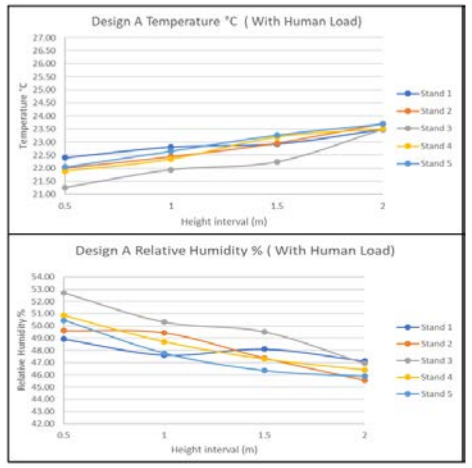


Figure 10:
Temperature and RH stratification of Design B at setpoint of 18°C

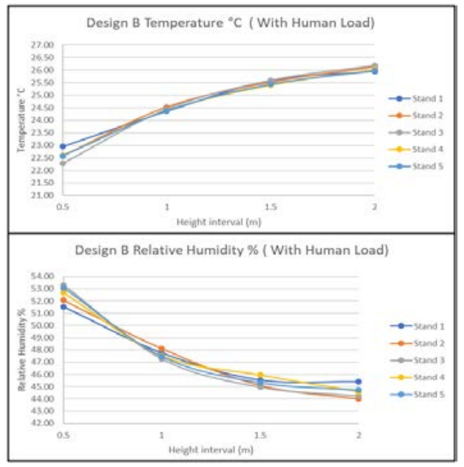
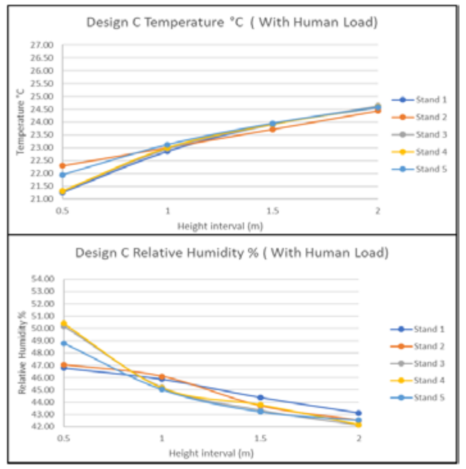


Figure 11:
Temperature and RH stratification of Design C at setpoint of 18°C



2.3 Room temperature setpoint of 23°C

The purpose of a setpoint of 23°C was to evaluate the capability of the PDC system under routine operating conditions and heat-loading.

2.3.1 Temperature distribution of the space at 1.5m

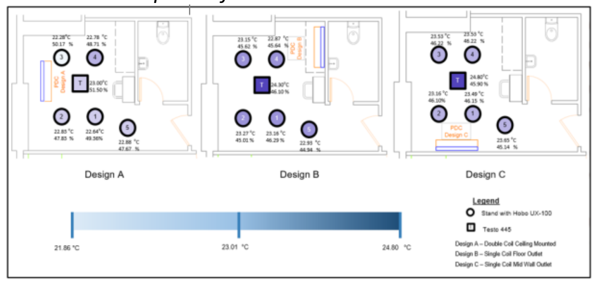
The pattern and trend of the temperature for the space throughout the day was observed to be highly similar to those at the setpoint of 23°C.

Throughout the day, Design A could maintain the temperature of the room just below the setpoint. Even during the hottest period of the day in the early afternoon, the average distribution of the space was 22.7°C.

Design B, averaging at a value of 23.1°C in the same period, was observed to be the most effective in maintaining the room temperature close to the setpoint. Design C measured a highest average distributed temperature of 23.5°C.

Figure 12 shows the temperature and RH distribution (with the scale and legend) in the presence of a human load for each of the designs at a time of 1400HRS, in the hottest period of a day.

Figure 12:
Temperature and RH distribution for all three designs at 1400HRS at setpoint of 23°C



The %RH distribution within the space was kept within an average range of between 45% and 50%, similarly to that of the setpoint at 18°C.

2.3.2 Temperature and RH stratification of the room

Similar trends and stratification for the temperature and RH of the room were observed in comparison with the results from Section 2.2.2.

Design A was observed to generate a temperature stratification of the smallest and lowest average range of 21°C at 0.5m to 23°C at 2m. However, the RH stratification was also at the largest average range of 52.5% at 0.5m to 48% at 2m. Figure 13 shows the temperature and RH stratification of Design A based on the five stands.

Design B generated the steepest as well as largest temperature and RH stratification with an average range of 20°C and 52% at 0.5m to 23.5°C and 45% at 2m respectively. Figure 14 shows the charts for temperature and RH stratification of Design B.

Figure 13:
Temperature and RH stratification of Design A at setpoint of 23°C

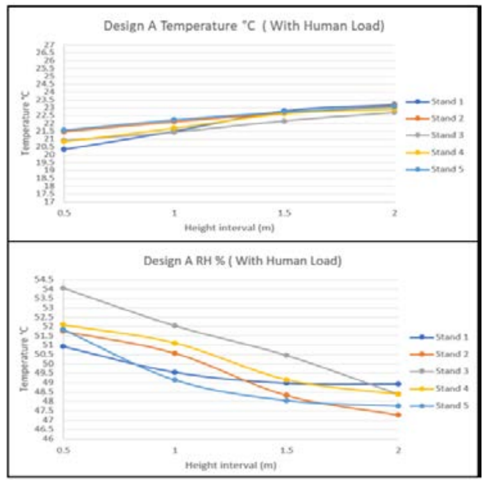


Figure 14:
Temperature and RH stratification of Design B at setpoint of 23°C

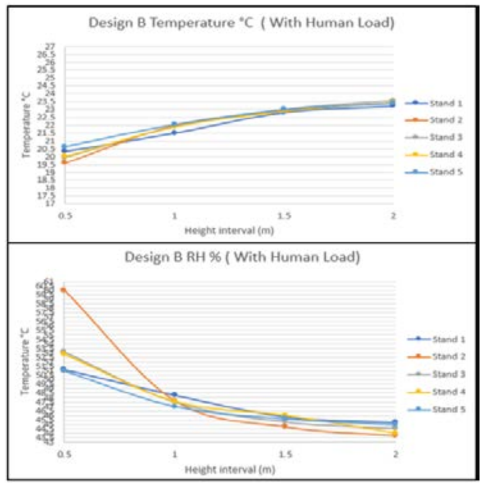
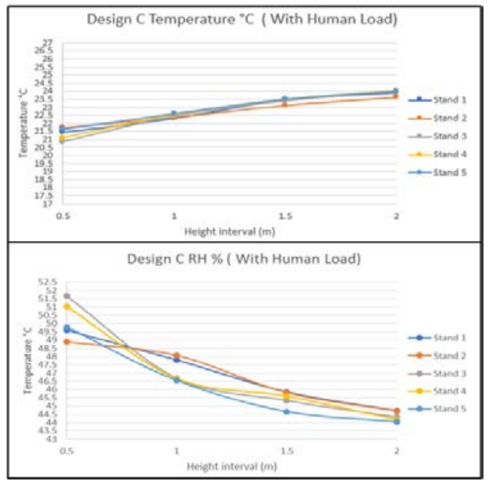


Figure 15:
Temperature and RH stratification of Design C at setpoint of 23°C



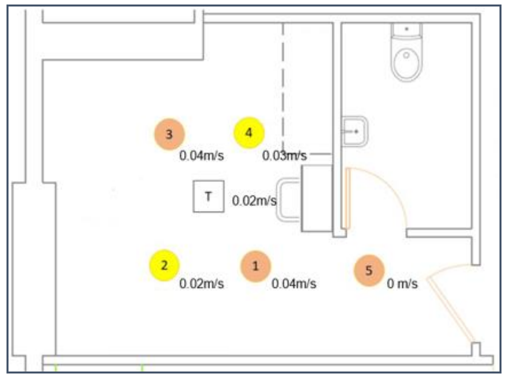
Design C generated a median temperature and RH stratification with an average range of 21.5°C and 50% at 0.5m to 24°C and 44.5% at 2m respectively.

Figure 15 shows the charts for temperature and RH stratification of Design C.

2.4 Air velocity of the room

Collected data on the air velocity trend within the space had shown that, despite fulfilling the SS554:2016 regulation: Table 1 – Recommended IAQ Parameters where the acceptable limit of the air movement is below 0.3m/s, the generated draft was consistently very low across all three designs, within a range of 0m/s to 0.04m/s [2]. Figure 16 shows a typical measured air velocity at the location of each of the 5 stands at the height of 1.5m.

Figure 16:
Typical measurement of air velocity in the room



2.5 PMV and PPD

The derivation of the PMV value considers the main variables for a cooling system - air velocity, humidity, and temperature. The PPD results are dependant on the PMV values.

Based on the average values of the measured data in the experiment, the derived results have shown that Design A would be deemed as significantly too cold for an occupant with a PMV of -1.44 and PPD of 47.87. Design B was the ideal design with a PMV of -0.36 and PPDC of 8.26. Design C was the median with a PMV of -0.78 and PPD of 18.41.

According to AHSRAE 55, the acceptable thermal comfort conditions call for a PMV range between -0.5 and 0.5, with a PPD value of under 10 [3]. Table 2 shows the summary of derived results for all three designs.

Table 2:
Derived PMV and PPD values for all three designs

PMV	Design A (Double Coil Ceiling Mounted)	Design B (Single Coil Floor Outlet)	Design C (Single Coil Mid Wall Outlet)
Average PMV	-1.44	-0.36	-0.78
Max PMV	-1.20	-0.20	-0.60
Min PMV	-1.70	-0.60	-1.00
Standard Deviation PMV	0.2	0.18	0.17
Average PPD	47.87	8.26	18.41

3. CONCLUSION

In this experiment, Design B has shown to be the most optimal for routine operations based on the data and analysis of the various critical parameters.

It was able to maintain room temperatures very closely within the setpoint, and the corresponding derived PMV values were well within the ASHRAE range of between -0.5 and 0.5, under 10% of the average PPD.

However, Design A has shown to have the huge potential for large-scale cooling applications due to the significantly higher cooling capacity and feasibility of operating at higher setpoint temperatures for the supplied chilled water

4. Future Study

A further research and performance study of Dual-coil PDC system were planned to evaluate its design parameters, such as fall duct geometry design, supplied chilled water operating condition, and various internal heat source. The study will be done through CFD simulation, testing in accredited controlled lab environment and actual implementation in a building.

ACKNOWLEDGEMENTS

This paper is supported by the National Research Foundation, Singapore, and Building and Construction Authority, Singapore under its Green Buildings Innovation Cluster (GBIC) Programme (GBIC Award no. 94.23.1.12). Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not reflect the views of National Research Foundation, Singapore and Building and Construction Authority, Singapore.

REFERENCES

1. Stevens, K., & Fuller, M, (2015). Thermoregulation and clothing comfort. *Textile-Led Design for the Active Ageing Population, 2015, p. 117-138.*
2. Singapore Standard 554:2016, (2016). Table 1. *Code of practice for indoor air quality for air-conditioned buildings, p. 21-23.*
3. ASHRAE 55-2010 (American Society of Heating, Refrigerating, Air-Conditioning Engineers, & American National Standards Institute). (2010). Table 5.2.1.2. *Thermal environmental conditions for human occupancy, p. 7.*

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE BUILDINGS AND TECHNOLOGY

PLEA SANTIAGO 2022
Will Cities Survive?

Towards occupant-driven district energy system operation

A digital twin platform for energy resilience and occupant well-being

MARTÍN MOSTEIRO-ROMERO[1,2], PRADEEP ALVA[1,2], CLAYTON MILLER[3] AND RUDI STOUFFS[1]

[1] Department of Architecture, National University of Singapore, Singapore
[2] Singapore-ETH Centre, Future Resilient Systems, Singapore
[3] Department of the Built Environment, National University of Singapore, Singapore

ABSTRACT: This paper presents a digital twin of a university campus in Singapore as a demonstrator for a digital-twin enabled approach to district energy resilience. This paper focuses mainly on the development of the building energy and occupancy models in the digital twin, which are complemented by a user interface for real-time data visualization and scenario assessment. The building energy demand model of the case study area was calibrated using measured hourly cooling and electricity data collected in the case study area. Occupant presence was estimated using WiFi connection counts, and a simple regression model was developed to assign electricity loads as a function of occupant presence and time of day. The digital twin's scenario assessment capabilities were explored through scenarios on the long-term effects of climate change and of the increase of remote working and studying as a result of the COVID-19 pandemic. Four different "work-from-home" cases were considered, and three different building operation strategies were assumed for each case. The results show that a decrease in building occupancy post-COVID-19 would lead to minimal space cooling savings in the case study area unless building operation was proactively adjusted to adapt to the new needs of the campus.
KEYWORDS: Urban building energy modelling, Occupancy modelling, Energy resilience, Digital twins

1. INTRODUCTION

With the increasing frequency and magnitude of major disruptive events in urban areas, the resilience of the built environment against climate change impacts and associated disruptions has received increasing attention in recent years [1]. As a low-lying, tropical island with a hot and humid climate, Singapore is particularly vulnerable to the impact of climate change [2]. In order to mitigate the effects of climate change on building occupants' health and well-being, resilient cooling is of principal importance to maintain indoor environmental quality against unexpected events such as extreme weather conditions, heat waves, and power outages [3]. Such vulnerabilities have been compounded by the COVID-19 pandemic and the societal shifts it has caused, leading to changes in the way energy is used and therefore putting further stress on existing energy infrastructure.

As a demonstrator for a digital-twin enabled approach to district energy resilience, a digital twin of a university campus in Singapore is under development. The campus, shown in Figure 1, includes a variety of building use types, including classrooms, laboratories, offices and residential buildings as well as a variety of amenities. The area is currently served by a number of district cooling networks of different scales. The digital twin will form the basis for a new approach to evaluate the vulnerability, efficiency, and resilience of future urban districts in the tropics.

This paper presents the framework and ongoing work on the construction of the digital twin of the campus' building stock. Special focus is given to the development of the building energy model developed for the digital twin and the assessment of sample scenarios on the effects of long-term changes in occupancy patterns as a result of the COVID-19 pandemic and increased temperatures due to climate change.

Figure 1:
Screenshot of the digital twin dashboard showing the case study area.

2. DIGITAL TWIN SCOPE

A digital twin is a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems [4]. Originating in the aerospace field, the digital twin concept has found applications in a number of different sectors, including health, meteorology, manufacturing and process technology, education, cities, transportation, and energy [5]. A number of works in the literature have focused on the development of digital twins to aid urban planning and citizen engagement [6, 7, 8, 9]. Digital twins have also found applications in district energy systems, particularly in system planning [10], energy management and optimization [11], and model predictive control [12, 13].

The present project seeks to study how both buildings and energy systems can help build resilience through coupling advanced numerical models and real-time data. As a first step in the development of this framework for district energy resilience, this paper focuses on the digital twin of the built environment. Previous work shows heat waves, power outages, and pandemics are some of the main types of disruptions affecting the built environment [3]. In order to demonstrate the possibilities of the approach presented, the long-term effects of climate change and the shift to increasingly working from home after the COVID-19 pandemic on the energy demands of a district were selected as test cases for this project.

3. METHODOLOGY

The digital twin comprises a user interface for real-time data visualization along with physical models of the buildings in the district, their occupants, and the energy demands that arise as a result of their activities. The platform is therefore intended to allow planners and system operators to not only analyze the district's past and present energy performance, but also interact with the systems and explore the effect of different disruption scenarios through simulations.

This paper focuses mainly on the development of the building energy and occupancy models in the digital twin. The development of the digital twin dashboard and data visualization capabilities has been detailed in a separate publication [14].

3.1 Physical model of the case study

As a first step, simplified three dimensional models of each building were created from building footprints obtained from OpenStreetMap (OSM) [15], which occasionally included each building's use type and number of floors. For most buildings, however, these had to be filled in based on openly-available information from the university and visual inspection. These polygons were then extruded to their building heights and converted into CityGML to form the basis of the physical model of the area. Detailed BIM models were available for a few buildings on the campus, which were also incorporated into the model using an IFC to CityGML work pipeline [16].

3.2 Building energy demand model

In order to project future demands in the case study district under different scenarios, a building energy demand model of the case study area was developed using the open-source tool City Energy Analyst (CEA). This tool was selected due to its lightweight energy demand model and simplified inputs. This software has previously been used to assess the effects of local climate and changes in occupancy patterns on energy demand, both desirable characteristics in this project.

Since detailed information about the building envelope and system operation were not available, these parameters were assigned using brute force calibration with discrete input parameters obtained from the CEA archetypes database. The parameters to be calibrated were selected from a previous sensitivity analysis of the tool's thermal models [17]. The calibration parameters and ranges used in this step are shown in Table 1.

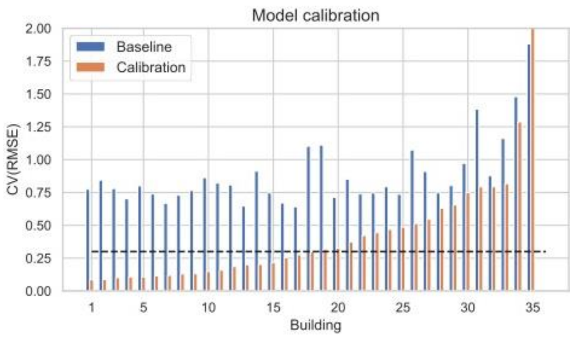
Table 1:
Calibration variables and their corresponding ranges.

Parameter	Minimum	Maximum	Increment
Cooling set point temperature [°C]	17	29	1
Cooling set back temperature [°C]	17	29	1
Window-to-wall ratio [-]	0.29	0.89	0.1
Infiltration rate [h^{-1}]	1	6	1
Window U-value [$W/(m^2 \cdot K)$]	1.8	5.4	[-][1]

[1] Only three types of windows from the CEA database were considered, with U-values 1.8, 2.2, and 5.4.

Each combination of parameters was input into the CEA energy demand model and the resulting coefficient of variation of root-mean square error (*CV(RMSE)*) was calculated. For this calculation, hourly measurements of electricity and cooling demands from 2018 were available, as well as measured data from one building from early 2020 (before the start of the COVID-19 pandemic). The calibrated model's performance was then assessed based on the benchmark values in AHSRAE Guideline 14 [18], that is, a building energy model was considered well-calibrated if the CV(RMSE) was below 30% for hourly calibration data. The resulting model performance before and after calibration is shown in Figure 2.

Figure 2:
Calibration results for 35 buildings in the case study area. The recommended CVRMSE threshold for hourly calibration is shown by a dashed black line.



3.3 Building occupant modeling

The calibrated building energy models are successively populated by building occupants with an assumed electricity consumption demand per occupant. Occupant presence was first estimated using WiFi connection counts from each building in the case study, using an approach similar to a previous study [19]. First, k-means clustering was used to assign typical WiFi connection profiles to each day of the year, generating a yearly profile of occupancy that differentiated between weekdays, weekends, and public holidays, as well as between semesters and holiday periods. The measured electricity loads were then used to fit a simple regression model, where plug loads were assumed to be directly proportional to occupant presence whereas lighting was assumed to be a function of the time of day. These occupant profiles and electricity demand schedules are then inputted back into the building energy demand model for the thermal load calculation.

3.4 Visualization platform

In order to allow users to explore and interact with live data and simulated results, a digital twin dashboard was created as web map application. Time-based sensor data are stored in an open-source, cloud-native serverless platform accessed through a robust API to display high-frequency building information. Simulation results and live data are displayed on the dashboard through Highcharts, a multiplatform charting Javascript library. The resulting dashboard is shown in Figure 1. A more detailed description of the construction of the digital twin dashboard can be found in the aforementioned publication [14].

4. CASE STUDY DISTRICT AND AVAILABLE DATA

Although the full digital twin comprises 362 building structures, this paper focuses on the buildings for which the full dataset is available that is required for the development of the building energy model, calibration and occupant modeling. The location and main building function of the 35 buildings for which both cooling and electricity meter data as well as WiFi counts were available are shown in Figure 3. Their function in CEA was mostly assigned the *"UNIVERSITY"* use type, which encompasses mixed classroom/research buildings. Other buildings include libraries and a performance hall.

Figure 3:
Distribution and main use type of the 35 buildings considered in this analysis.

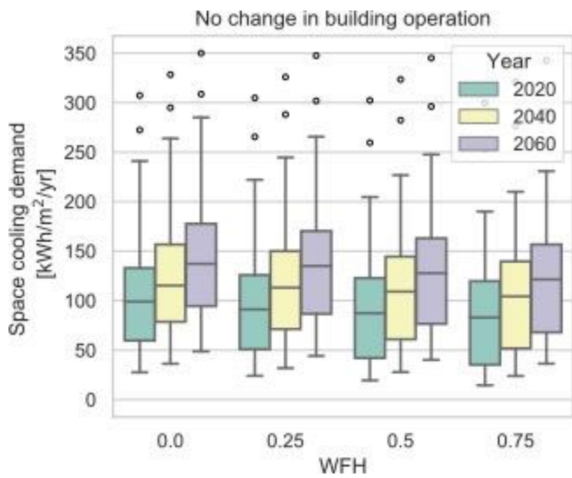
5. RESULTS

As a test case for the digital twin platform, different scenarios were defined in order to explore the long-term effects of climate change and of the increase of remote working and studying as a result of the COVID-19 pandemic. The R package *epwshiftr* [20] was used to generate future weather files for Singapore using Coupled Model Intercomparison Project Phase 6 (CMIP6) data. Four different "work-from-home" cases were considered (0%, 25%, 50% and 75%) and in each case the predefined percentage of students and employees were assumed to stay at home, consequently reducing the share of occupancy in university and office buildings. Furthermore, three different building operation strategies were assumed for each of these cases in order to assess how building operators might affect the cooling demands of the case study area in each scenario: "no change", whereby buildings are operated normally in spite of the decrease in occupancy; "operational floor area", whereas only the share of the building floor area that is actually occupied is conditioned; and "selective closure", whereby those occupants who do go to work or study on campus are assumed to be rerouted to specific, fully-occupied buildings, and all other buildings are assumed to be closed.

5.1 No change in building operation

The results of the first scenario (Figure 4) show that a decrease in building occupancy as a result of an increased reliance on home office and home schooling post-COVID-19 would lead to minimal decrease in the building cooling demand for the buildings in the case study area. Indeed, a university in the Netherlands found that energy demand only decreased by 3% in 2020 in spite of the fact that its buildings were only occupied 25% of the time due to the pandemic [21]. Maintaining the status quo in building operation would therefore lead to large amounts of energy waste if an increased share of home-based work and schooling becomes the norm moving forward. These effects are exacerbated by the increased temperatures due to climate change, as seen in Figure 4.

Figure 4:
Distribution of the space cooling demand for each building under different work-from-home (WFH) scenarios for the case of no change in building operation.



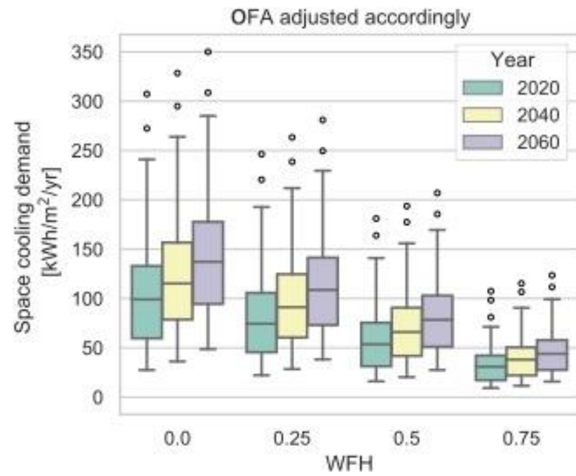
5.2 Operational floor area

Figure 5 shows the results for the case where the operational floor area is assumed to be varied along with the share of home-based employees and students. Unsurprisingly, the space cooling demand in each WFH scenario decreases proportionally to the decrease in building occupancy, unlike Figure 4. Therefore, by introducing such dynamic building system controls, such that only occupied spaces are conditioned, the space cooling demand could be significantly reduced.

5.3 Selective closure

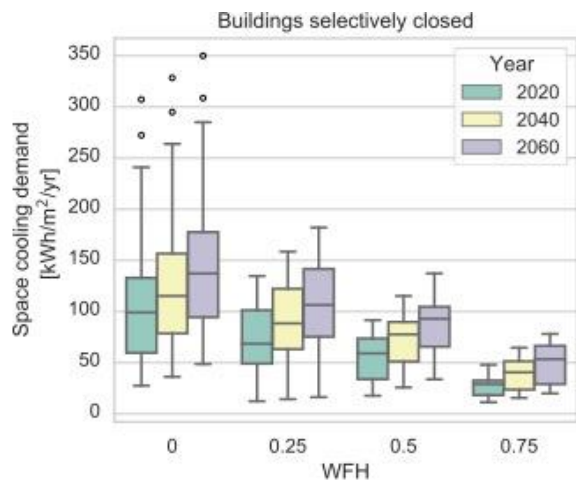
A decrease in the number of people physically attending their offices and classrooms could potentially create an opportunity to re-develop the

Figure 5:
Distribution of the space cooling demand for each building under different work-from-home (WFH) scenarios for the case of adjusted operational floor area (OFA).



area's building stock and prioritize the operation of more energy-efficient buildings. In the final scenario, occupants' activities are assumed to be relocated in order to ensure full building occupancy even in cases of increased shares of remote working and studying. As seen in Figure 6, the outliers observed in the case with no remote working are eliminated, and instead more efficient buildings are prioritized, thus further reducing the space cooling demands in the case study area. While this scenario represents a somewhat idealized case, it does raise the question of what opportunities might be created by the changes in energy demand patterns in the future as a result of the changes observed over the past few years.

Figure 6:
Distribution of the space cooling demand for each building under different work-from-home (WFH) scenarios for the case of selective closure of unoccupied buildings.



6. DIGITAL TWIN EVALUATION AND FUTURE WORK

The digital twin platform appears to be a promising interface for planners and operators to interact with a district's building and energy infrastructure in order to assess their robustness under different planning and disruption scenarios. Some potential use cases were explored as demonstrative examples in order to test the performance of the model and its implementation in decision making.

The major difference between a traditional simulation model and a digital twin is that the former predicts future states of a physical system based on a set of initial assumptions, while the latter tracks current and past states of a physical system through data exchange between the physical and virtual systems [4]. While the model is not yet able to meet the calibration targets for all buildings, these results are expected to improve as further data is collected and the energy demand models continue to be updated.

Furthermore, the scenarios presented in terms of climate and occupancy were relatively simplified. Work is ongoing to integrate an urban microclimate simulation into the platform in order to incorporate more reliable estimates of local climate and its effects on the area's needs. Additionally, the WiFi data is also being used to develop an agent-based model of building occupancy, which will allow us to explore occupant comfort in the building stock considered and potentially let occupant behavior be the driver of the types of choices in activity location that we have so far determined using a top-down approach.

7. CONCLUSIONS

A digital twin approach to urban energy resilience was presented through a case study in a university campus in Singapore. The digital twin comprises a dashboard and visualization platform as well as a building energy demand model. The building energy demand model is calibrated using hourly meter data and populated with occupants generated using WiFi connection patterns as a proxy for building occupancy.

The model was then used to explore the effects of the shift to remote working and studying on the space cooling demands of the area under different building system operation scenarios. The results stress the importance of dynamic building system operation that can adapt to changes in occupants' needs with increasing flexible work arrangements and remote working and studying.

These results demonstrate the potential for the platform to be used by planners and system operators to analyze the effects of their decisions on the performance of the case study district. Ongoing work to incorporate microclimate simulations as well as an agent-based model of building occupancy will allow such scenarios to be driven by occupant behavior and thermal comfort rather than defined in a top-down manner as presented in this paper.

ACKNOWLEDGEMENTS

The research was conducted at the Singapore-ETH Centre, which was established collaboratively between ETH Zürich and the National Research Foundation Singapore. This research is supported by the National Research Foundation, Prime Minister's Office, Singapore under its Campus for Research Excellence and Technological Enterprise (CREATE) program.

We would like to thank Prof. Adrian Chong for providing access to the meter and WiFi data, as well as providing feedback on the calibration of the building energy demand model.

REFERENCES

1. McAllister, T. (2013). *Developing Guidelines and Standards for Disaster Resilience of the Built Environment: A Research Needs Assessment, National Institute of Standards and Technology (NIST)*. Gaithersburg, MD, USA.
2. National Climate Change Secretariat (2020). *Charting Singapore's low-carbon and climate resilient future.* Prime Minister's Office, Singapore.
3. Attia, S., Levinson, R., Ndongo, E., Holzer, P., Kazanci, O., Homaei, S., Zhang, C., Olesen, B. W., Qi, D., Hamdy, M. and P. Heiselberg (2021). Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. *Energy & Buildings*, 239: p. 110869.
4. VanDerHorn, E. and S. Mahadevan (2021). Digital Twin: Generalization, characterization and implementation. *Decision Support Systems*, 145: p. 113524.
5. Rasheed, A., San, O. and T. Kvamsdal (2020). Digital Twin: Values, Challenges and Enablers From a Modeling Perspective. *IEEE Access*, 8: p. 21980–22012.
6. Schrotter G. and C. Hürzeler (2020). The Digital Twin of the City of Zurich for Urban Planning. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 88: p. 99–112.
7. Kent, L., Snider, C. and B. Hicks (2019). Early Stage Digital-Physical Twinning to Engage Citizens with City Planning and Design. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Osaka, Japan.
8. Ruohomäki, T., Airaksinen, E., Huuska, P., Kesäniemi, O., Martikka, M. and J. Suomisto (2018). Smart City Platform Enabling Digital Twin. In *2018 International IEEE Conference on Intelligent Systems (IS)*, Funchal, Portugal.
9. National Research Foundation (NRF) (2020). *Virtual Singapore*. [Online]. Available: https://www.nrf.gov.sg/programmes/virtual-singapore
10. Rämä, M., Pursiheimo, E., Sokka, L. and K. Klobut (2018). New tool for planning district cooling systems. In *Digital Proceedings 13th SDEWES Conference, the Conference on Sustainable Development of Energy, Water and Environment Systems*, Palermo, Italy.
11. Agostinelli, S., Cumo, F., Guidi, G. and C. Tomazzoli (2021). Cyber-Physical Systems Improving Building Energy Management: Digital Twin and Artificial Intelligence. *Energies*, 14(8): p. 2338.
12. Zabala, L., Febres, J., Sterling, R., López, S. and M. Keane (2020). Virtual testbed for model predictive control development in district cooling systems. *Renewable and Sustainable Energy Reviews*, 129: p. 109920.
13. O'Dwyer, E., Pan, I., Charlesworth, R., Butler, S. and N. Shah (2020). Integration of an energy management tool and digital twin for coordination and control of multi-vector smart energy systems, *Sustainable Cities and Society*, 62: p. 102412.
14. Alva, P., Mosteiro-Romero, M., Miller, C. and R. Stouffs (2022). "Digital twin-based resilience evaluation of district-scale archetypes: A COVID-19 scenario case study using a university campus pilot". Full paper accepted for *CAADRIA 2022*. Sydney, Australia.
15. OpenStreetMap contributors (2017). *OpenStreetMap*. [Online]. Available: https://www.openstreetmap.org.
16. Tauscher, H., Lim, J. and R. Stouffs (2021). A modular graph transformation rule set for IFC-to-CityGML conversion. *Transactions in GIS*, 25(1): p. 261-290.
17. Mosteiro-Romero, M., Fonseca, J. and A. Schlueter (2017). Seasonal effects of input parameters in urban-scale building energy simulation. *Energy Procedia*, 122: p. 433-438.
18. ASHRAE (2014). *Guideline 14-2014: Measurement of Energy, Demand and Water Savings*. American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, USA.
19. Zhan, S. and A. Chong (2021). Building occupancy and energy consumption: Case studies across building types. *Energy and Built Environment*, 2(2): p. 167-174.
20. Jia, H. and A. Chong (2021). *epwshiftr v0.1.3*. [Online]. Available: https://github.com/ideas-lab-nus/epwshiftr.
21. TU Delft, *Brains 4 Buildings Research Theme: Energy*. [Online]. Available: https://www.tudelft.nl/en/innovatie-impact/home-of-innovation/innovation-projects/projects-2022/b4b. [Accessed 2 March 2022].

PLEA SANTIAGO 2022
Will Cities Survive?

Multi-objective optimisation of bio-based thermal insulated panels using evolutionary algorithms

MARCO IANNANTUONO [1] FRANCESCA CATALOGNE [2] JUAN PABLO CARDENAS-RAMÍREZ [3]

[1] DA - Department of Architecture, University of Bologna, 40136 Bologna, Italy
[2] FaBiT - Department of Pharmacy and Biotechnology, University of Bologna, 40136 Bologna, Italy
[3] Departamento de Ingeniería en Obras Civiles, University of La Frontera, 01145 Temuco, Chile

ABSTRACT: Sustainability has been continuously incorporated into the building policies and regulations of several countries. However, this has led to a complexity in the application of these regulations and the determination of optimum parameters for different projects. In this context, the use of a method such as multi-objective optimisation is particularly interesting. For this study, a workflow that includes the OpenBIM methodology was used in the calculation model generation procedure. A total of nine parameters were used in JEPlus for the optimisation of a case study, evaluating more than 500,000 design options. The objective functions to be minimised were initial cost and Global Warming Potential (GWP) during 50 years of the building's life cycle. For all best solutions that had a cost between USD $2,500-$10,500 with GWP ranging of 1-62 tonCO_2, the type of thermal insulation material played a key role along with its thickness. Insulating materials such as EPS and Glass wool were then compared with a Bio-based insulated material, using Evolutionary Algorithms and JEA, an Interactive Optimisation Engine. The interoperability between the software and the effectiveness of the optimisation algorithms have allowed for an expansive comparison to predict models that cannot otherwise be explored with conventional methods. Finally, based on the results, a new construction system based on digital manufacturing was prototyped.
KEYWORDS: Multi-objective optimisation, Bio-based insulated material, Evolutionary Algorithms, OpenBIM, Sustainability

1. INTRODUCTION

Current environmental and economic conditions around the world call for a radical change in society's developmental strategies.

In response to the emergencies that we are experiencing and to promptly limit the effects of climate change; the energy consumption and emissions of our buildings must be drastically reduced. Moreover, the cities need a dynamic management adapted to the requirements of the Smart City of the 21st century, for an increasingly digital world with an urgent call.

Due to the global residential building sector that consumes 60% of the sector's energy and emits 43% of greenhouse gas (GHG) emissions [1], the concept of sustainability has been continuously incorporated into the building policies and regulations of several countries mainly according to their own global commitments. However, this has led to a complexity in the application of these regulations and the determination of the optimum parameters for different projects.

If a few years ago, project decisions were solely based on economic cost and energy efficiency standards, today these indicators must be combined with many more sustainability indicators, which complicates the realisation of optimal solutions.

In this context, the use of a method such as multi-objective optimisation (MOO) is particularly interesting [2].

MOO focuses on conflicting objectives that are functions of optimisation variables and these can be subject to various constraints. In fact, in a typical MOO problem, optimisation parameters, objective functions and constraints are defined [3]. The aim of this study was to analyse and optimise the costs of the construction systems and minimise the environmental impacts of a house in Chile, designed with wood panels that are insulated with a bio-based thermic material, during its life cycle.

Through a multi-objective optimisation, the initial costs, and Global Warming Potential (GWP) of the optimised house in this assessment were evaluated, and the advantages of using wood panels insulated with biomaterial and different energy efficiency strategies were discussed.

2. ANALYSIS AND METHODS

Achieving optimal building performance is a complex challenge, especially if the design options are numerous and there are two or more potentially conflicting objectives, e.g., to reduce both environmental impacts, and the cost of the construction systems.

In this sense, parameters refer to all of the multiple types of data that influence project decision-making.

The purpose of parametric analysis is to build a system that integrates all variables/categories involved in the design process, more than just geometry and form.

In such cases, standard simulations are often inefficient, even if based on methods such as parametric analysis, due to the time and resources that would be required to evaluate a very large number of solutions. To overcome these limitations, methods such as simulation-based optimisation have been developed.

In this field, optimisation usually consists of coupling a simulation engine, such as EnergyPlus, with an optimisation engine, e.g., a Genetic Algorithm. Genetic Algorithms are based on evolutionary selection processes, which ensure that only the most suitable solutions remain through several generations. This allows a wide range of design solutions to be explored efficiently, also in term of time and computational resources.

It is necessary to have a comprehensive information model and data that takes into consideration the architectural aspect, energy, and resource consumption, as well as exterior/interior comfort in order to perform calculations and simulations to optimise the design of the building's components.

For this study, a workflow that includes the OpenBIM methodology was used in the calculation model generation procedure (Figure 1).

Autodesk Revit, one of the most utilised BIM software, was used for the generation of the IFC file, that was exchanged which Cype's IFC Builder software to generate the geometric model of the building and create the thermal zones.

The result file was imported in CYPETHERM Eplus software, which was used for the dynamic energy modelling and simulation of the case study using EnergyPlus™. After the simulations, the EnergyPlus (E+) calculation file was exported from CYPETHERM EPlus in its .idf format.

The .idf file was used in JEPlus+EA, an open-source tool originally developed to manage complex parametric E+ simulations, which uses a combination of optimisation algorithms such as Evolutionary Algorithms (EAs). Thus, providing a convenient and highly efficient way to perform optimisation for building design and use [4].

The next step was to place a number of search strings inside the .idf file to mark the locations of where the parameter values should be applied, then specifying all the alternative values for the parameters.

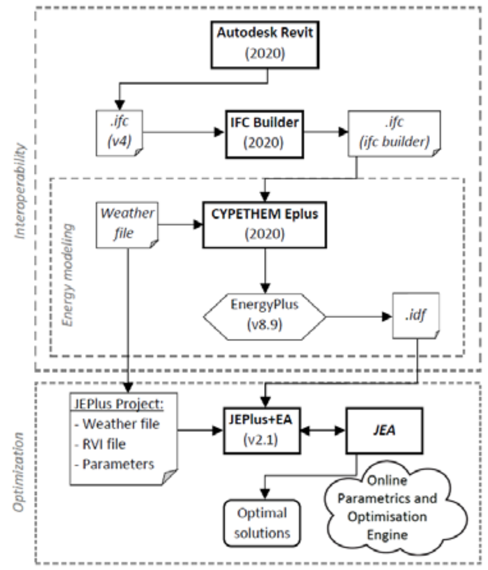
Once we have defined the parameters, JEPlus creates the list of cases and simulations for EnergyPlus; each case contains a unique set of parameter values placed in the .idf model.

In this way, it was possible to quickly set up a large amount of simulation runs to explore the research space.

After the pre-processes, JEPlus runs simulations on each selected case until completion**.** Once the simulations are done, it uses the information defined in the RVI object to collect results.

The results obtained are exchanged to the JEA online optimisation engine. JEA is a multi-objective constrained algorithm based on EA's and has been tuned for a wide range of problems found in applications in the built environment. Additional methods such as parametric analysis and uncertainty/sensitivity analyses are provided to aid the interactive design approach [5].

Figure 1:
Interoperability and optimisation workflow.



3. CASE STUDY

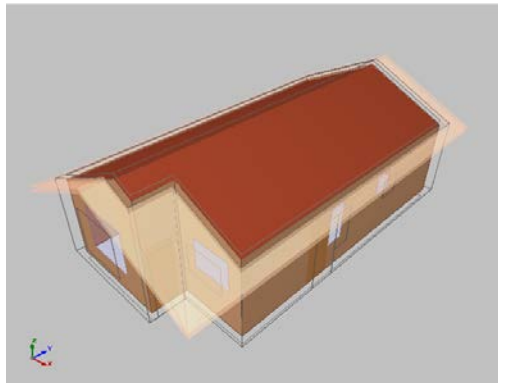
The analysed building for the case study is a one-story detached house with a floor area of 53.36 m^2 and a ceiling height of 2.4 m, the envelope wall area is 66.95 m^2 and the roof area is 59.04 m^2 representative of a typical house available on the market for a family of four. The house has three bedrooms and two bathrooms.

This study focused on the optimal design of a house made of prefabricated wooden panels and insulated with biomaterial.

The key objectives were increasing the comfort and health for the users, choosing ecological materials to achieve high energy efficiency while having a low environmental impact, and, if possible, keep construction costs lower.

Implementing a simulation-driven design approach from the start of the project was a strategic technique for achieving these objectives.

Figure 2:
IFC model of the case study.

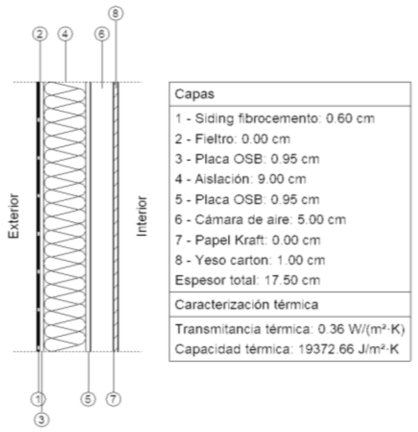


The study had two principal stages, which will be further discussed. Firstly, parametric configuration and multi-objective optimisation based on genetic algorithms, aimed to investigate the architectural design solutions that offer the best performance regarding carbon emissions and construction cost. Secondly, implementation and fabrication of a prototype.

4. PARAMETRIC CONFIGURATION

The first parameter corresponds to the location, for this study we selected only the result referencing the climatic zone of Temuco, capital of the Cautín Province and of the Araucanía Region in southern Chile. The next one refers to the orientation, simulating different values of solar radiation as the house rotates. The next four parameters refer to the variables for the walls, roof and floor considering the thickness and the material of the panel insulation. Figure 3 shows the composition of the wall envelope solution.

Figure 3:
Wall envelope solution.



Parameter 7 refers to the different types of windows, while 8 and 9 refer to the ventilation system with heat recovery and air tightness.

For each element, the cost was evaluated, by reference to prices in the market at a given time, which may be subject to change. However, it is possible to easily update parametrically the simulations to adapt them to new economic conditions.

Thus, more than 500,000 possible combinations of energy optimisation measures were configured, which is not a huge issue for optimisation, however, well above what a person can successfully investigate manually - without limiting creativity and design culture within the architectural field, which is the basis of the project.

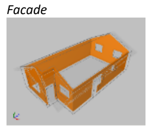
In addition to the costs of the construction and energy elements considered, the environmental impact was also included in the optimisation using a simplified life cycle analysis for 50 years, that included the CO_2 annual average conversion factor.

Figure 4 shows the values and design options used in JEPlus configurations for the case study parameters.

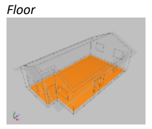
Figure 4:
Matrix of design options for the optimisation analysis.

Bio-based Thermal Insulated Panels

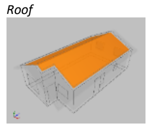
Facade



Floor



Roof



Location	**Temuco**								
Orientation	**0**	**45**	**90**	**135**	**180**	**225**	**270**	**315**	
Thickness	**44**	**58**	**76**	**99**	**129**	**172**	**236**	**343**	**556**
Material	**EPS**	**Glass wool**	**Biomaterial**						
Conductivity (W/mK)	*0.043*	*0.041*	*0.045*						
Density (kg/m3)	*15*	*11.5*	*73*						
Specific Heat (J/kgK)	*1200*	*840*	*1415*						
GWP (kgCO2eq/m³)	*2.92*	*1.58*	*-0.71*						
Type of windows	**Aluminium, double-glazed**	**PVC, double-glazed**	**PVC, low-e double-glazed**	**PVC, low-e triple-glazed**					
U-Factor (W/m²K)	*3.0*	*2.0*	*1.6*	*0.9*					
Solar Coefficient	*0.75*	*0.65*	*0.70*	*0.55*					
Cost (US$/m²)	*92*	*144*	*209*	*327*					
Heat recovery	**0%**	**60%**	**70%**	**80%**					
Cost (US$)	*500*	*1877*	*2816*	*3754*					
Airtightness (ACH50)	**1**	**0.6**							
Cost (US$)	*700*	*900*							

As shown in Figure 4, the biomaterial has a negative GWP value. Since plants acquire carbon via the process of photosynthesis, bio-based products can help lower carbon dioxide levels in the atmosphere and minimise the threat of climate change. As a result, biogenic carbon - that is carbon stored in biological materials such as plants or soil within a buildings component might be considered a "negative emission." This indicates that carbon is stored in the material during the growth stage of bio-based products.

However, if the biomass is harvested and burned this carbon is released back to the atmosphere.

For this reason, some LCA methodologies do not include carbon dioxide emissions from burning renewable materials in GWP.

In any case, the carbon accumulated or released into the atmosphere by bio-based insulation materials is just a proportion of the total carbon emitted during the life cycle of the buildings.

5. MULTI-OBJECTIVE OPTIMISATION

The sheer quantity of multi-modal objectives and parameters calls for the use of metaheuristic algorithms that are capable of optimising solutions to efficiently approximate outcomes [6]. A subset of these metaheuristic algorithms is Evolutionary Algorithms, where relationships between problems that involve multi local optima, nonlinearity, constraints, and non-convexities can be explored and exploited with each iteration [7].

Based on Darwin's articulation on the theory of evolution, EA's refer to the analogy of competition amongst a set of 'parameters' corresponding to the genes; these make up the individual. The individual's genes join to form a chromosome, which are the potential 'solutions'. The set lies within the environment as the 'optimisation problem' with a particular emphasis on approaching the true Pareto-optimal front (Table 1).

Table 1:
Analogy of evolution to optimisation problems.

Metaphor	Optimisation
Genes	Parameters
Chromosome	Solution
Fitness	Objective function
Environment	Optimisation problem
Evolution	Problem solving

This allows EA's to find various Pareto-optimal solutions in a single simulation run [8].

The population-based nature allows for modifications in a way that preserves the multi optimal solution or also referred to as the 'Pareto-optimal solutions' in multi-objective optimisations.

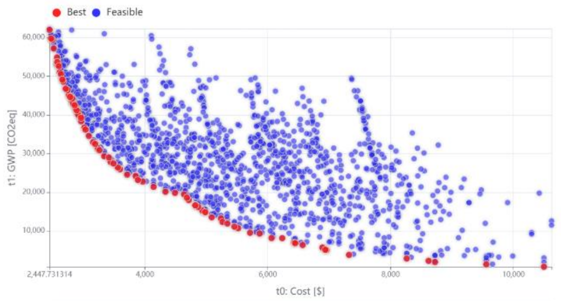
The process first starts with a population of randomly sampled solutions which are binary encoded, that then carry out a fitness-based selection utilising an objective function [9].

Recombination, cross-over, and mutation occurs creating a successor population based on the parental genetic material which thus produces the child chromosomes that get passed into the next cycle.

Upon each iteration, the optimised population is stored in the archive. Once the population evolves and the average fitness increases, the cycle ends, and terminal criterion or optimality is reached [10].

Figure 5 shows the Pareto solutions with 200 iterations and a total of only 1,471 solutions identified, carried out by the mentioned genetic optimisation, compared with the total of 559,872 possible solutions considering the combinations of the variable values included in each design option.

Figure 5:
Population and Pareto best solutions.



The characteristic curve of the best 78 results is also shown. In general, the optimal solutions obtained show improvements in GHG emissions while reducing the construction cost. This shows the usefulness of MOO in the early stages of building design. Table 2 shows the two configurations with the lower values for each objective, that are minimised simultaneously during the optimisation.

Table 2:
Comparison of the two Pareto solutions corresponding to the lowest cost and CO_2.

	Lowest Cost	Lowest CO_2
Parameters		
Location	Temuco	Temuco
Orientation	225	180
Material	Biomaterial	Biomaterial
Wall (m)	0.058	0.556
Floor (m)	0.058	0.556
Roof (m)	0.044	0.556
Type of Window	Aluminium, Double-glazed	PVC, low-e triple-glazed
Ventilation	No recovery	80% recovery
Airtightness	ACH50 = 1	ACH50: 0.6
Objectives		
Cost ($)	2,448	10,497
CO_2 (kg)	62,005	714

To exemplify, all Pareto solutions had a cost between USD $2,448 and USD $10,497 with GWP ranging 714 kg of CO_2 to 62,005 kg of CO_2.

By analysing these two cases only, it can be seen that investing four times more, compared to an optimised benchmark at a lower cost can reduce the carbon footprint 86 times over the lifetime of the building.

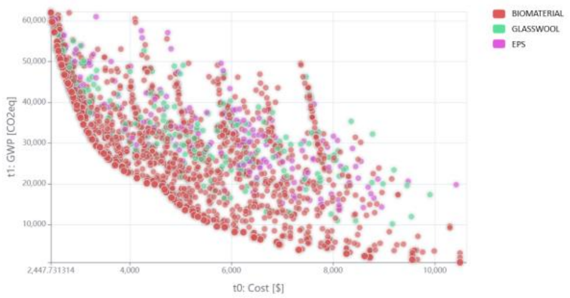
This benefit can also extend to a proportional energy and economic savings over the operational lifespan of the building. If the final disposal stage is considered, the benefit can be even greater, because of the possibility of incorporating part of these materials into a circular cycle.

For example, the type of thermal insulation material played a key role along with its thickness in the life cycle of the case study.

Figure 6 shows that all of the Pareto solutions approaching the Pareto front are indeed those that contain biomaterial as a parameter, as well as the entire population's majority of solutions.

This confirms biomaterial as a solution for this optimisation problem.

Figure 6:
Population by insulation materials.



Due to the abundance of information, decision-makers must analyse this data meticulously, selecting a set of solutions based on their general preferences according to the level of importance for each parameter.

Additionally, using the interactive characteristic of JEA it was possible to control in real time the progression of the search process and adjust the configurations and parameters of the algorithms.

These functions have made possible to improve the entire optimisation process compared to other optimisation tools that, for most users, work like a "black box" [5]. Indeed, one problem with current optimisation tools is that the user cannot do much more than wait to see whether they eventually get the desired results, so with an interactive optimisation process it is possible to avoid innocent mistakes when setting up the problem or when configuring the algorithms which can lead to significant time losses.

6. IMPLEMENTATION AND FABRICATION

Based on the analysis of the optimisation results related to the thickness of the wall element, a construction system was sought that could be easily adaptable to different thicknesses. In south-central Chile, light wood partition walls are commonly used for housing, with a wood structure of 2x3" to 2x4", so adapting this solution to 12" thickness is complex because of the availability and quality of wood of these dimensions. In this context, the Wikihouse system is a manufactured building system for houses. It uses structural timber (usually plywood) sheets which are cut to 0.1mm precision, and assembled into basic building blocks, which can be delivered to the site, then rapidly and accurately assembled by almost anyone, even if they don't have traditional construction skills [11].

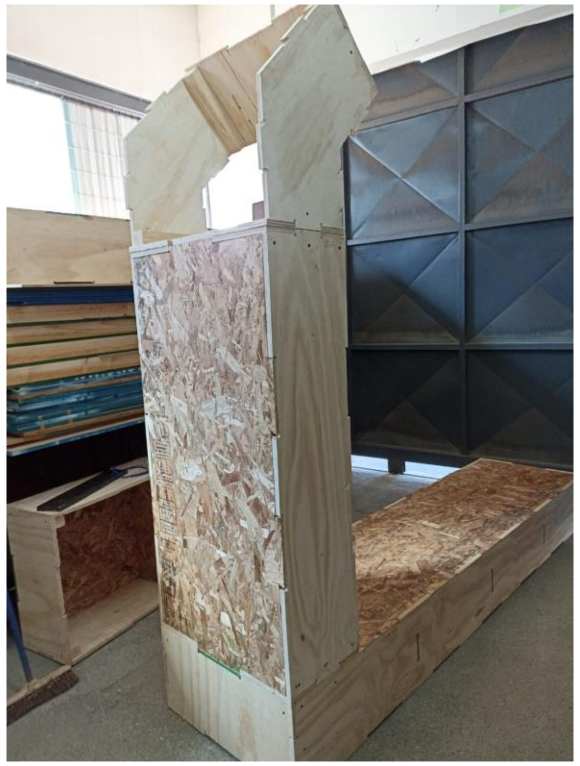
Specifically, the proposal considered the wikished system which has wall thicknesses of 8" but due to the composition of the elements it is easily extendable to 12" which was the test aim.

Thus, the first test was a section of the Wikihouse system changed to 12" floor, wall, and ceiling thicknesses. Figure 7 shows the test section. However, the system was not optimal in terms of the use of the plywood sheet and generated significant material loss because of the material complexity.

Figure 7:
First prototype based on WikiHouse building system.

A second manufacturing system was developed to optimise the use of the plywood sheet, which was also designed parametrically so that it can be easily adapted to different optimisation results in other climates or other optimisation objectives. The final system is shown in Figure 8. In this system, if a bio-based insulating material is considered, a thermal transmittance value close to 0.12 W/m^{2}K is achieved.

Figure 8:
Second prototype developed, named "casalibre".



7. CONCLUSION

The workflow used for building optimisation can be particularly useful in the early design stages of the project. Optimisation variables and objective functions can be customised and enhanced according to the project. Another important feature is the interactivity of the JEPlus Online Service, which allows users to: control the progression of the search process; adjust configuration and parameters of the algorithms; add, remove, or change optimisation criteria; refine search space and adjust design options; switch and combine simulations models and collaborate online with other users.

The interoperability between the software and the effectiveness of the optimisation algorithms allows for an expansive comparison and thorough analysis of predictive models that cannot otherwise be explored with conventional methods.

A parameterised workflow from optimisation to manufacturing is very promising and although it is a major challenge, it may be a milestone in the possibility of achieving carbon neutral massive custom homes and meeting individual's needs while improving the environmental and economic condition.

REFERENCES

[1] Lebot, B. "Global Status Report 2017," p. 48.
[2] Naji, S., Aye, L., Noguchi, M. "Multi-objective optimisations of envelope components for a prefabricated house in six climate zones," *Appl. Energy*, vol. 282, p. 116012, Jan. 2021, doi: 10.1016/j.apenergy.2020.116012.
[3] Delgarm, N., Sajadi, B., Delgarm, S. "Multi-objective optimisation of building energy performance and indoor thermal comfort: A new method using artificial bee colony (ABC)," *Energy Build.*, vol. 131, pp. 42–53, Nov. 2016, doi: 10.1016/j.enbuild.2016.09.003.
[4] Zhang, Y. (2012) "Use jEPlus as an efficient building design optimisation tool", CIBSE ASHRAE Technical Symposium, Imperial College, London UK – 18th and 19th April 2012.
[5] Zhang Y, Jankovic L, (2017), "JEA, An Interactive Optimisation Engine for Building Energy Performance Simulation", IBPSA Building Simulation 2017, August 7-9, San Francisco, USA
[6] Talbi, E.-G. (2009). Metaheuristics: From design to implementation. John Wiley & Sons.
[7] Zheng, Y.-J., Chen, S.-Y., Lin, Y., & Wang, W.-L. (2013). Bio-inspired optimisation of Sustainable Energy Systems: A Review. Mathematical Problems in Engineering, 2013, 1–12, doi:10.1155/2013/354523
[8] Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. IEEE Transactions on Evolutionary Computation, 6(2), 182–197. doi.org/10.1109/4235.996017
[9] Bandaru, S., & Deb, K. (2013). A parameterless-niching-assisted bi-objective approach to multimodal optimisation. 2013 IEEE Congress on Evolutionary Computation. doi.org/10.1109/cec.2013.6557558
[10] McCall, J. (2005). Genetic algorithms for modelling and Optimisation. Journal of Computational and Applied Mathematics, 184(1), 205–222. https://doi.org/10.1016/j.cam.2004.07.034
[11] Open Systems Lab (March 25, 2021). What is Wikihouse. Wikihouse frequently answers and questions. Retrieved on March 25, 2021 from https://www.wikihouse.cc/faq

PLEA SANTIAGO 2022

Will City Survive?

Life cycle analysis of typical buildings in Chile

From materials production to building construction and demolition

KATHERIN FRÍAS-PASTÉN[1] PAMELA HERRERA-LEÓN[1] MASSIMO PALME[2]

[1] Universidad Católica del Norte, Departamento de Ingeniería Ambiental
[2] Universidad Técnica Federico Santa María, Departamento de Arquitectura

ABSTRACT: Construction sector has high impacts on the environment, in terms of energy consumption, water use, and emissions to the atmosphere of CO2 and other greenhouse gases. Life-Cycle Analysis is an international recognized method to assess the environmental impact of complex objects, such as buildings. In this work, we use information from national and international databases to develop a methodology to quantify the environmental impact of construction in Chile. We considered two locations in different climatic emplacements and four building typologies. The results show that steel and reinforced concrete generate a greater impact compared to the other materials analyzed. However, some strategies to reduce, reuse, recover and recycle the materials, in particular steel, can be adopted to reduce the environmental impact of those building typologies.

KEYWORDS: Life Cycle Analysis, Chile, Construction Industry, Steel, Wood, reinforced concrete, Material

1. INTRODUCTION

Sustainable Development Goals (SGD) [1] consider the importance of green and circular economy to shift our society to sustainable levels and reduce the impact of climate change (SGD 8 and 13).

Building sector is one of the most important economic activities to be regulated. Cities are directly or indirectly responsible of about the 70% of energy use and greenhouse gases emissions to the atmosphere.

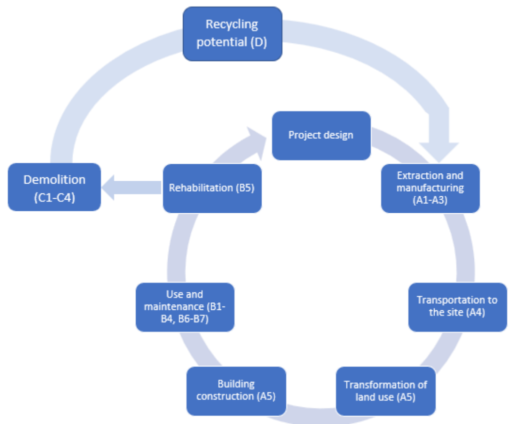
In Chile, construction industry is one of the most important sectors contributing to national GDP, after mining industry and comparable with agriculture activities.

Life cycle analysis (LCA) is a methodology to account environmental costs of any kind of object production, including complex structures like buildings [2]. Typically, LCA consider three phases in the life of an object: production, use and destruction/recover. The three "R" (reuse, recover and recycle) are key factors in developing circular strategies to reduce the emission footprint of human activity.

In the case of buildings, the production phase should be further divided in materials production and building construction/assembly [3]. Figure 1 shows the different phases of the LCA assessment from raw materials extraction to building demolition. A very complete ecological and energetical analysis should also account for raw materials formation (EMERGY – Energy Memory Analysis) [4]. In Chile, among most used materials we find reinforced concrete, bricks, wood, and steel; combined in different structural systems depending on the building size. Materials and prefabricated structures should then be translated to the location where the building is assembled, increasing in many cases the ecological footprint.

In this work, a methodology to integrate materials production and transportation is developed for four typical buildings: two small houses of wood and steel/plasterboard respectively, a medium sized building of bricks and a tall building of reinforced concrete.

Figure 1:
Phases of LCA for building sector



2. METODOLOGY

In this work we develop a methodology to account for energy consumption, water usage, and greenhouse gases emissions due to buildings construction, operation, and demolition. We divided the methodology in four steps. We started evaluating the materials production, constructing a database for Chile incorporating information about the most common materials used in construction.

Once constructed a complete database with all materials to be used in our buildings, we established the quantities of each component needed in the construction. For this, we analyzed four typical buildings, and quantified the volume or the number of elements used.

The four buildings analyzed are representative of the common houses used in Chile: a tall building of apartments, a medium sized block of apartments (5 storeys), a single-family house built on wood and a single-family house built on steel frames and plasterboards. To compare the LCA results, we consider occupancies of 648, 50, 6 and 4 people respectively.

Buildings were placed in two different cities, Antofagasta and Temuco. Climatic regulations [5] were followed to establish values of thermal transmittances and select the appropriate material for the envelop. Thus, block work tall building and steel framed house were analyzed in Antofagasta, while brick and wood buildings were analyzed in Temuco. Figure 2 shows the climate-habitational zones of the north and central-south regions of Chile where Antofagasta and Temuco are placed. Table 1 resumes the transmittance values for walls, roofs, and windows in both locations.

Figure 2:
Climate zones for habitational analysis in Chile

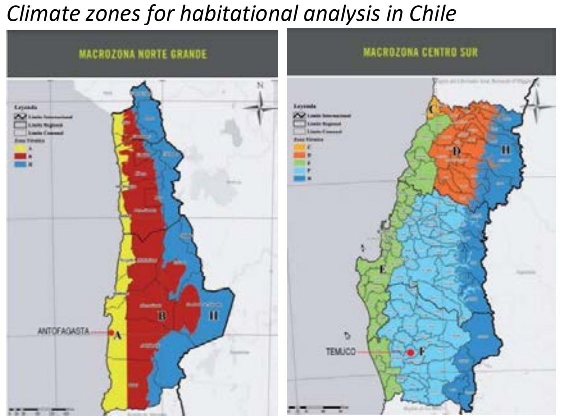


Table 1:
Transmittances values for considered locations (W/m²K)

Location	*Walls*	*Roofs*	*Windows*
Antofagasta	4.0	0.84	5.8
Temuco	1.6	0.33	3.6

2.1 Material production

First step in assessing LCA is to obtain production data for the most important parts that composes the building typologies. In Chile, recently some data have been done available through the database "Ecobase" [6], which incorporates CO2 eq emissions, energy consumption and water consumption. Unfortunately, many materials and structures are missing in this database, so we also referred to international databases "BEDEC" [7] and "DAPcons" [8]. In some cases, we referred directly to the environmental impact declarations provided by suppliers [9,10,11,12]. Once the data was obtained, it was incorporated into the amount of material needed to build the buildings.

Figure 3:
Databases consulted in this study

	PARAMETER	MATERIAL	Reinforced concrete	Cement mortar	Bricks	Plaster Board	Steel bars	Steel profiles	Laminated steel	Wood board	Structural wood	Rock Woole	Windows
ECOBASE	Water consumption	m3	✓	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗
	Energy consumption	MJ	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
	Emissions	Kg CO2 eq	✓	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗
BEDEC	Water consumption	m3	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
	Energy consumption	MJ	✓	✓	✓	✓	✗	✗	✓	✗	✓	✓	✗
	Emissions	Kg CO2 eq	✓	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓
DAPCON	Water consumption	m3	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✓
	Energy consumption	MJ	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✓
	Emissions	Kg CO2 eq	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✓

2.2 Transportation of materials, excavation and construction

Obtained the data in the materials production phase, we developed a strategy to consider the water, energy and emissions related to the assembly of materials in buildings. In this phase, the emissions to the atmosphere and the energy consumed by the transport of materials, excavation of foundations and operation of the tower crane were calculated. For transportation, the distance from the closest material production center to the location of the building was considered, considering a standard 23-ton truck with a power of 415.27 HP and a fixed road speed of 100 km/h. [13]. Two excavators were used for the excavation, one with a power of 149 kW and the other with a power of 73 kW. For the construction, a tower crane with power corresponding to 75.6 MKH was considered. The formulas used to calculate energy consumption and emissions into the atmosphere were as follows:

Figure 4:
Energy consumption and emissions of machinery

$E = P * t$	$Emission = E * D$
E: energy consumption of machinery	**Emission:** CO2 eq emissions
Q: electrical power of machinery	**E:** energy consumption of machinery
t: activity duration time	**D:** 74,100 (kg CO2/TJ)
Eq.1	Eq.2

2.3 Buildings operation

Buildings were considered to have a lifetime of 80 years. During this period, people will use the building as residential, with climate systems providing comfort established as a range 18-26 degrees Celsius, a standard charge of electricity due to lightening and use of other domestic appliances. Water consumption was set to 150 l/person every day. Thermal demand was obtained by simulation using TRNSYS v. 17 tools. Weather files were obtained from the website climate.onebuilding.org, a standard reference for this kind of purposes [14].

Final energy consumption was assessed by considering fixed values of efficiency for a standard heating (boiler) and cooling (heat pump) systems. Emissions were obtained by applying transformation coefficients depending on the fuel. In the case of electricity, two transformation coefficients were used, respectively belonging to the old SIC (Sistema Interconectado Central) and the old SING (Sistema Interconectado del Norte Grande). Today both systems were unified in the Sistema Eléctrico Nacional (SEN), however it seems reasonable still differentiate the emissions coefficients to reflect the different share of renewable (including hydroelectricity) and fossil fuels of different regions of Chile [15].

Table 2:
Efficiency and transformation coefficients of fuels

Fuel	Efficency	Carbon generation Temuco	Carbon generation Antofagasta
		kg CO_2/GJ	kg CO_2/GJ
GPL	0,85	12.684,44	63
Wood	0,70	3.805,33	109
Electricity	3,50	1.123,59	278

Window to wall ratio depended on structural system used. For wooden and steel framed houses, we used a 20% value. For bricks buildings, 30% and for cement blockwork buildings, 80%. This kind of constructive systems are very common in Chile, with a strange repetition across climates.

Table 3:
Windows to wall ratio

Wood	Steel	Reinforced Concrete	Bricks
20%	20%	80%	30%

Operational parameters considered in simulations include: light gains, other appliances, heating and cooling set points, people and solar protection.

Table 4:
Operational parameters used in simulation

Description	Schedule or control	Value
Light gains	18-22 h	5 W/m^2
Other gains	Variable	45 W/m^2
Cooling set point	0-24 h	26 °C
Heating set point	6-23 h	18 °C
Heating set point	23-6 h	15 °C
People activity	0-24 h	1 mt
Solar shading open	120 W/m^2	1,0
Solar shading closed	140 W/m^2	0,4

2.4 Demolition and transportation of waste

The buildings were demolished at the end of their useful life. A shear crane with a power of 234 kW was considered for the demolition of 1-2 story houses and 317 kW for high and medium-rise buildings [16].

In turn, the transport of waste from the place of generation to the authorized final disposal sites in Antofagasta and Temuco was considered. The distances were traveled with a dump truck with a power of 442.89 HP and a cargo volume equal to 27.5 m^3 [17] at a constant average speed equal to 100 km/h.

The energy consumption and carbon dioxide emissions generated by the machinery were determined using equations Ec.1 and Ec.2.

Regarding the reuse, recovery and recycling of materials, we include the possibility of doing so during the last phase of building demolition [18,19,20].

3. RESULTS

The results show that the brick and wood buildings have a lower impact on the environment compared to the reinforced concrete building and the prefabricated steel house. However, there is potential to reduce the impact of these types of buildings by incorporating "R" options, especially for prefabricated steel houses. The detailed results can be analyzed under different points of view: by phase, by materiality and by location. Following our methodology, we first discuss the results by phase. We then discuss the general context of the construction sector in Chile, further analyzing the use of materials and the corresponding climatic location.

3.1 Production phase

Production phase assessment was done measuring the water, energy, and emissions per m3 of material (or ensembled system) provided.

Table 5:
Water, energy, and emissions for materials production

Material	Water Consumption	Energy Consumption	Emmisions
	m^3/m^3	MJ/m^3	kg CO_2 eq/m^3
Reinforced Concrete	459,250	1.324,760	229,080
Bricks	0,888	3.427,912	259,099
Plasted Board	704,700	4.491,900	256,800
Wood Board	3,000	8.407,100	418,300
Rock Woole	401,500	1.612,500	107,750
Cement Mortar	487,090	4.252,191	237,980
Steel Bars	10.566,100	297.672,000	20.096,000
Steel Profiles	4,792	32.041,667	362.500
Laminated Steel	98.468,300	100.350,950	7.530,600
Structural Board	107,300	3.345,830	89,800
Windows	4,740	4.057,000	136,000

Values obtained show very clearly that, per unit volume, steel industry is the most contaminant and unsustainable. However, in the construction phase the quantity of material needed to configure the structural system will equilibrate the global evaluation.

Table 6:
Quantities of materials needed for building construction (m3)

Material [m^3]	Reinforced concrete	Steel	Bricks	Wood
Reinforced Concrete	4.196,135	11,944	138,997	0,576
Bricks	-	-	52,781	-
Plasted Board	1.263,631	6,874	11,975	-
Wood Board	15,415	0,179	0,856	4,921
Rock Woole	308,275	13,748	48,652	6,700
Cement Mortar	218,825	-	16,900	-
Steel Bars	5,345	0,015	0,177	-
Steel Profiles	27,562	2,220	1,592	-
Laminated Steel	-	0,065	-	-
Structural Board	5,385	0,214	0,135	7,983
Windows	52,356	0,443	1,945	0,199

The total impact of the first stage of the life cycle of each building was obtained from the sum of the parameters associated with each material, classifying the final results by dwelling.

Table 7:
Data inventory for material manufacturing stage

Vivienda	Water Consumption	Energy Consumption	Emmisions
	m^3	MJ	kg CO_2 eq
Reinforced Concrete	2.219.762,909	9.851.650,998	1.179.772,387
Bricks	101.990,400	688.419,726	62.625,906
Steel	22.446,351	155.070,025	8.879,864
Wood	3.826,749	80.455,615	3.656,264

3.2 Construction phase

The construction phase considered the excavations of the building's foundations, transport of the material to the site and everything related to the assembly of the buildings. The work of people was not considered, only machinery. Tables 8, 9 and 10 summarize the consumption for the three activities.

Table 8:
Water, energy, and emissions for building foundation

Building	Energy Consumption	Emmisions
	MJ	kg CO_2 eq
Reinforced Concrete	32.332,05	2.395,81
Bricks	13.049,54	966,97
Steel	1.050,15	77,82
Wood	1.041,74	77,19

Table 9:
Water, energy, and emissions for transport of materials to work

Building	Energy Consumption	Emmisions
	MJ	kg CO_2 eq
Reinforced Concrete	194.154,28	14.386,83
Bricks	48.784,41	3.614,93
Steel	101.917,69	7.552,10
Wood	17.469,82	1.294,51

Table 10:
Water, energy, and emissions for other assembly work

Building	Water Consumption	Energy Consumption	Emmisions
	m^3	MJ	kg CO_2 eq
Reinforced Concrete	882,99	113.400,00	8.402,94
Bricks	31,18	34.020,00	2.520,88
Steel	2,39	-	-
Wood	0,12	-	-

3.3 Operation phase

Respect to operation phase, we obtained first the energy demand for heating, cooling, hot water, illumination, and other purposes (including elevators and other common services). Then we applied the efficiency coefficients to obtain the final energy, and the conversion factors of table 2 to obtain the emissions. Table 11 resumes the values of final energy per person by building typology.

Table 11:
Final energy per person by building typology

Building	Heating	Cooling	Water	Lights	Other
Wood	3900	9	195	210	286
Steel	12	15	182	153	478
Reinforced concrete	0	25.072	205	320	112.348
Bricks	1.160	16	234	457	8.640

Most important part of operational energy consumption must be attributed to heating and other appliances in Temuco. In Antofagasta, the case of the steel framed family house and the tall building should be analysed separately. Tall building has cooling needs (due to the glazed surface) and an enormous consumption for elevators, waterpool, and other amenities of that kind of buildings. These results are in accordance with the problem of overheating of buildings and the needs for shifting from heating-guided design to cooling-guided design [21,22]. Operational amount of energy wasted is directly relate to the climate location, so results should be considered as only partially representative of the whole building sector in Chile.

3.4 Demolition phase

In demolition phase, the work done by machines to dismantle the building and the transportation of residual to the closest place adapted to that end were accounted. Tables 12 and 13 summarize the consumption for the three activities.

Table 12:
Energy and emissions for dismantle buildings

Building	Energy Consumption	Emmisions
	MJ	kg CO_2 eq
Reinforced Concrete	171.180,00	12.684,44
Bricks	51.354,00	3.805,33
Steel	15.163,20	1.123,59
Wood	30.326,40	2.247,19

Table 13:
Energy and emissions for waste transportation

Building	Energy Consumption	Emmisions
	MJ	kg CO_2 eq
Reinforced Concrete	47.424,87	3.514,18
Bricks	2.021,57	149,79
Steel	214,05	15,86
Wood	202,16	14,98

3.5 Global results discussion

Figures 5-7 show the water, energy, and emissions for each building.

Figure 5:
Water consumption per person.

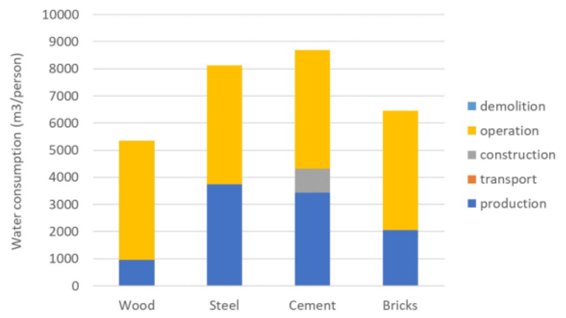


Figure 6:
Energy consumption per person.

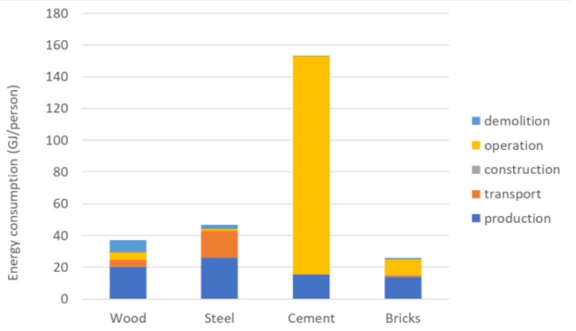
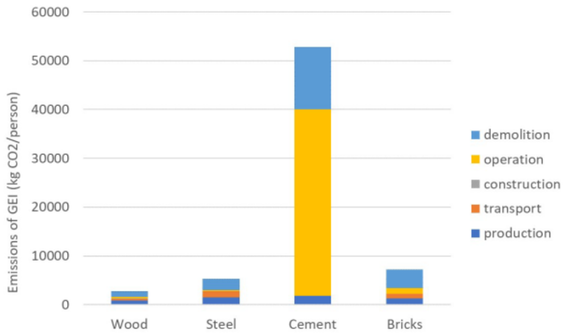


Figure 7:
Emissions consumption per person.



A deep analysis of the results permits to extract many relevant implications. Firstly, the consumption of water is higher during operation than during production and construction phases. This imply that, besides the enormous quantities of water needed by some industrial processes, as minerals extraction and refrigeration during processing of steel, the amounts of materials disposed on buildings is not so high to overpass domestic water use. People behaviour seems to be the key factor to save potable water, and the value of 150 l/day per person should be drastically reduced.

As a second observation, operational energy is relevant only for the tall building case. This indicate that the amount of energy needed for cooling and other appliances use is much higher than other energy needs, even compared to heating needs in cold locations. Of course, that the operation of tall buildings includes elevators, water-pool and other amenities that are not present in the other building typology. However, it is relevant to notice that the sprawl of that type of building across Chile indicate a change in expectation of the population, indicating the probable increase in a near future of the operational environmental costs.

A third observation is that demolition is relevant only for tall buildings, where machinery working hours are long. At the same time, the decommissioning process can offer many possible alternatives for the circular economy: The "3Rs", recover, reuse and recycle are strictly related to this last phase of the building life cycle [23,24,25,26].

The transportation of elements plays a relevant role in the case of steel-framed buildings, due to the number of different parts that are needed to assemble a house and the long distances that trucks must travel to reach its destination, generating high emissions into the atmosphere and consuming a large amount of energy.

Finally, wood and bricks seem to be more sustainable manner to built residential buildings, offering some facilities in both construction and dismantle phases. That buildings have also a lower water consumption in the production and construction phase.

4. CONCLUSION

In this work, an approximate view of the current panorama facing the construction industry in Chile was recreated. The evaluation carried out shows that, of the four construction systems analyzed, plasterboard and steel buildings, followed by reinforced concrete, have the highest environmental impact values, both located in the city of Antofagasta. Since the cities were chosen in order to cover the climatic variability of the country, it is inferred that the construction systems located in the south of Chile, corresponding to structural brick and wooden houses, have a friendlier behavior with the environment. compared to those in the north. However, this may vary depending mainly on the duration of each stage, the distances covered in the transfer of material and the technologies and machinery used.

In relation to the parameters analyzed, it is concluded that energy expenditure and emissions are directly proportional to the size of the buildings and the associated common domain assets, unlike water consumption, which clearly depends on the average consumption of the inhabitants.

Finally, incorporating recycled materials into production, or directly reusing some construction waste after its useful life is over, is extremely important to reduce the environmental impact generated by the construction industry.

ACKNOWLEDGEMENTS

This work was done as graduation thesis of K. Frías and P. Herrera in Environmental Engineering. The thesis had the financial support of the "Tesis verde" programme of the Séché Group Chile in collaboration with UCN and of the Fondecyt project 1200275 awarded by ANID.

REFERENCES

1. United Nations (2015). Sustainable Development Goals. Available on-line: https://www.undp.org/sustainabledevelopment-goals (last accessed on March 2022)

2. Simonen, K. (2014). Life Cycle Assessment. Rutledge, NY

3. American Institute of Architects (2010). Guide to Building Life Cycle Analysis in Practice. Available online: https://www.aia.org/resources/7961-building-life-cycleassessment-in-practice (last accessed on March 2022)

4. Srinivasan, R. and Moe, K. (2015). The Hierarchy of Energy in Architecture. Emergy Analysis. Rutledge, NY

5. Housing Ministry MINVU (2006). Manual de Aplicación de la Normativa Térmica. Available on-line: http://sodal.cl/media/file/53 (last accessed on March 2022)

6. Ecobase (2013). Metodología para el Desarrollo de Inventarios de Ciclo de Vida. Report of the INNOVA CORFO 13BPC3-19204 Project.

7. BEDEC (2021). Base de datos del Instituto de Tecnología de la Construcción de Cataluña. https://itec.es/servicios/bedec/

8. Gobierno de España (2021). Declaración Ambiental de Productos de la Construcción.

9. Compañia de Acero del Pacífico (2021). Declaración Ambiental de Productos.

10. Volcán. (6 de mayo de 2021). Ficha técnica Volcanita estándar. https://www.volcan.cl/productos/volcanitastradicionales/volcanita-st

11. Cerámica Santiago (2022). Catálogo de Ladrillo Santiago Estructural. Available on-line https://www.ceramicasantiago.cl/wpcontent/uploads/2020/12/FICHA_LADRILLO-SANTIAGOESTRUCTURAL.pdf (last accessed on March 2022).

12. Pizarreño Romeral (2022). Ficha técnica Placa Yeso Cartón Glypac. Available on-line: https://www.pizarrenoromeral.cl/siteassets/documentos/fichas-tecnicas/placasyesocarton.pdf?v=4a2318/Download (last accessed on March 2022)

13. Borquez, D. (2017). Cálculo del consumo de combustible y emisiones de CO2 de camiones mineros, mediante simulación discreta. Revista Ingeniería Industrial, 151-168.

14. Climate.onebuilding project (2015). Available on line: https://climate.onebuilding.org (last accessed on march 2022)

15. Chilean Government. Comisión Chilena del Cobre (2015). Informe sobre las emisiones indirectas de gases de efecto invernadero al 2015. Available on-line: https://www.cochilco.cl/Listado%20Temtico/Informe%20GEI%20Indirectas%202015%20RBA%20Final.pdf (last accessed on March 2022)

16. CAT: Catálogo de Excavadoras (2022). Available online https://www.cat.com/es_US/products/new/equipment/excavators/demolition-excavators.html (last accessed on March 2022)

17. Kauffman. Avaliable online. https://www.kaufmann.cl/documents/68916/8693bba5-a439-34fe-95f4-6f3bbbea7630 (last accessed on September 2022)

18. Burgos, D. (2010). Guía para la gestión y tratamiento de residuos y desperdicios de proyectos de construcción y demolición. Tesis para optar al título de Ingeniero en construcción, Universidad Austral de Chile.

19. Cabezas Marcillo, I. A. (2018). ¿Residuos o Recurso? Impacto de la demolición en zona consolidada. Caso Quito (Bachelor's thesis, PUCE-Quito). Available online: http://repositorio.puce.edu.ec/handle/22000/15920 (last accessed on March 2022)

20. Ramos Jara, J. D. (2017). Evaluar el potencial de reciclaje de los materiales de construcción de edificios en Chile. Repositorio Académico de la Universidad de Chile.

21. Palme, M., Inostroza, L., Salvati, A. (2018). Technomass and cooling demand in Southamerica: A superlinear relationship? Building Research and Information

22. Lomas, K. and Porrit, S. (2017). Overheating in buildings: lessons from research. Building Research and Information 45 (1), 1-18

23. Plaza Gámez, B. (2014). Estudio de la posibilidad de sustitución de hormigones tradicionales por hormigones ecológicos fabricados con conglomerados procedentes de residuos industriales y áridos reciclados (Doctoral dissertation, Universitat Politècnica de València).

24. Moreira, S. (2020). Deconstruir, no demoler: por una práctica de reutilización de materiales en la arquitectura. Plataforma Arquitectura. Available on-line: https://www.plataformaarquitectura.cl/cl/972166/deconstruir-no-demoler-por-una-practica-de-reutilizacion-demateriales-en-la-arquitectura (last accessed on March 2022)

25. Sanchez Soloaga, I., Oshiro, A., & Positieri, M. (2014). Uso del plástico reciclado en el hormigón: Una alternativa para reducir la huella ecológica. Revista de la construcción, 13(3), 19-26.

26. Rivero Camacho, C. (2020). Estudio de huellas en el ciclo de vida del edificio residencial. Tesis doctoral, Universidad de Sevilla. Depósito de Investigación Universidad de Sevilla. Available on-line: https://hdl.handle.net/11441/102354 (last accessed on March 2022)

PLEA STGO 2022

November 22 - 25, 2022

EDUCATION AND TRAINING

DAY 02
16:30 — 18:00

CHAIR
GIOVANNI VECCHIO

PAPERS
1119 / 1130 / 1619 / 1580 / 1176

28TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

Systems-Oriented Building Design (S.O.B.D.)

A new way of storytelling on the design of high-performance buildings for sustainable tomorrow

ALIAKBAR KAMARI[1]

[1] Department of Civil and Architectural Engineering, Aarhus University, Aarhus, Denmark

ABSTRACT: Successfully delivering building design objectives requires a robust systems approach to integrate knowledge from ecology, economy, society, functional, technology, processes, and site aspects within a holistic view, and let them interact with each other in order to solve the often very complex problems connected to the design of sustainable high-performance buildings. This paper presents details about Systems-oriented Building Design (S.O.B.D.), as a new way of storytelling based on systems thinking and theory embedded as the theoretical foundation through an (already) developed integrated design methodology, to carry out problem-solving in complex systems. SOBD is built to include characteristics from both soft- and hard- systems thinking views. The methodology is being developed and practiced through a teaching-based research position.
KEYWORDS: Systems Thinking, Building Design, Design Methodology, High-Performance Building, Complexity.

1. INTRODUCTION

Modern society is firmly focused on performance and efficiency. Performance is an expression of how well a building fulfills its purpose, carries out its functions, or meets the users' needs and requirements [1]. It has typically grown in association with buildings' energy efficiency, indoor environmental quality, and comfort, lighting, etc. In general, building performance provides a powerful solution for the built environment to design sustainable buildings. Today, one can define a high-performance building as a sustainable building with better environmental, economic and socio-cultural features and performance than standard practices, but which also requires aesthetical attractiveness, safety, health and comfort, and economic efficiency throughout the life cycle [2].

Moving towards developing high-performance buildings to include and deal with broader perspectives from sustainability implicates handling enormous complexity concerning many design objectives that need to be fulfilled, besides involving multiple actors and addressing many factors that influence the final design performance [3]. The major challenge for the design stakeholders in this is how to get to grips with such a level of complexity where interrelated forces play out over time in complex relation fields. Thus, crucial tasks have to be performed concerning complex design decision-makings with respect to ecology, economy, and socio-cultural aspects (known as the three traditional pillars of sustainability), as well as functional, technology, processes, and site (e.g., to be aligned with the overall sustainability categories defined in the German DGNB sustainability certification system [4]). The tasks become even more complex with emerging new building design concepts and their required standards, regulations, and needs. Rapid globalization of sustainability (as a globally desired design value [5]), twins of green and digital transformation of the built environment, and the increasing causes and demands to act responsibly add to the challenges too.

This paper presents a new perspective on *systems thinking and theory* applied to design of sustainable high-performance buildings, with the ability to perform problem-solving in complex systems. It is named (for the first time) *Systems-oriented Building Design* (SOBD). SOBD is developed to implement through an integrated design methodology with iterative design stages. The design methodology and its relevant phases were elaborated and published before in [6]. The aim of this paper, on the other hand, is to shed light on the theoretical foundation behind *systems thinking and theory,* and its key concepts and role for building design, upon the ability to integrate knowledge and joined-up thinking to go deeper to address underlying causes in the design of high-performance buildings to thoroughly shift the whole system onto a sustainable path. This paper is, therefore, composed in complementary to [6].

SOBD's scope is to involve deeper in all aspects of the design of high-performance buildings, enabling stakeholders to deal with complexity, adapt and exchange very large amounts of information to create new innovative sustainable building design solutions. Built upon the systems thinking key concepts, the methodology aims to understand the different needs of projects and involved stakeholders, and then create a new value network that synthesizes different needs and values in ways acceptable to all involved.

2. SYSTEMS THINKING AND ITS KEY CONCEPTS

We are a member of hundreds of systems, i.e., a family, a company, a community, and a society. Our own body is a complex biological system comprising many sub-systems. In addition, we are surrounded and regularly interact with larger and often more complex systems every day, such as buildings and cities we live in, human economies, ecosystem, and climate. These complex systems (i.e., climate) often behave in a greater way than the sum of their individual parts, and Systems Thinking (ST) has been emerged as the ability or skill to cope with problem-solving in such complex systems [7-10]. It is an attempt to see a "forest" as well as "trees".

ST is an approach to integration that is based on the belief that the components of a system will act differently when isolated from the system's environment or other parts of the system [11]. ST places a greater emphasis upon understanding systems in their entirety and within the environment that gives them context. Standing in contrast to *reductionist* thinking, which is based on components analysis, ST is founded on the synthesis of elements and can be referred to as *holism* (or whole [12]), which is a term known from modern philosophy [11].

Analytical reductionism is a process of reasoning where we try to understand something by removing it from its environment, decomposing it into individual parts, studying the properties of those parts, and then putting them back together so as to drive an account of the whole as some combination of these individual building blocks [11]. It is based on the assumption that the system is nothing more than some of its parts, and the system is relatively closed. In contrast, the *synthesis holism* is a process of reasoning where we try to understand something by looking at it in relation to the whole system or environment that it forms a part of its interactions with other systems and how it is shaped by those interactions in the overall context [11].

Looking more holistically to understand the 'whole' in tackling complex problems [13], ST in practice explores inter-relationships and interactions (context and connections), perspectives (each actor has their own unique perception of the situation), and boundaries (agreeing on scope, scale and what might constitute an improvement). Blockley and Godfrey [14] discuss ST related to civil engineering projects as a joined-up thinking - getting the right information (what) to the right people (who) at the right time (when) for the right purpose (why) in the right form (where) and in the right way (how).

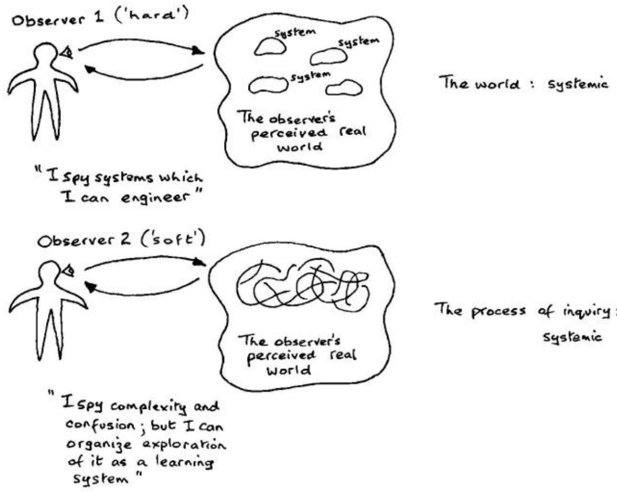
Bertalanffy [15] masterminded General Systems Theory in the 1950s, who initially sought to find a new approach to the study of living systems. Bertalanffy's ideas were adopted by others working in mathematics, psychology, biology, game theory, and social network analysis. Thus, many key concepts have emerged and are used in this context. A brief summary of these key concepts, which (in the author's opinion) are essential for the readers, are presented in the following:

- Integration: refers to the process of bringing together the component sub-systems into one system and ensuring sub-systems are together as a system.
- Emergence: refers to the existence or formation of collective behaviors — what parts of a system do together that they would not do alone. It is subdivided into weak and strong (or irreducible) emergence.
- Hierarchy & Abstraction: are used to manage and hide information and complexity among sub-systems.
- Evolution: refers to the gradual development of systems from simple to more complex forms.
- Adaptation: refers to the physical or behavioral characteristic of systems to survive better in the surrounding environment.
- Nonlinearity: is used to describe a situation with no straight-line or direct relationship between independent and dependent variables. In a nonlinear relationship, changes in the output do not change in direct proportion to changes in any of the inputs.
- Resilience: refers to how a system rapidly and effectively protects its critical capabilities from disruption caused by adverse events, conditions, and external circumstances.
- Robustness: refers to the ability of a system to remain functioning under disturbances.
- Efficiency: is the ability to avoid wasting materials, energy, efforts, money, and time in doing something or in producing the desired result. It indicates how the system uses the inputs.
- Dynamic of systems: is used to understanding the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions, and time delays.
- Causal diagrams: are a directed graph that displays causal relationships between variables in a causal model subdivided into negative and positive links.
- Causal loop diagrams: is a snapshot of all relationships that matter. It is a visual representation of key variables (i.e., factors, issues, processes) and how they are interconnected. To read and learn more, visit the "Systems Innovation" platform in [16].

2.1 Hard systems thinking vs. Soft systems thinking

Another often problematic and non-clear concept related to ST comes across discussing *hard* and *soft* systems [17]. In thinking embodied in hard-ST, the word 'system' is used simply as a label for something taken to exist in the world outside. The taken-as-given assumption is that the world can be taken to be a set of interacting systems, some of which do not work very well and can be engineered to work better. In the thinking embodied in soft-ST, the taken-as-given assumptions are quite different. The world is taken to be very complex, problematical, and mysterious. However, according to [18], the process of inquiry into it, assumed that, can itself be organized as a *learning system*. Thus, the use of the word 'system' is no longer applied to the world; it is instead applied to the *process* of our dealing with the world (see Fig. 1). This shift of systemicity (or 'systemness') from the world to the process of inquiry into the world is the crucial intellectual distinction between the two fundamental forms of ST, *hard* and *soft* (as discussed in [18]).

Figure 1:
Hard and soft systems stances (source: [18]).



For further clarification, it can be stated that:
- hard systems: involve simulations, often computers, and the techniques used in operations research (OR) [19]. Hard systems consider the "How?" meaning of best attaining and examining the selected option of expansion and analysis. Hard-ST is beneficial for problems that can justifiably be quantified [18, 20]. However, it cannot easily take into account unquantifiable factors (opinions, culture, qualities, etc.) and may treat people as inactive rather than having complex incentives. Hard systems have an explicit objective governed by fixed rules such as those encountered in decision-making [21]. While,
- soft systems: are used to tackle systems that cannot easily be quantified, particularly those involving public interacting with each other or within systems. It is useful for comprehending motivations, viewpoints, and interactions, but it does not give quantified answers [18]. Soft Systems looks at the "What?" of the system; what to do to gain an improvement, usual analyses before application?

Checkland and Holwell [20] summarize that the soft systems view moves away from an *ontological* commitment and treat the definition as a question of *epistemology*, i.e. what can we know or find out about the world? Therefore, soft-ST improves the conceptual model using the formal system model. On the other hand, hard-ST optimizes the world, using the defined performance criterion, and selects the alternative that best meets the need and is feasible.

3. SYSTEMS THINKING (ST) IN DESIGN DISCIPLINE

ST in design has been being explored and developed in the work of Birger Sevaldson and colleagues [22-23], at Oslo School of Architecture and Design in Norway, in the last two decades. The approach has been named Systems-oriented Design (SOD), and its main intention is set to develop design priority skills, techniques, and methods for ST and systems practice in design.

SOD has been influenced by modern ST and generative diagramming [23]. In an eclectic way, SOD strives to transform the different theories' thoughts to fit the design process. The approach is being built to develop practices for addressing increased *complexity* in design, e.g., due to globalization, the need for sustainability, and the introduction of new technology and increased use of automation. SOD's specific influence is soft-ST, acknowledging conflicting worldviews and people's purposeful actions [24], and a systems view on creativity. Its intention is primarily to deal with the challenges that designers meet today in the form of wicked problems [25-26].

In summary, SOD is a new version of ST and systems practice tailored by and for designers. It draws from designerly ways [27] of dealing with super-complexity derived from supreme existing design practices as well as refers to established perspectives in modern ST, especially soft-ST [17], critical-ST [28], and systems architecting. Furthermore, it is based on design skills like visual thinking and visualization in processes and for communication purposes. For this purpose, multiple techniques have been developed and currently been applied, such as GIGA-mapping, ZIP-Analysis, Rich Design Space, Incubation Techniques or War rooms, and Layered Scenario Mapping [22-23].

4. SYSTEMS ORIENTED BUILDING DESIGN (SOBD)

To determine whether a building design performs well or not, a goal or aim is needed. Performance design criteria [29] are used to set goals for often measurable (e.g., energy consumption, thermal comfort, environmental impacts, etc.), and non-measurable (e.g., aesthetics, health and wellbeing, safety, etc.) performance level. This will help both architects and engineers in the design process make decisions with contractors and owners, which ultimately leads to improved final quality throughout more informed design decisions [30].

PLEA STGO 2022
WILL CITIES SURVIVE? EDUCATION AND TRAINING

Building design solutions can emerge from replacing poor solutions with rich or more effective ones following the patterns in the design process. Design processes fulfill solutions that satisfy a given set of design constraints and criteria, often evolving from abstract to measurable indicators. Even a design solution far from being perfect could be accepted when the design intentions are met. In this view, the design solution is improved if a) more attention and time is spent, b) more choices/solutions are considered and evaluated thoroughly, and c) positive and negative synergies of the decisions are explored cautiously. This adaptive-evolving character identifies concepts and solutions then transforms them progressively towards meeting the project goals, using the design criteria. This emphasizes the heuristic and circular nature of the design process, which needs to regularly re-characterize the initial design intentions to meet the project requirements. Finally, this process involves many actors and decision-makers who influence the final design.

The discussion above is based on the understanding that given a building project, there are both many actors involved and many factors that influence the final design. As an outcome, there is not appeared to be one best/optimal solution to high-performance building design problems, but a broad set of possible solutions, which depends on actual circumstances (e.g., cultural or geographical), should carefully be considered and assessed by the design team from multiple perspectives. It hints to the fact that finding a solution for a carefully defined and structured design problem is not a linear/straight process. Instead, the designer team should develop possible design solutions relevant to its environment, being only partly able to evaluate the consequences of their preferences to the final design. It requires continually identifying, developing, optioneering, and adapting optimal solutions while synthesizing the aims, design criteria [29], and target values [5].

This overarching approach can be found in critical-ST [28], which aims to combine STs and participatory methods to look at the whole (i.e., socio-economic and environmental impacts) and address the challenges of problems characterized by large scale, complexity, uncertainty, impermanence, and imperfection, through using adaptive-evolutionary-integrated-and-dynamic processes. This unfolds and codifies causal relationships between context, design, and performance variables [6] in a causal model, exploring positive and negative synergies of the decision and demonstrating the design causal loops. That also includes systematically defined design phases consisting of iterative cycles to deal with often non-linear performance characteristics of design criteria in relation to the building components for the entirety of their life cycle, ultimately contributing to more robust decision-makings and emerging most optimal and resilient final design solutions/strategies.

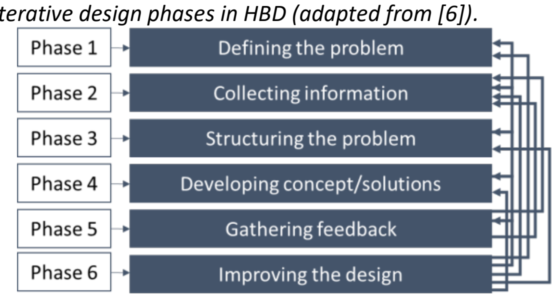
Walking in this worldview, to include both soft-ST and hard-ST characteristics, buildings are not considered as a one-off, independent entities made up of separate building systems that are isolated from their surroundings-but instead as part of a holistic system (on macro and micro-level), an interdependent living part of the environment into which it is placed and belongs. In light of this, soft-ST improves the conceptual model using the formal system model. On the other hand, hard-ST optimizes the design, using the defined performance criterion and select the alternative, which best meets the need and is feasible. Similar ideas are found in learning theories developed from same fundamental concepts in ST realm, emphasizing how understanding results from knowing concepts both in *part* and as a *whole,* referred also as *bottom-up* vs. *top-down* characters. The outcome leads to examining the complexity and simplify it; recognize patterns, and create effective solutions. The goal is for all the sub-systems to work harmoniously, effectively, and synergistically, where each system is made stronger and not compromised by the presence of the others [31].

5. SOBD IN PRACTICE

As mentioned earlier, SOBD concept and its capability to deal with complexity in building design comes to life when implemented in an integrated design methodology, named Holistic Building Design (HBD), and it has been published before in [6]. HBD is described as a collaborative approach for designing buildings that focus on developing sustainable high-performance buildings. The methodology is being researched and conceptualized by the author and empirically practiced on the design of high-rise buildings, with students from multiple specializations (i.e., tectonic design, construction management, structural engineering, ventilation, energy and indoor climate, and geotechnical engineering), in the master's level course, Integrated Engineering Project, at Aarhus University, Denmark, since 2017.

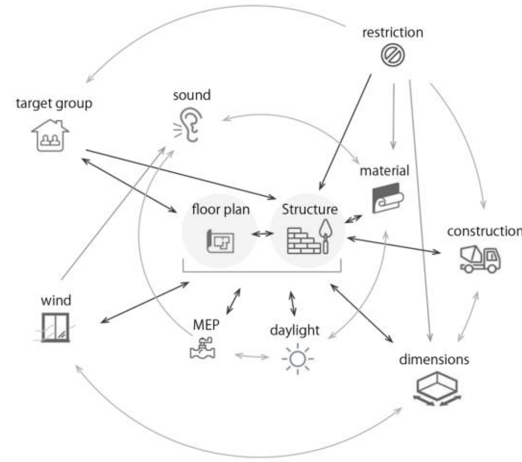
The main elements of HBD are Integrated Design Process (IDP), Building Information Modeling (BIM), and Sustainability. The whole approach is built on top of ST to capture and face the complexity. In this framework, HBD strives to be holistic in that it involves multiple stakeholders (i.e., architect, engineers, contractors, and clients) from multiple specializations and backgrounds, and from the earliest design phases, each having input into what goes into making the decisions that will lead to the project ending (refers to the potential use of IDP). HBD's effort is to consider every stakeholders' demands and priorities so as to fulfilling the design objectives and criteria. It makes sure these decisions are made with all the information shared at one time, and not in the more conventional linear way, in which each stakeholder maintains and controls its data and information (refers to the potential use of BIM). HBD simplifies and streamlines working relations and decision-making while dealing with the complexity incorporating ST's skills and awareness. This removes the traditional constraints and restrictions to a successful outcome (refers to the design of sustainable high-performance buildings) for all involved parties. To do so, the author has developed a version of ST (refer to the SOBD in this paper), which in contrary to SOD (as described in section 3), is related to combined soft-ST and hard-ST, where proprietary design concepts and simultaneous systems approaches are implemented through six phases (see Fig. 2), and occurs as follows:

Figure 2:
Iterative design phases in HBD (adapted from [6]).



- In phase 1, where the design problem is being defined as broad or holistic as possible through the lenses of product, people, process, policy, and technology [32]. Questions answered: What are you doing? How are you doing it? What are you trying to achieve? Who should you involve? What technology do you need to use, and why? What data do you need to collect? Likewise, questions used to expand the view on the design are: What are the trends? Where are they going? What will be the future price we pay? How do we want the future to play out?
- In phase 3, when the design problem is structured by selecting and identifying the interconnections and interactions between the context, performance, and design variables [6]. Decisions are made about flows having consequences that impact upstream and downstream and are visualized (i.e., see Fig. 3). Rich pictures and PQR methods from [18] are proposed.
- In phase 4, when the design stakeholders reach a point in the design process where design variables are being synthesized with context variables to meet performance variables for improving sustainability objectives and high-performance criteria. Likewise, the various elements used in the project should be optimized, and detailed calculation models document the building performance. This is done within a two-stage (a) optioneering – (b) synthesizing process. Questions answered: How do conditions arise and change? What are the critical conditions? What is the rate of change? What may bring a better change? Rich Design Research Space [33] and Gigamapping [34] are proposed.

Figure 3:
Typical exploration and representation of inter-connections and so causal-diagram among design variables.



- In phase 5, when the concepts are presented, and design team begins to answer the following questions in order to see if the feedback loops are operating in the process. Questions answered: Do we have the same picture of the issue or strategy? If not, how do we get it? Is it clear and unambiguous? Is it rigorous?
- In phase 6, when the design team has to continuously present, test, and improve the whole picture until there is nothing left to improve. The team knows they have done it well if their mental model of the solutions is as simple as possible. Questions answered: How do we build confidence in the theory? How do we keep it as simple as possible, but not simpler? Is the model too complex? Could we remove some of that complexity?
- In phases 1-6, when the design team is guided into an integrated, iterative, adaptive, and evolutionary-oriented and featured design process.

In the case of soft-ST, when the design problem is not clear, the methodology consists of additional stages, which uses system analysis to orchestrate debate about change via proposed questions. These additional stages reflect the main characteristic of the human activity system and are embedded throughout the main body of the methodology. However, the human activity can never be described in a single account, which will be either generally acceptable or sufficient in the case of hard-ST. Here, soft-ST treats the problem as ill-defined or not easily quantified (occurs mainly in early phases, while defining and structuring the problem), and hard-ST assume that the problems associated with such systems are well-defined, have optimum solutions, and that technical factors will tend to predominate (occurs mostly in middle/late design phases, where the design concepts/solutions are proposed, conceptualized, developed, simulated, and assessed). As a result, soft-ST improves the conceptual design model using the formal system model, and hard-ST optimizes the design, using the defined performance criteria [29], and selects the alternative that best meets the need and is feasible. In other words, soft-ST lead to implement the agreed system, and hard-ST implement the designed system. This simultaneous *top-down* and *bottom-up* character, besides the integrated, iterative, and adaptive-oriented process in the actual design practice, ensures working with both the measurable (or hard nature [35]) and non-measurable (or soft nature [35]) design criteria.

6. CONCLUSION

This paper presented details about SOBD, a new way of storytelling based on *systems thinking* and *theory* embedded as the theoretical foundation through an already developed integrated design methodology in [6], to carry out problem-solving in complex systems. SOBD is being developed through a teaching-based research position. That is based on and positioned in the pedagogy of inquiry (similar to [20]). There are many feasible perspectives yet to be explored. The methodology as a R&D project will be moving through other stages where experiences will be considered more systematically while the concept is developed further. Emerging patterns of use and application will be elaborated on and reported.

REFERENCES

1. Bortolini, R., & Forcada, N. (2018). Facility managers' perception on building performance assessment, *Frontiers of Engineering Management*, 5(3): p. 324-333
2. Ren, J. (2013). High-Performance Building Design and Decision-Making Support for Architects in the Early Design Phases (Doctoral dissertation, KTH, Sweden).
3. Kamari, A., Jensen, S. R., Corrao, R., & Kirkegaard, P. H. (2019). A Holistic Multi-methodology for Sustainable Renovation. *International Journal of Strategic Property Management*, 23: p. 50-64.
4. German Green Building Council (2021). Overview of the criteria. Available: https://www.dgnb-system.de/en/
5. Biskjaer, M. M., Kamari, A., Jensen, S. R., & Kirkegaard, P. H. (2019). Exploring Blind Spots in Collaborative Value Creation in Building Design: A Creativity Perspective. *CoDesign*, DOI: 10.1080/15710882.2019.1654521
6. Kamari, A., & Kirkegaard, P. H. (2020). Holistic Building Design: An integrated building design methodology based on systems thinking for reaching sustainability. In *eCAADe 2020 conference*, Berlin, Germany.
7. Checkland, P. (1981). *Systems Thinking, Systems Practice*. Chichster: John Wiley & Sons.
8. Stroh, P. D., (2000). Leveraging Change: The Power of Systems Thinking in Action. *Reflections*, 2(2): p. 13-26.
9. Mingers, J. (2014). *Systems Thinking, Critical Realism and Philosophy: AConfluence of Ideas*. London: Taylor & Francis.
10. Sanko, J. S., Gattamorta, K., Young, J., Durham, C. F., Sherwood, G., & Dolansky, M. (2021). A multisite study demonstrates positive impacts to systems thinking using a table-top simulatio experience. *NurseEduc*, 46(1): p. 29-33.
11. Weinberg, G. M. (2001). *An Introduction to General Systems Thinking*. New York: Dorset House.
12. Jackson, M. C. (2003). *Systems Thinking: Creative Holism for Managers*. Chichester: John Wiley & Sons.
13. Learning for Sustainability (2020). Systems thinking. Available: link
14. Blockley, D., & Godfrey, P. (2017). Systems thinking for infrastructure professionals. Available: link
15. Bertalanffy, L. von (1968). *General System Theory: Foundtions, Developmet, Applications*. NY: George Braziller.
16. Systems Innovation, [Online], Available: https://www.youtube.com/c/ComplexityLearningLab/about
17. Checkland, P., and J. Scholes, (1990). *Soft Systems Methodology in Action*. Chichster: John Wiley & Sons.
18. Checkland, P. (2004). *Soft Systems Methodology: A 30 Year Retrospective*. Chichester: John Wiley & Sons.
19. Churchman, C.W., Ackoff, R.L., & Arnoff, E. L. (1957). *Introduction to Operations Research*. NY: Wiley & Sons.
20. Checkland, P., & Holwell, S. (2004). "Classic" OR and "soft" OR – an asymmetric complementarity. In M. Pidd (Ed.), *Systems Modelling: Theory and Practice*. Wiley.
21. Pidd, M., (2004). *Systems modelling: theory and practice*. Chichester: John Wiley & Sons, Ltd.
22. Sevaldson, B., Hensel, M., & Frostell, B. (2010). Systems-oriented Design and Sustainability. In *Sustainability in Design: NOW!*, p. 465–474.
23. Sevaldson, B. (2013). Systems Oriented Design: The emergence and development of a designerly approach to address complexity. In 2nd International Conference for Design Education Researchers, Oslo, p. 1-22.
24. Checkland, P., & Polter, J. (2006). *Learning For Action: A Short Definitive Account of Soft Systems Methodology, and its use Practitioners, Teachers and Students*. Wiley.
25. Churchman, C. (1967). Wicked Problems. *Management Science*, 14(4): p. 141-146.
26. Rittel, H.W.J., & Webber, M. M. (1973). Dilemmas in a General Theory of Planing. *Policy Sciences*, 4(1): p. 155–169.
27. Cross, N. (2001). Designerly Ways of Knowing: Design disc. versus design science. *Design Issues*, 17(3): p. 49-55.
28. Flood, R.L., & Romm, N.R.A. (1996). *Critical systems thinking: current research and practice*. NY: Plenum Press.
29. Attia, S., Hensen, J.L., Beltrán, L., & De Herde, A. (2012). Selection criteria for building performance simulation tools: contrasting architects' and engineers' needs. *Journal of Building Simulation*, 5(3): p. 155-169.
30. Christiansen, M., & Kamari, A. (2022). Integrated Informed Design Processes: A mapping of building performance criteria in the Danish conventional design practice. In *ICSA 2022*, Aalborg, Denmark.
31. Deutsch, R. (2011). *BIM and Integrated Design*. Wiley.
32. Kamari, A., & Kirkegaard, P. H. (2019). Potential shift of Integrated Design (ID) through BIM in Sustainable Building Renovation. In *SBE 2019 conference*, Cardiff, UK.
33. Sevaldson, B. (2008). Rich Design Research Space. FormAkademisk - forskningstidsskrift for design og designdidaktikk, 1(1).
34. Sevaldson, B. (2018). Visualizing Complex Design: The Evolution of Gigamaps. In *Systemic Design, Translational Systems Sciences*, Springer Japan, part of Nature 2018.
35. Kamari, A., Corrao, R., Petersen, S., & Kirkegaard, P. H. (2017). Sustainable Retrofitting Framework: Introducing three levels of Integrated Design Process Implementation and Evaluation. In *PLEA 2017 conference*, Edinburgh, UK.

PLEA STGO 2022
WILL CITIES SURVIVE? EDUCATION AND TRAINING

PLEA SANTIAGO 2022
Will Cities Survive?

The power of individual choices

The research on sustainable initiatives and environmental activism analysed in the building context

BARBARA WIDERA [1]

[1] Wrocław University of Science and Technology, Faculty of Architecture, Wrocław, Poland

ABSTRACT: This paper presents results of research conducted in 2021 and aimed at better understanding of the significance of individual sustainable initiatives and environmental activism. Qualitative and quantitative analysis was based on the results of 104 interviews followed by survey with the same participants. This allowed us for the identification of the most popular environmental actions and the assessment of their influence on energy savings and reduced CO_2 emissions computed for individual households. The author examined the correlation between the ease and replicability of particular decisions and their measurable environmental impact. It was determined that the replacement of the major households appliances with the ones with the highest Energy Efficiency Index was the most popular decision (97%), resulting with energy savings of 126.2 MWh/y and avoided emissions of 36.6 ton CO_2/y. The highest annual energy savings (172.64 MWh/y) and avoided emissions (42 tons CO_2) were achieved in the households whose users decided to change their everyday means of transportation from car to bicycle or walking, and switched to renewable energy sources and natural ventilation while eliminating the use of air conditioning systems. The results were compared to the annual savings achieved in the reference LEED certified building occupied by 100 users. This comparison proved that individual decisions brought significantly higher savings with no extra costs.

KEYWORDS: energy efficiency, CO_2 emissions, climate resilience, environment, citizen engagement

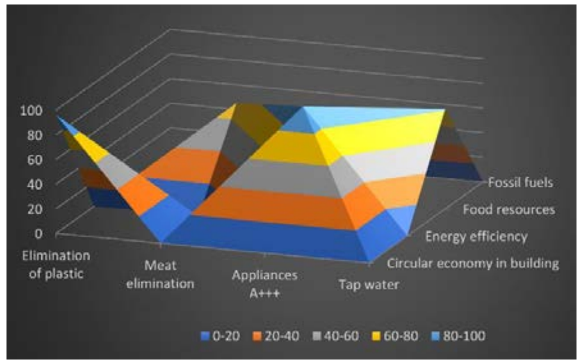
1. INTRODUCTION

The choices we make today shape the world of the future. No matter how often this sentence might be repeated, the significance of individual environmental decisions constantly remains underestimated. Considering the pace of climate change it is absolutely crucial to intensify the efforts towards transition to sustainable living. Although the pandemic crisis diverted our attention from the climate problems, making us more focused on health issues, it turned out that for some individuals and for certain social groups, the problems of resilience and subsistence of humanity are critical and more deeply perceived.

The environmental activism is gaining more and more popularity, especially among young people. This research was inspired by persons like Severn Cullis-Suzuki famous for her statement during The Earth Summit in Rio de Janeiro (1992) "If you don't know how to fix it, please stop breaking it!" or Greta Thunberg who does not hesitate to criticise world leaders for the lack of sufficient climate action, but also by dozens of anonymous people who understood that if humanity is to survive, we need to live in a responsible way.

The identified research gap addressed the significance of personal choices and decisions, taking into account their popularity and ease of implementation (**Figure 1**) as well as the real environmental effects of the actions taken.

Figure 1:
The comparison of significance and popularity of individual environmental choices [%].



2. AIM AND METHODS

The aim of this paper is to present the results of research on the individual sustainable initiatives and environmental activism analysed in the building context. The study was conducted in 2021 and applied methods of interviews, survey and qualitative and quantitative analysis. The interviews (on-line and/or in person) were carried out with 104 persons. This was completed by the short survey with the same participants. Based on the achieved results, the most popular environmental actions were identified and their significance in terms of energy savings and reduced GHG emissions was assessed. In the next step, out of 31 various forms of environmental activism declared during the first stage of research, 10 most popular conservation habits were selected for further analysis. For each activity the detailed calculations of environmental impacts, both positive and negative, were carried out. The outcomes were computed for individual households represented by the survey participants.

The interviews consisted of 6 open questions and were conducted with 104 persons living in 12 countries. Residents of the following states contributed to this research: Denmark (20%), United Kingdom (18%), Germany (16%), Poland (14%), Spain (8%), Italy (8%), France (4%), Austria (2%), Czech Republic (4%), Brazil (4%), Columbia (1%), and USA (1%). The first 46 participant were selected by the author, based on personal knowledge of sustainable initiatives undertaken by invited persons. Other respondents were indicated by the individuals already interviewed, also based on their personal knowledge. An astonishing observation was that over 80% of invited persons, although most of them very busy with their professional activities, agreed to participate in the interview. Additionally, over 50% of participants proposed at least one person to be interviewed due to the similar activities undertaken. This suggests that individuals with pro-environmental attitudes are community oriented.

The questions asked during the interview addressed the individual sustainable initiatives and environmental activism. This part was designed to collect the information of the existing initiatives and understand the motivation behind them. The following questions were asked:

1. What are your environmental / sustainable choices / initiatives? Please list up to 5.
2. Do you believe your choices / initiatives have rather temporary or constant character? If possible, please indicate the timeline.
3. What was the main rationale behind undertaking the aforementioned decisions?
4. Do you think that your individual choices have an influence on your household (the consumption of energy, water and other resources, recycling, reduced amount of waste and other elements of circular economy, etc.)?
5. Do you observe the influence of your personal choices / sustainable initiatives on your friends / family / people you know? Could you provide any examples / numbers?
6. Do you believe you contribute to the overall planet health and resilience? Have you ever tried to evaluate / calculate your environmental impact? Could you provide some examples?

The survey that followed the interview consisted of 10 questions with multiple choice answers. This part of research was aimed at better understanding of the effects of individual sustainable choices and initiatives on the society, and the models applied in the households, in buildings and 'green neighbourhoods' scale.

The results of the survey were analysed in terms of their technological, societal and economic potential. The first round of calculations addressed the embodied energy and environmental emissions using LCA method (Dettore, 2009), (Brunzell and Renström, 2020), (Tsang, Sonnemann, and Bassani, 2016). The second step involved the comparative analysis of energy savings [MWh/y] and reduced GHG Emissions [kg CO_2/y]. The applicability of particular approaches was evaluated and the number of followers was checked. In the last step, the achieved impact indicators resulting from individual decisions undertaken by the survey participants were compared to the average impacts computed for the reference unit model, established on the basis of data collected from ten LEED certified facilities occupied by similar groups of users (about 100 persons per facility).

3. RESULTS AND DISCUSSION

3.1 Predominant individual environmental initiatives identified through research

The following 10 environmental initiatives were identified as the most popular in the building scale:

1. Replacement of all the major appliances in the households with the ones with the highest Energy Efficiency Index (59 ≤ EEI < 68 replaced with EEI ≤ 46), declared by 97% of respondents;
2. Elimination of all the disposable plastics from households, 96%;
3. Drinking tap water (instead of bottled), 81%;
4. Meat elimination from the diet, 70%;
5. Replacing AC with natural ventilation, 66%;
6. Transition from car to bicycle for short travels, 59%;
7. Laundry limited to 1 cycle/week, 33%;
8. Decision not to fly (mid-distance travels), 28%;
9. Using renewable energy from PV roof panels instead of non-renewable energy, 25%;
10. Replacing the lawn with a meadow, 13%.

3.2 Energy efficient appliances

The analysis of the aforementioned results allowed us to conclude that the most popular decision was related to the energy efficiency of all major household appliances. This action required an initial investment but was not only environmentally

Table 1:
Electricity prices (including taxes) for household consumers, first half 2021. Source: Eurostat (Eurostat, 2020)

beneficial but also economically profitable. In all the households in which this measure was implemented, energy consumption was significantly reduced (total annual energy savings of 126.2 MWh/year achieved in 101 households, giving an average of 1.25 MWh per household), which was reflected in the energy bills. Total savings of about €29290 and average savings of €290 per household were achieved in the first half of 2021 which translates to €380 per household in 2022 (due to the significant increase in energy prices at the beginning of 2022). These savings were quantified on the basis of an average price of 1KWh of energy for household consumers €0.2322 kWh in Europe (**Table 1**). Simultaneously, the avoided carbon dioxide emissions resulting from increased efficiency of main household appliances equalled 36.86 tons CO_2 (**Table 2**). At the same, it was confirmed that this conservation habit had the highest technological, social and economic potential.

Table 2:
Summary of annual reduction of energy consumption and carbon dioxide emissions from main household appliances

Appliance Type	Reduced Energy (MWh)		Reduced Emissions (ton CO_2)	
	p/Household	Total	p/Household	Total
Refrigerators	0.23	23.42	0.067	6.803
Cookers	0.70	70.90	0.206	20.8
Dishwashers	0.21	21.18	0.061	6.149
Washers	0.11	10.71	0.031	3.108
	1.25	126.21	0.365	36.86

3.3 Disposable plastic

The second most popular decision dictated by environmental concerns was the elimination of all the disposable plastics from the households. This has been achieved through a fundamental change in the way the survey participants would shop. Respondents explained that they used solely reusable packaging when shopping, giving preference to shops and distribution points that allow this. Despite initial difficulties due to the need for a change in behavioural patterns, the decision was ultimately found to be easy to implement. The calculation shown significant benefits resulting from this conservation decision, and in particular the annual energy savings of 75.1 MWh (270.3 GJ) and reduced CO_2 emissions of 12.72 tons CO_2 per year. Reduction of energy consumption from plastic production was computed using the Equation (1):

$$RE_P = R_{PHw} \cdot 53 \cdot C_n \cdot E_P \qquad (1)$$

Reduction of carbon dioxide emissions from plastic was calculated using Equation (2):

$$R_{CP} = R_{PHw} \cdot 53 \cdot C_n \cdot C_{EP} \qquad (2)$$

Where:
RE_P - annual energy savings resulting from disposable plastic (MWh)
RC_P – annual reduction of carbon dioxide emissions of plastic (ton CO_2)
R_{PHw} - an average weekly reduction of disposable plastic per household estimated on the basis of the survey results (kg)
53 - a number of weeks per year
C_n - a number of households
E_P – embodied energy of plastic (MJ)
C_{EP} - carbon emission from plastic per kilogram of material produced (kg CO_2)

Embodied primary energy of plastic, i.e., the total amount of energy required to produce 1 kg of plastic (from crude oil), was calculated by (Gutowski, Sahni, et al., 2013) and remains in the range of 62-108 MJ with the average value of 85 MJ/kg. Carbon emission from plastic per kilogram of material produced calculated by (Gutowski, Sahni, et al., 2013) may vary from 3 to 5 kg CO_2 per 1 kg of plastic produced, and the average value is 4 kg CO_2.

3.4 Car vs bicycle or pedestrian transportation

The highest annual energy savings of 172.64 MWh and reduced emissions of 42 tons CO_2 resulted from a simple but sometimes challenging decision to change everyday transportation methods from car to bicycle or walking. The number of avoided travels was estimated based on the assumption that the average sum of car travels per week is 100 km excluding longer holiday trips. This value was calculated for the 3 groups of travels: everyday travels to work and school, frequent journeys such as shopping and entertainment, and occasional weekend trips. The survey participants declared that the aforementioned journeys were avoided by giving preference to bicycle and walking.

Energy reduction for 100 km per week per person was computed for the average fuel consumption estimated as 6 litres/100 km. This method has limitations since carbon dioxide emissions were calculated using EEA data for performance of new passenger cars in Europe. It is important to note that for other regions and less efficient engines, the emissions might alter.

Annual energy savings from fossil fuel consumption of car travel were calculated using Equation (3):

$$RE_{FC} = R_{FCw} \cdot 53 \cdot C_n \cdot 8.9 \text{ kWh/L} \qquad (3)$$

Taken the calculation rate of CO_2 emissions from passenger cars provided by European Environment Agency (EEA, 2019) as 130 grams of CO_2 per kilometre, the annual reduction of CO_2 emissions from fossil fuels from car travels for a survey group can be calculated using Equation (4):

$$RC_{FC} = R_{Dw} \cdot 53 \cdot 130 \text{ g } CO_2\text{/km} \cdot C_n \qquad (4)$$

Where:
RE_{FC} - reduced fossil fuel consumption per person per week (L)
RC_{FC} – annual reduction of carbon dioxide emissions from fossil fuels from car travels (ton CO_2)
R_{Dw} - reduced travel distance per week (km),
C_n - a number of people who declared this change
53 - a number of weeks per year,
8.9 kWh - an energy equivalent of 1 litre of gasoline.

3.5 Renewable Energy Sources

The energy savings resulting from transition from non-renewable energy sources to the solar systems installed in 25% of analysed households reached a considerable value of 104 MWh per year. Respectively, the annual carbon emissions from non-renewable grid electricity (replaced with photovoltaic electricity) were reduced by 17.37 tons CO_2. Taken the average PV system size of 4.5 kW, an annual production of photovoltaic energy per household (EPVh) was computed and it equalled 4000 kWh. For the carbon emission savings an average grid carbon intensity, estimated by (European Commission, 2021) at 255 g CO_2 for a kWh of electricity produced for the grid in 2019, was used, and with the SunEarthTools Calculator (SunEarthTools Calculator, 2021) the savings of CO_2 emissions were estimated to be 1020 kg CO_2. Furthermore, cradle-to-grave method was applied to calculate the footprint of solar panels (a functional unit of an average kWh of electricity generation over 25 years using a solar rooftop array) and it equalled 88 g CO_2/kWh (Houses of Parliament, 2011).

3.6 Air Conditioning vs Natural Ventilation

The analysis of the survey results revealed that one of the most significant environmental choices was related to the avoidance of air-conditioning systems in favour of benefiting from natural ventilation. In 23 analysed households the residents decided not to use anymore the AC devices installed in their premises, while other 44% of respondents opted not to have any AC systems in households and learned the correct natural ventilation patterns instead. The environmental impact from AC for cooling purposes was calculated for the energy efficiency class A under average climate conditions for medium temperature. The average cooling capacity of the air conditioner for the average dwelling size reported in the survey was 6.8 kW. The maximum input energy consumption of the air conditioner was determined as 2.3 kW and the average energy consumption per hour was assumed to be 2 kW. Typically, the air conditioning systems were used for 6 hours per day, 90 days per year.

Consequently, total annual reduction of energy consumption for cooling purposes achieved 74,52 MWh, which was computed using Equation (5):

$$RE_{AC} = T_{ACd} \cdot N_{ACd} \cdot E_{ach} \cdot C_n \qquad (5)$$

Where:
RE_{AC} – annual reduction of energy consumption for cooling purposes (MWh)
T_{ACd} – an average daily operational time of air conditioner estimated through survey as 6 (h)
N_{ACd} - a number of AC system working days per year estimated as 90 (days)
E_{ach} - an average energy consumption per hour, estimated as 2 (kWh)
C_n - number of people who declared this change.

The total annual reduction of carbon emissions from AC devices reached the value of 21.63 ton CO_2/year and it was computed per kWh from electricity and heat for 74.52 MWh/year, using SunEarthTools calculator (SunEarthTools Calculator, 2021) for the European region.

The limitation of this method is due to the fact that the calculation was performed for the European region, while for other regions the results may vary. Additionally, the emissions from production and installation of AC devices were not calculated in this study.

3.7 Water savings

The results shown that the water conservation was observed in changed laundry habits and replacing a traditional lawn in front of the house with a natural meadow. In the first model, the participants limited the number of washing cycles in the households to one per week while using lower washing temperature (30 up to 40°C). This brought annual energy savings of 6.49 MWh and reduced emissions of 1.89 tons CO_2. The second intervention was related to water savings from irrigation as well as reduced emissions (0.057 tons CO_2/year) and energy savings from avoided mowing (0.2 MWh/year). The calculation demonstrated that these savings were relatively low in comparison to other pro-environmental activities identified within the research.

3.8 Environmental vegetarianism

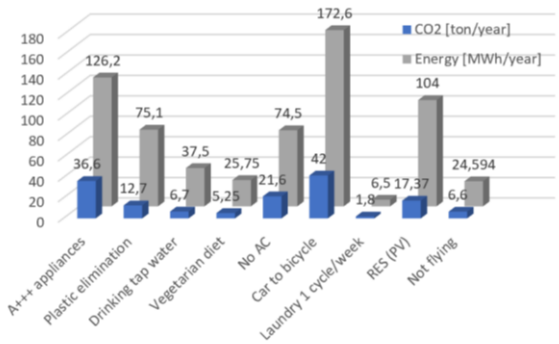
Significant number of participants declared the transition to environmental vegetarianism. As many as 70% refrain from eating meat products in purpose to limit their carbon footprint. The calculation allowed to assess thus achieved energy savings: 25.8 MWh/year, and reduced GHG Emissions: 5.25 tons CO_2/year. The environmental costs of producing cultured meat (Clune, Crossin, and Verghese, 2017), namely the energy consumption and GHG emissions were computed with the application of LCA methodology based on ISO14044:2006 guidelines (ISO, 2006) applied by (Tuomisto, Teixeira de Mattos, Joost, 2010).

3.9 Evaluation of results

The analysis of individual choices and the calculation of their environmental impacts established the basis for the sustainable living behavioural model in the building scale. The most popular decisions were not always the easiest, nor the most significant in terms of energy and emission direct savings. The example of such a choice was an elimination of disposable plastic from households which required radical change in consumer's patterns. The computed annual savings were high but still about 30% lower than the savings resulting from the installation of photovoltaic panels. On the other hand the long-term environmental impact of disposable plastic is remarkable and the initiative undertaken by 96% of survey participants aimed at its reduction is truly impressive.

While it is commonly believed that plane travels generate some of the highest environmental footprint both in terms of non-renewable energy (fossil fuel consumption) and high CO_2 emissions, this research allowed to assess the real-life impacts of avoided plane travels in comparison with other conservation habits. This allowed us to conclude that an average family can safe seven times more on everyday short distance trips and five times more on energy efficient household appliances, than on a single plane travel on 1000 km distance avoided once per year. The information how significant are our routine journeys to work, school, shopping and entertainment facilities may be an important argument in favour of 15-minutes city concept.
The summary of results is presented in **Figure 2**.

Figure 2:
The environmental impact of individual decisions in terms of energy and GHG emissions annual savings.



In the last part of research the author compared the calculated savings resulting from individual initiative of 104 persons who have taken part in the survey to the benefits and costs of LEED certified office and mixed-use building occupied by an average number of 100 persons for 12 months. Ten LEED buildings located in climatic and economic conditions corresponding to the distribution of locations characterising the research participants' premises were selected for analysis. The model of LEED Certified Reference Facility (LCRF) was established. The comparison was made for energy consumption and energy savings calculated per 1 m^2. Similar calculations were performed for the reduced CO_2 emissions. An average size of dwelling estimated on the basis of the respondents statements was 68 m^2. This allowed us to create a model of a Standard Reference Dwelling (SRD). In the SRD (new construction from last 10 years), the primary energy consumption was estimated as 212 kWh/m^2 per year (Skanska, 2016). For the LCRF the average annual energy consumption was calculated as 170 kWh/1 m^2 (Montgomery, 2018). Therefore, the energy savings were about 42 kWh/m^2, which means that the calculation results are in line with the assumption that the LEED certified building typically consume about 20-25% energy less than non-LEED buildings.

The average annual energy savings achieved by the research participants through their individual environmental decisions were calculated per household and equalled 91,48 kWh/m^2. This means that the savings compared to SRD were more than twice bigger than the savings achieved in LCRF. The comparison of results with the energy savings in the passive house is in favour of the passive house with the energy savings of approximately 180 kWh/m^2/year.

4. CONCLUSIONS

The research allowed us to evaluate the significance and applicability of specific individual choices and environmental initiatives identified through the survey with 104 participants. The annual energy and carbon emission savings in a building scale were calculated for the 10 most popular initiatives. The correlation between the ease and replicability of particular decisions and their measurable environmental impact was examined. The results of the study shown that the most popular decision, undertaken by 97% of survey participants, was the replacement of the major households appliances with the ones with the highest Energy Efficiency Index. This resulted with energy savings of 126.2 MWh/y and avoided emissions of 36.6 ton CO_2/y. The most significant impacts were achieved in the households where users decided to change their everyday transportation means from car to bicycle or walking. This brought about the highest annual energy savings of 172.64 MWh/y, and the avoided carbon dioxide emissions of 42 tons CO_2 per year. The second most valuable decision in terms of reducing the negative environmental impact was related to the switch from non-renewable to renewable energy sources (photovoltaic energy) and natural ventilation, while eliminating the use of air conditioning systems in the examined households.

The calculation results were compared to the similar benefits achieved in LEED Certified Reference Facility occupied by the group of 100 users for one year (reductions vs costs). This comparison has proven that the individual decisions brough about more than twice higher savings with no extra costs. The final conclusions addressed the underestimated significance of individual environmental choices and new conservation habits resulting from the awareness of climate change and the urgent need to combat its effects.

REFERENCES

1. Dettore C. (2009) Comparative life-cycle assessment of bottled vs. tap water systems, Center for Sustainable Systems, Rep. CSS09-11, Michigan
2. Brunzell R., Renström L. (2020) Recommendations for revising the energy label system for dishwashers: supporting sustainable development and usage through the interaction of energy labels, technical improvements and consumer behaviour. Energy Efficiency 13, 2020, pp 145–155.
3. Tsang M., Sonnemann G., Bassani D (2016) Life-cycle assessment of cradle-to-grave opportunities and environmental impacts of organic photovoltaic solar panels compared to conventional technologies, Solar Energy Materials and Solar Cells, Vol. 156, 2016, pp 37-48.
4. Clune S., Crossin E., Verghese K. (2017) Systematic review of greenhouse gas emissions for different fresh food categories, Journal of Cleaner Production, vol. 140, part2, 2017, pages 766-783, https://doi.org/10.1016/j.jclepro.2016.04.082.
5. ISO 14044:2006. Environmental management — Life cycle assessment — Requirements and guidelines. https://www.iso.org/standard/38498.html (accessed 22 Aug 2021).
6. Tuomisto H. Teixeira de Mattos L., Joost M. (2010) Life cycle assessment of cultured meat production. 7th International Conference on Life Cycle Assessment in the Agri-Food Sector, 22nd - 24th September 2010, Bari, Italy.
7. Gutowski, Timothy, G.; Sahni, Sahil; Allwood, Julian, M.; Ashby Michael, F., Worrell, Ernst. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Philosophical Transactions of the Royal Socaity A 371: 20120003. http://dx.doi.org/10.1098/rsta.2012.0003.
8. European Environment Agency (EEA) (2019). Monitoring of CO2 emissions from passenger cars – Regulation (EU) 2019/631 provided by EEA. on-line: CO2 performance of new passenger cars in Europe — European Environment Agency (europa.eu) (access 14 Aug 2021).
9. Eurostat (2021) Electricity price statistics - Statistics Explained (europa.eu) ISSN 2443-8219 (access 17 Aug 2021)
10. SunEarthTools Calculator (2021), https://www.sunearthtools.com/tools/CO2-emissions-calculator.php (access 10 Aug 2021)
11. European Commission. Data and Maps. CO2 Emission Intensity (2021). Available on-line https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-8#tab-googlechartid_googlechartid_googlechartid_googlechartid_chart_11111 (access 23 June 2021)
12. Houses of Parliament, Parliamentary Office of Science and Technology, Carbon Footprint of Electricity Generation, Number 383 June 2011, https://www.parliament.uk/globalassets/documents/post/postpn_383-carbon-footprint-electricity-generation.pdf (access 27 July 2021).
13. Montgomery L. (2018), How LEED Certification Can Save Your Organization Money, My Tech Decisions, 26 December 2018, How LEED Certification Can Save Your Organization Money - My TechDecisions
14. Skanska, Energy Consumption in Office Buildings: a Comparative Study, 2016 https://www.skanska.pl/4a58d8/siteassets/oferta/biura/raporty-i-standardy/raport-zuycia-energii-w-budynkach-biurowych/energy-consumption-in-office-buildings-report.pdf

PLEA SANTIAGO 2022
Will Cities Survive?

An innovative approach for teaching physics of the built environment

KARIN MARIA SOARES CHVATAL[1], ROBERTA CONSENTINO KRONKA MÜLFARTH[2], KELEN ALMEIDA DORNELLES[1], ALESSANDRA RODRIGUES PRATA SHIMOMURA[2], PEDRO HENRIQUE SILVA MATTIA[1], RANNY LOUREIRO XAVIER NASCIMENTO MICHALSKI[2], WELLINGTON SOUZA SILVA[1]

[1] Institute of Architecture and Urbanism (IAU), University of São Paulo (USP), São Carlos, Brazil
[2] Faculty of Architecture and Urbanism (FAU), University of São Paulo (USP), São Paulo, Brazil

ABSTRACT: This article addresses an innovative proposal for the teaching of building physics of the built environment that considers both active learning and visualization through two or three-dimensional models. The focus is on some aspects related to passive thermal design and acoustics, taught in the first years of Architecture and Urbanism undergraduate courses in Brazil. The proposal consists of four workshops to be held in disciplines of physics of the built environment in 2022, namely natural ventilation, building materials, solar incidence, and acoustics, and that will use traditional and novel equipment and tools, such as heliodon, wind tunnel, water table, didactic hot box, and scale models for acoustics. Both equipment and tools, as well as the didactic procedure of the workshops are described. The research aims at contributing to the literature by integrating visualization and active learning methodologies into a unique approach.
KEYWORDS: Energy, Comfort, Acoustics, Teaching.

1. INTRODUCTION

The proposed approach refers to the teaching of physics of the built environment to future architects and urban planners. The focus is on the interface between physics and architectural and urban design, which is essential for preparing professionals for dealing with complex environmental issues that frequently arise.

The difficulties faced by integrating physics in the design process include the understanding of the phenomena involved and the consequent proposition of solutions; thus leaving a gap between scientific knowledge and design learning and practice [1] that can be reduced by visualization in two- or three-dimensional models [2].

Concerning teaching and the design process, the use of active learning methodologies is another approach that has provided good results. Students are stimulated to observe, analyze, ask, discuss, and solve problems on what they see or measure [3].

The Solar Decathlon Competition [4] is a good example of active methodologies that apply the learning process through problem-solving and a transdisciplinary approach. It has been held since 2002 and is currently the most prestigious international student competition for sustainable habitat. Teams must design, build, and manage a house prototype taking into account sustainability, energy efficiency, self-sufficient houses powered by renewable energy and comfort, among other aspects. The process of solving social and urban problems and its design, construction, and testing with scientific and humanistic parameters has been highlighted from a pedagogical and teaching perspective [4].

The application of active learning methodologies enables students to become active subjects of their own learning, instead of passively receiving knowledge [5]. Therefore, the integration of active learning and visualization of physical phenomena seems to be a promising alternative to be explored.

On the other hand, few studies have addressed didactic proposals in the area, and even fewer have considered visualization and active methodologies. The present article introduces a proposal that enables students to more effectively understand the theoretical foundations of building physics through active learning and visualization. The focus is on aspects related to passive thermal comfort and acoustics in the built environment.

2. METHOD

2.1 Proposal format

The research was jointly developed at Institute of Architecture and Urbanism (IAU) and Faculty of Architecture and Urbanism (FAU), both from the University of São Paulo (USP), in Brazil.

The topics chosen were natural ventilation, building materials (thermal behaviour), solar incidence, and acoustics (sound propagation), taught in the first years of the Architecture and Urbanism undergraduate course in both Faculties and whose correct understanding is the foundation for physics of the built environment. They were organized into four workshops, since it was considered the most adequate manner to apply the didactic proposal to the places where they will be offered.

The elaboration of the workshops was based on the existing equipment of the Environmental Comfort Laboratories of both faculties, so that the resources could be used in a complementary and efficient way. Innovative equipment and tools were also created towards enabling any type of visualization or measurement not yet available.

The Results section addresses the workshops' proposals; however, their application was postponed to the year of 2022 due to COVID-19 pandemic. The Method section describes the objective of each workshop and the equipment or tools used for their application.

2.2 Natural ventilation workshop: objectives and equipment

The objective is to teach wind driven ventilation in the built environment (indoor and outdoor), since it is an important comfort strategy for hot and humid climates - this is the case of most Brazilian bioclimatic zones, at least during the summer [6]. Airflow is a complex phenomenon that can be easily understood through visualization in scaled models. Tests will be applied in two pieces of equipment, namely water table and wind tunnel, used in a complementary way.

Water table (Fig. 1) simulates wind driven ventilation and enables airflow visualization in two-dimensional models [7, 8]. The water table of Institute of Architecture and Urbanism has two water tanks of 92.5 liters each and 1.10 meter length, and a 0.74 meter wide test area. The usual indicator for visualizations is dishwasher detergent.

Figure 1:
Water table of Institute of Architecture and Urbanism, University of São Paulo.

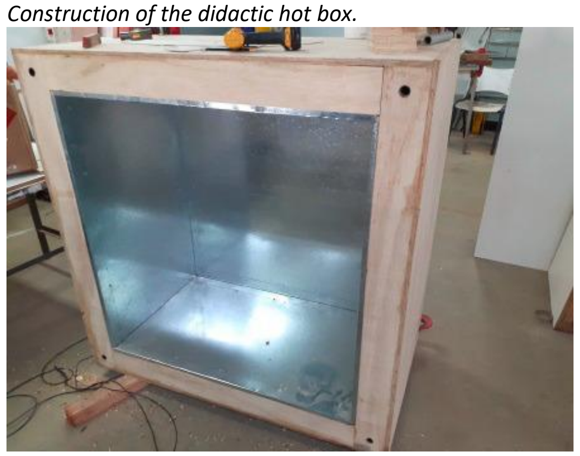
Tests in wind tunnels (Fig. 2) determine the influence of natural ventilation on the performance of architectural projects, as well as any physical structure to be verified for aerodynamic effects. Evaluations are conducted in a qualitative/ quantitative way and based on the use of physical models on a reduced scale (in this case, in the Atmospheric Boundary Layer Wind Tunnel).

Figure 2:
Wind tunnel of Faculty of Architecture and Urbanism, University of São Paulo.

2.3 Building materials workshop: objectives and equipment

A simplified version of the box prescribed by ASTM and ISO standards [9-11] will be adopted, and the main objective of the proposed didactic hot box (Fig. 3) is the understanding of the heat flow through an opaque envelope and its thermal properties in an intuitive and experimental way, through an infrared visor.

Figure 3:
Construction of the didactic hot box.



The specificity of the equipment stems from the simplification of more complex models, e.g., elimination of part of the device called cold box towards prioritizing analyses of the thermal properties of materials worked in undergraduate and graduate projects of Architecture and Urbanism and Engineering.

The envelope to be analyzed will be fitted to the front of the hot box. Then, one surface will be heated, increasing the temperature difference between the two surfaces of the analyzed element. Stimulating a heat flow from the inside to the outside through the analyzed wall will facilitate the thermal transmittance measurement methods.

2.4 Solar incidence workshop: objectives and equipment

A heliodon, which simulates sun beam and shadows in small scale models in several latitudes will be used.

It is important equipment for the teaching of solar geometry, since it represents the path of the sun throughout the day and the year in an easy way that is close to reality [12].

The heliodon from the Institute of Architecture and Urbanism has fixed arches and a tilting table. This type is not the best for teaching purposes; therefore, it has been remodelled for the workshop (Fig. 4), and changes included insertion of a fixed table, rotation of the arcs, and use of automation for turning on the lights and for all movements of the arcs.

Figure 4:
Heliodon before and during remodelling.

2.5 Acoustic workshop: objectives and equipment

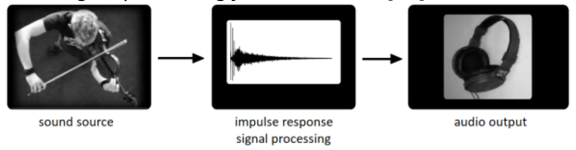
Acoustic phenomena and sound propagation are complex and difficult to understand. Some didactic approaches with physical scale models can be used towards facilitating their comprehension; they range from visualization of sound waves in two-dimensional models filled with water, visualization of sound rays in simple optical models, and a complete study of phenomena in three-dimensional scale models.

Despite advances in computational modelling in acoustics, reduced models remain useful, since they enable a complete physical reproduction of some phenomena that are not fully known and complex to be numerically modelled (e.g., diffusion, scattering, and sound absorption) [13-16]. They also have a high didactic value and act as pedagogical tools that demonstrate basic phenomena of sound propagation [13, 17]. Scale models and changes in their configurations and materials lead to quick reproductions of different effects of sound propagation within them.

Covering particular surfaces of the model with sound-absorbing materials helps the identification of various defects, which include significantly delayed reflections, reflected sound concentrations, and others in the reflection profile. Changes in the shape of the model or addition of a new reflective surface promote quick checks into the effect achieved.

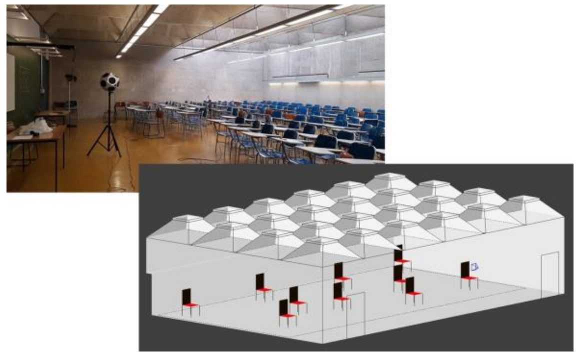
Another didactic approach, called auralization [18], Fig. 5, is subjective and related to sound perception (with the students listening to different acoustic responses in different situations and feeling different sensations). Although not so simple, the possibility of producing a sound similar to that of real space in a model (and hearing how it would sound if it were emitted in a real room) is very attractive.

Figure 5:
Block signal processing for auralization [18].



The acoustic workshop aims to integrate both visualization and perception of acoustic phenomena. Two classrooms from the Faculty of Architecture and Urbanism, Fig. 6, will be built in small scale models mounted with a suitable set of equipment that measures room acoustic parameters, such as reverberation time, and obtains their impulsive responses.

Figure 6:
Classroom of Faculty of Architecture and Urbanism, University of São Paulo – in situ measurements and model.



In a simple definition, the room impulsive response is a type of "acoustic signature" of the room, from which several acoustic parameters can be obtained through signal processing and some transformations. They enable the determination of practically the entire acoustic behavior of the room and generation and reproduction of sounds in it, which can be heard through auralization.

The scale measurements will follow the procedures for real scale described in international standards ISO 3382-2 [19] and ISO 18233 [20]. Different impulse responses of the room (for different situations) and their corresponding acoustic parameters will be obtained and sound recordings will be heard by the students, so that they can quantitatively and qualitatively analyze the different acoustic situations. Along with pre-workshop measurements and collection of objective results, images of the procedure will be provided for explanations during the workshop.

3. RESULTS

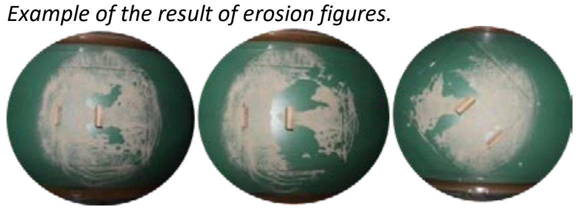
This section details the didactic procedure developed for each workshop.

3.1 Natural ventilation workshop

A very brief theoretical explanation will be given prior to the presentation of the wind tunnel and the water table so that students can better evaluate the tests to be conducted in the equipment.

Wind tunnel will be the first equipment to be used. The erosion figures [21] resulting from the tests will be used for the visualization of the velocity field at ground level. Images obtained from different wind flow velocities during the test correspond to the contours where the friction velocity assumes the limit value of saltation or sand drag (Fig. 7). Variations in the flow velocity provide a set of lines (sand displacement) where the resulting figures of each flow are formed, and, therefore, areas of stronger or weaker influence of wind and those where its effect can be more or less perceived on the flow can be identified.

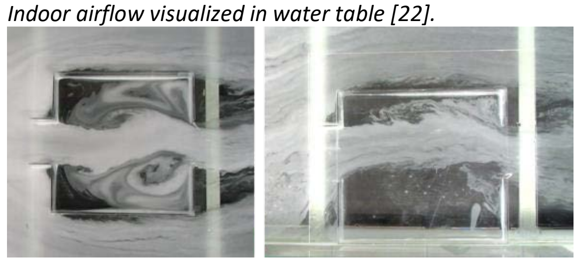
Figure 7:
Example of the result of erosion figures.



According to the active learning methodology, first tests are applied and students observe what occurred, take notes, think, discuss, and try to explain the phenomena. The complexity of the analyzed configurations gradually increases, and models scale varies towards helping students consider airflow in the built environment in an integrated manner (inside and outside buildings for a same configuration).

Evaluations in the water table are either conducted in sequence, or intercalated with those carried out in the tunnel. First tests consider the configurations used in the tunnel for the understanding of complementary aspects. For example, indoor airflow is visualized in a two-dimensional water table model (Fig. 8), whereas the same configuration is measured/visualized in a three-dimensional wind tunnel model. After students have acquired a better domain of test procedure and natural ventilation concepts, complementary configurations can be explored in the two pieces of equipment.

Figure 8:
Indoor airflow visualized in water table [22].



The number of configurations to be analyzed in the workshop is variable and depends on the time available, number of students, and desired knowledge level.

3.2 Building materials workshop

Theoretical methods of calculating the thermal transmittance of opaque envelopes will be presented. The importance of the envelope in the energy balance of buildings and the way students can evaluate the most appropriate constructive elements for the climate to be inserted will also be explained.

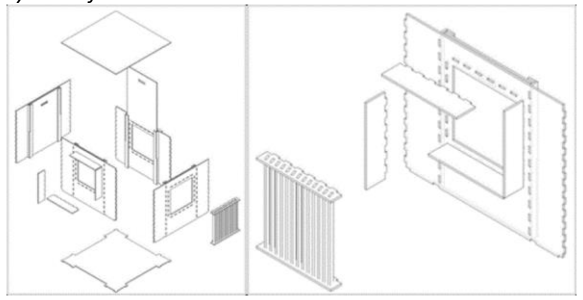
Students will be encouraged to understand the physical phenomena and theoretical calculations, build walls through different construction methods, and predict the way of heat flow occurrence in the tested samples. Films of samples of different transmittance values will be edited by the time lapse technique for a comparison by the students.

Simultaneously with the capture of the images, data will be collected for calculations of the thermal transmittance values through the flow-metric method described in the ISO 9869-1 [23] and ASTM C1155 [24] standards, and compared with those predicted theoretically.

3.3 Solar incidence workshop

A theoretical explanation of solar geometry will be given prior to the presentation of the heliodon equipment and students will perform several sun beam and shadows simulations with small scale models. The simulations will consider both building and urban scales. Regarding the former, a simplified small building model with windows and different detachable solar shade systems for façades can simulate shading for openings at several times of the day and for different solar orientations (Fig. 9).

Figure 9:
Small scale building model with detachable solar shade systems for heliodon.



In this proposal and according to the active learning methodology, students can change the detachable solar shading systems and observe what occurs. They can take notes, think, discuss, and try to find the best solution for each façade according to the time of the day, latitude, or season of the year. Moreover, they can verify if the solar shading system is necessary or not - for example, when sunlight is considered important for indoor heating or health purposes.

A small urban scale model will assess the influence of tall buildings or the presence of vegetation near a building on the shading land area. Students will be able to change the position of the building in the land area and verify the importance of neighbouring buildings and solar orientation to correctly place rooms in the building. They can discuss the best solution for the analyzed site conditions.

With a better domain of solar geometry concepts and the heliodon operation, students can explore complementary configurations in both urban and building scales.

3.4 Acoustic workshop

The first part of the workshop will consist of theoretical explanations about sound phenomena, including their generation, propagation, reflection, absorption, diffusion, and scattering.

The second part will involve a brief presentation of the real classrooms, followed by listening activities. The students will listen to sound recordings previously obtained in the reduced-scale physical models under two different conditions: with reverberation times suitable for their use as teaching environments, and with very high reverberation times for which speech intelligibility is compromised. The students will not be told which recording corresponds to the high or to the adequate reverberation time. According to the active learning methodology, they shall take notes, think, discuss, and try to find and explain the differences they perceive in sounds. After an open discussion, the way the different recordings were obtained will be revealed and a detailed description of the experiments through images, films, and graphics will be provided.

In a third and last part of the workshop, the students will conduct tests in the scale models of classrooms. As in the natural ventilation workshop, the number of analyzed configurations can vary according to the group of students and available time.

In the first workshop, only room acoustics will be addressed; however, the same small scale urban models used in both natural ventilation and solar incidence workshops will be further used in studies on urban acoustics.

4. CONCLUSIONS

This paper described the didactic procedures of four workshops for the teaching of basic concepts of acoustics and passive thermal design through traditional and novel equipment and tools, such as heliodon, wind tunnel, water table, didactic hot box, and scaled models for acoustics.

The proposal offers an innovative approach for teaching physics of the built environment by integrating visualization into two- or three-dimensional models and active learning methodologies and contributes to the considerably scarce literature on the subject.

Due to COVID-19 pandemic, the workshops will be held during the year of 2022 and enable evaluations and adjustments for their improvement. Future studies will also expand the proposal by including new topics, workshops, equipment, and tools.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by University of São Paulo (USP).

REFERENCES

1. Maciel, A. A., Ford, B., Lamberts, R. (2007). Main influences on the design philosophy and knowledge basis to bioclimatic integration into architectural design - The example of best practices. *Building and Environment*, 42(10), 3762–3773. https://doi.org/10.1016/j.buildenv.2006.07.041.
2. Kowaltowski, D. C. K., Labaki, L. C., Pina, S. M. G., Gutierres, G. C. R., and Gomes da Silva, V. (2005, May) *The challenges of teaching bioclimatic architectural design* [Paper presentation]. International Conference "Passive and Low Energy Cooling for the Built Environment, Santorini, Greece. https://bit.ly/3ugln4e.
3. Barbosa, E. F., MOURA, D. G., (2014, March 16-19). Metodologias ativas de aprendizagem no ensino de Engenharia [Paper presentation]. XIII International Conference on Engineering and Technology Education, Guimarães, Portugal. http://copec.eu/intertech2014/proc/works/25.pdf.
4. Herrera-Limones, R., Rey-Pérez, J., Hernández-Valencia, M., Roa-Fernández, J. (2020). Student competition as a learning method with a sustainable focus in higher education: the University of Seville "Aura Projetcs" in the "Solar Decathlon 2019". *Sustainability*, 12(4), 1634. https://doi.org/10.3390/su12041634.
5. Bonwell, C. C., Eison, J. A. (1991). *Active learning: creating excitement in the classroom.* AEHE-ERIC Higher Education Report No. 1. Washington, D.C. The George Washington University. https://files.eric.ed.gov/fulltext/ED336049.pdf.
6. ABNT, Associação Brasileira de Normas Técnicas (2005). *NBR 15220-3, Desempenho Térmico de Edificações - Parte 3: Zoneamento Bioclimático Brasileiro e Diretrizes Construtivas para Habitações Unifamiliares de Interesse Social,* ABNT.
7. Royan, M., Vaidya, P. (2020). Construction, validation and testing of a water table for natural ventilation analysis. *Energy and Buildings*, 226, 110356. https://doi.org/10.1016/j.enbuild.2020.110356.
8. Toledo, A. M., Pereira, F. O. R. (2003, November 5-7). *O potencial da Mesa d'água para a visualização analógica da ventilação natural em edifícios* [Paper presentation]. VII ENCAC - Encontro Nacional de Conforto no Ambiente Construído, Curitiba, Paraná, Brazil. https://bit.ly/37MFnE8.
9. ASTM, American Society for Testing and Materials (2019). *ASTM C1363-19, Standard test method for thermal performance of building materials and envelope assemblies by means of a hot box apparatus*, ASTM International. www.astm.org.
10. ASTM, American Society for Testing and Materials (2014). *ASTM C1199-14, Standard test method for measuring transmittance of fenestration systems using hot box methods*, ASTM International. www.astm.org.
11. ISO, International Organization for Standardization (1994). ISO 8990, *Thermal insulation – Determination of Steady Determination of Steady - State Thermal Transmission Properties - Calibrated and Guarded Hot Box*, International Organization for Standardization.
12. Szokolay, S. V. (2007). *Solar Geometry, PLEA Notes* (2nd ed.). Passive and Low Energy Architecture International and University of Queensland. http://www.plea-arch.org/wp-content/uploads/PLEA-NOTE-1-SOLAR-GEOMETRY.pdf
13. Nascimento, R. L. X. (2005). *Medição dos coeficientes de absorção sonora de materiais utilizados em modelos reduzidos*. [Master thesis, Universidade Federal do Rio de Janeiro].
14. Pan, L., Zhao, Y., Gao, J. (2020). Factors influencing scattering coefficient measurement accuracy in scaled reverberation room. *Applied Acoustics*, 159, 107072. https://doi.org/10.1016/j.apacoust.2019.107072.
15. Lee, H., Cha, C., Jeong, D. (2022). Development of realistic scale model auditors. *Applied Acoustics*, 188, 108544.https://doi.org/10.1016/j.apacoust.2021.108544.
16. Jeon, J. Y., Ryu, J. K., Kim, Y. H., Sato, S. (2009). Influence of absorption properties of materials on the accuracy of simulated acoustical measures in 1:10 scale model test. *Applied Acoustics*, 70 (4), 615-625. https://doi.org/10.1016/j.apacoust.2008.06.009.
17. Lisot, A. (2013). *Modelo em escala reduzida ao ar livre como ferramenta de validação de simulação computacional de barreiras acústicas*. [Doctoral dissertation, Universidade Estadual de Campinas].
18. Vorländer. M. (2008). *Auralization: fundamentals of acoustics, modelling, simulation, algorithms and acoustic virtual reality*. Springer.
19. ISO, International Organization for Standardization (2008). *ISO 3382-2, Acoustics — Measurement of room acoustic parameters — Part 2: Reverberation time in ordinary rooms. International Organization of Standards, Inte*rnational Organization for Standardization.
20. ISO, International Organization for Standardization (2006). *ISO 18233, Acoustics - Application of new measurement methods in building and room acoustics, International Organization* for Standardization.
21. BORGES, A. R. J., SARAIVA, J. A. G. (1980) An erosion technique for assessing ground level winds. *Wind Engineering*, 1, 235-242. https://doi.org/10.1016/B978-1-4832-8367-8.50028-0.
22. Rossi, M. M., VALE, F. I., SHIMOMURA, A. R. P., CHVATAL, K. M. S. (2019). A mesa d'água como ferramenta de apoio para a caracterização de um modelo genérico a ser ensaiado em túnel de vento. *Revista IPT/ Tecnologia e Inovação*, 2(10), 70-80.
23. ISO, International Organization for Standardization (2014). *ISO 9869, Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance – Part 1: heat flow meter method, International Organization* for Standardization.
24. ASTM, American Society for Testing and Materials (2021). *ASTM C1155-95, Standard Practice for Determining Thermal Resistance of Building Envelope Components from the In-Situ Data,* ASTM International. www.astm.org.

Toward zero-carbon built environments
Best practices for integrated design studio teaching

MICHAEL MCGLYNN [1] KENDRA KIRCHMER [2]

[1] Dept. of Architecture, College of APDesign, Kansas State University, Manhattan, KS, USA
[2] Dept. of Interior Arch. and Industrial Design, College of APDesign, Kansas State University, Manhattan, KS, USA

ABSTRACT: The current 2020 NAAB Conditions for Accreditation call for teaching a truly integrated architectural design approach – one in which students' formal, spatial, and aesthetic decision-making is informed, if not driven, by environmental and building performance considerations. We consider the AIA Framework for Design Excellence and related COTE Top Ten for Students Competition for their potential to serve as guides or models for structuring integrated design coursework, given that this competition studio is by nature an integrated design studio and that in some programs it serves as such for the purposes of meeting NAAB accreditation. To determine best practices for such a studio and related coursework, we conducted a survey of competition-winning faculty. Our research revealed three themes – while all 10 design principles of the AIA Framework for Design Excellence are essential, the climate crisis dictates the priorities; various forms of collaboration are key to managing the complexity of an integrated design approach with measurable environmental and building performance outcomes; and the addition of the COTE Top Ten for Students Competition to the integrated design studio increases the breadth and depth of student learning opportunities without constraining student or faculty creativity.
KEYWORDS: Architectural Education, Integrated Design, Zero-carbon

1. INTRODUCTION

The climate crisis warrants a wholesale reconsideration of our approach to architectural education in North America. However, the need for climate action is so profound that we must find ways within our current approach to educate architecture students for zero-carbon built environments. While many courses come into play, particularly those within a typical technical course sequence, perhaps the course with the greatest untapped potential is the so-called "integrated" design studio.

1.1 The NAAB Conditions for Accreditation and the Integrated Design Studio

The now replaced 2014 National Architectural Accrediting Board (NAAB) Conditions for Accreditation required programs to demonstrate that students possessed "*Ability* to make design decisions within a complex architectural project while demonstrating broad integration and consideration of environmental stewardship, technical documentation, accessibility, site conditions, life safety, environmental systems, structural systems, and building envelope systems and assemblies" (NAAB 2014). Programs typically met this criterion, C.3: Integrative Design, with evidence from what many called the "integrated" design studio. The current 2020 NAAB Conditions for Accreditation are a substantive revision, and the conditions make clear that the corollary Student Criteria, SC.5: Design Synthesis and SC.6: Building Integration, can be satisfied with evidence from a single course or multiple courses (NAAB 2020). However, both criteria state that the program must ensure "that students develop the ability to make design decisions within architectural projects…" (NAAB 2020), which means that the integrated design studio will likely maintain its central role in achieving these objectives.

Moreover, the broad and immeasurable concept of "environmental stewardship" mentioned in the 2014 criterion has been replaced in SC.5 by the phrase "…consideration of the measurable environmental impacts of their design decisions" and in SC.6 by "…the measurable outcomes of building performance" (NAAB 2020). These phrases represent a seismic shift for NAAB student learning objectives. Environmental and related building performance considerations are no longer relegated to criteria that apply only to the technical courses, but now must be considered "within architectural projects". As with many, if not most, of the 172 NAAB-accredited programs, our institution's integrated design studio learning objectives do not include measuring building performance, so we set out to determine how best to structure and implement a design studio in support of these expanded objectives.

1.2 The AIA Framework for Design Excellence and Integrated Design Studio Teaching

The opportunity here is to not only meet the new NAAB accreditation criteria, but to teach a truly integrated architectural design approach – one in which students' formal, spatial, and aesthetic decision-making is informed, if not driven, by environmental and building performance considerations. A framework in support of such an approach has been developed by the American Institute of Architects (AIA) Committee on the Environment (COTE). Proposed in 1997, the COTE Top Ten Measures for Sustainable Design provided the framework for the COTE Top Ten Awards Program, and, in 2019, these measures were adopted by the AIA as their definition of design excellence. The AIA Framework for Design Excellence, as it is now called, consists of 10 design principles: integration, equitable community, ecosystems, water, economy, energy, well-being, resources, change, and discovery (AIA 2022).

With the introduction of the COTE Top Ten for Students Competition in 2014 based on the original COTE Top Ten Measures, these principles are now spurring change in North American architectural education. The 2021 competition alone had over 800 participants from 67 schools, nearly 50% of NAAB-accredited institutions. Given that this competition studio is by nature an integrated design studio and that we were aware that in some programs it serves as such for the purposes of meeting the NAAB accreditation criteria mentioned above, we decided to conduct a survey of competition-winning faculty to determine the best practices for integrated design studio teaching.

2. RESEARCH STUDY METHODOLOGY

Referring to the competition website, we gathered basic information on all the winning entries from the competition's inception in 2015 through 2021, the time of this study (ACSA 2022). From this initial data collection, we identified 74 faculty sponsors from 31 institutions (approximately 23% of the 136 NAAB-accredited institutions). We then determined the quantity of winning entries per faculty and/or faculty team. We limited survey participants to those faculty with repeated success sponsoring winning student teams as it seemed reasonable to assume that such success was at least in part due to the teaching approach. Nineteen faculty representing 12 institutions fit this criterion, approximately 26% of winning faculty sponsors and approximately 39% of winning institutions. Nine faculty representing 10 institutions agreed to participate in the study, an 83% response rate among institutions to our request for participation. Of note, four of these institutions won the competition four or more years, often consecutively.

We used structured interviews (Seidman 2006) to collect detailed information from the participants on three major topics related to design studio teaching – Course Goals & Objectives, Course Structure, and Course Implementation. These topics and the questions under each were generated from both our own design studio teaching experiences and a recent publication by Prof. Ulrike Passe (2020), "A design workflow for integrating performance into architectural education". Additional questions served to introduce the study and prompt conversation as well as conclude the discussion. The study was approved by the Internal Review Board at our institution and was conducted in compliance with their procedures and policies. Further, respondents are referred to anonymously unless they have given written consent to be referred to directly. Interviews were conducted remotely via Zoom, a video conferencing application, and were recorded with participant permission. We used Adobe Premiere Pro software to generate written transcripts that we edited manually.

To analyse and synthesize the content of the interview transcripts, we used textual analysis, a common method of analysis in grounded theory (Charmaz 2006). We read the transcripts and notes, highlighting salient responses and then used these highlighted sections to develop more generalized descriptions or codes that could be evaluated and synthesized. From this process, themes and concepts, commonalities and differences in teaching approaches emerged.

3. RESEARCH STUDY FINDINGS

3.1 Course Goals & Objectives

We asked participants to briefly discuss the course goals for their integrated design studios and the following themes emerged: *net-zero energy* and issues related to *water* were mentioned four times, general *ecological literacy* was mentioned three times, *zero-carbon buildings* were mentioned twice, and *passive design, adaptive reuse, and equity* were each identified once by respondents. We followed with a question asking participants to describe the degree to which the individual principles for design excellence were emphasized – were they all emphasized equally or did some criteria have greater emphasis over others, and, if so, which criteria where emphasized? Perhaps unsurprisingly given the results of the previous question, both *Design for Energy* and *Design for Water* (ACSA 2022) were mentioned most frequently, receiving five mentions each. Issues and topics related to *Design for Resources*, *Design for Well-being*, *Design for*

Economy, and *Design for Equitable Community* (ACSA 2022) were highlighted twice by participants throughout the responses to this question and *Design for Ecology* (ACSA 2022) was mentioned by one participant group. It is worth noting that, although Design for Integration was not specifically mentioned in response to this question, integrated design was the driving factor behind most of the courses discussed.

3.2 Course Structure

All participants taught students within the discipline of architecture exclusively, although some programs' students had backgrounds in other disciplines before matriculating to the architecture program or, in some cases, students were pursuing dual degrees in allied disciplines such as landscape architecture. Seven of the courses were taught at the graduate level, one at the undergraduate level, and two had both undergraduate and graduate students integrated in a vertical educational model. Class size ranged from 8 - 18 students per section. Six participant groups structured the students into teams of two or three, two structured the studio around individual projects, and one allowed students to choose between individual and team projects.

A major issue that arises when structuring an integrated design studio is how best to integrate robust content delivery needs and technical, performance-based design methods into the traditional design studio format. We assumed that, while some faculty may significantly augment the design studio course itself, many might rely on another course to meet these additional needs. To test this assumption and develop an understanding of the participants' specific course and curricular dynamics, we asked, "Was this taught as a stand-alone competition studio or was it explicitly tied to a support course or courses?" Five participant groups taught the studio as a stand-alone course, three taught the studio alongside a coordinated, linked support course, and one participant group moves strategically between a stand-alone or linked model based on alignment of course/faculty goals each year. Significantly, four of the participant groups and their institutions coordinated the integrated design studio/COTE Top Ten for Students Competition across an entire cohort/year-level. The remaining five participant groups, across six institutions, taught the integrated design studio/COTE Top Ten for Students Competition individually. Further, six of the nine participant/participant groups taught alone, one group always taught in collaborative, synchronous teams of two or more faculty, and the remaining two groups taught in asynchronous teams, with faculty coming together for major milestones.

In their paper "Applying Performative Tools in the Academic Design Studio: A Systemic Pedagogical Approach", Professors Ian Caine and Rahman Azari (2017) proposed three distinct course models for integrating performance considerations into design studio teaching – *unlinked, linked, and integrated*. The linked model consists of a design studio course and a coordinated, concurrent support course that delivers the building technology and performance content. The stand-alone studios fall into one of the other two models, unlinked or integrated. In an unlinked model, the design studio and building technology courses are not coordinated and may not even happen during the same semester (Azari & Caine 2017). Students rely on previous coursework and independent study to develop and integrate performance-based design strategies. The integrated model embeds building technology and performance content into the design studio itself through either a collaborative teaching model or a single faculty with the necessary expertise (Azari & Caine 2017). Of the six participant groups surveyed who taught the integrated design studio as a stand-alone course, only two used the integrated model described above. The remaining four used a variety of models discussed further in Section 3.3.

We also asked questions about the project type, use, typical overall square footage, number of stories, location, etc. and found that projects ranged from small religious structures in rural settings to large high-density towers in urban centres. All but one participant group defined the program to some degree. Three participant groups defined a set of programmatic parameters to start (e.g. site and community engagement), allowing students to then develop the program, while four participant groups gave students detailed programs.

3.3 Course Implementation

When asked, "What aspects of teaching a performance-based design studio such as this differ from a more traditional approach?", the participants unanimously indicated that it was the incorporation of measurable outcomes and performance metrics as tools to inform design decision making from the beginning of the process that set this type of studio apart. This sentiment was echoed in various ways throughout the discussion on course implementation. Also, most participants structured the design studio in phases akin to the traditional design phases found in professional architectural practice.

Related to the linked or integrated course models described in Section 3.2 for the delivery of the breadth and depth of content needed for integrated design studio teaching is what we term the *consultant* model. Three models of consultation emerged from discussion with participants regarding the studio design process – *linked course as consultant*, *additional faculty as consultants*, and *practitioners/stakeholders as consultants*. The linked course as consultant model was described earlier and consists of a coordinated support course acting as a vehicle for technical consultations. The additional faculty as consultants model is one in which faculty across the institution are brought into the design studio for lectures, workshops, informal feedback sessions, and formal design reviews. For example, faculty with expertise in structures, mechanical systems, or daylighting might meet with individual students or student groups at key points during the semester to give targeted feedback. The practitioners/stakeholders as consultants model works similarly to the previous model, the primary difference being that expertise comes from outside practitioners or community members, rather than from experts within the institution. All but one participant group used consultants in at least one of these ways. Further, two of the three most successful participant groups described a studio design process that integrated practitioners and stakeholders at multiple stages throughout the semester. Notably, three participant groups devoted significant time at the end of the semester, as much as three weeks, for students to work on performance simulations and design communication.

The discussion on studio design process was followed by a question regarding which design methods or tools participants felt were key to the design studio's success. The open-ended nature of the question yielded a wide range of answers that we grouped into roughly three categories – drawing types used for both design development and communication, thematic prompts used to generate student interest, and frameworks used to manage the complex task of performance-based design.

Three of the participant groups cited specific drawing types as key. For example, Participant A assigns a large-scale wall section "as big as the room" immediately following the schematic design phase, which is much earlier than a drawing of that detail level is typically assigned. This facilitates the critical discussion of room proportions and their relationship to the flow of forces. Participant B (Prof. Steven Juroszek) described another such example, a rendered and annotated section perspective that serves as both a primary design visualization tool and the basis for the communication of a wide range of outcomes. Another group, Participant Group F, emphasizes what they describe as "performance drawings" in place of typical presentation drawings to go beyond "pretty pictures" and provide a greater depth of information. Further, many participants discussed the importance of analytic diagrams throughout the design process for design development and communication.

Another discussion revolved around methods and tools for generating student buy-in. For example, Participant Group C leaves the project parameters entirely up to the student team but generates a detailed thematic design prompt to launch the project and guide its development. They have found that "it's very empowering for students, they really get to love the project because each project is completely unique, completely different." Participant D described a "mission-driven design" approach that is

> *"about thinking deeply about the context within which you're designing, the people for [whom] you're designing; making sure that these environments [are] welcoming to everybody and also that [they] are speaking to this idea of giving hope to the future."*

This sentiment was echoed by many participant groups that use various strategies and degrees of engagement with local communities to ground the project and foster student investment.

Embedded within much of the discussion regarding design methods and, more broadly, the studio design process, was a conversation regarding pedagogical frameworks used to synthesize the wide array of design and performance considerations. For example, Participant E described a series of performance-based analysis assignments organized as a workbook. The workbook provides students with a centralized source from which they can pull content to inform their design development and project visualization. This feedback loop between analysis and design development was echoed by participant groups using linked and integrated course models.

A matrix of deliverables is another tool that was described by Juroszek. This comprehensive chart maps the relationships among NAAB-accreditation criteria SC.5 and SC.6 (NAAB 2020), the preferred method of representation, and the typical drawing requirements such as plans, sections, elevations, etc. Students can use this tool to make connections and visualize relationships between design criteria such as ecological considerations and the design of the building envelope through wall sections.

Lastly, although most participants added the COTE Top Ten for Students Competition and its related AIA Framework for Design Excellence to an already existing integrated design studio, many participants discussed its utility in focusing and guiding student project development. For one of the participants, the AIA Framework was the primary driver and pedagogical tool of the studio.

4. THREE THEMES TO GUIDE INTEGRATED DESIGN STUDIO TEACHING

4.1 The climate crisis dictates the priorities

All 10 design principles of the AIA Framework for Design Excellence – integration, equitable community, ecosystems, water, economy, energy, well-being, resources, change, and discovery – are essential to an integrated architectural design approach. However, most participants emphasized two principles – design for energy and design for water. This is unsurprising, given the perilous state of the climate. If energy and water issues are addressed, the rest can follow. Participant D said it best,

> *"But the first thing we have to do is we have to decarbonize as rapidly as [we] possibly can… We have a responsibility and the skills to do this. We have to do it now. We can't wait and if we don't do it, all of those other things that we're worried about are just going to get a lot harder… So, thinking about energy first, water second, and everything else after that, but the trick is not forgetting everything else after that."*

4.2 Collaboration is key to success

Much of the conversation throughout this study revolved around strategies to demystify the complex nature of teaching an integrated design studio. Various forms of collaboration – among students, faculty, consultants, courses, etc. – emerged as major strategies for managing this complexity. Beginning with students, we found that most participants structured the students into teams of two or, perhaps, three. Six of the nine participant groups found that a student team structure helped them to better manage project expectations. Team structuring approaches varied from allowing students to select their own partners to faculty-assigned pairings. In one instance, students start individually, but team in the second half of the semester.

In addition to student collaborations, faculty collaborations were a frequent topic of discussion. Three participant groups employed either synchronous or asynchronous team-teaching structures, including a highly collaborative, synchronous model that Participant Group G described as follows,

> *"We have a very unique way of co-teaching… We have three or four faculty with different backgrounds that are actually influencing the students for the whole semester at the same time."*

They find this creates a dynamic conversation about the work, providing students with multiple and, at times, opposing viewpoints. This empowers the students, allowing them to "develop their own thing." In addition to team-teaching, some faculty act as consultants, collaborating across multiple design studio sections.

In fact, we found consultation, following one of the three models discussed in Section 3.3, to be the primary means of collaboration. Participants frequently mentioned inviting additional faculty from across their institution to provide feedback to the students in their areas of expertise. With similar frequency, participants mentioned bringing in outside practitioners or stakeholders to engage with students, helping them to, as Participant E remarked, "calibrate their work". Lastly, a support course often acts as a consultant to the design studio, as is the case with Juroszek's, where the support course faculty structures the assignments to evaluate project performance.

Running parallel to the above discussion was a conversation regarding the largely graphic strategies for managing these collaborations. Juroszek's annotated section perspective and deliverables matrix, Participant F's performance drawings, Participant A's large wall section, and Participant E's workbooks all serve as frameworks to manage the complexity of the performance-based design process.

4.3 More is better

While combating the climate crisis must be our first priority, one of the most important lessons learned from this study is that there are a plethora of approaches to teaching an integrated design studio. In fact, the variety of approaches the participants describe reveals a wide array of opportunities to tailor the studio to fit the unique needs of each faculty and institution. While it can be intimidating to take on the task of teaching a studio that requires juggling the complex demands of performance-based design, collaboration makes it possible for any design studio faculty to do so. Four participant groups' programs demonstrate that an entire cohort of students can be taught in this manner.

The complexity and depth of content may seem to necessitate a rigid, fixed course structure. However, this is not the case. Instead, we found a range of teaching approaches, course structures, project types, sizes, locations, etc., akin to what one might find across any design studio curriculum. Given the diversity of project variables among the participants, any project type and site can work. Additionally, the design brief or prompt can be as defined or open as faculty need for their student body and pedagogical approach. Some faculty provide a detailed program, while others only basic guidelines. For example, Participant A states,

> *"The program is always consistent, but it has only three components and they have to figure out all the rest. It says live, work, community… and they develop the program based on their site and community analysis and conversations with stakeholders usually."*

Participant E used a similar strategy, letting the site dictate programmatic response. "…all the building[s]… always have a lens of sea-level rise where they're generally on the coast". Lastly, Participant C leaves nearly everything up to the student to define. "Instead of being very specific in terms of the size, the program and so on, we are very specific in terms of thematic approach." The addition of the COTE Top Ten for Students Competition to the integrated design studio increases the breadth and depth of student learning opportunities without constraining student or faculty creativity.

The COTE Top Ten for Students Competition should become the vehicle for teaching an integrated architectural design approach. The underlying AIA Framework for Design Excellence not only aligns with NAAB-accreditation criteria but provides a comprehensive set of principles to foster "a zero-carbon, equitable, resilient, and healthy built environment" (AIA 2022).

5. NEXT STEPS

One strength of this research study lies in the participant selection criteria. By selecting those faculty sponsors who had had repeated success in the COTE Top Ten for Students Competition, we drew our data from a pool of peer-reviewed expertise. Another strength lies in the semi-structured interview methodology employed, which led to thorough conversations resulting in a large amount of data on a wide range of topics. This scoping approach enabled us to identify important practices related to integrated design teaching.

However, we acknowledge that the relatively small number of participants in our study – 9 faculty sponsors representing 10 institutions drawn from 74 faculty sponsors representing 31 institutions – is a limiting factor. Expanding the scope to include all competition-winning faculty sponsors would be an effective way to test the validity of our initial conclusions. The number of participants could be further expanded by identifying other performance-based design studios similar in scope that have undergone a comparable peer-review, such as winning a design competition in which demonstrated effectiveness of integrated design strategies is a primary evaluative criterion. Additional study instruments, such as online surveys, could be used to collect data more efficiently from this greater number of participants.

REFERENCES

1. National Architectural Accrediting Board, Inc., (2014). *2014 Conditions for Accreditation*.
2. National Architectural Accrediting Board, Inc., (2020). *NAAB Conditions for Accreditation, 2020 Edition*.
3. American Institute of Architects. "Framework for Design Excellence." aia.org. https://www.aia.org/resources/6077668-framework-for-design-excellence (accessed Mar. 7, 2022).
4. Association of Collegiate Schools of Architecture. "2022 COTE Competition: AIA COTE® Top Ten for Students." acsa-arch.org. https://www.acsa-arch.org/competitions/2022-cote-competition (accessed Mar. 7, 2022).
5. Seidman, I. (2006). *Interviewing as qualitative research: A guide for researchers in education and the social sciences* (3rd ed.). New York: Teachers College Press.
6. Passe, U. (2020). A design workflow for integrating performance into architectural education. *Buildings and Cities*, 1(1), 565–578. DOI: http://doi.org/10.5334/bc.48
7. Charmaz, K. (2006). *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. SAGE Publications.
8. Azari, R. and I. Caine (2017, June 14-17). Applying performative tools in the academic design studio: A systemic pedagogical approach," *ARCC, Architecture of Complexity: Design, Systems, Society, and Environment*, University of Utah, Salt Lake City, UT. pp 38 – 45.

PLEA SANTIAGO 2022
Will Cities Survive?

Climate change urbanism state of the art
A scientometric analysis

JOSÉ FRANCISCO VERGARA PERUCICH [1] CARLOS AGUIRRE-NUÑEZ[2]

[1] Universidad de Las Américas, Centro Producción del Espacio
[2] Universidad San Sebastián, Escuela Arquitectura

ABSTRACT: This article seeks to present the main findings of the systematic review of this literature based on a scientometric analysis of the sources. The analysis technique is based on the Rstudio package called bibliometrix which allows a statistical analysis of the productivity in the subject. From the results of the analysis, it is possible to identify the main keywords, topics with the greatest capacity to generate content and the progress of different lines of research. It is also possible to identify the main groups of researchers for each thematic line and the international collaborations that have been part of the research on climate change and cities.
In the scientific discussion of the topics, thematic lines are established to address the various elements of the complexity of the phenomena. In this sense, the different thematic lines may highlight some issues and push others into the background or leave them latent. In that logic, the main conclusion of this research is the need to highlight the interaction between the built environment, energy, and climate change, in the light of their evident relationship.
KEYWORDS: Scientometric analysis; Change Climate; Buildings

1. INTRODUCTION

This paper seeks to contribute to a systematic analysis of the results of research in urban studies and climate change based on a bibliometric analysis, identifying categories and dominant corpus, reviewing secondary sources in internationally recognised and validated databases in the national academic sphere. This analysis allows us to generate a general framework of the state of the art of urbanisms for climate change, identifying gaps and visualising opportunities for the development of new research. This study is relevant because of the relationship between knowledge production and the epistemology of urban studies in the face of climate change. That is, how large volumes of scientifically grounded findings and arguments are shaping theoretical corpuses that can feed new, urgent, relevant and influential disciplinary discussions. For this purpose, a bibliometric analysis is applied within the methodological framework of scientometrics.

The production of publications is increasing at a high rate worldwide, which may be a virtue, but this has generated large volumes of literature that make up a complex corpus of specialised information of complex and fragmented arrangement, with trends that are difficult to follow, thus harming the accumulation of knowledge [1,2]. In this context, bibliometrics allows knowledge to be systematised in a transparent and reproducible way on the basis of statistics on scientific activity, generating reliable results [3]. For Ana Andrés, there are three main sub-areas of application of bibliometrics: (i) methodological research on the ways in which different researchers apply bibliometric techniques, (ii) research on scientific disciplines to understand the metrics behind each field of study where bibliometrics are applied, and (iii) application to scientific policies that seeks to review the metrics to determine how to allocate resources or make decisions on specific scientific aspects or public policies [4]. For publications in architecture and urban studies, contributions in this regard are scarce. For example, in Web of Science, only 63 articles are found for these areas of knowledge that develop bibliometric studies, between 1975 and 2021.
Among the 63 articles mentioned above, one of the most relevant is that of Sara Meerow et al., who problematise the definition of urban resilience based on the tensions that arise from the contradictions that seek to define this concept and, based on the results, propose a new definition for urban resilience, elaborating an operational concept [5]. Another relevant article using bibliometrics is that of Christian Matthiessen et al, who identify trends in scientific productivity from the 100 largest cities in the world to identify how thematic intensities are produced in some places over others [6]. The application of bibliometric techniques is valuable as it allows one to trace the variations in a topic and organise trends over time. For example, Fu & Zhang published a study that identifies research variations on the topic of urban sustainability over a 35-year period, detecting changes in trends and assessing the recent major interaction of this concept with the Smart city idea [7]. Wang et al. present a very pedagogical article in its methodological details to present the results of their research on the topic of urbanisation in global knowledge production networks. Using the Web of Science, they conducted an advanced search for the term "urbani*", thus identifying all possible variations of the concept of urbanisation. This search returned 14,338 articles. The database was searched for patterns on types of publications, languages, indicators, disciplinary categories of journals, geographical distribution of publications, temporal evolution of keywords and the relationship of urbanisation research to the material process of global urbanisation. The authors were able to identify that there was an important trend towards studies on land use, mathematical modelling techniques of urban phenomena and problematisation of the ecology of cities [8]. Bibliometric studies on architecture and urban studies in Latin America are not abundant. According to Torres Lima and González Martínez, one of the problems in the region is the scarce effective circulation of peer-to-peer publications, because although there is significant productivity, ideas do not necessarily become known and shared. To achieve a better culture of research dissemination, they argue, bibliometric approaches need to be broadened; combining evaluations, improving regional impact indicators and coordination between channels of distribution of results [9]. In 2017, a review of publications on urban environmental justice in the region was published, indicating that the largest amount of research in this regard has been developed in Mexico and Chile, with an emphasis on the social effects of environmental problems in cities [10]. That same year, Campos, Orellana and Carrasco published a bibliometric study that characterises in detail the contributions and lines of research published in the INVI Journal of the University of Chile [11].

2. Methodology

This research is inductive in nature with an exploratory approach, applying mixed quantitative and qualitative techniques. The products to be developed are mainly theoretical with epistemological value, based on the consultation of secondary sources that are analysed with advanced text processing techniques by algorithms and quantitative study on aggregated databases. In addition to providing epistemological information based on recent disciplinary production, the research will be able to generate descriptions of the ontologies of architecture and urban studies in Chile, elaborating categories on the theoretical currents that influence disciplinary research, groups of results according to objects of study, differences between groups of researchers with intellectual affinity and thematic analysis of research results to produce a contribution to the epistemology of the disciplines of architecture and urban studies in Chile.

The research procedure is based on an initial stage of data collection from the publication databases, which then go through a study of descriptive statistics based on the information of each reference included. Using the same database, a qualitative analysis is carried out, focusing mainly on abstracts, references and titles. From these two analyses, quantitative and qualitative, the results are reviewed to identify the theoretical contributions of each analysis process. The data for this research will be obtained mainly from the most widely circulated publication indexes: Web of Science and Scopus. The Web of Science search routine is as follows:

[(SU=(Urban Studies OR Regional & Urban Planning OR Architecture) AND ALL=Climate Change AND TIPOS DE DOCUMENTOS: (Article) Índices=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI Período de tiempo=2000-2020]

For Scopus the routine was as follows:

[(AK=(Architecture OR Urbanism OR Urban Planning OR Urban Design OR Urban Development OR Urbanization OR Urban)) AND ALL=Climate Change AND TIPOS DE DOCUMENTOS:(Article) Índices=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI Período de tiempo=2000-2020]*

For the descriptive stage of the data, the analyses are run in two main software packages: Rstudio using the Bibliometrix package with its biblioshiny application [1] and in VOSViewer [12]. Bibliometrix allows the development of a set of cross-references between documents in a database to identify associations between groups of researchers and content, similar to those presented in the previous pages of this formulation. VOSViewer, for its part, makes it possible to analyse trends in knowledge development over time and to develop visualisations of relationships between sources under study. The results are presented below.

3. Results and Discussion

From the application of the analysis techniques, some initial descriptive results are obtained that allow the sample to be sized. The collection of information yielded 4806 documents from 775 sources, with a total of 10,507 authors. Scientific productivity for the topic of urban studies and climate change has a key moment in 2009, when a sustained upward trend in productivity of over 200 articles per year began, as can be seen in Figure 1. Between 2009 and 2015 there was an increase in the annual citation rate between articles, which can be seen in Figure 2, indicating that during this period there was a dialogue between results that contributed to producing a body of critical thought associated with urbanism and climate change. This trend has a slight drop during the pandemic.

Figure 1: Annual scientific production

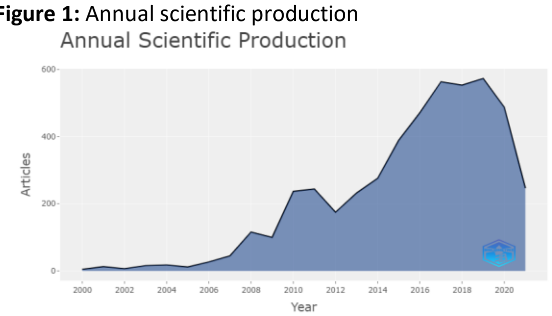
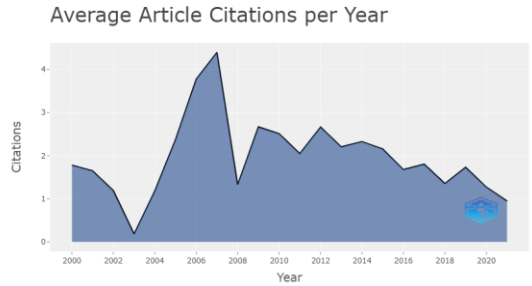


Figure 2: Average article citations per year



Al revisar los textos más influyentes en este campo disciplinar (figura 3), se observa que el mas citado es el de Reid Ewing y Robert Cervero sobre la dependencia del automóvil para la movilidad entre ciudades [13]. El segundo artículo más citado es de McGranahan, Balk y Anderson sobre el riesgo al que se exponen zonas costeras pobladas ante el alza del nivel del mar por efecto del cambio climático [14]. Finalmente, entre los artículos más citados está el de Bowler et al., quienes aportan una revisión sistemática sobre estrategias para reducir la temperatura de las ciudades mediante infraestructura verde [15]. A partir de esto, se puede plantear que las principales líneas de investigación sobre cambio climático y urbanismo apuntan a movilidad sustentable, reducción de riesgo de desastres climáticos y urban greening.

Figure 4 presents a thematic map based on the keywords used by the authors of the articles. It can be seen that basic themes of the reviewed articles are sustainability, planning and energy. On the other hand, themes that drive research for most of the articles are climate change, adaptation and resilience. Emerging themes include governance of cities and local governments, along with ecosystem services planning for adaptation. Finally, among niche topics, i.e. with good productivity but few researchers developing these topics, are green infrastructure, heat islands and urbanisation processes.

Figure 3: Most global cited documents.

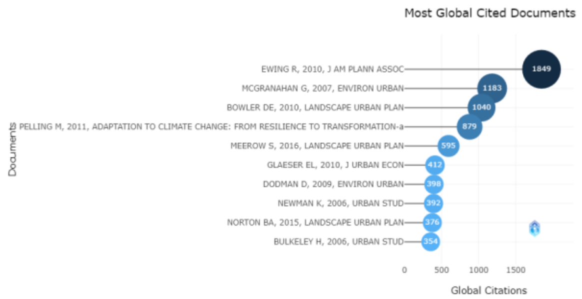
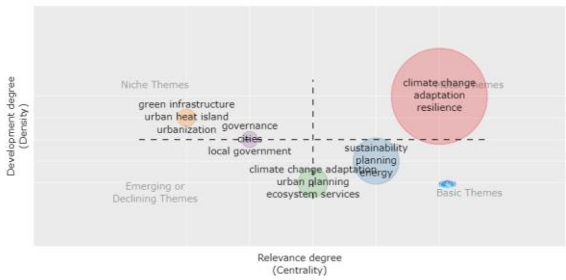


Figure 4: Thematic map of author's keywords.



In the thematic evolution, little novelty can be seen in relation to the thematic map. Mainly, it is observed that the concepts studied at the beginning of the 21st century are very similar to the concepts studied in recent research (figure 5). From this finding, it can be seen that the space of emerging and niche themes in Figure 4, present research spaces that still fail to configure main trends for the themes developed in research on urbanism and climate change, but that could become dominant themes in the coming years.

Figure 5: Thematic evolution by author's keywords.

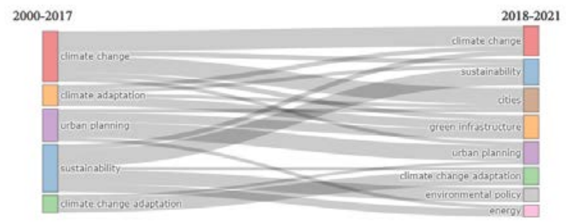
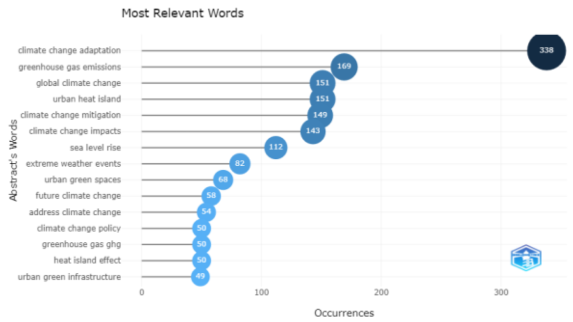


Figure 6 presents the result of analyzing the abstracts of the 4806 documents analyzed. Specifically, the trios of serial words that are most repeated among the documents reviewed are indicated. By far the most used is climate change adaptation, which is almost twice as frequent as greenhouse gas emissions, global climate change and urban heat island. It can be seen that the articles tend to focus on measures that, mainly from urban planning, operate on trying to reduce the effects of climate change. The absence of housing as a problem of study is striking.

Figure 6: Trigrams of most commonly used words in the abstracts of the articles analysed.



4. Conclusions

The process of scientometric analysis allows us to establish how knowledge has been generated and how it is articulated on the basis of cultural hegemonies. In this logic, the most relevant finding is the absence, in this field, of the relationship between built space and climate change as an urban problem, which is striking, given that it allows us to identify a knowledge vacuum on which to investigate. Because this issue, as well as housing, does not appear massively among the documents analysed, it is possible to identify a problem based on separating residential or interior space from the configuration of the general urban form of cities in the context of climate change. For example, the issue of energy poverty and its social effects or the relationship between climate change and healthy urban development did not appear massively. On the other hand, there are well advanced topics referring to green infrastructure development, disaster risk reduction and sustainable mobility. These factors reactively complement other disciplinary fields, but do not enter into the direct discussion on urban form, spatial design and spatial construction techniques. Possibly, the line of heat islands does enter into this type of discussion, but more from the point of view of diagnosis than the development of research with prepositive results.

There is an epistemological insinuation in the findings of this research. The literature on urbanism and climate change has produced responses to specific issues that arise as effects of climate change, however, the production of a theoretical line of urbanistic thinking for climate change is still absent. There is a set of practical solutions that are recommended to be implemented, but they fail to constitute a theoretical corpus that accounts for an epistemological shift from the paradigms inherited from the neoliberal model towards a way of making cities that focuses on the survival of the planet and the human species. This theoretical vacuum calls for a disciplinary discussion that considers the current times and allows for the transformation of current theories, shifting the focus from economic-statistical evaluation to broadening the volume of discussions on an urban ecology ad-hoc to the climate emergency.

New research on green infrastructure, disaster risk reduction and mobility can be framed to generate theoretical contributions. This is relevant for these strategies to move forward to constitute an urban ethos, where climate change is a thematic axis that orders the discussion, which in addition to solutions produces a philosophical framework for interpreting the problem.

REFERENCES

1. Aria, M.; Cuccurullo, C. Bibliometrix : An R-Tool for Comprehensive Science Mapping Analysis. *Journal of Informetrics* **2017**, *11*, 959–975, doi:10.1016/j.joi.2017.08.007.
2. Briner, R.B.; Denyer, D. Systematic Review and Evidence Synthesis as a Practice and Scholarship Tool. In *Handbook of evidence-based management: Companies, classrooms and research*; Oxford University Press: London - Oxford, 2012; pp. 112–129.
3. Diodato, V. *Dictionary of Bibliometrics.*; Haworth Press: New York, 1994;
4. Andres, A. *Measuring Academic Research. How to Undertake a Bibliometric Study*; Chandos Publishing: Oxford - Cambridge - New Dehli, 2009; ISBN 9781843345282.
5. Meerow, S.; Newell, J.P.; Stults, M. Defining Urban Resilience: A Review. *LANDSCAPE AND URBAN PLANNING* **2016**, *147*, 38–49, doi:10.1016/j.landurbplan.2015.11.011.
6. Matthiessen, C.W.; Schwarz, A.W.; Find, S. World Cities of Scientific Knowledge: Systems, Networks and Potential Dynamics. An Analysis Based on Bibliometric Indicators. *URBAN STUDIES* **2010**, *47*, 1879–1897, doi:10.1177/0042098010372683.
7. Fu, Y.; Zhang, X. Trajectory of Urban Sustainability Concepts: A 35-Year Bibliometric Analysis. *CITIES* **2017**, *60*, 113–123, doi:10.1016/j.cities.2016.08.003.
8. Wang, H.; He, Q.; Liu, X.; Zhuang, Y.; Hong, S. Global Urbanization Research from 1991 to 2009: A Systematic Research Review. *Landscape and Urban Planning* **2012**, *104*, 299–309, doi:10.1016/j.landurbplan.2011.11.006.
9. Torres Lima, P.; Gonzalez Martinez, A. Temáticas Sobre Procesos de Urbanización En América Latina. *arq.urb* **2011**, *1*, 203–222.

10. Mayorga Henao, J.M.; Vasquez, A.E. A REVIEW OF RESEARCH ON URBAN ENVIRONMENTAL JUSTICE IN LATIN AMERICA. *REVISTA DE DIREITO DA CIDADE-CITY LAW* **2017**, *9*, 1247–1267, doi:10.12957/rdc.2017.29161.
11. Campos Medina, L.; Orellana Mejías, C.; Carrasco Pérez, G. Características de La Producción Científica de La Revista INVI En La Era SciELO, 2009-2016. *Biblios: Journal of Librarianship and Information Science* **2017**, *67*, 42–55, doi:10.5195/BIBLIOS.2017.348.
12. Liao, P.; Wan, Y.; Tang, P.; Wu, C.; Hu, Y.; Zhang, S. Applying Crowdsourcing Techniques in Urban Planning: A Bibliometric Analysis of Research and Practice Prospects. *Cities* **2019**, *94*, 33–43, doi:10.1016/j.cities.2019.05.024.
13. Ewing, R.; Cervero, R. Travel and the Built Environment. *Journal of the American Planning Association* **2010**, *76*, 265–294, doi:10.1080/01944361003766766.
14. McGranahan, G.; Balk, D.; Anderson, B. The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones. *Environment and Urbanization* **2007**, *19*, 17–37, doi:10.1177/0956247807076960.
15. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence. *Landscape and Urban Planning* **2010**, *97*, 147–155, doi:10.1016/j.landurbplan.2010.05.006.

PLEA STGO 2022
WILL CITIES SURVIVE? EDUCATION AND TRAINING

PLEA STGO 2022

November 22 - 25, 2022

ANALYSIS AND METHODS

DAY 02
16:30 — 18:00

CHAIR
ROBERTO LAMBERTS

PAPERS
1160 / 1170 / 1265 / 1381 / 1586

29TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Effect of building properties and lifestyle on electricity consumption in the home

Case study at a Mediterranean desert city

DIANA BOGIN [1] MEIDAD KISSINGER [1] EVYATAR ERELL [1]

[1] Dept. of Geography and Environmental Development, Ben-Gurion University of the Negev, Israel

ABSTRACT: Policies seeking to promote energy efficiency in residential buildings may be inadequate unless they recognize and address the effect of lifestyle on electricity consumption. This paper introduces a comprehensive lifestyle classification methodology that analyzes the complex relationship between diverse household attributes and electricity consumption patterns. Households are characterized by lifestyles using hierarchical cluster analysis, employing two approaches: Electricity Use Behavior (EUB) and Household CHaracteristics (HCH). The method was demonstrated in the dry Mediterranean city of Beer Sheva, Israel. The HCH approach performed better than EUB at classifying households into distinct sub-groups of similar size. Five main clusters were found, of which two - high-income pensioners with large houses, and high-income middle-aged persons in large houses - have the highest potential for energy saving. Implementation of the HCH approach will allow policy makers to identify and target specific populations for effective intervention, relating specific energy efficiency policy measures to selected lifestyles.
KEYWORDS: household electricity consumption, lifestyle, cluster analysis, demand side management policy

1. INTRODUCTION

Electricity plays an essential role in human well-being and development. Household consumption accounts for roughly half of all electricity consumed in buildings. Because electricity generation has numerous negative effects on natural systems and human health at both the local and global scales, reducing consumption is essential. Studies of the effects of specific socio-economic factors and building characteristics on electricity consumption show that the effects of different factors are inter-related and may be attributed to occupant 'lifestyles' (Bin & Dowlatabi, 2005). Understanding people's lifestyles may help to explain the gap between expected and observed electricity consumption (Nielsen, 1993), to devise an effective energy efficiency policy, and to analyze scenarios of future electricity demand (Le Gallic et al, 2017).

The term 'lifestyle', initially introduced by sociologists and marketing scholars (Michman, 1991), has been used in discussions of energy policy at least since the 1970s. Energy-related lifestyles can be described as "patterns of activities that are defined by habits, norms, and social structures and which shape domestic energy consumption" (Gram-Hanssen et al, 2004). Lifestyles are reflected in the characteristics of the household and dwelling, as well as by behavioral patterns of the occupants. Each of these groupings of factors will be reviewed in brief in the following sections.

1.1 Household and dwelling characteristics

Dwelling properties have a dominant effect on consumption. Large houses require more energy for temperature regulation than smaller ones (Parker, 2003). Energy consumption in apartments is typically lower than in detached houses, because they are usually smaller, but also because they have a smaller exposed envelope (external walls and roof) area (McLoughlin et al, 2012). New buildings typically implement modern energy efficiency standards that require better thermal insulation and higher quality glazing. It is often assumed that new residential buildings will consume less energy, but studies have also found that since affluent populations tend to live in such buildings, they consume more energy (Santamouris et al, 2007).

Income is correlated directly with electricity consumption, in absolute terms (Hache et al, 2017). It also has an indirect influence (Yohanis et al, 2008), since it affects residence size and quality; and ownership of electrical appliances – all of which may have an effect on electricity consumption.

Education is correlated with higher income, often resulting (indirectly) in a larger house and more electrical appliances. In addition, the presence of adult tenants at home during the day may increase household electricity consumption (Bin & Dowlatabi, 2005), but, paradoxically, both high income and low income may be associated with long working hours and less time spent at home.

1.2. Behavioral attributes

Energy use behavior can be explained by a variety of psychological, sociological, technological, and economic decision theories. For a detailed review see Heydarian et al (2020) and Wilson & Dowlatabadi (2007). The theories can be categorized into psychological frameworks (values, attributes, and personal norms) and conceptual ones (available choices, economic incentives, social norms, technologies, and infrastructures). Many of the theories are connected since they share the same frameworks. However, each theory has limitations, and none can explain human behavior in all its complexity.

Household electricity consumption is influenced by the family's *'life cycle'*, in particular the head of household's (HoH) age and presence of children at home (McLoughlin et al, 2012). Energy consumption tends to grow as the family lives longer in the same residence (Cho, 2019). The change in energy consumption through families' life cycle depends also on residential stability or mobility. Households that rent their residence are more flexible and can change the size of their house (floor area) as their family size changes.

Habits, defined as "learned sequences of acts that have become automatic responses to specific cues and are functional in obtaining certain goals or end states" (Verplanken & Aarts, 1999), also play a crucial role in household energy consumption practices. Habitual electricity use is unconscious, such that the use of household appliances is driven by habits rather than a rational choice between appliance operation options (Pierce et al, 2010).

Santin (2011) suggests four user profiles: seniors, families, singles/couples, and high-income couples. Energy consumption was lower among seniors that showed higher preference for thermal comfort comparing to families that had the highest energy consumption due to heavy appliance use.

As this brief review has shown, energy consumption lifestyles have been defined through behavioral patterns (the EUB approach), or by household demographic attributes and physical characteristics of the dwelling (HCH). We hypothesize that the definition used to identify lifestyles will itself impact the results of the analysis.

2. METHODOLOGY

Detailed data about household use of electricity and explanatory factors such as demographic characteristics, socio-economic factors and the physical properties of the buildings were collected from 146 households in the city of Beer-Sheva, Israel, selected by snowballing and complemented by recruitment of specific populations such as pensioners, recent immigrants, and young families.

Cluster analysis was used to classify households, implementing two strategies: identification of factors that were expected to influence domestic electricity consumption, such as house floor area; and identification of lifestyle factors.

Detailed household demographic and socio-economic attributes, ownership and use of electrical appliances, and physical attributes of the building were recorded in in-situ interviews. Monthly utility records were used to calculate total annual electricity consumption, consumption per capita and energy use intensity (per unit floor area).

Sample characteristics were first analyzed with basic descriptive statistics. Multiple linear regression was performed to establish the total impact that a household's characteristics have on domestic electricity consumption. The effect of house size on ownership of electric appliances was obtained by logistic regression.

Lifestyle identification was performed by means of hierarchical cluster analysis using two distinct approaches for classifying households: The electricity-use behavioral approach (EUB), based on self-reported consumption habits, and the household characteristics (HCH) approach, based on socio-economic and dwelling properties (Table 1).

Table 1:
Attributes selected for the classification approaches

Electricity use behavioral approach (EUB)	
Building heating during the winter [a]	[kWh]
Building cooling during the summer [a]	[kWh]
TV use [annual number of hours watching]	[hours]
Washing and cleaning appliances use [b]	[kWh]
Water heater use (annual)	[kWh]
Oven use (annual)	[kWh]
'Households' characteristics approach (HCH)	
Average age of adults	[years]
Floor area	[sqm]
Number of children	
Home ownership (owner/rented)	
Income level [rank on 7-point scale]	
Number of electric appliances at home	
Religious belief [c]	[Boolean]

a. Building space heating and cooling use was estimated as the product of the number of (self-reported) hours of operation of the units and their rated electricity consumption.
b. Plug loads for white goods (refrigerator, washing machine etc.) were estimated as the product of their (self-reported) hours of operation and their rated energy consumption.
c. Households were classified as being religious based on ownership of appliances specifically designed for autonomous operation on the Sabbath.

3. RESULTS

3.1 Factors affecting electricity consumption

The contribution of various explanatory factors to household electricity consumption was first estimated by multiple linear regression (Appendix A). The analysis explains 56% of total electricity consumption per household (p-value<0.001), but only 35.5% of consumption per capita (p-value<0.001) and 35.5% of energy use intensity per unit floor area (p-value<0.001).

In our sample, household income, apartment floor area, and adult presence at home during the day are significant explanatory factors for all three dependent variables. Larger families increase both total annual household electricity use and energy use intensity. Annual electricity consumption per capita increases with age and is highest among households with adults aged 60-70. These households have a significantly lower number of residents but large houses in terms of floor area.

Building characteristics had an important effect on electricity consumption, which was almost two times higher in detached and semi-detached buildings than in row buildings (which tended to have a smaller floor area). These effects are illustrated in Figure 1.

The sample was binned into groups by the average age of adults in each home (Table 2). Annual electricity consumption per capita increases with age and is highest among households with adults aged 60-70. These households have a significantly lower average number of residents but large houses in terms of floor area. This trend is highly significant for all building types - compact (p-value: 0.002, r=0.346), row (p-value: 0.02, R=0.374) and detached or semi-detached (p-value: 0.005, R=0.387) buildings.

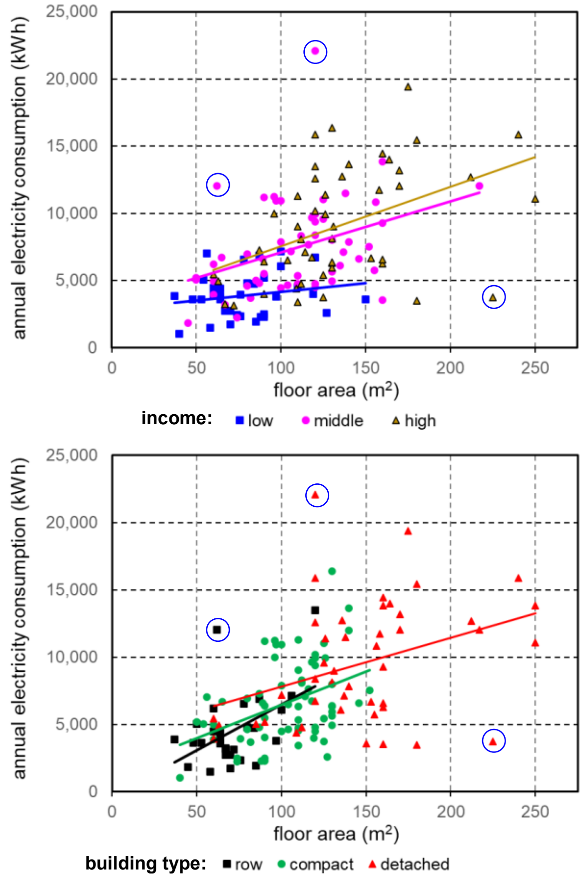


Figure 1:
Effect of apartment size (floor area) on household electricity consumption, stratified by income level (top) and by building type (below). Circles indicate extreme outliers.

3.2 Clustering lifestyles

Cluster analysis based on the HCH approach identified five lifestyle clusters (Table 3), which provide a good representation of each group's family life cycle stages, combined with variety of income levels, house floor area and building type.

Table 2:
Household characteristics stratified by age of head of household

		age of head of household					
		20-30	30-40	40-50	50-60	60-70	70-80
Dependent variables							
1	Total consumption [kWh]	3,855	5,873	8,758	9,769	7,122	4,238
2	Consumption per capita [kWh/person]	1,538	2,010	2,307	2,781	3,202	3,082
3	Energy use intensity (EUI) [kWh/m²]	57	61	78	76	57	60
Explanatory variables							
4	No. of residents	2.50	3.10	3.92	3.61	2.56	1.57
5	Income level (1-7)	3.00	3.94	3.88	3.91	3.74	2.57
6	Number of children	0.50	1.13	2.04	1.74	0.64	0.14
7	Children's age [years]	2.00	3.77	11.73	20.6	22.79	33.00
8	Floor area [m²]	71.75	103.90	116.62	124.87	126.36	88.43

Table 3:
Lifestyle clusters. Upper part of table - clusters identified by both methods. Lower part - identified only by EUB.

	age	income	apt size	notes
YoLoS	Young	Low	Small	childless couple
YoMeM	Young	Med.	Med.	young family
MiHiL	Mid-age	High	Large	large affluent family
PeLoS	Pensioner	Low	Small	low-income retired
PeHiL	Pensioner	High	Large	affluent pensioner
MiHiRe	Mid-age	High		very religious
TV				TV use high
Wash				washing machine use high

Figure 2 shows consumption patterns for major appliances in each of the five clusters. Z-scores greater than '0' indicate above average use of the appliance in question relative to our entire sample, while values smaller than '0' indicates below average use.

Clusters PeLoS and PeHiL represent the elder population and have the highest electricity consumption per capita among all the clusters. Electricity consumption per capita tends to increase as the number of household residents decreases, but older households consume twice the electricity per capita compared to young households between the ages of 20-30. Combining age with large houses and high income, as was observed in PeHiL cluster, results in the largest electricity consumption per capita. The lifestyles with the highest electricity consumption (Clusters PeHiL and MidHiL) are associated with large detached and semi-detached buildings; households have a high income and own numerous electric appliances; and they have high electricity consumption per floor area compared to

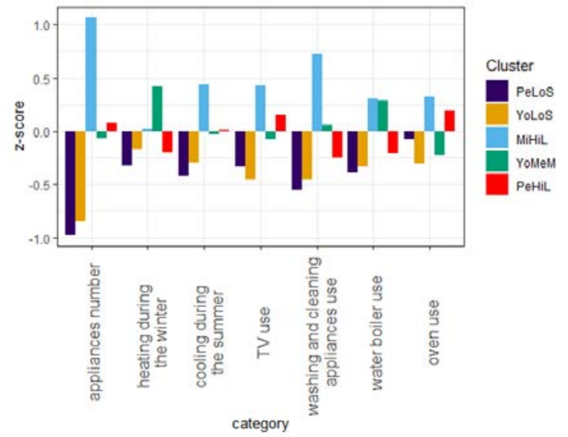


Figure 2:
Electricity use patterns identified using the HCH approach

other building types, except the PeHiL cluster in the HCH approach. These clusters have a substantial potential for electricity reduction, possibly by raising awareness of appliance energy ratings and energy-efficient operation.

Clusters identified only by the EUB approach were either characterized by a single additional attribute, such as extensive use of a specific appliance (**TV**, **wash**), or by a demographic that is defined by an unusual attribute (**MiHiRe**) rather than age, income, or house size.

4. DISCUSSION AND CONCLUSIONS

Electricity consumption, and by extension, energy consumption in general, may have unique local characteristics that reflect a variety of factors, including (but not limited) to those explored in the present study. However, the two-step methodology proposed for identifying clusters, if performed on a suitably constructed survey sample, may be applied anywhere.

Household lifestyles clearly influence domestic electricity consumption. The use of lifestyle classification may thus provide a useful tool to target specific energy efficiency policies at selected groups, to increase their adoption rate. Our study presents a method for identifying relevant cluster that has two main steps. The first is identification of the main socio-economic, demographic, and physical factors that influence domestic electricity consumption patterns. It is essential to recognize these factors prior to analyzing lifestyles. Note that relying exclusively on studies conducted elsewhere may not reflect unique characteristics of the target population, as well as changes in electric appliances and usage trends over time. The second step is assessment of the performance of hierarchal cluster analysis used to identify lifestyles. In this study two approaches were compared: The HCH approach was based on household characteristics that were identified as influencing residential electricity consumption. The EUB approach focused on the main electricity consumption behaviors.

Income, building floor area, number of residents, and children's age have a significant effect on domestic electricity consumption. Our study did not find that education level and employment status influenced electricity consumption directly, but these factors influence the average time adults spent at home, and thus may have an indirect effect on consumption.

Electricity consumption *per capita* tends to increase as the number of household residents decreases: our study found that older households consume twice the electricity per capita compared to young households between the ages of 20-30 (Table 2). Clusters PeLoS and PeHiL, which represent the elder (pensioner) population, have the highest electricity consumption per capita among all the clusters.

The PeHiL cluster, combining advancing occupant age with large houses and high income results in the highest electricity consumption per capita. This cluster, which comprises mainly 'empty nesters' who live in large-sized houses despite their small number of residents, may become increasingly dominant as the proportion of elderly people in the overall population increases.

The lifestyles with the highest electricity consumption (clusters PeHiL and MidHiL) are associated with large detached and semi-detached buildings. Most of these clusters, except the PeHiL cluster in the HCH approach, have high electricity consumption per floor area compared to other building types. They all have high income and own numerous electric appliances. These clusters have a substantial potential for electricity reduction. Raising awareness of appliance energy ratings and energy-efficient operation and maintenance might be an effective policy directed towards energy saving in this population.

Comparison of the two approaches indicated that the HCH approach was better at classification of the general population, resulted in more evenly divided clusters and was better at distinguishing among lifestyles with significant electricity consumption differences. It is also easier to apply because it relies on data that are more widely available. The EUB approach showed better performance in identifying small and uniquely high electricity use patterns, which the HCH approach could not treat adequately. However, the EUB approach failed in identification of groups that have a significant annual electricity use difference. Each group, except for cluster MidHiL, has at most one unique consumption pattern. This appears to be insufficient for proper classification of the population. Therefore, we recommend using the household characteristics (HCH) approach as the main classification method and the electricity use behavior (EUB) approach as a supporting one only.

Although both clustering methodologies allowed us to identify distinct lifestyles, we acknowledge that the specific outcomes reflect the limitations of the survey, the sample size and the data available to us. For example, current household income is an incomplete indicator of financial circumstances that might affect consumption. Free income (after fixed expenses such as mortgage payments) is a better indicator. We have attempted to account for the compound effects of various economic factors by seeking information about ownership of fixed assets such as the home or automobiles, but it was not possible to carry out a complete audit of the survey participants.

Further research should combine this kind of work with in-depth interviews that explore households' perceptions and awareness of environmental issues and electricity consumption, or examine the roots of their electricity use habits. In addition, future study could use smart meters, which are expected to provide better insight regarding tenants' electricity consumption patterns, with regard to both end use and temporal variations.

The findings of the analysis presented in this manuscript imply that an application of a single electricity-saving policy measure might not be effective in a highly heterogeneous population. For example, our study revealed that households comprising young couples with small children have different electricity usage patterns compared to pensioners. Thus, application of policies that target efficient electricity use for heating might be effective for young couples but less effective in the case of pensioners in our context, due to their relatively low heating demand during winter. Furthermore, families in the same life cycle stage that live in different building types or have economic differences might not have the same propensity to adopt energy efficiency measures. In such cases, different policy measures are required. Energy saving policies may also vary among neighborhoods or geographic regions.

Using the two steps for lifestyle classification, as proposed here, creates a flexible tool that can be adjusted to different population groups. The number of influencing factors and clusters can and will differ among different populations and over time, allowing policymakers to have updated and detailed data that will provide optimal policy fit to the target population.

ACKNOWLEDGEMENTS

Author 1 is supported by a scholarship from the Kreitman School for Advanced Graduate Studies at BGU. The research was supported by a grant from the Israel Ministry of Energy.

REFERENCES

1. Bin, S. and H. Dowlatabadi, (2005). Consumer lifestyle approach to US energy use and the related CO_2 emissions. *Energy Policy*, 33: p. 197–208.

2. Nielsen, L. (1993). How to get the birds in the bush into your hand: results from a Danish research project on electricity. *Energy Policy*, 21: p. 1133–1144.

3. Le Gallic, T., E. Assoumou, and N. Ma, (2017). Future demand for energy services through a quantitative approach of lifestyles. *Energy*, 141: p. 2613-2627.

4. Michman, R.D. (1991). Lifestyle market segmentation, Praeger Publishers, 1991.

5. Gram-Hanssen, K., C. Kofod, and K.N. Petersen, (2004). Different Everyday Lives: Different Patterns of Electricity Use. *Proc. 2004 ACEEE Summer Study on Energy Efficiency in Buildings*, p. 1-13.

6. Parker, D., (2003). Research highlights from a large-scale residential monitoring study in a hot climate. *Energy and Buildings*, 35: p. 863–876.

7. Yohanis, Y., J. Mondol, A. Wright, And B. Norton, (2008). Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use. *Energy and Buildings*, 40: p. 1053–1059.

8. Lutzenhiser, L., & Gossard, M. (2000). Lifestyle, Status and Energy Consumption. *Proc. American Council for an Energy Efficient Economy*, 8: 208-222.

9. McLoughlin, F., A. Duffy, M. Conlon, (2012). Characterising domestic electricity consumption patterns by dwelling and occupant socio-economic variables: An Irish case study. *Energy and Buildings*, 48: p. 240-248.

10. Santamouris, M., K. Kapsis, D. Korres, I. Livada, C. Pavlou, and M.N. Assimakopoulos, (2007). On the relation between the energy and social characteristics of the residential sector. *Energy and Buildings*, 39: p. 893–905.

11. Hache, E., D. Leboullenger and V. Mignon, (2017). Beyond average energy consumption in the French residential housing market: A household classification approach. *Energy Policy*, 107: p. 82–95.

12. Heydarian, A., C. McIlvennie, L. Arpan, S. Yousefi, M. Syndicus, M. Schweiker, F. Jazizadeh, R. Rissetto, A.L. Pisello, C. Piselli, C. Berger, Z. Yan, and A. Mahdavi (2020). What drives our behaviors in buildings? A review on occupant interactions with building systems from the lens of behavioral theories. *Building and Environment*, 179: 106928.

13. Wilson, C. and H. Dowlatabadi, (2007). Models of Decision Making and Residential Energy Use. *Annual Review of Environment and Resources*, 32: p.169-203.

14. Cho, J., (2019). Does moving home affect energy use? Exploring the micro-dynamics of residential energy consumption in the United States. *Energy Research in Social Science*, 54: p. 85–95.

15. Verplanken, B. and H. Aarts, (1999). Habit, Attitude, and Planned Behaviour: Is Habit an Empty Construct or an Interesting Case of Goal-directed Automaticity? European Review of Social Psychology, 10: p. 101-134.

16. Pierce, J., D.J. Schiano, and E. Paulos, (2010). Home, habits, and energy: Examining domestic interactions and energy consumption. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, p. 1985–1994.

17. Santin, O., (2011). Behavioural patterns and user profiles related to energy consumption for heating, Energy and Buildings, 43: p. 2662-2672.

APPENDIX A: Multiple linear regression between electricity consumption and household characteristics.

	Annual electricity use											
	total				per capita				per unit floor area			
	B^a	*Beta*^{b}	t^c		B^a	Beta^b	t^c		B^a	Beta^b	t^c	
(Constant)	6.898		**20.709**	***	*7.120*		21.812	***	3.292		10.004	***
No. adults	.002	*.002*	.028		*-.380*	-.452	**-4.428**	***	.042	.049	.485	
Average adult age	.007	*.184*	**2.251**	**	*.007*	.231	**2.313**	*	.006	.189	1.907·	
Adult education	-.027	*-.039*	-.569		*-.028*	-.051	-.631		-.036	-.064	-.800	
Adult hours @home/ day	.026	*.152*	**2.161**	**	*.026*	.179	**2.092**	*	.029	.197	**2.317**	*
Income level	.086	*.237*	**3.002**	**	*.081*	.272	**2.826**	**	.077	.254	**2.661**	**
Floor area	.003	*.218*	**2.781**	**	*.003*	.261	**2.729**	**	-.006	-.515	**-5.422**	***
Religious belief	.108	*.081*	1.287		*.136*	.124	1.623		.090	.810	.293	
Infant	.212	*.229*	**3.337**	**	*-.123*	-.161	-1.917·		.191	.247	**2.967**	**
Young child	.174	*.181*	**2.768**	**	*-.104*	-.131	-1.644		.175	.218	**2.752**	**
Teen	.122	*.107*	1.681·		*-.157*	-.167	**-2.150**	*	.102	.107	1.391	
Young adult	.329	*.230*	**3.434**	**	*-.003*	-.003	-.032		.340	.284	**3.496**	**
Adult	.236	*.239*	**3.724**	**	*-.081*	-.100	-1.279		.225	.272	**3.515**	**
employed	.133	*.193*	1.870		*.063*	.112	.895		.103	.179	1.447	
unemployed	.112	*.077*	1.030		*.089*	.075	.816		.102	.084	.924	
	R^2= 0.562				**R^2=0.354**				**R^2=0.356**			

PLEA SANTIAGO 2022
Will Cities Survive?

Assessment of the building stock performance to obtain requirements for energy codes

A building stock modelling approach aiming efficient cities

MATHEUS S. GERALDI[1], MARIA ANDREA TRIANA[1], LARISSA PEREIRA DE SOUZA[1], LORRANY MENDES[1], ANA PAULA MELO[1], ROBERTO LAMBERTS[1]

[1] Federal University of Santa Catarina, Florianópolis, Santa Catarina, Brazil

ABSTRACT: Actions to stimulate commercial buildings to be more energy-efficient are necessary. For cities administrations, requiring compliance with energy codes are an efficient path to assure adequate conditions of energy efficiency in third-party buildings. The aim of this paper is to conduct a building stock model to assess energy efficiency requirements for commercial buildings located in Florianópolis, Brazil. A tailored archetype of the commercial building stock was developed, considering regional particularities, such as construction patterns and predominant building sizes. Then, the archetype was submitted to different scenarios regarding its envelope features to improve the building performance. Also, a building performance evaluation was carried out through an Energy Performance Certificate (EPC)-based metamodel on assessing thermal loads. The scenario combinations were analyzed to select adequate envelope combinations in accordance with the best EPC rate. Consequently, those envelope combinations were set as the city energy code requirement.
KEYWORDS: Commercial buildings, building stock model, energy performance, energy codes.

1. INTRODUCTION

Commercial buildings are responsible for a significant share of the energy demand of society. In Brazil, this sector accounted for around 17.4% of the total energy demand, and buildings are responsible for 33% in 2019, according to the Brazilian National Energy Balance Report [1].

Therefore, actions to stimulate commercial buildings to be more energy-efficient are necessary. For cities administrations, the requirement of building compliance with energy codes is an efficient path to assure adequate conditions of energy efficiency in third-party buildings. However, energy codes must have accordance with the city context. Thus, effective energy code's requirements are tailored considering a building stock model and suitable conditions.

To do so, a comprehensive analysis of the building performance of an archetype might be carried out. Archetypes are representative buildings that summarise the characteristics of the building stock. The literature supports the use of archetypes for different purposes, for example, to obtain benchmarks [2] and baselines [3]; to understand behaviour patterns [4]; and to address urban building modelling [5].

The Efficient Cities project (in Portuguese "Cidades Eficientes") is a project conducted by the Brazilian Council for Sustainable Construction (in Portuguese "Conselho Brasileiro de Construção Sustentável" - CBCS). The project helped the municipal administration of the city of Florianópolis, Southern Brazil, propose actions to make the city more energy efficient. Among other objectives, the proposition of a set of requirements to compose an energy code for buildings was performed. Hence, a comprehensive database of the actual building stock was used to develop a building stock model and test energy-effective measures.

The Brazilian EPC labelling program for commercial buildings was adopted to provide guidance in those energy efficiency measures. The Brazilian EPC labelling is denominated INI-C (in Portuguese "Instrução Normativa do INMETRO para edificações comerciais") and it requires compliance with a set of standards and prerequisites. To evaluate and label a building according to its performance, the method employs a comparison between the energy performance of the building in a standardized condition and the energy performance of a reference building. The determination of the performance can be obtained by the simplified method if the building complies with the requirements. The simplified method uses a metamodel as an alternative to energy simulation to estimate energy performance, in order to amplify and simplify the labelling application, once energy simulation is a time and effort task.

Thus, the aim of this paper is to conduct a building stock model to assess energy efficiency requirements for commercial buildings located in Florianópolis, Brazil. An archetype of the commercial building stock tailored using city data was developed, considering regional particularities, such as construction patterns and predominant building sizes. Then, the archetype was submitted to different scenarios regarding its envelope features to improve the building performance. Also, a building performance evaluation was carried out through an Energy Performance Certificate (EPC)-based metamodel on assessing thermal loads. Then, the scenario combinations were analysed to select adequate envelope combinations in accordance with the best EPC rate. Consequently, those envelope combinations were set as the city energy code requirement.

2. METHOD

2.1 Building stock characterisation

The data was obtained from the municipal administration who provided a comprehensive registration history of all buildings constructed in the city, sorted by their floor-plan area, number of floors and building typology. Complementary aspects of the buildings were disposed of such as wall, roof and window type. A preliminary ratio of the building stock is presented in terms of the floor-plan area.

To carry out the archetype composition, only commercial buildings typology was selected. Bins of floor-plan area were used and the frequency of buildings that fit in each bin was accounted. Also, the average floor-plan area for each bin was determined showing the predominant building sizes.

2.2 Archetype composition

The archetype was composed of seven massing models, one representing each typical building size of each bin of floor-plan area. Then massing models were adopted as square-shaped buildings with four perimetral thermal zones and one internal thermal zone, as suggested by the Brazilian EPC code [6]. All perimetral thermal zones are sun and wind exposed and have the same window-to-wall ratio.

For each bin of floor-plan area, the average building floor-plan area was obtained according to the ratio between the total floor-plan of the stock and the number of buildings in the stock. Also, for each bin of floor-plan area, the most frequent number of storeys (mode) was identified in the building stock. Table 1 shows this data obtained from the building stock database.

Table 1:
Stock analysis in terms of the floor-plan area and number of storeys.

Bins of Floor-plan area	Amount of buildings	Total floor-plan area of the stock (m²)	Building average floor-plan area (m²)	Storeys (mode)
< 50m²	93	2,536.9	27.3	2
51 - 200m²	202	24,031.7	119.0	2
201 - 500m²	229	73,787.9	322.2	3
501 - 2000 m²	141	138,192.8	980.1	3
2001 - 5000 m²	38	127,371.7	3,351.9	8
5001 - 10000 m²	30	228,802.7	7,626.8	9
> 10000 m²	2	47,461.8	23,730.9	12
TOTAL	**735**	**642,185.4**	**873,7**	**-**

A single archetype was composed for each bin of floor-plan area, resulting in seven archetypes, to represent better the influence of the size of building in the thermal load calculation. Then, for each bin of floor-plan area of the stock, their respective building average floor-plan area was divided by the typical number of storeys to obtain typical storeys floor-plan area. Then, the typical storey floor-plan was used to represent a square-shaped storey measuring "L", obtained through the square root of the typical floor-plan area. The "L" dimension was adjusted to the integer value. Consequently, the tested archetype was defined as a core and shell type of building, with a square-shaped building, measuring "L by L" and having the median number of storeys of their respective bin of floor-plan area of the stock. The typical storey height was 3 m.

For example, for buildings with area from 201 to 500 m² (third bin of floor-plan area), the archetype was a 3-storey building measuring 10 m by 10 m (100 m² by each storey, 300 m² in total, similar to the 322 m² of the average in the stock).

Since the energy efficiency classification relies on the shape factor, this parameter was also calculated. The shape factor is obtained through the ratio between the external envelope area (walls and roofing areas) and the total volume of the building. For square-shaped buildings, the shape factor is calculated according to Equation (1):

$$SF = [(4 \times L \times S_H) + L^2] / (L^2 \times H \times S) \qquad (1)$$

where: *SF – Shape Factor (dimensionless);*
L – dimension of the square-shaped building (m);
H – Storey height (m);
S – Number of Storeys.

2.3 Scenario composition

Construction aspects of the building archetype such as transmittance and thermal capacity were set in a scenario analysis. Typical values were obtained from the building stock dataset, considering the most frequent construction elements, and better construction elements were proposed to be tested. Table 2 summarises the scenario composition for this analysis. Also, the reference scenario, representing the class D in the Brazilian EPC was tested. The combination of all cases resulted in the test of 7,200 simulations.

Table 2:
Scenario composition to assess building performance of archetypes.

Parameter	Scenarios			
	Refe-rence	1	2	3
Occupancy (m²/person)	10			
Equipment power density (W/m²)	15			
Lighting power density (W/m²)	8.5			
Roof thermal capacity (kJ/m³K)	233	36.3	13.8	
Wall thermal capacity (kJ/m³K)	150			
Roof Solar absorptance	0.8	0.3		
Wall solar absorptance	0.7	0.4		
Roof thermal transmittance (W/m²K)	2.06	1	0.55	
Wall thermal transmittance (W/m²K)	2.46	1.75	0.5	
Window-to-wall ratio (%)	40	60	80	
Glazing thermal transmittance (W/m²K)	5.7	2.7		
Solar Heat Gain Coefficient (SHGC)	0.82	0.76	0.29	0.27
Shading (vertical) (º)	0	30		-

2.4 Building performance analysis

The building performance analysis was conducted in a metamodel developed for the Brazilian National Regulation. This metamodel was developed considering an artificial neural network regarding several combinations of building stock in Brazil [6]. The metamodel is applicable for simplified cases, and the archetype fits the requirements.

The input data of the metamodel are the geometric parameters (Table 1), the scenario parameters (Table 2) and climatic information. Regarding the climatic context, the metamodel employs a climatic weighting considering the results of the simulations used to build it, which used EnergyPlus Weather File (EPW) with data from INMET 2018. The climatic parameters adopted in the metamodel, and their respective values adopted for the city are:

- Latitude (-27.597 S) and Longitude (-48.549);
- Average annual temperature (20.9 °C);
- Standard deviation of the average daily temperature (2.88 °C);
- Annual average amplitude of the temperature (7.2 °C);
- Standard deviation of the average o the temperature amplitude (0.825 °C);
- Average annual solar radiation (172.39 kWh/m²).

The city of Florianópolis is located in a climatic zone Cfa (Köppen-Geiger classification) and classified as climatic zone 1A according to the ASHRAE 169 [7].

The output of the metamodel is the cooling thermal load, in kWh/m².year, for each thermal zone modelled.

2.5 Defining the requirements for the energy code

The definition of the requirements for the construction parameters used as a criterion the cases of buildings that reach level A in the Brazilian EPC classification. To do so, the classification of all cases tested was performed. Although the Brazilian EPC considers lighting, equipment, water heating, HVAC and envelope efficiency to classify the overall energy efficiency of the building, in this study only envelope efficiency was considered due to the alignment with the objective of the study.

The envelope efficiency is obtained considering the reduction of the cooling thermal load gained from the envelope, according to Equation (2).

$$RC = (TCool_{CASE} - TCool_{REF}) / TCool_{REF} \quad (2)$$

where: RC – *reduction coefficient (dimensionless);*
$TCool_{CASE}$ – Total cooling thermal load of the case analysed (kWh/m².year).
$TCool_{REF}$ – Total cooling thermal load of the reference case (kWh/m².year).

For each building, their total cooling thermal load was obtained from the building performance analysis, and the scenarios analysed were compared to the reference scenario, in order to measure the reduction of the thermal load. It is important to highlight that a combinatory analysis was employed, meaning that the parameters combine with themselves along the different scenarios.

The next step was to obtain the minimum reduction coefficient, which depends on the shape factor of the building analysed. Table 3 is the transcription of the reference for minimum reduction coefficients (class D to class A) from the guidelines of the Brazilian EPC [6].

Table 3:
Minimum reduction coefficients from class D to class A for office buildings.

Class of Shape Factor	Minimum Reduction Coefficient
FF ≤ 0,20	0.3
0,20 < FF ≤ 0,30	0.33
0,30 < FF ≤ 0,40	0.34
0,40 < FF ≤ 0,50	0.35
FF > 0,50	0.36

Note: Adapted from [6].

The minimum reduction coefficient is used to determine the interval between classes, according to Equation (3):

$$i = TEC_B \times MRC / 3 \quad (3)$$

where: *i – the interval between classes (dimensionless);*
$TCool_{REF}$ – Total cooling thermal load of the reference case (kWh/m².year).
MRC – Minimum reduction coefficient (dimensionless).

The interval between classes is used to determine the scale of energy efficiency, according to Table 4. Each building has its own scale.

Table 4:
Scales of energy efficiency.

Class of Energy Efficiency	Lower limit	Upper limit
A	$\leq TCool_{REF} - 3i$	-
B	$\leq TCool_{REF} - 2i$	$> TCool_{REF} - 3i$
C	$\leq TCool_{REF} - i$	$> TCool_{REF} - 2i$
D	$\leq TCool_{REF}$	$> TCool_{REF} - i$
E	-	$> TCool_{REF}$

Note: $TCool_{REF}$ stands for Total cooling thermal load of the reference case (kWh/m².year).

Then, the classification of all cases was obtained according to the INI-C certification schema. Finally, the paraments set for requirements were: roof solar absorptance; external wall solar absorptance; roof thermal transmittance (W/m²K); Wall thermal transmittance (W/m²K); window-to-wall ratio (%); glazing thermal transmittance (W/m²K); glass solar heat gain coefficient; vertical shading (º). The requirements to be adopted in the energy code were defined as the lower value of the parameters that provide 50% of cases level A.

3. RESULTS

3.1 Building stock characterization

Figure 1 shows the frequency of building in each bin of floor-plan area, and the average floor-plan area of each bin. These values were used to determine the typical area of each floor for each floor-plan bin, expressed in Table 5.

Figure 1 shows that most buildings have floor-plan areas between 201 and 500 m². A total average indicates an average floor-plan area of 873.72 m² due to some buildings with high floor-plan areas in the stock.

Figure 1:
Frequency of building according to their floor-plan area and average building sizes.

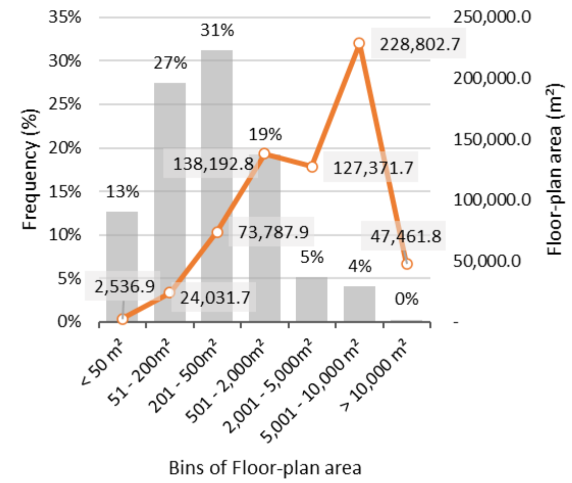


Table 5:
Massing model characteristics of the archetypes according to each bin of floor-plan area.

Bins of floor-plan area	Adopted test-storey dimensions (m)	Archetype floor-plan area (m²)	Shape Factor
< 50m²	4 x 4	32	1.17
51m² - 200m²	8 x 8	128	0.67
201m² - 500m²	10 x 10	300	0.51
501m² - 2000m²	18 x 18	972	0.33
2001m² - 5000m²	20 x 20	3,200	0.24
5001m² - 10000	29 x 29	7,569	0.17
> 10000	44 x 44	23,232	0.12

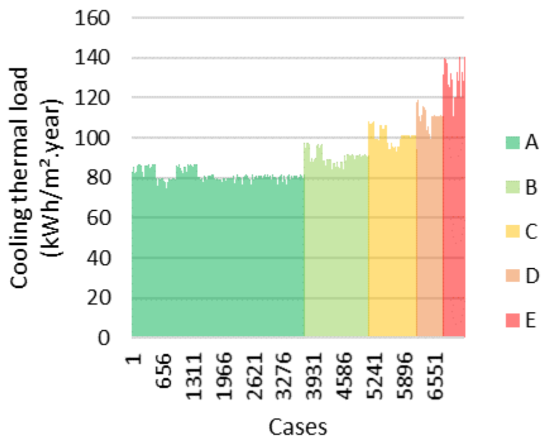
The scenarios were used to estimate several situations of cooling thermal load in the stock.

3.2 Cooling thermal load estimation

The cooling thermal load estimation was performed considering the method of Brazilian EPC [6]. For each case analysed, a total cooling thermal load was obtained. Figure 2 shows the total cooling thermal load for all cases, in ascending order.

It is possible to see that the total cooling thermal load varied from 73.29 to 140.51 kWh/m².year. The average value considering all cases was 84.99 kWh/m²year, with a standard deviation of 15.57 kWh/m².year. The reference case provided an average cooling thermal load of 111.21 kWh/m².year, ranging from 104.05 to 118.83 kWh/m².year.

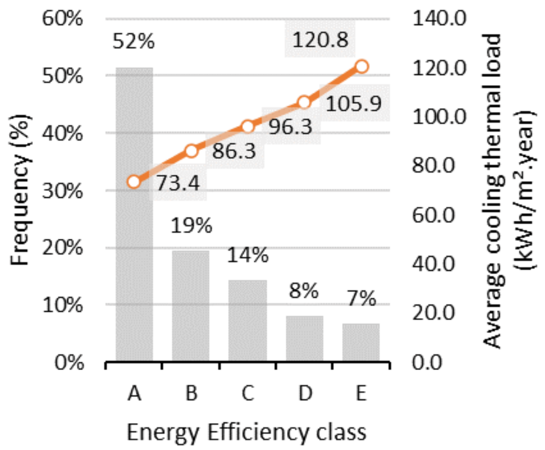
Figure 2:
Total cooling thermal load for tested cases.



3.3 Summary of the energy code requirements

The cooling thermal was used to classify the energy efficiency of the analysed cases. Figure 3 shows a histogram of cases according to each energy efficiency class.

Figure 3:
Frequency of cases according to each energy efficiency class.



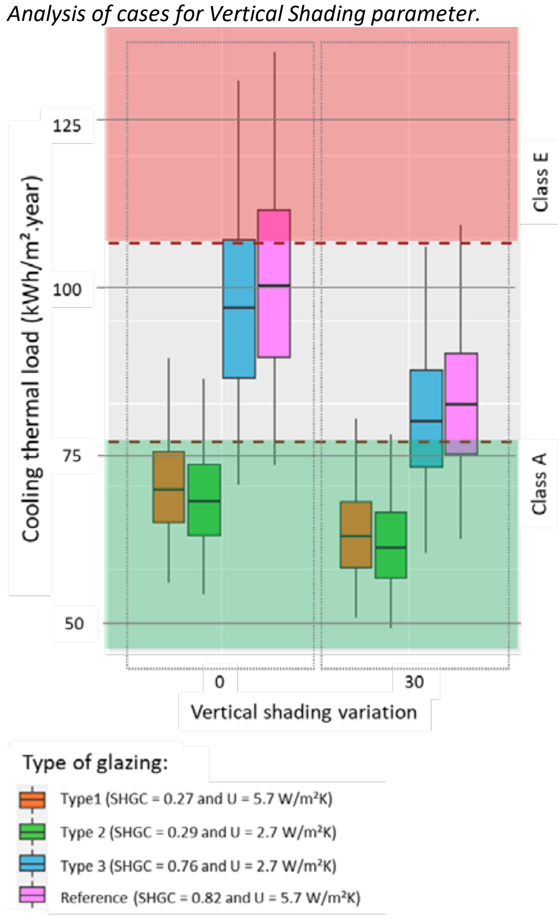
Most of results were classified as highly efficient buildings (Class A), with a lower average cooling thermal load.

As expected, the average cooling thermal load increases as the energy efficiency decreases.

In order to select minimum parameters to be set on the energy code requirements, the combination of parameters that determine a building to be class A was investigated. The following parameters were analysed according to the window-to-wall ratio (%) and vertical shading (°) of the building: roof solar absorptance; external wall solar absorptance; roof thermal transmittance (W/m²K); Wall thermal transmittance (W/m²K); glazing thermal transmittance (W/m²K); glass solar heat gain coefficient (SHGC).

To provide an example of the conducted analysis, Figure 4 shows the cases for the parameter "Vertical Shading" (other analysis will be suppressed in this paper to maintain conciseness). Two cases of "Vertical Shading" were tested: a scenario with no shadings and a scenario with a vertical shading causing a 30° obstruction to the windows. Figure 4 shows the boxplots of the cooling thermal load for the two cases differentiated according to the type of glazing (Reference Glass, Types 1, 2 and 3, with different Thermal Transmittance and SHGC. Also, the Figure shows the limits for the cases being class "A", illustrated with the green area, and the limit for the cases being class "E", as a red area. The boxplot shows the minimum and maximum quantiles (5% to 95%) of cases with each configuration, while the vertical bars shows the minimum and maximum limits of the combination tested. The line in the middle o the box shwos the median (50% of cases).

Figure 4:
Analysis of cases for Vertical Shading parameter.



According to Figure 4, it is possible to see that glazing types "Reference" (U = 5.75 W/m²K and SHGC = 0.82) and type 3 (U = 2.7 W/m²K and SHGC = 0.76) provides very few cases in class A, while glazing types 1 and 2 provides most of cases in Class A. Quantitatively, the glazing type 1 achieved 87.6% of cases in class A, type 2 achieved 90.9%, type 3 achieved 15.4% and the reference glazing achieved 12.1%.

By investigating the specific cases of each type of glazing that achieved class A, it was possible to see that the reference glazing type only achieved class A if the window-to-wall ratio was 40%. Thus, the requirement adopted was: the glazing with U = 5.75 W/m²K and SHGC = 0.82 is acceptable for buildings with WWR lower than 40%.

The exact process was performed for each parameter evaluated in this study, resulting in a table summarizing all requirements according to the WWR and shading. The final summary of the requirements is presented in Table 6.

Table 6:
Summary of the energy code requirements.

Window to Wall Ratio	Vertical Shading	Glazing	U walls (W/m²K)	Solar Absorptance of Walls	Thermal capacity of the Roof (kJ/m²K)	U roof (W/m²K)	Solar Absorptance of Roofs
Lower than 40%	Without (AVS ≤ 30°)	SHGC < 0.82 Uglass <5.75	0.5 < U < 2.5	Absor Walls < 0.7	TC > 230	U < 2.0	Absor Walls < 0.4
						U < 0.55	Absor Walls < 0.7
	With (AVS ≥ 30°)	SHGC < 0.82 Uglass <5.75	0.5 < U < 2.5	Absor Walls < 0.7	TC > 230	U < 2.0	Absor Walls < 0.7
40% to 60%	Without (AVS ≤ 30°)	SHGC < 0.5 Uglass <5.75	0.5 < U < 2.5	Absor Walls < 0.4	TC > 230	U < 2.0	Absor Walls < 0.4
	With (AVS ≥ 30°)	SHGC < 05 Uglass <5.75	U < 2.5	Absor Walls < 0.4	TC > 230	U < 2.0	Absor Walls < 0.4
60% to 80%	Without (AVS ≤ 30°)	SHGC < 0.3 Uglass <5.75	U < 2.5	Absor Walls < 0.4	TC > 230	U < 2.0	Absor Walls < 0.4
	With (AVS ≥ 30°)	SHGC < 0.5 Uglass <5.75	U < 2.5	Absor Walls < 0.4	TC > 230	U < 2.0	Absor Walls < 0.4

Note: For buildings with a window-to-wall ratio higher than 80%, a specific analysis must be conducted and justified.

4. CONCLUSION

This paper aimed to propose energy code requirements for commercial buildings located in Florianópolis, Brazil. To do so, a building stock analysis was carried out considering a database of 735 buildings. Specific information regarding their geometry was used to support the development of archetypes. The archetypes were used to estimate the cooling thermal load for each case, and then, to classify each case according to the Brazilian EPC method. Requirements were obtained from cases that reached level A of energy efficiency. Thus, the minimum requirements for energy efficiency were obtained for the parameters analysed. The results obtained in this study support that a set of different solutions can be used as requirements for high-performance buildings, depending on the combination of parameters, i.e., there is a multiple solution instead of a unique solution. The authors point out that the sensitivity analysis of the parameters for further explorations on the selection of such energy codes. Also, further studies might prospect the financial feasibility and also measure the impact of such measures proposed on the endeavouring of new buildings and retrofits.

ACKNOWLEDGEMENTS

The authors are grateful to the municipal administration of Florianópolis that contributed with information for this study. The data used in this research was made available by the Project "Cidades Eficientes", conducted by the CBCS ("Conselho Brasileiro de Construção Sustentável") and financed by ICS (Instituto Clima e Sociedade).

REFERENCES

1. BRAZIL, National Energy Balance, Report. from Brazilian Res. Energy Co. (2020). [in Portuguese].
2. E.H. Borgstein, R. Lamberts, Developing energy consumption benchmarks for buildings: Bank branches in Brazil, Energy Build. 82 (2014) 82–91. https://doi.org/10.1016/j.enbuild.2014.07.028.
3. T. Alves, L. Machado, R.G. de Souza, P. de Wilde, A methodology for estimating office building energy use baselines by means of land use legislation and reference buildings, Energy Build. 143 (2017) 100–113. https://doi.org/10.1016/j.enbuild.2017.03.017.
4. H. Ben, K. Steemers, Household archetypes and behavioural patterns in UK domestic energy use, Energy Effic. 11 (2018) 761–771. https://doi.org/10.1007/s12053-017-9609-1.
5. O. Pasichnyi, J. Wallin, O. Kordas, Data-driven building archetypes for urban building energy modelling, Energy. 181 (2019) 360–377. https://doi.org/10.1016/j.energy.2019.04.197.
6. CB3E - Centro Brasileiro de Eficiência Energética em Edificações, Proposta de método para a avaliação da eficiência energética com base em energia primária de edificações comerciais, de serviços e públicas (INI-C), (2021) 151. [in Portuguese].
7. ASHRAE, Climatic data for building design standards, ANSI/ASHRAE Stand. 169-2013. 8400 (2013).

PLEA SANTIAGO 2022
Will Cities Survive?

The influence of colour and the light in the study environment

GABRIELLE GALVÃO PEREIRA DE CARVALHO [1] DENISE DAMAS DE OLIVEIRA MORELLI[2]

[1] Adventist University of Sao Paulo, Engenheiro Coelho, SP, Brazil
[2] Adventist University of Sao Paulo, São Paulo, SP, Brazil

ABSTRACT: Concentration and focus are fundamental to successful learning in the study and research environment. Light and colour are essential to understanding an individual's behaviour and how comfortable it is in a given environment. The goal is to study the influence of colour and light in the study environment, considering the physical elements (light and vision) and the visual sensations that define the most different emotional states, which contribute or not to the individual's learning process. For this research, the method is a case study of a university library, with on-site measurement and the application of a survey to users in two distinct places of higher and lower lighting. The highest concentration of students in the study area is in the afternoon, where the predominant colours are brown, beige, grey, and wine, and the lowest luminous index is 217.2 lux, which does not meet the minimum illuminance standard of 300 lux. This results in drowsiness, poor attention, demotivation, and sadness. Thus, one can conclude that the choice of colour and percentage of lighting for the study environment must be adequate to provide success in learning.
KEYWORDS: visual comfort; study area; colour and light.

1. INTRODUCTION

This article highlights the study of colours and light and their influence on the study environment of a university library in the countryside of São Paulo, Brazil. When it comes to studying environments, we observe that the amount of light and colour applied in colour or higher intensity can affect the user's feeling of discomfort [1]. The research seeks to understand why colours and the amount of light can affect, interact, and even modify the place at hand. In the case of a library area of study, maintaining concentration and focus are critical to successful learning.

However, we need to consider many issues when studying the environment and how its elements affect its users – light and colour are essential to understand an individual in a given space and how comfortable it feels. These two elements (colour and light) are related, as light is crucial when perceiving colour. Because if there is no light, the colour will not convey the sensations it carries or obtain the impact, whether absent or not. Furthermore, it is also worth mentioning how the individual, their cultural factors, and their lived experiences affect how they perceive colours, causing the most varied sensations [1].

Thus, one can say that colour becomes part of the individual and is internalized within him, not limited only to the field of vision. Furthermore, colour can be perceived differently by each person. Therefore, correctly using each colour in the environment can provide several benefits, such as increasing efficiency in activities, improving mood, reducing visual effort, and making the environment more pleasant.

There is an importance in determining the colours; besides showing personality, they make the environments more pleasant and functional, adapting to each case. Therefore, the choice of colours and the amount of light in an environment must be coherent with the sensations and impacts intended to affect the individual, especially in a library's study and research areas. The justification for this work is based on the insufficient number of surveys on light and colour in a library's study area and the qualitative result on student behaviour and learning. The research consists of the need to analyse the study environment of a university library in the interior of the state of São Paulo, Brazil, and to identify if the colour and the amount of light provide adequate conditions for the study.

2. GOAL

This study aims to show an in-depth research method on the relationship between colour and light in the study environment of a university library.

3. METHOD AND RESULTS

For this research, the method is a case study of a university library, with an area of approximately 1,915 m², which has an administrative area, a collection of rare books, a museum, a locker, periodicals, rooms for individual and group studies, an internal garden and the other places that make up the building.

The method applied consists of a measurement taken in the internal area of the library, and four distinct environments were chosen, with different lighting levels and a higher concentration of use by students. In addition, we surveyed the students who frequent the library environments. The survey is related to the lighting influence and colours of their respective places on the student's perception of their performance and learning during their studies.

The parameter used for the lighting measurement was the Associação de Normas Técnicas do Brasil - ABNT 5413 - Iluminância de Interiores, which establishes specific values for each activity in an enclosure. The standard also specifies the determining factor of adequate illuminance as age, speed, accuracy, and reflectance of the task background, according to the characteristics of the task and the observer. For example, since the audience is under 40 years of age, the weight is lower for speed and precision, and the reflectance of the task background is higher than 70%. For the library and data-informed, the standard establishes the reading and study room with an average level of 500 lux, bookshelves and binders area of 300 lux [2].

Another critical point is using colours in the environment, which affects the user's behaviour and emotional state. According to Eva Heller, each colour is determined by its context and reveals itself pleasantly or not. The prominent colours appreciated by men are 45% blue, 15% green, and 12% red, and the least enjoyed are brown with 20%, pink with 17%, and grey with 14% [3].

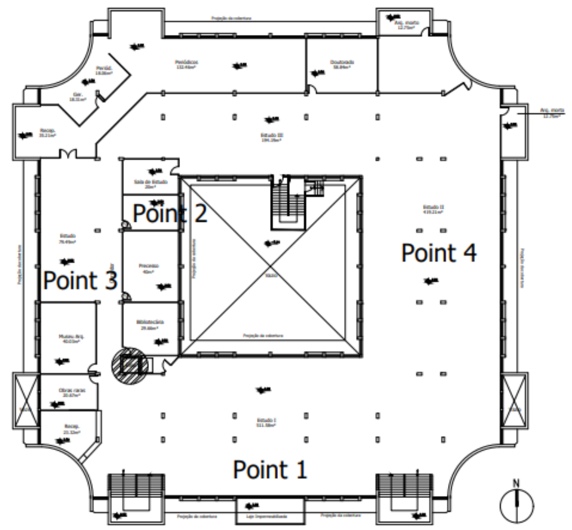
We made the measurements on a sunny day, from 8:00 am to 5:00 pm. The equipment used to perform the measurement is the Thermo-hygro-decibel-luxmeter model THDL-400, emphasises the luxmeter function with a range from 0.01 to 200000 Lux. This function captures the amount of light incidence received in a given location (Fig. 1). Accuracy: ±5% of reading + 10 digits (calibrated in the standard incandescent lamp at 2856K colour temperature).

Figure 1: *Measurement Equipment – Luxmeter.*

Source: Author's photo.

In this case, we measured four locations: Free Study Area 1 (Point 1); Study Rooms (Point 2); Study Area - Periodicals (Point 3); and, finally, Free Study Area 2 (Point 4) (Fig. 2).

Figure 2: *Library floor plan and lighting points.*



Source: Prepared by the author.

The photos (Fig. 3) show spacious environments with a ceiling height of 3.50 meters, a layout with good spacing between the work desks (which allows good circulation), window sizing, and typology (tilting) that promotes good air circulation and good natural lighting. The building also contains an internal finish of exposed concrete walls and ceilings in grey, carpet flooring with a predominance of brown, but which also has dark blue stripes and light wood chairs with red and blue upholstery. The work tables have a black metal structure with a MDF top and a Formica finish in light grey.

Figure 3: *Image of the measured points.*

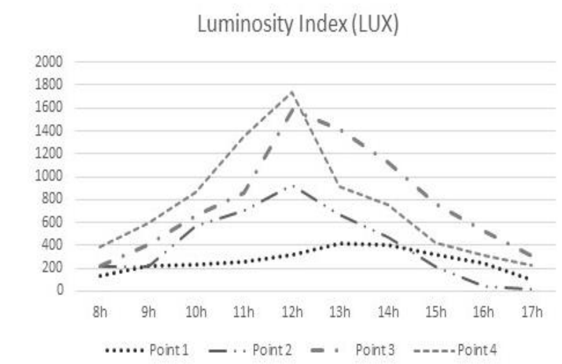
Source: Author's photo.

About the colours of the environment, there are different variations in reflectance and absorption of light, so an environment can appear to be lighter or darker, affecting the user's perception regarding the dimension of the environment, with the variation of colours according to the intensity of natural light in the room, which directly affects the arousal of emotions in people, such as mood, concentration, joy or discouragement.

One can understand that the point with the highest light incidence is located in the accessible study areas of point 1 (southern facade), reaching the maximum incidence of lux in the afternoon. On the other hand, in point 2, which consists of the study rooms (closed environment with windows on the east facade), one notices a much lower index of illumination oscillating between morning and afternoon since it is characterized as a more isolated place with windows to the internal garden.

Point 3 (west facade) is characterized by the free area for studying the journals and has a lot of sunlight, especially in the afternoon. Therefore, and to minimize this effect, smoked glass was installed, affecting the lighting levels that leave something desirable concerning adequate lighting for the study, as smoked glass, according to the ABNT 5413 Standard, has a reflection coefficient of 0.5. Finally, point 4 (east facade) presents adequate light levels in the morning, but in the afternoon, these levels decrease, affecting the lighting of the place (Fig.3)

Figure 4: *Light Index Measurement Chart (Lux).*



Source: Prepared by the author.

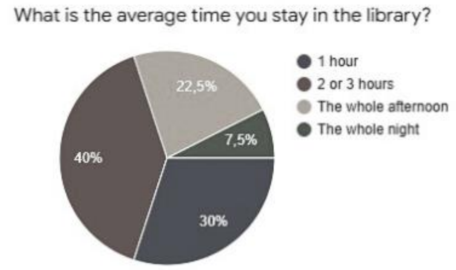
The lux required for a study environment is 500lux [2]. It is reflected in the space quality and in the individual's learning who uses the place as shown in point 1, which is configured as the point of lowest light density since, at some times, it is below the value required by the standard, which interferes with the concentration of students. Point 2 is in the 500 lux range in the morning until 10 am and in the afternoon between 1 pm and 3 pm, where natural light is insufficient for studies. Point 3 has adequate light only in the morning because in the afternoon, even with the smoked glass, it has a high lux index, making local use impossible. Point 4, during the first hours of the day, has a good lighting index, but with the solar incidence during the following hours, it also cannot be used on-site. However, the lighting returns to a reasonable level in the afternoon from 1 pm.

It is essential to inform that during the period from 11:00 a.m. to 2:00 p.m., all environments receive a great deal of light, but these are the times of least attendance by the students. It is worth mentioning that on the measurement day, a survey was carried out with 40 students aged 18 to 44 who use the library, and the points were measured at least once a week. This survey consists of evaluating the colours and lighting of the library and classifying the pleasant and unpleasant areas for study.

In the following paragraphs, we analyse the results of the student perception of the environment survey.

The duration of study or research in a library environment shows that time is low due to the lighting conditions in the background (Fig. 5).

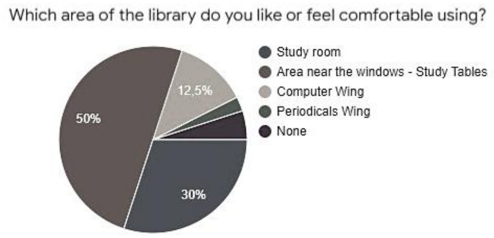
Figure 5: *What is the average time you stay in the library?*



Source: Prepared by the author.

The result of 50% of the students seeking to stay near the windows indicates the search for better use of natural lighting for their studies. The sunlight reflected by surfaces, especially in the outdoor area with the direction of the light flow through the library windows, falls first on the ceiling, distributing the light fairly. The amount of light is reasonable because the ceiling is grey and the environment is predominantly brown, causing low reflectivity (Fig. 6).

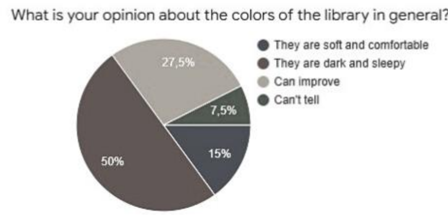
Figure 6: *Which area of the library do you like/feel comfortable using?*



Source: Prepared by the author.

Library surfaces brightness in study areas to their clarity allows the evaluation of the environment; that is, there are changes in the intensity of the colours throughout the day that influences the perception of the environment, colour, and the students' feeling. Therefore, for the practice of study and to ensure its efficiency, it is necessary to have light backgrounds due to the predominant colour of brown, which reminds us of laziness, and sleepiness, confirming the research (Fig. 7).

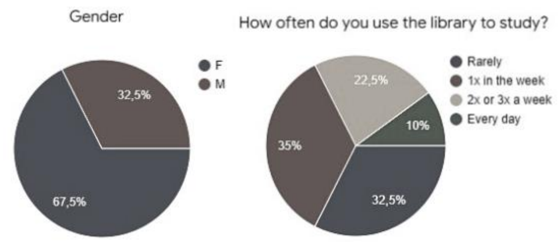
Figure 7: *Do you think the colours and lighting of this location influence your study?*



Source: Prepared by the author.

The largest student public is female, and their highest frequency is once a week. This result shows that the demand for the library's study areas is low, and the male public has a lower frequency. As a result, the perception of the library's study areas is of emptiness and unused, promoting a negative version of the place (Fig.8).

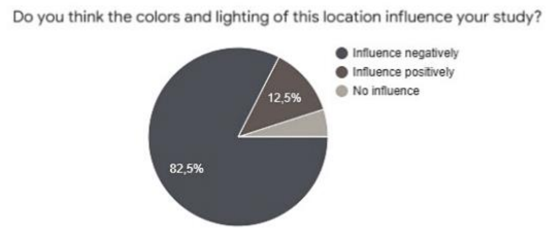
Figure 8: Gender. How often do you use the library to study?



Source: Prepared by the author.

The students, with 82.5% of response, consider that the natural lighting, in some hours, is insufficient or blinding, influencing the discomfort that increases with the exposure time in a predominantly brown environment, causing discouragement, drowsiness, and low productivity in studies (Fig. 9).

Figure 9: *Do you think the colours and lighting of this location influence your study?*



Source: Prepared by the author.

As a result, it was found that, regarding brightness, the pleasant places would be points 1 and 2; however, in point 1 (as well as most of the environments in the library), it is necessary to use artificial lighting due to the low light index. On the other hand, the unpleasant places would be points 3 and 4 due to the high lighting index during most of the day. Another issue to be highlighted about the survey result is the dissatisfaction of students regarding the colours of the library (Table 1), claiming that these directly affect their emotional state and learning, bringing negative consequences to their study.

Table 1: *Library colours according to the measured points.*

Points	Colours
Point 1 - Free study area 1	**Grey, dark beige, dark blue, brown, and red**
Point 2 - Study rooms	**Beige, dark blue, and brown**
Point 3 - Free study area of Periodicals	**Beige, dark blue, brown, and red**
Point 4 - Free study area 2	**Grey, dark beige, dark blue, brown, and red**

Source: Prepared by the author.

When analyzing the colour chart, one can notice the predominance of dark colours and earthy tones spread throughout the library, where, according to the students, it gives the feeling that the environment is dark and poorly lit. Moreover, the colour with the slightest appreciation by humans is brown, the predominant colour in the library study areas; therefore, the students' sensations correspond directly to the colour of the environment [3].

From the survey, we see that students would like a lighter environment with light colours to encourage attention and calmness in studying. We can notice the preference for areas near the windows in the settings of points 1, 2, 3, and 4 in morning hours to get as much natural light as possible.

4. DISCUSSION

Natural lighting and its intensity are crucial to making an activity easier to perform, such as reading, writing, and studying. For example, when distributing light in a study room through windows, skylight falls mainly on the floor near the window, while the light reflected from the floor illuminates the ceiling near the window. The library floor is brown carpet, and the desktop is light grey, not providing enough light for the walls and ceiling, consequently creating a dark environment. In addition, at certain times the tables near the windows can cause glare, causing discomfort and impairing the students' performance. One solution to this problem would be using movable sun shades to control the solar incidence at more excellent solar illumination times. Therefore, it is noticeable that the colours that predominate the environments are not favourable for the students' visual and emotional balance. The result is the low demand of students in these library environments for study and research. Therefore, to improve the attention and concentration of students, it is essential to apply colours in the library environments in a way that favours intelligence, science, novelty, confidence and security in the individual's learning. For this to happen, the colours blue, grey, and white are applied because they refer to intelligence and science, causing feelings of concentration, learning, and lightness. Another vital colour that brings essential lighting to the study environment (especially in areas with low light incidence) is yellow, which is the colour of light that brings out sensations of discernment, clarity, and incitement to research. Moreover, it is worth mentioning that the colour green refers to success and safety, bringing sensations of tranquillity, shelter, and functionality to the applied place. [3]

Furthermore, it is essential to emphasize that, so that the space does not become monotonous, there is a need to streamline the distribution of the cited colours suitable for each environment as a proposed solution (Table 2), for example,

Table 2: *Solutions.*

Points	Solutions (colour and light)
Point 1 - Free study area 1	The solution for this area, characterized as the one with the lowest light incidence, would be applying the yellow colour that highlights the lighting and brightens the environment, also bringing the blue or grey colour, neutralizing and encouraging concentration and learning. It will result in a clearer and lighter environment for students.
Point 2 - Study rooms	In this environment, colours that highlight the lighting, such as yellow, are also required, bringing illumination and encouraging creativity. In addition, it is necessary to apply colours that also bring neutrality to the environment, such as grey.
Point 3 - Free study area of Periodicals	This area has lighting problems caused by the Red tinted windows, leaving the environment lit with that colour due to the presence of a lot of sunlight. The solution to this problem would be the implementation of solar louvres on the windows to contain the sun's high incidence applying of colours in the environment that emphasize the lighting and concentration, such as blue, white, grey and yellow.
Point 4 - Free study area 2	Because there is a lot of lighting, it is necessary to apply colours that soften the lighting and make the environment visually lighter, such as blue, green and grey. The combination of these colours will bring concentration, safety, and functionality to the students.

Source: Prepared by the author.

5. CONCLUSION

Therefore, we conclude that the quality of colours and brightness in the study environment of the university library studied is unsatisfactory for users. We understand that the colours brown and beige have their symbolism and acceptance but are not recommended for study environments because they promote negative feelings for students. It is, therefore, necessary to promote more natural light in the environment because it stimulates the degree of attention, visual field, and colour differentiation and promotes well-being. Moreover, this set of elements (light and colour) in the study areas of a library is of utmost importance for intellectual maturation, which is an ideal place for the impulse of search, promoting the discovery that sediments the habit of reading and studying.

Furthermore, it is valid to reaffirm that natural lighting and colour are engaging factors in the interaction of students with their study environment. Studies show the importance that natural light and colour have on mood, attention, creativity, and motivation, as well as on their performance and learning required in their roles as students. Therefore, it is necessary to recognize the importance of light and colour in the reactions generated by the individual. It is also up to architectural professionals to pay attention to the theme of light and colour in the performance and learning of the student when preparing educational projects.

ACKNOWLEDGEMENTS

Acknowledgments to the Adventist University of São Paulo, Engenheiro Coelho, SP, Brazil for the support and investment with the PROBIC grant to make this work possible.

REFERENCES

1. Pinheiro, D. and Schwengber, E. C, (2002) As Cores Em Ambientes Internos Com Foco Em Suas Influências Sobre O Comportamento Dos Estudantes. p. 1–18.
2.ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT 5413 – Iluminância de Interiores, 1992.
3.Heller, E. A Psicologia das Cores. Como as cores afetam a emoção e a razão. Ed. GG. São Paulo, 2008.
4. Igawa, N. and H. Nakamura, (2001). All Sky Model as a standard sky for the simulation of daylight environment. *Building and Environment*, 36: p. 763-770.
5. Kittler, R., (1985). Luminance distribution characteristics of homogeneous skies: a measurement and prediction strategy. *Lighting Research and Technology*, 17(4): p. 183-8.
6. Perraudeau, M., (1988). Luminance models. In *National Lighting Conference*. Cambridge, UK, March 27-30.
7. International Daylight Monitoring Programme, [Online], Available: http://idmp.entpe.fr/ [16 June 2008].

PLEA 2022 SANTIAGO

Will Cities Survive?

Window design to improve natural ventilation performance including climate-based metrics and human factor analysis

LAURA MOLINA BOTERO[1] MARIA JIMENA OROZCO MESA[1] MARIA ALEJANDRA OROZCO SOSA[1] JORGE HERNÁN SALAZAR TRUJILLO[1]

[1] Universidad Nacional de Colombia, Facultad de Arquitectura, Grupo EMAT

Housing is characterized by being a complex space due to its spatial and functional diversity. In addition, the direction and speed of the wind present a high variability in small fractions of time. Some of these variables are often simplified in natural ventilation analyses, and it is possible to subject the users to annoying situations in their daily life. For this research, we developed analytical tools that could serve architects in the design process. This approach combines short-term CFD simulations and measurement tools. The analysis was done during certain periods of time (morning, midday, afternoon, night) and in different space planes defined by users' daily activities. The analysis links the performance of each space with its respective use, evidencing the inconvenience and/or convenience of some air speed ranges throughout the day inside a home. The results succeeded in estimating the annual frequency when the apartment had desirable or inconvenient speeds, allowing a spatial and temporal approach to the performance of the natural ventilation throughout the year.

KEYWORDS: Annual ventilation performance, housing, CFD simulation, climate dataset.

1. INTRODUCTION

For years energy and lighting performance decisions in buildings have been supported by annual climate-based metrics. Nowadays the computer tools needed for these tasks are commonly used in many architectural design workshops and environmental advice offices [1]. This is not the case with the natural ventilation analysis applied to buildings, that shows a significant methodological backwardness compared with energy performance studies or natural lighting simulations. Regulations concerning indoor air quality and natural ventilation in architectural spaces reveal a similar situation: they are briefly oriented to consider the minimum Air Changes per Hour (ACH), lacking a climatological approach. In our tropical context, in Colombia, meeting certain window size or estimating standard ventilation rates in every room suffices to accomplish national regulations [2,3,4].

Estimating how much air flows through a space during an hour based on the mean wind speed provides valuable information to support some informed design decisions, but leaves aside spatial and temporal approaches that could improve the analysis's representativeness. It is the case of the variation of the speed wind profiles, the inside wind flow patterns, the convenience of certain ventilation modes depending on schedule, human activities and body positions. These aspects remain excluded in the ACH approach.

Last decade brought a notorious improvement of the CFD tools, but they are still oriented to obtain results from a single speed and wind direction. Annual climate-based ventilation metrics are desirable, but even though some annual simulations for natural ventilation have already been explored [5,6], they are still complex and inefficient processes because of the intensive computational needs associated. Most of the revised research papers in our tropical context used mean wind speed and the most frequent wind direction as the representative conditions of the studied site [7,8,9,10]. It is a pragmatic approach to save computational needs, but this simplification leads to the generalization of the wind conditions, as stated in the discussion part of these works.

Unlike energy consumption analysis now considering hourly simulations during a complete year [11], natural ventilation analysis are usually limited to an average annual speed based on data measured at an airport [12,13]. The consequence of such simplification goes beyond ignoring the daily variability of wind direction and speed during the day, a relevant issue in the Andean Tropics; the procedure overestimates ventilation rates during the frequent wind calms in deep valleys, especially in the first hours of the day. It should be noted that in hot humid climates it is convenient to have air flowing in the sectors and heights where people are located, for this reason in tropical regions the arrangement of the furniture obeys the internal air flow patterns. Besides, maximum ventilation is not always the most convenient strategy because in the presence of indoor guts, it is likely that papers and objects begin to fall or that gas cooking tasks become hindered. These and other annoyances explain why high speed ventilation comes with people deciding to close the windows despite experiencing heat [14]. In cold climates, the opposite situation happens, and users make efforts to ensure natural ventilation with sufficient flow rates, avoiding guts in places where they stay the most, especially during sleeping time.

In the typical ventilation analysis used to evaluate single use rooms (i.e. offices, stores, or classrooms) major variables are discarded and the requirements are standardized without detailing about the activities that take place. The main activity defines the ventilation rates to be accomplished. In the residential buildings, characterized by its spatial and functional complexity, furniture, body posture and activity change depending on habits at different times of the day [15,16,17]. In this context complex analyses are needed to include factors that also affect the ventilation assessment in order to include local wind pattern variations [18].

The availability of abundant climatic records in the region allows a detailed characterization of the wind in a place [19], but this type of meteorological information, continuous and on an annual basis, is rarely applied by architects. There is sufficient information to estimate the annual ventilation performance without waiting for the expected rise of the computation speed needed to make Annual CFD metrics a feasible tool. This research proposes a method to integrate computer simulations, human factor analysis (daily home use patterns) and meteorological data to calculate climate-based ventilation metrics. The objectives were: a) To use the results of a CFD simulation to add spatial criteria to make differential evaluations of the heights and sectors of the room through which the air flows. b) To identify temporal wind patterns in a place, to prepare several CDF simulations to valuate wind speed in consideration of the ventilation needs during the typical schedule in a house.

This methodological exploration is intended to improve the natural ventilation analysis during the early design phase of residential projects. Some applications are being tested to refine window sizing and distribution, but the basic methodological scheme is presented here estimating the annual natural ventilation performance of an apartment.

2. METHODOLOGY

The city of Medellín, Colombia (Lat: 6.217, Long: -75.567, Altitude 1530 masl) has a multiparametric sensor network that continuously monitors the meteorological conditions of the deep Andean Valley where it is located. The facility, named “Sistema de Alerta Temprana del Valle de Aburrá” (SIATA) [20] collects minute-by-minute continuous wind data in 39 places distributed along the city since 2012. From this public dataset the records of the 2019 year near downtown were selected (Figure 1).

The complete year dataset, classified by schedule (4 ranges of hours), speed (3 ranges of wind speed), and direction (3 groups of wind direction) allowed to characterize the typical wind conditions of the site. (Figure 2).

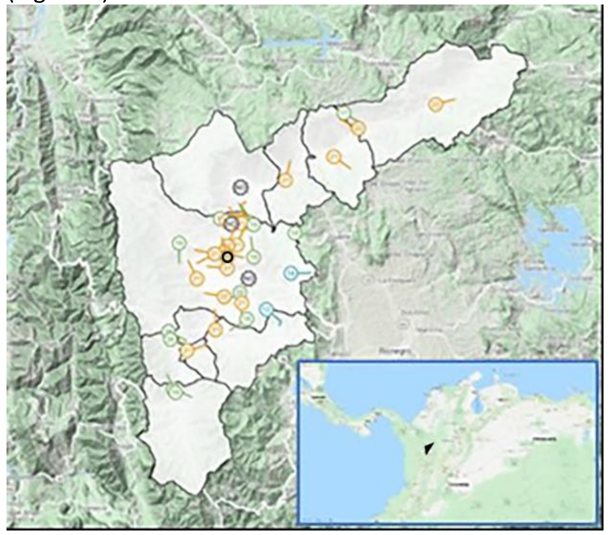
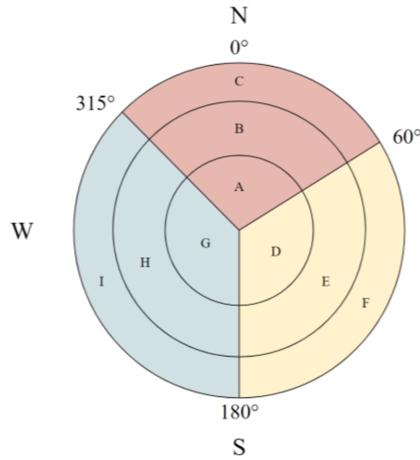


Figure 1: Medellín is located into a deep valley in the Andean Tropic. The meteorological network has 39 wind measuring stations. The 202 station that was used is highlighted.



Groups			Air speed ranges m/s
A	D	G	0.5 - 1.5
B	E	H	1.5 - 2.5
C	F	I	2.5 - 3.5

Figure 2: Classification of a complete year wind conditions measured during 2019 in the 202-AMVA station near the city downtown. The image shows 3 groups of wind direction and 3 ranges of wind speed.

2.1 Dataset pre-processing

The original dataset contains minute by minute measurements of both wind speed and direction, a volume of data nowadays impossible to manage in a CFD platform. The frequency distribution of representative conditions for every range of daily hours characterizes the temporal distribution of the local wind, increasing the time resolution of the ventilation analysis and widely surpassing the resolution of a standard EPW or TMY file.

The 24 hours of the day were grouped in four periods of time comprising 16 hours per day: Morning: (6:00 am - 10:00 am), Midday: (10:00 am - 2:00 pm), Afternoon: (2:00 pm - 6:00 pm) and Night: (6:00 pm -

10:00 pm). The midnight hours were excluded from the analysis. Most of the time there is no wind in Andean valleys and climatic conditions in the city makes it desirable to keep windows closed during night time.

The list of 525.600 wind values (total minutes in a typical year) were classified according to the already mentioned four schedules to make basic statistical analysis to know the most frequent wind speeds and directions month by month in the four schedules. The wind speed was classified in 4 groups: (a) Calms, (b) 0.5m/s to 1.5m/s, (c) 1.5m/s to 2.5 m/s, (d) 2.5m/s to 3.5 m/s. The processed dataset included as few groups as possible in order to include the 80% of the complete year data. Every pair of values of this list was used as a boundary condition to the corresponding CFD simulation (Figure 3).

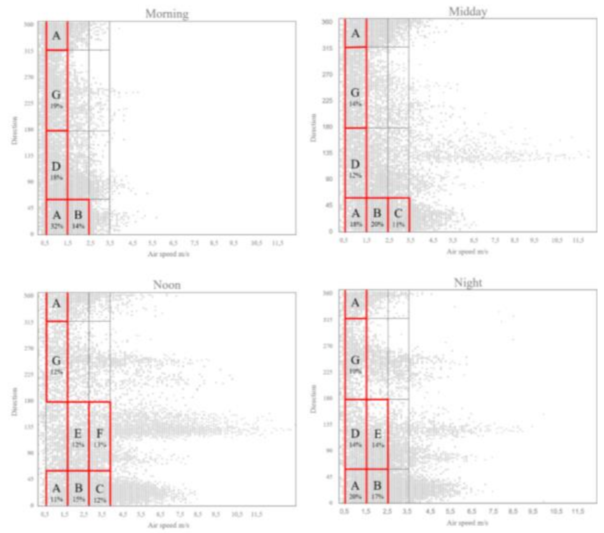


Figure 3: Wind speed and direction of every minute during the complete year in the studied location. The number of cases finally simulated varies according to the schedule: (4 cases in the morning, 6 at midday, 7 at afternoon and 6 at night). In every portion of the schedule the selected groups correspond to the 80% of the dataset ignoring the less frequent wind events

Every group contains thousands of values but in order to make the simulation feasible it is necessary to transform them into a pair of values to be used as the boundary conditions of every CFD simulation. To achieve this task the median value of each wind direction range and the mean speed of every group were calculated. The schedule structure was maintained and there are results for each one of the four lines of the daily schedule (Table 1).

These boundary conditions were used to prepare the ventilation simulation recipes of a typical 70m2 apartment located in the 3 floor of a standard residential building ventilated through 4 different windows (Figure 4).

2019	GROUP	MEAN SPEED (m/s)	DIRECTION(°)	ANNUAL FREQUENCY
Morning	A	1.0	15	32%
	B	2.0	15	14%
	D	1.0	130	18%
	G	1.0	250	19%
Midday	A	1.0	15	18%
	B	2.0	15	20%
	C	3.0	15	11%
	D	1.0	130	12%
	E	2.0	130	10%
	G	1.0	250	14%
Afternoon	A	1.0	15	11%
	B	2.0	15	15%
	C	3.0	15	12%
	D	1.0	130	9%
	E	2.0	130	12%
	F	3.0	130	13%
	G	1.0	250	12%
Night	A	1.0	15	20%
	B	2.0	15	17%
	C	3.0	15	9%
	D	1.0	130	14%
	E	2.0	130	14%
	G	1.0	250	10%

Table 1: Selection of values to simulate obtained from each classification group that add up to more than 80% in each schedule.

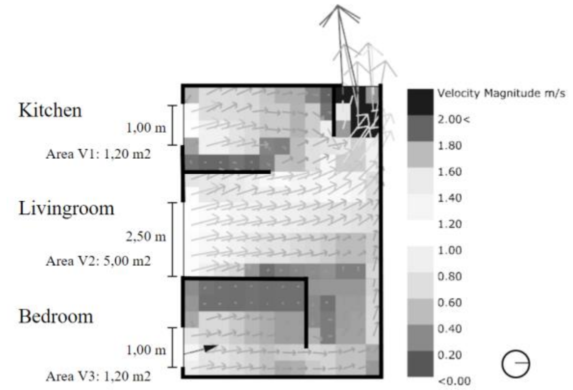


Figure 4: Typical 70m2 apartment ventilated through 4 different windows. The image also shows a CFD simulation using the wind speed and direction corresponding to the group A.

2.2 CFD simulations

Ladybug, Honeybee and Butterfly are open-source plugins for Grasshopper and Rhinoceros that help evaluate environmental performance in architecture [21]. In this computational environment several validated simulation engines such as EnergyPlus, Radiance, Daysim or OpenStudio can be used through the visual programming environment of Grasshopper. To connect the Rhino model geometry to the computational fluid dynamic simulation (CFD), prepare the OpenFOAM engine simulation cases [16] and run the simulations required, the Butterfly tools (Version 0.0.05 2019-02-23) were implemented [17].

To estimate the air speed in a room the standard practice is to prepare a single probe array and gather the results in a single mean value considered representative of the complete room ventilation scheme. The methodological approach applied was oriented to improve the spatial resolution of the analysis, for this reason we defined small different probe groups located on two horizontal planes at different heights for each space (Figure 5). The kind of activities to develop in every studied room and the expected body position according to the most probable furniture layouts allowed us to assess the air speed conditions in sub-sectors of every room (Table 2).

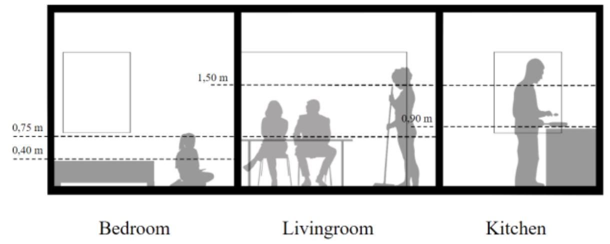


Figure 5: Each space is divided into two planes, each one at a different height, related to the activities of the users.

ROOM	PLANE 1	PLANE 2	SCHEDULES
KITCHEN	0.90m	1.50m	Morning: (6:00am - 10:00am) Midday: (10:00am - 2:00pm) Night: (6:00pm - 10:00pm)
BEDROOM	0.40m	0.75m	Afternoon: (2:00pm - 6:00pm) Night: (6:00pm - 10:00pm)
LIVINGROOM	0.75m	1.50m	Moring: (6:00am - 10:00am) Midday: (10:00am - 2:00pm) Afternoon: (2:00pm - 6:00pm) Night: (6:00pm - 10:00pm)

Table 2: Rooms, corresponding heights to locate the measuring probes and the simulated schedules to calculate the interior wind speed. Daily use of every room and furniture layout were considered to reduce the total simulation cases and the number of required probes.

2.3 Evaluation of the performance of natural ventilation

To assess the obtained conditions, both the air flow entering the space during every hour and the air speed inside every room were evaluated, computing the total number of hours the results accomplished the desirable indoor ventilation conditions.

Different threshold air speed values were applied depending on the occupation conditions, expected activity and corresponding schedule. The values used to define these intervals were determined subjectively, starting from the experience of the authors and matching it with the results of a field work still unpublished. It is reasonable to consider that local preferences could induce bias to a standard value, but the technical literature in ventilation doesn't report any recommendation with such detail level. The national standards, oriented to promote energy savings in HVAC systems rather than comfort in passive architecture, neither include any threshold recommended value.

Usually the ventilation analysis is oriented to calculate the air volume passing through a room. The air changes per hour methodology ACH lacks to consider the wind annoyances inside some rooms because a suitable air change condition could be obtained by uncomfortable wind patterns. Hanging objects tend to fall, the kitchen flame turns off, the breakfast colds too fast… To assess the convenience or inconvenience of a definite speed in every sub sector of a room different air speed thresholds values were considered, according to the time of the day, the probable activity level or the associated clothing, amongst other possible considerations. (Table 3).

ROOM	LOW AIR SPEED	HIGH AIR SPEED	SCHEDULES
KITCHEN	< 0.5 m/s	> 0,7 m/s	Morning
	< 0.5 m/s	> 0,7 m/s	Midday
	< 0.5 m/s	> 0,7 m/s	Night
BEDROOM	< 0.5 m/s	> 0,7 m/s	Afternoon
	< 0.3 m/s	> 0,5 m/s	Night
LIVINGROOM	< 0.5 m/s	> 0,7 m/s	Moring
	< 0.5 m/s	> 0,9 m/s	Midday
	< 0.5 m/s	> 0,9 m/s	Afternoon
	< 0.5 m/s	> 0,7 m/s	Night

Table 3: Air speed threshold values classified by schedule and room. The probe values were evaluated according to these bounds to assess every ventilation condition.

To determine if each space was over or under ventilated during every schedule and at a specific height, the number of points on each plane that corresponded to air speed data from one of the ranges mentioned before (low or high air speed) was calculated. And the following premises were established, based on previous research [18]:

If more than the 80% of the total points simulated in each plane corresponded to the range "Low air speed", the space was evaluated as *under ventilated.*

If more than the 15% of the total points simulated in each plane corresponded to the range "Low air speed", the space was evaluated as *over ventilated.*

If none of the previous premises were true, the space was evaluated as *desirable.*

Finally, we calculated the annual frequency for each evaluation, based on the database that was already processed (Table 1).

3. RESULTS

For each space, the results were analyzed for the two planes at different heights, at the specific schedule that was evaluated. The results were organized in a horizontal bar chart, where it is possible to see the percentage of instants in the year that each space was evaluated as under ventilated, over ventilated or desirable, depending on the height of the plan used for the simulation, and the time of day (Figure 6).

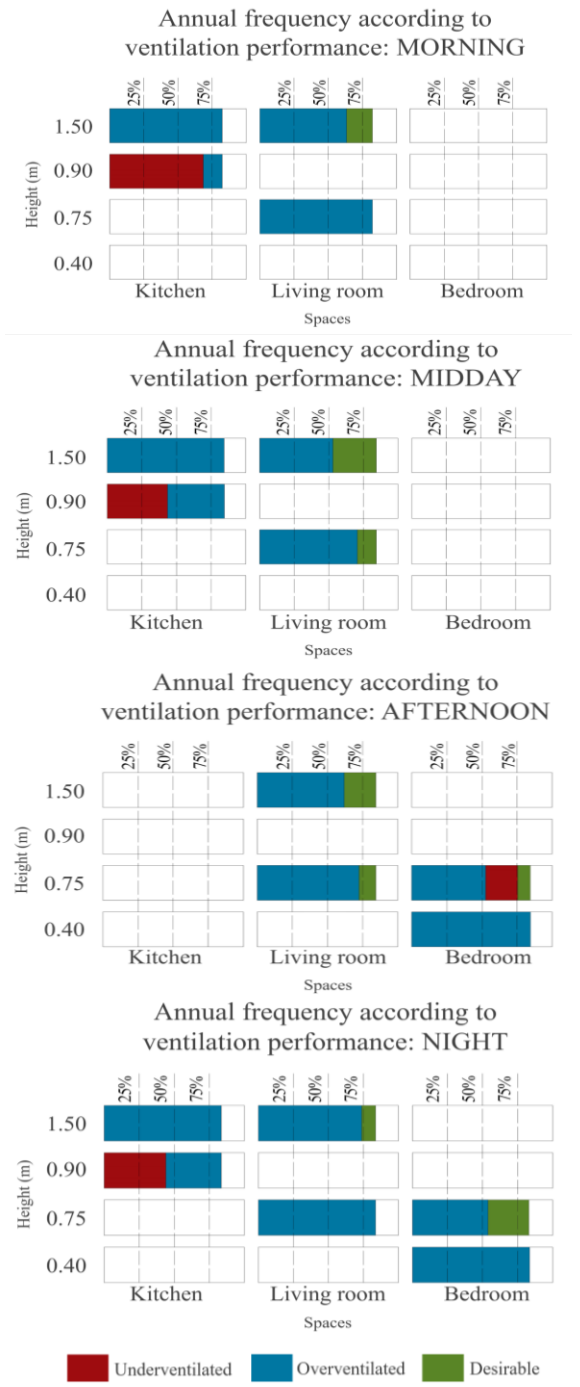


Figure 6: Annual frequency according to ventilation performance in two different planes for the three spaces in each schedule.

Figure 6 shows that the kitchen, that was the only space evaluated at 0.90 m, was under ventilated more than the 44% of the year during the morning, midday, and night, when it was evaluated at 0.90 m, also there wasn't any instant with desirable conditions throughout the year. On the other hand, when the kitchen was evaluated at 1.50 m, it was over ventilated more than the 80% of the year for the whole day.

The living room is the only space that has at least a frequency of 10% of the year with desirable conditions, when the 1.50 m plane was evaluated. During midday, 45% of the year had desirable conditions, 34% of the year in the afternoon, and 19% of the year in the morning. On the other plane (0.75 m), at least 12% of the year during the afternoon has desirable conditions, this also happened during the midday 14% of the year.

Finally, the bedroom was the only space evaluated at 0.40 m, and was over ventilated 84% of the year during the afternoon and night. When the 0.75 m plane was analyzed, 30% of the year the room had desirable conditions at night, and only 9% during the afternoon.

3. DISCUSSION

Having in mind the results, one of the problems that the apartment has, is that the kitchen at the height of the stove was under ventilated almost 70% of the year during the morning, and almost half of the year during the midday and night. Those are the times of the day when the kitchen is most likely to be in use, specifically for cooking. This situation can cause smells and gases to build up. For this reason, it is recommended from the architectural design, to increase the size of the opening located in this space, in order to reduce the moments in the year in which the space was under ventilated.

The bedroom also was under ventilated during the afternoon when the 0.75 m plane was evaluated. 0.75 m corresponds to the height of a desk where a person can work, or a child can study during this time of the day. However, more than half of the year the room was over ventilated, this condition can cause papers and objects to begin to fall, forcing the user to completely close the window most of the year. For this reason, it can be worse if window size is increased. Also, having in mind that at 0.4 m more than 80% of the year the bedroom was over ventilated, it might be more important to fix this condition and reduce the size of the window. However, it must be taken into account that only a change in the size of the window is being considered, but it could be possible to look for other solutions such as a change in position that help increase the number of annual instants with desirable wind conditions.

Finally, the general results show that most of the year, in almost every space, during the 16 hours that were evaluated, the apartment was over ventilated. This condition can seriously affect the comfort of the user and the activities carried out every day, the specific consequences were previously mentioned. Taking this into account, it is important to study other alternatives for the design of the windows of the 3 spaces that were analyzed, with the objective of increasing the number of instants with desirable conditions during the year.

4. CONCLUSION

Every wind condition corresponds to a definite pair of values: wind direction and air speed, but it is impractical to make 525.600 CFD simulations to analyze the ventilation performance of a room during the complete year because in this hypothetical case the results for every studied room would consist of millions of values to be grouped by schedule, probe zone, height and so on. Many places show a stable wind pattern during the year, specially in the Equatorial Zone where there are no major seasonal changes, but exchanging the mentioned complexity to a single pair of values could be too much simplification. The developed method is a mixture of two routes: starts with the statistical processing of the meteorological data and entwines the wind history of the place with the wind profiles inside the room via computational simulation.

The temporal resolution now offered by the meteorological networks are rarely used in the natural ventilation analysis. In this research, we calculated the total number of annual instants three different rooms maintained a good ventilation performance. This type of mixed analysis is practical and can be adapted for other architectural applications to make informed decisions based on climatological data and CFD simulations.

Classifying meteorological data by hourly groups, and then post-process these results according to different room/schedule air speed thresholds, improves the analysis and makes it possible to include Human Factor issues to the ventilation discussion without major methodological refinement.

REFERENCES

1. Mardaljevic, J., Heschong, L., and Lee, E. (2009). Daylight metrics and energy savings. *Lighting Research and Technology*, 41(3), p.p. 261–283. https://doi.org/10.1177/1477153509339703
2. Ministerio de Educación. República de Colombia. Norma Técnica Colombiana NTC 4595. Planeamiento y Diseño de Instalaciones y Ambientes Escolares. [Online], Available: http://www.mineducacion.gov.co/1621/articles-96894_Archivo_pdf.pdf [11 March 2022].
3. INSTITUTO COLOMBIANO DE NORMAS TÉCNICAS Y CERTIFICACIÓN (ICONTEC). NTC 5138. Ventilación para una calidad de aire aceptable en espacios interiores. (s.f).
4. Ministerio de Vivienda, Ciudad y Territorio. República de Colombia. Resolución número 0549, 10 julio 2015. Parámetros y lineamientos de construcción sostenible.
5. Zhang, R., Lam, K., Yao, S., (2012). Annual coupled energyplus and computational fluid dynamics simulation of natural ventilation. SimBuild 2012.
6. Sakiyama, N., Mazzaferro, L., Carlo, J., Bejat, T., Garrecht, H., (2020). Natural ventilation potential from weather analyses and building simulation. *Energy & Buildings*.
7. Marin Restrepo, Laura et al. Natural Ventilation and Indoor Noise Reduction. Development of a prototype of an architectural device. PLEA2013, Munich, Germany 10-12 September 2013.
8. Castro Gallego, Viviana et al. Evaluation of the Relationship between Natural Ventilation and the Grouping of Five Year Old Children in a Kindergarten Classroom of Medellin. PLEA2012. Lima, Perú 7-9 November 2012.
9. Garcia, Ader (2012). Recomendaciones técnicas para aulas de jardines infantiles en el clima tropical andino colombiano. Universidad Tecnológica de La Habana.
10. García, A. A., Bolaño, M., Medina, D., Arango, J.P., (2018). Evaluación integrada de iluminación natural, ventilación y ruido en tres aulas infantiles de Medellín, Colombia. MACDES 2018. Habana, Cuba.
11. Zarnikau, J. and Zhu, S.S. (2014) The Identification of Peak Period Impacts When a TMY Weather File Is Used in Building Energy Use Simulation. *Open Journal of Energy Efficiency*, 3, 25-33.
12. Daemei, A., Osmavandani, P., Nikpey, M., (2018). Study on Vernacular Architecture Patterns to Improve Natural Ventilation Estimating in Humid Subtropical Climate. *Civil Engineering Journal*, Vol. (4) No. 9, 2097-2110.
13. Meiss, A.; Padilla-Marcos, M. A.; Feijó-Muñoz, J., (2017). Methodology Applied to the Evaluation of Natural Ventilation in Residential Building Retrofits: A Case Study. *Energies*, 10, 456.
14. Molina, Laura. Evaluación de la ventilación natural de espacios arquitectónicos a partir de registros meteorológicos locales y simulaciones CFD. Universidad Nacional de Colombia, Medellín, Nov 2022.
15. Morales, Catalina et al. Método de evaluación de condiciones ambientales aplicado a dos viviendas en la ciudad de Medellín, Colombia. VI Encontro Nacional e IV Encontro Latino-americano sobre Edificações e Comunidades Sustentáveis. Vitória-Es-Brasil, September 2011. DOI: 10.13140/RG.2.1.1944.2647
16. Salazar, Jorge and Maria Alejandra Orozco. Estimación de la eficiencia de la ventilación natural en un edificio de oficinas. XII Encontro Latino-Americano de Conforto no Ambiente Construído. Palmas(TO) [Online], 2021. Available: <https//www.even3.com.br/anais/encac2021/327523. [15/02/2022 18]
17. Orozco, María Alejandra; Orozco, Maria Jimena; Salazar, Jorge. Cálculo de coeficientes de eficiencia de ventilación natural para la evaluación y predicción de la ventilación en edificios. XII Encontro Latino-Americano de Conforto no Ambiente Construído. Palmas (TO) [Online] Available: https//www.even3.com.br/anais/encac2021/340679. [15/02/2022].
18. Molina, Laura and Santiago Becerra. Incidencia de la altura en la ventilación natural en torres de vivienda. XII Encontro Latino-Americano de Conforto no Ambiente Construído. Palmas (TO) [Online] Available: https//www.even3.com.br/anais/encac2021/337156 [15/02/2022].
19. IDEAM. Atlas de Viento de Colombia. [Online] Available: //atlas.ideam.gov.co/visorAtlasVientos.html [nov 2022]
20. SIATA. Sistema de Alerta Temprana del Valle de Aburrá. Geoportal. [Online] Available: https://siata.gov.co/siata_nuevo/ [feb. 2022].
21. Sadeghipour Roudsari, Mostapha; Pak, Michelle, 2013. Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. 13th International IBPSA Conference. Lyon, France. [Online] http://www.ibpsa.org/proceedings/BS2013/p_2499.pdf

PLEA SANTIAGO 2022
Will Cities Survive?

Calculating the carbon footprint of different construction options during the building design phase in the Latin American context

The EVAMED case study

VÍCTOR ALBERTO ARVIZU-PIÑA [1] ANDRÉS ALBERTO GARCÍA GONZÁLEZ[1] ANDRÉS TORTOLERO BAENA[1] JOSÉ FRANCISCO ARMENDÁRIZ LÓPEZ[2] RODRIGO ROBERTO ARCE ANGUIANO[1] MARIANA ABIGAIL CARMONA GUZMÁN[1] CRISTINA GAZULLA SANTOS[3] JUAN PABLO CHARGOY AMADOR[4]

[1] Universidad Iberoamericana Ciudad de México
[2] Universidad Autónoma de Baja California
[3] Elisava Design and Engineering School of Barcelona
[4] Centro de Análisis de Ciclo de Vida y Diseño Sustentable

ABSTRACT: This work presents an overview of the functionality of the EVAMED tool (Environmental Assessment of Buildings with a Life Cycle approach). The main objective of this tool is to assist building designers and constructors, mainly in Mexico and the rest of Latin America, from the first design phases, to create buildings with a lower environmental impact throughout their whole life cycle. EVAMED's interface is friendly and intuitive, as it is aimed at a non-LCA expert user. The configuration of the project to be evaluated through EVAMED is done over a 'wizard' type process. The results are presented through interactive graphs that allow visualizing the potential environmental impacts from different approaches: by life cycle stages or by construction systems and materials. This allows different types of evaluations to be carried out, for example, analysing the building Carbon Footprint, the environmental impact of its use phase, or evaluating its complete life cycle. A case study is presented where the carbon footprint of four construction solutions is evaluated from a basic building geometry modelled in Revit.
KEYWORDS: LCA, Building Environmental Assessment Tools, EPD, BIM, Sustainable Buildings

1. INTRODUCTION

The building sector is generally recognized as one of the sectors with the greatest environmental impact globally. According to Passer, et.al. (Passer et al., 2012), the optimization of energy consumption during the buildings operational phase has reached its limit, which has caused the rest of their life cycle stages to take on greater relative importance on its potential environmental impacts. This means the strategies implemented to reduce the buildings energy consumption (passive and / or active strategies), may transfer the environmental impacts of the use phase, to other life cycle phases, such as the materials production, transportation, construction, or the end-of-life stage (Hollberg et al., 2018).

Life Cycle Assessment (LCA) is a widely recognized methodology for evaluating, rethinking processes, and eventually improving the energy and environmental performance of a building. However, it has also been recognized that its application in the building sector is generally complex and time consuming. The lack of experience and knowledge on this methodology by architects, as well as the lack of information on construction products and processes, are other factors that slow down its widespread application (Di Bari et al., 2019; Hollberg et al., 2018; Meex et al., 2018; Obrecht et al., 2020).

Despite the fact that the decisions made in the early stages of the architectural design process are those with the greatest relevance in the environmental performance of a building, little information is available about the building in those stages to carry out a complete LCA , for example, the exact amount and type of construction materials to be used are not known (Hollberg & Ruth, 2016).

In recent years, tools have been developed to facilitate the LCA application in buildings, saving time and reducing information requirements. This has been possible due to the 3D computational models (mainly through Building Information Modeling, BIM), and to the environmental information that has been generated on various construction materials (mainly through Environmental Product Declarations, EPDs). The interoperability of these tools with several databases is another feature that remark their usefulness and operation (Crippa et al., 2020; Di Bari et al., 2019; Hollberg et al., 2021; Meex et al., 2018; Soust-Verdaguer et al., 2017).

Although the use of these tools to develop LCAs of buildings is increasingly common, it is important to mention that most of them have arisen in developed countries, for local use, and generally do not allow national or regional variations. That is, the databases they use are not usually appropriate for use in contexts other than those for which they have been developed.

The objective of this work is to present an overview of the functionality of the EVAMED tool (Environmental Assessment of Buildings with a Life Cycle approach). The main objective of this tool is to assist building designers and constructors, mainly in Mexico and the rest of Latin America, from the first design phases, to create buildings with a lower environmental impact throughout their whole life cycle. It is an online platform (currently under development), which looks to be freely access, through user registration and password.

A case study is presented where the incorporated carbon footprint of four different construction solutions for a house are evaluated. This exercise does not include operational energy, neither the transport, construction nor end of life phases, since the objective of this case study is to show how EVAMED could assist for the selection of construction solution from the environmental perspective. The analyzed house of this case study is based only on a basic geometry, where the construction systems and building materials to be used are not yet known. EVAMED calculates different construction system options, based only on the geometry of the building, to calculate their potential environmental impacts, and provide this information to the user to facilitate decision-making during the early design phases.

2. EVAMED METHODOLOGY

EVAMED is based on a series of algorithms that implement the calculation logic of the LCA methodology. This methodology is based on the phases of the life cycle and the modules defined in the EN 15978 standard. The EVAMED interface is friendly and intuitive, since it is aimed at a user who is not an LCA expert. The tool is made up of five general parts:

2.1 Project Description

General information of the project to be evaluated is defined: type of project (housing, business, office, etc.), location, construction surface, habitable surface, number of levels and useful lifetime.

2.2 Quantification of construction materials

The quantification of construction materials is one of the most time-consuming processes during the LCA of buildings. As part of the EVAMED project, a DYNAMO file has been developed that allows the quantity of materials in a building model made in Revit to be quantified. According to the American Institute of Architecture (AIA), the Level Of Detail (LOD) that can be achieved for a building model can be classified into five levels: LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500 (Soust-Verdaguer et al., 2017). The DYNAMO file (which can be downloaded from the EVAMED platform and installed on the user's computer) allows materials to be quantified under two scenarios, depending on the LOD level reached:

1) *Automatic quantification of construction materials for a Revit model with LOD 300.* When the user has specified construction materials in a Revit model, a file with an xlsm extension can be generated with the quantification of construction materials, cataloged in the different construction components that make up the building (foundations, floors, walls, roofs, etc.). This file can be uploaded to EVAMED, whose information will be cataloged as 'Revit Model'.
2) *Automatic quantification of construction materials for a Revit model with LOD 200*. When user has just modeled a basic geometry (floor, walls and ceilings), without specifying materials or construction systems, an xlsm file can be generated with the quantification of different construction systems, calculated from the modeled basic geometry. This feature is useful to support the user in the selection and combination of different construction systems based on their environmental performance throughout their life cycle. This information will be cataloged within EVAMED as 'EVAMED Options'.

A third building material quantification option is available for users who do not have a Revit building model. In these cases, it is possible to download from the EVAMED platform, a template in xlsm format that can be filled in manually, selecting the construction materials that are preloaded in the EVAMED database.

2.3 Project configuration

The project configuration is carried out through a wizard-type process that is made up of four general stages:

2.3.1 Production

In this stage, the quantification of construction materials is shown, which is read from the xlm file that has previously been imported. This information is cataloged in the main components of a building: foundations, interior walls, exterior walls (facades), floors, intermedial floors, ceilings, structure, doors, windows, special installations, and others. New materials can be added directly to EVAMED. Each material is associated with the internal EVAMED database to quantify their respective environmental impacts (stages A1, A2 and A3 of the building's life cycle). For each construction material, it is possible to edit the quantity, as well as to specify up to two types of transport (stage A4). Similarly, it is possible to specify lifetime or number of replacements for each material during the useful life of the building (stage B4).

2.3.2 Construction

In this stage (A5) the energy consumed during the construction process of each construction element (foundation, floors, interior walls, etc.) is specified.

2.3.3 Use

The energy consumed during the building use phase is specified (B6). It is possible to select between energy from the country electricity grid, another source of energy such as natural gas, and the use of photovoltaic panels for the self-generation of electric energy (the calculation of the energy requirement is carried out externally to EVAMED).

2.3.4 End of life

As in the construction phase, the energy used during the deconstruction process of each construction element is specified (stage C1).

2.4 Databases

For the production phase (A1-A3), EVAMED is based on three sources of information:

2.4.1 MEXICANIUH

It is a database of the main construction materials produced and used in Mexico's building sector. It is developed by the Center for Life Cycle Analysis and Sustainable Design (CADIS), which participate in the EVAMED project. Among the materials considered are brick, hollow block, cement, sand, and gravel, as well as the Mexican elecricity mix. The potential environmental impacts of each material have been calculated under the LCA rules, using the CML 2 baseline 2000 V2.05 evaluation method.

2.4.2 Environmental Product Declarations (EPDs)

EPDs are a type III environmental label that "presents quantified environmental information on the life cycle of products to allow comparison between products that fulfill the same function" (AENOR, 2010). The quantification of the potential environmental impacts is based on the Product Category Rules (PCR) that specify the calculation rules and the way of presenting the results within an EPD document. The calculations and results are reviewed by an independent third party, thus ensuring the transparency of the information (AENOR, 2010). EVAMED considers the EPDs published by The International EPD System for construction products manufactured in Mexico, as it is the one with the greatest presence worldwide (Ibáñez-Forés et al., 2015).

2.4.3 Environmental Performance in Construction (EPiC)

It is an extensive database of different building materials. Unlike MEXICANIUH and the EPDs, EPiC only considers construction materials from Australia, and is limited to quantifying the energy and water consumed during the manufacture of the materials, as well as the equivalent CO_2 emissions [13]. EVAMED uses this information to contribute to the calculation of the carbon footprint.

For the transportation (A4), construction (A5), replacement (B4), operational energy use (B6), and demolition (C1) phases, EVAMED considers the ECOINVENT V3 database, using the CML-IA calculation method. baseline V3.06/EU25.

2.5 Results

After configuring the project, the results are presented through interactive graphs that allow visualizing the potential environmental impacts in the following categories: Abiotic depletion (PAAe), Abiotic depletion (fossil fuels) (PAAf), Global Warming (GWP), Ozone Depletion (ODP), Acidification for soil and water (AP), Eutrophication (EP), Photochemical oxidation (PFOF), Acidification (PA), Eutrophication (PE), and Water scarcity potential (EA). The results can be visualized from different approaches: (1) by life cycle stages, (2) by construction elements, and (3) construction elements by life cycle stages.

These results allow different types of evaluations to be carried out, for example, analyzing the embodied carbon footprint of a building, evaluating the environmental impact of its use phase, or evaluating its complete life cycle.

After viewing the results, the user has the possibility to adjust his proposal to improve its energy and environmental performance. For example, these adjustments can focus on implementing bioclimatic design strategies, using alternative materials, implementing renewable energy generation systems, using local materials, changing transportation systems, modifying construction and/or demolition processes, etc. After adjusting, the user can compare the results of various proposals on his case study. These results can serve as a reference to comply with some regulation, environmental-energy certification system, or just to improve the environmental performance of the building.

3. CASE STUDY

The case study analyzed for this work is based on a social housing project developed by the Mexican company CONSULTE Hogar. This case study is based on a Revit geometric model of LOD 200, where only the basic geometry has been modelled. The geometric proposal of this house is made up of a surface of 42.31 m^2 with a height of 2.7 m. This analysis is limited to evaluating the potential environmental impacts of four possible construction systems for a housing project during the production phase (A1-A3).

3.1 Project configuration

DYNAMO was used to quantify the amount of construction materials for the most used construction systems in Mexico. In this exercise, four construction systems were considered with their respective materials (Table 1). The materials calculated for each of them are shown in Table 2. These data were integrated in the xlsm format within the 'EVAMED Template' option to be later read by the tool. Figure 1 presents an example of how this information is displayed.

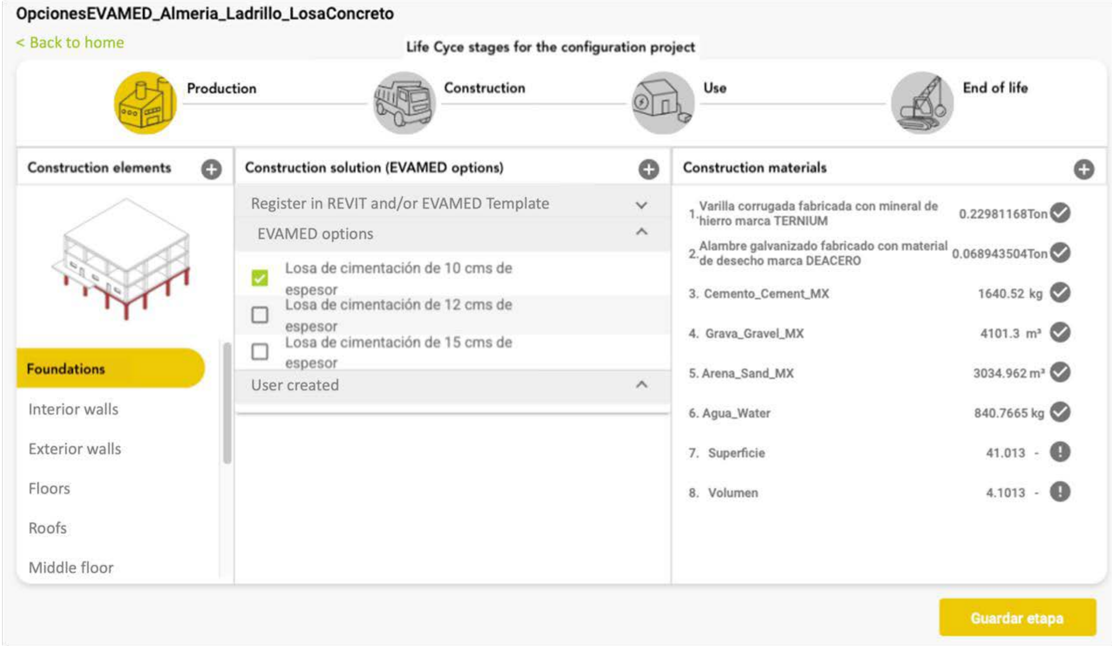
Table 1:
Construction solutions proposed

Construction element	Constructive solution 1	Constructive solution 2	Constructive solution 3	Constructive solution 4
Foundation	Foundation slab 10 cms	Foundation slab 10 cms	Foundation slab 10 cms	Foundation slab 10 cms
Interior wall	Brick 7x14x28	Brick 7x14x28	Hollow block 15x20x40	Hollow block 15x20x40
Exterior wall	Brick 7x14x28	Brick 7x14x28	Hollow block 15x20x40	Hollow block 15x20x40
Celling/Roof	Concrete slab	Joist and vault	Concrete slab	Joist and vault
Structure	Concrete columns	Concrete columns	Rods embedded in concrete	Rods embedded in concrete

Table 2:
Construction materials calculated for the different construction solutions proposed

Material	Unity	Foundation	Interior Wall	Exterior Wall	Floor	Celling/Roof	Structure	Database
Sand for concrete	M^3	X				X	X	MEXICANIUH
Sand for mortar	M^3		X	X	X		X	MEXICANIUH
Sand for finish flattening	M^3		X	X				MEXICANIUH
Gravel	M^3	X				X	X	MEXICANIUH
Cement for concrete	Kg	X				X	X	MEXICANIUH
Cement for mortar	Kg		X	X	X		X	MEXICANIUH
Cement for finish flattening	Kg		X	X				MEXICANIUH
Water for concrete	Kg	X				X	X	EPiC
Water for mortar	Kg		X	X	X		X	EPiC
Water for finish flattening	Kg		X	X				EPiC
Steel rod	Ton	X				X	X	EPD
Stirrup wire	Ton	X				X	X	EPD
Tie wire	Ton	X				X	X	EPD
Brick 7x14x28 cms	Kg		X	X				MEXICANIUH
Hollow block 15x20x40 cms	Kg		X	X				MEXICANIUH
Ceramic tile	Kg				X			EPiC
Joist 16 cms	Kg					X		MEXICANIUH
Vault 16 cms	Kg					X		MEXICANIUH

Figure 1:
Project configuration during production stage



3.2 Case study results

Table 3 shows the carbon footprint of each of the proposed construction options.

Table 3
Carbon footprint of the constructive solutions (kg CO2 eq).

Constructive solution 1	Constructive solution 2	Constructive solution 3	Constructive solution 4
1.73e+4	1.64e+4	1.76e+4	1.50e+4

EVAMED allows the user to explore the results through interactions in the graphs. Figure 2 shows the potential environmental impacts of the construction systems of the four construction solutions proposed for the case study. It is observed that the exterior walls present the greatest environmental impact in all the categories, in the four cases analyzed, except for global warming.

Figure 2:
Potential environmental impacts by construction elements

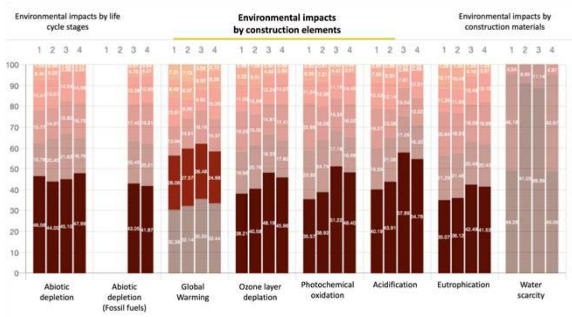
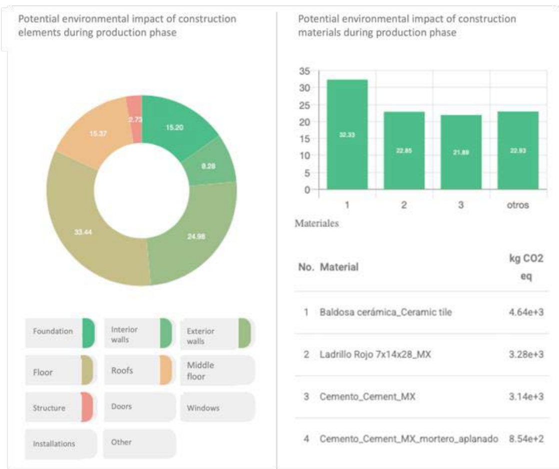


Figure 3 shows the materials that contribute the most to the carbon footprint of construction solution 1, where it is observed that the ceramic tile is the one that has the greatest impact, followed by brick and cement. Same graph could be displayed for all projects analyzed.

Figure 3:
Potential environmental impacts by construction materials



4 CONCLUSIONS

The application of LCA in the construction sector is complex and time consuming. The existing tools are focused on a user with medium or high experience in LCA. The databases used generally limit the application of these tools in Latin American countries, where there is still not enough information on the environmental impacts of materials and regional construction processes. The objective of EVAMED is to help the stakeholders in the construction sector to make decisions during the design process to achieve buildings with a lower environmental impact throughout their life cycle. It is aimed at a non-expert user in LCA and uses databases with information attached to the Mexican and Latin American reality. The project configuration process and the interactive visualization of results in EVAMED is intuitive and facilitates focused analysis and decision making to improve the environmental performance of a building.

As an example of what the tool can do, in this work a case study has been presented where the carbon footprint of different construction solutions has been analyzed from a basic geometry modeled in Revit. This allows the user to evaluate construction options from the first design phases, from an environmental perspective.

EVAMED represents a step forward in building sector sustainability, mainly in the Latin America region. Its evolution in the coming years will play a fundamental role in favoring the best practices during the planning, design, operation, and end-of-life phases of buildings in the region.

ACKNOWLEDGEMENTS

We thank 'CONSULTE Hogar' for providing the case study information for this work. We also thank the RUV for providing the information on the carbon footprint of the use phase of housing sector in Mexico, which has served as a baseline to compare the cases analysed in EVAMED. This project is funded by the Research Direction of the Universidad Iberoamericana, Ciudad de México.

REFERENCES

1. AENOR. (2010). *UNE-EN ISO 14025 Etiq*uetas y declaraciones ambientales. Declaraciones ambientales tipo III. Principios y procedimientos. (pp. 1–34).
2. Crippa, J., Araujo, A. M. F., Bem, D., Ugaya, C. M. L., & Scheer, S. (2020). A systematic review of BIM usage for life cycle impact assessment. Built Environment Project and Asset Management. https://doi.org/10.1108/BEPAM-03-2019-0028
3. Di Bari, R., Jorgji, O., Horn, R., Gantner, J., & Ebertshäuser, S. (2019). Step-by-step implementation of BIM-LCA: A case study analysis associating defined construction phases with their respective environmental impacts. IOP Conference Series: Earth and Environmental Science, 323, 012105. https://doi.org/10.1088/1755-1315/323/1/012105
4. Hollberg, A., Kiss, B., Röck, M., Soust-Verdaguer, B., Wiberg, A. H., Lasvaux, S., Galimshina, A., & Habert, G. (2021). Review of visualising LCA results in the design process of buildings. Building and Environment, 190(January), 107530. https://doi.org/10.1016/j.buildenv.2020.107530
5. Hollberg, A., & Ruth, J. (2016). LCA in architectural design—a parametric approach. International Journal of Life Cycle Assessment, 21(7), 943–960. https://doi.org/10.1007/s11367-016-1065-1
6. Hollberg, A., Tschetwertak, J., Schneider, S., & Habert, G. (2018). Design-Integrated LCA Using Early BIM. Designing Sustainable Technologies, Products and P. https://doi.org/10.1007/978-3-319-66981-6_30
7. Ibáñez-Forés, V., Pacheco-Blanco, B., Capuz-Rizo, S. F., & Bovea, M. D. (2015). Environmental Product Declarations: exploring their evolution and the factors affecting their demand in Europe. JOURNAL OF CLEANER PRODUCTION, 116, 157–169. https://doi.org/10.1016/j.jclepro.2015.12.078
8. Meex, E., Hollberg, A., Knapen, E., Hildebrand, L., & Verbeeck, G. (2018). Requirements for applying lca-based environmental impact assessment tools in the early stages of building design. Building and Environment, 133(January), 228–236. https://doi.org/10.1016/j.buildenv.2018.02.016
9. Obrecht, T. P., Hoxha, E., & Passer, A. (2020). BIM and LCA Integration : A Systematic Literature Review. July. https://doi.org/10.3390/su12145534
10. Passer, A., Kreiner, H., & Maydl, P. (2012). Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings. International Journal of Life Cycle Assessment, 17(9), 1116–1130. https://doi.org/10.1007/s11367-012-0435-6
11. Soust-Verdaguer, B., Llatas, C., & García-Martínez, A. (2017). Critical review of bim-based LCA method to buildings. Energy and Buildings, 136(December), 110–120. https://doi.org/10.1016/j.enbuild.2016.12.009

PLEA
STGO
2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 02
16:30 — 18:00

CHAIR
FELIPE ENCINAS

PAPERS
1169 / 1644 / 1192 / 1367

30TH PARALLEL SESSION / ONSITE

Building Façade Through the Ages

How Architectural Envelope Reflects a Changing Awareness of Nature and Climate Responsiveness

MANAL ANIS [1] YUN KYU YI [1]

[1] University of Illinois at Urbana-Champaign, Champaign, IL, USA

ABSTRACT: The different epochs in architectural history have been characterized by extraordinary shifts in building systems innovation, facade aesthetic, and technology. While a great number of historians have traced architectural evolutions in terms of changes in formal expression, building construction, and technology, how our awareness to nature and climate has grown to impact façade design has largely remained unexplored. This paper investigates the chronology of building façade evolutions and the concomitant changes in people's interpretation of nature that, together, brought about distinctive transformations in architectural styles over centuries. This link between building façade and our changing perception of nature is explored with the help of selected treatises that have helped shape architecture theory. The changes in façade conception involve building systems improvements due to new scientific discoveries, transformation of the wall from a volumetric solid entity to a mere 'curtain' due to technological advancements, and the treatment of windows not only as an outlet for ventilation and view but also an element to define space and light due to a changing sense of aesthetics. The outcome of the paper is to present a historical timeline that provides a context within which the relationship between nature and façade construction has unfolded.
KEYWORDS: Building façade, Climate responsive, Façade chronology, Nature, Architectural heritage

1. INTRODUCTION

Throughout architectural history there appears to be a paradigm shift that takes place in the way people live their lives that fundamentally changes the concept of space and how we inhabit it. What follows below is a chronological look at how building facades have evolved as our understanding of, and relationship with, nature has progressed. The central idea of the paper is to explore how we interpret nature in designing building facades using the available technology of the time. The problem here is that although the study of building facade design is a well-researched one, employing different historical and technical points of view, its relationship to how people perceived the natural environment surrounding the built space throughout time has remained largely unexplored. As such, the paper aims to trace how humans have interpreted nature throughout time using the available technology and evolving sensibilities, and how that interpretation has shaped building façade designs. This chronological perspective toward understanding building façade evolution is presented through the lens of qualitative research methods with historiographic research. The paper is divided into four principal sections, beginning with the Classical period up to the Industrial Revolution, followed by significant façade innovations during the Industrial age, the Modern Movement, and finally ending with the contemporary parametric design space. Each section looks at the wall and window design of the time period, with the only exception of Classical which also looks at the Orders in addition to walls and windows. Informed by the in-depth discussion on façade developments, a brief comparative analysis is presented thereafter, which examines the shifting paradigms through history and attempts to provide a probable picture of future direction façade innovation may take

2. NATURE AS AN INSPIRATION FOR PERFECTION

The classical era in architecture was distinguished by a profound synthesis of art and science (Giedion 1967). Laugier (1755) echoed the same sentiment when he argued, in An Essay on Architecture, for strict, unwavering principles to guide the architectural process, starting from conception to construction. Nature was taken as this guiding principle, which is why architecture had to incorporate specific rules as seen in nature, all to achieve perfection.

The façade treatments of classical times focused heavily on Orders, their proportion, and materials employed. Whatever the building typology, columns in an Order were to be vertical and free standing, in order to be most efficient in supporting load, and rounded and taper toward the top, resembling trees (Laugier 1755). However, Viollet-le-Duc concluded that material transportation was the reason for columns being round. Capitals at the top of each column that were made to spread the load coming from horizontal lintels over a wider area, can also be argued to have been inspired from wide canopy of trees at the top of a vertical trunk. Fletcher's assertion of Doric order being a 'carpentry in marble' implies that fluting was a concept originating in timber construction. In fact, flutes are believed to be a representation in stone of the vertical grooves left in trees after they were debarked to form timber columns (Fletcher 1924).

Walls, the principal constituent of buildings, were required to be strong and firm, intended to provide a sense of permanence, strength, and security, with any connection to outside kept at a minimum. Viollet-le-Duc remarks at how the same need for solidity dictated that openings be located away from building corners by a minimum distance equal to their width. Opening up of the corners was seen as weakening the building form (Viollet-le-Duc 1881), a sentiment shared by Palladio (1738) as well. With solidity as an underlying character, buildings were made to last.

The solidity of buildings, a recurring theme in classical architecture, started to disintegrate a little, as he opened up the loggia of the hospital through arches (Fig. 1: left) (Giedion 1967). This kind of loggias, though not uncommon in Florentine hospitals of the time, adopted a new mathematical order under Brunelleschi, with the height of columns being equal to the span of the arches (James-Chakraborty 2014). While Alberti (1430) spoke of the usefulness of the loggia, in providing shelter and a place to meet other people or sit and relax, its role in breaking the solidity of walls appears to have a much stronger and far-reaching impact in the evolution of building facades.

A somewhat similar façade treatment is seen in the Pazzi Chapel (1430-1442) where the wall was made independent from the structure, acting simply as a screen to cover the vault behind (Giedion 1967). Supported by six Corinthian columns and a central round arch, the exterior facade strongly resembles ancient Roman architecture style (Fig. 1: middle) (Barolsky 2017). This marks the beginning of the long journey of the façade as a flat surface analogous to a 'skin', free from the trappings of structural loads, which would lead many innovations in the years to come.

Figure 1: *(left) Ospedale degli Innocenti. Source: (Wkimedia Commons. https://commons.wikimedia.org/wiki/File:UNICEF_Innocenti_Research_Centre.jpg. Accessed 16 August 2021) (middle) The Pazzi Chapel in Florence. Source: (Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Pazzi_Chapel_Santa_Croce_Apr_2008_P.JPG. Accessed 16 August 2021) (right) San Carlo alle Quattro Fontane (Rome), Borromini. Source: (Wikimedia Commons. https://commons.wikimedia.org/wiki/File:SCarloQuattroFontaneRome2.jpg. Accessed 16 August 2021.)*

Windows were typically small in proportion to the façade surface, and, as instructed by Vitruvius and later reiterated by Palladio, the ratio between the height of the façade to the opening was to be 3.5 to 2. Palladio reasons that windows bigger than the specified ratio run the risk of letting in too much heat or cold air. In line with this, Banham (1984) explains that poorly developed mechanical services of the time meant that bigger windows would translate to a higher cooling load.

2.1 First attempts at De-solidification and Undulation

Attempts at experimentation in façade treatment were slow and cautious. Between 1419 to 1424, Brunelleschi erected the first Renaissance building in Florence: *The Ospedale degli Innocenti*.

Undulations in wall surfaces was another innovative strategy that developed in later years, with Quattro Fontane (1662-67) being the first of its kind in Rome (Fig. 1: right) (Huemer 1999). Borromini's masterpiece, with its wave-like travertine wall, expresses an energetic movement and molds the space within, creating a brilliant array of light over the front of the church. Calling it a 'pulsating membrane', Tansey and Kleiner (1996) note how the traditional rigid wall separating the interior from exterior is discarded here in favor of a more fluid transition between the two. In fact, much like a fluid skin, the façade wraps around the corner, following the curved street. The period of Baroque was distinguished with several such attempts at façade construction that defied gravity, taking inspiration from natural elements, as opposed to being an impenetrable solid enclosure.

3. INDUSTRIALIZATION AND A SKELETAL FAÇADE TREATMENT

A major shift in people's perception of architecture took place during the Industrial Revolution of 18th century, with innovations in steam engines, power loom, iron, steel, and glass manufacturing techniques etc. As such, mass-production of new building materials became possible, which inspired a reconceptualization of form, function, and space. The natural and few manmade building materials used so far such as timber, brick, stone, lime and mortar, concrete gave way to stronger, more durable materials. The enhanced structural capabilities of these newer materials, initially used in railroads and bridges, gradually allowed buildings to possess monumental scale and be open and light at the same time.

The freedom to design that industrialization afforded allowed architects to attempt increasingly daring pursuits. Invention of elevators coupled with fire-proof steel frame structure coincided with several skyscrapers springing up in many urban cities in America, one of which was Chicago (Frampton 1985). It is said that the true potential of iron was explored in the first skyscraper, the 10-storey Home Insurance Building by William Jenney in 1883-85 with its ability to carry load without collapsing under its own weight. The walls were invariably transformed into simple 'skins', to provide shelter from inclement weather. Horizontally elongated windows, that later came to be known as 'Chicago windows' dominated the walls in most buildings of this time as can be seen in the Reliance Building, the Manhattan Building, the Chicago Building, and many others. The tripartite Chicago window, with its large, fixed glass panel flanked by the two double-hung sash windows, served to maximize light, ventilation, and views. Variations were introduced by changing window types as in William Jenney's the Manhattan Building with its bay windows in lower floors.

3.1 Reactionary Movements with New Interpretation of Nature

Contrary to the preceding centuries, 19th century witnessed a growing concern toward dehumanizing architecture through mass production and division of labor. A natural resistance to this increasingly industrialized age ushered in a romanticized look back at life in the countryside. In the 1850's England, the Arts and Crafts Movement that developed the concept of 'house beautiful', welcomed a new interpretation of nature in architecture, one that was based on an idealistic synthesis of natural landscape and handmade craft. Walls were made of red bricks and tiles, with stained-glass windows. Born out of nostalgia for the unspoiled rural countryside, the movement aspired to connect humans with the natural world, while having full control over every aspect of the making of architecture, including furniture, glazing, metalwork, woodwork etc., thereby creating what Frampton observes to be 'a total work of art.'

Another reactionary architecture style that developed because of industrialization was Art Nouveau, pioneered by Belgian architect Victor Horta. By 1890 much of Belgium's economy had been industrialized, contributing heavily to the global production of iron and steel (James-Chakraborty 2014). As such, there was an acceptance of, and adapting to, industrialized mass production to create a new decorative vocabulary. Similar to Arts and Crafts movement, there was a move toward natural, curvilinear elements as inspiration for façade ornamentation. In fact, James Grady (1955) observes a return of the 19th century architect to nature for inspiration for the first time since the Gothic period. However, instead of rejecting modern materials like the Arts and Crafts architects, Art Nouveau embraced cast iron and glass to create a sense of fluidity through delicate, sinuous lines and exposed rivets (Giedion 1967). This time around, botanical forms were taken as inspiration to express modernity in structure and decoration, rather than provide a nostalgic escape to nature

4. MODERNISM AND THE MACHINE AESTHETIC

The evolution of Modernism reveals how nature, so far considered as a source of inspiration for façade construction and ornamentation, was slowly replaced by the starkness of the machine. Nature was instead treated as a realm outside the built environment; something to be observed and appreciated, but not quite integrated into architecture. Particularly, with a growing cultural shift led by a modern industrial society there was a need for a new architectural language, with Functionalism and a Machine Aesthetic ushering in 20th century Rationalism (Yi and Yi 2010). Prefab facades and non-loadbearing glass curtain walls became possible due to advancements in HVAC systems and flexibility in placement of windows, afforded by newer construction techniques. Although the history of building environmental control systems goes as far back as 1784 when James Watt used steam to heat his office, use of energy efficient equipment only became commonplace after mid-19th century (Tzikopoulos, Karatza, and Paravantis 2005).

Facades, as transparent surfaces, brought nature visually closer to the built environment. Building without decoration also shifted the focus of design aesthetic from façade embellishment toward a visual relationship between building and environment, emphasizing daylight and views. Gropius and Meyer's Fagus Factory of 1911, often regarded as the first building of the Modern Movement shows a façade that is merely a curtain to protect from inclement weather. The expansive use of glass, clean geometry, and perceived weightlessness was a common principle of Modernism, as seen in Bruno Taut's Glass Pavilion and Gropius's Deutz Pavilion of 1914 as well as the Bauhaus Dessau (Banham 1980).

In fact, taking ferro-concrete as a preferred media to express his support for the free façade, Le Corbusier went on to create an unprecedented lightness previously unseen in architecture (Banham 1980). White-washed walls, long horizontal strips of windows, large voids cut cleanly within facades, and a strong style of plain square forms characterize the Corbusier aesthetic. Be it the Maison Citrohan of 1920, or Villa Savoye of 1928 – there was always an open visual connection between interior and exterior by opening up of the house.

4.1 Modernism and an Organic Aesthetic

Around the same time, in America, Frank Lloyd Wright was rethinking residential architecture on the most fundamental level. His response to heavy use of iron and glass to construct walls was to reimagine them as flat, plain surfaces instead that were reorganized in different ways. He sought to use machines intelligently to create abstract and pure forms as a way to save architecture from industrialization (Frampton 1985). Horizontally striped walls were dominated by overhanging horizontal eaves – the outcome being a complete disintegration of solid volume into multiple juxtaposed forms, as in Robie house in 1908. Ornamentations were geometric abstraction of nature rather than a direct evocation of nature. As an exemplar of 'organic architecture' (Adams 1957), his walls exhibited a strong contrast in material, some often borrowed directly from nature - light colored wall with heavy timber or rugged stone wall, with no use of iron or ferrocement. Cleanly cut casement windows were a representation of nature at its most rudimentary form – simple lines and surfaces that effortlessly come together to form an enduring shelter. One notable element was the corner window – opening up of corners and allowing expansive views in most of the Wright buildings shows there was a deliberate move away from the Classical notions of weakening building forms through open corners.

4.2 Iconography and Nature

Post Modernism in the 60's, as a reaction to Modernism, offered a strong critique to the irrelevant subtleties of architecture. In a fast-paced world of automobile and commercialism Venturi and Brown (1972) argued in favor of iconography and mixed media. As architecture moved away from implicit abstraction toward explicit articulation, nature became a mere background against which architecture needed to stand out and express itself. Walls and windows were no longer constrained by the rules of aesthetic and function but were allowed to be ornate and bold, or fragmented and curvilinear, or bright and outlandish. Venturi and Brown's Sainsbury Wing at London's National Gallery depicts a particularly humorous façade treatment with the neoclassical columns that gradually bunch up toward the side, creating a curtain-like quality. James Wines's façades for the Best Products Showrooms present a similar take on the modernistic notions of purity, clarity and order, with its crumbling and peeling brick walls (Levin 1979). Additionally, the energy crisis of the 70's, establishments of the Environmental Protection Agency (EPA), and amendment of the Clean Air Act of 1963 led to a change in attitudes toward reducing energy consumption in buildings, creating a new environmental awareness among the public and emphasizing a deeper relationship between humanity and nature (Calder 2021).

5. PARAMETRIC FAÇADE - TOWARD AN ANIMATE AESTHETIC

Following the development of the first computer aided design (CAD) program in the 60's to aid drafting works, called Sketchpad, architecture gradually saw CAD being used to aid design works. This led to the emergence of Building Information Modelling (BIM) later in the early 2000's (Andia & Spiegelhalter, 2014). By allowing all the elements of a building to be created and managed digitally (Holzer, 2015), BIM has allowed architects to create digital 3D models of buildings for a better visual representation, inspiring more complex and exciting geometry ideas. All this was further improved by the emergence of parametric design, a pre-programmed rule-based technique of design whereby changing a rule, or a 'parameter', will automatically update all the components generated from that parameter. Changing designs by merely changing their input data, such parametric approaches afford more control and customizing options to designers, threatening to overthrow the age-old concepts of stasis, permanence, and verticality (Lynn 1999). The adaptive shading screen of the Al-Bahar Towers in Abu Dhabi, the optimized bowl geometry façade of the Beijing National Stadium for the 2008 Olympic Games, the fluid façade forms of the National Maritime Museum of China etc. are all noteworthy examples of parametric designs based on unique algorithms and scripting. As such, nature as a phenomenon began to permeate architecture with the help of computational design practices. Generative systems in nature were taken as inspiration to develop design approaches that emulate the underlying principles and algorithms in nature.

With recent technology, the reconceptualization of traditional architectural norms has led walls, moving further away from earlier volumetric and planar expressions, to be rethought into modular units, each shaped by the intricate fluid field in which it inhabits (Lynn 1999). Greg Lynn, one of the earliest practitioners of animated design, notes how this has allowed facades to be intricately linked to the surrounding field, responding to it in real time. However, a time-dependent design, instead of being a final output representing the culmination of the design process, often becomes just one of many temporal solutions. It calls into question the validity of the performance of the selected geometry over others (Yi and Yi 2010).

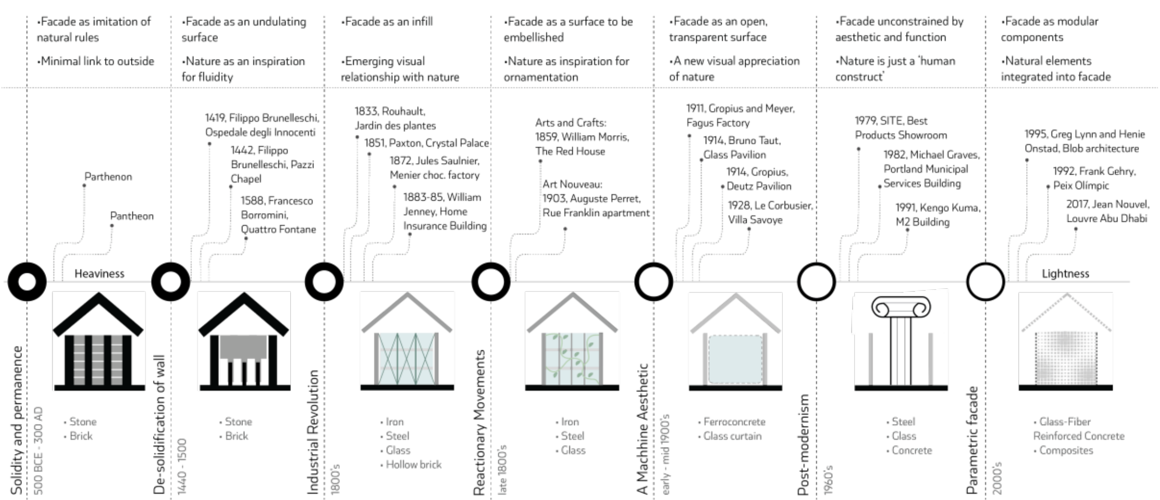
various post occupancy surveys can be used to train AI and perform real-time autonomous analysis.

6. A COMPARATIVE ANALYSIS

The relationship between nature and built environment has gone through many transformations over centuries, with innovations in environmental technology. Figure 2 illustrates the façade evolution that makes apparent our growing appreciation of nature. While the immutable rules of Classical architecture based on limited construction techniques that gave rise to massive walls with small openings arose from a desire to achieve perfection as seen in nature, the representation of natural elements was only through a cosmetic application of ornamental motifs. However, the thermal storage capacity of these thick-walled structures was key in rendering classical architecture habitable in both warmer and colder climates.

During post-industrialized era, a growing connection to the exterior took shape as facades lost their heavy volumetric quality to industrially produced iron and steel. The aesthetic that came about preferred the honesty of expression, with exposed framings and expansive glass. Around the same time, as incandescent lights were replaced, first by gas mantle and later by electric lights, the

Figure 2: *Building façade evolution and the perception of nature*



Embracing artificial intelligence (AI) to perform certain complex tasks seems to be the next big leap in architecture. Data-driven design has made it possible to test out an infinite number of models before construction, research site, optimize design, and create multiple possible solutions. Moving further ahead, AI can also be used to monitor user preferences and learn user routines to predict and generate design solutions. BIM data, along with

extra cooling load was reduced, and walls no longer needed to be massive solid objects (Banham 1984).

However, as can be seen repeatedly over the next century, no technological revolution comes without being followed by a strong critique offering an alternate solution to the same problem. As such, the architecture styles generated as a response to the industrial society attempted a stronger connection to nature – whether it be through handcrafted natural materials or integrating natural motifs with modern industrial materials. With newer conceptual and mechanical advancement in the 19th century allowing bigger apertures, a stronger visual relationship with the outside occurred. Interestingly, the resultant problems of lack of thermal capacity, heat and sound insulation, visual privacy, pushed the discipline further, leading to innovations in mechanical conditioning, low-e glazing technology, shading devices etc. Indeed, Olgyay (1963) notes the role of shading and tinted single-pane glass wall in reducing heat transmission.

Current innovations in climate adaptive buildings, facilitated by 3D printing technology, strive toward a stronger data-driven relationship to nature, particularly the climate. With growing use of simulation tools, like Computational Fluid Dynamics (CFD) and Building Energy Simulation (BES) for assessment or prediction during different stages of the design generation process, it is now possible to refine building form, try multiple façade options and optimize performance. For instance, photovoltaic panels integrated with building envelopes can now simultaneously address daylight, energy efficiency etc. More recently, the global pandemic has been a key driver in realizing a stronger direct relationship between the built environment and nature, bringing vegetation indoor to improve health and wellbeing in the long run.

4. CONCLUSION

Technological advancements in different eras have always ended up shaping cultural and social norms for generations to come. Breaking away from the very first concepts of architecture: the verticality of structures and integrity of the solid, parametric architecture is challenging the very notion of enclosure. The wall can now disintegrate into modular units, move, rotate, bend, twist – in response to user needs or environmental stimuli. There is no need for architecture of today to embody timelessness and permanence. Instead, buildings can be made to remain only as long as necessary, and then be dismantled and recycled elsewhere with prefab units. All these offer endless possibilities and direction for architecture to take in the coming years and set in motion the next paradigm shift that will usher in new advancements and a new façade concept.

REFERENCES

1. Adams, R. P., (1957). Architecture and the Romantic Tradition: Coleridge to Wright. *American Quarterly*, 9(1): p. 46–62.
2. Andia, A. and Spiegelhalter, T., (2014). *Post-parametric automation in design and construction*. Artech House.
3. Banham, R. (1980). *Theory and design in the first machine age*. MIT Press.
4. Banham, R. (1984). *Architecture of the Well-tempered Environment*. University of Chicago Press.
5. Barolsky, P. (2017). The Visionary Architecture of the Pazzi Chapel. *Arion: A Journal of Humanities and the Classics*, 25(2): p. 1–10.
6. Calder, B. (2021). *Architecture: From prehistory to climate emergency*. London: Penguin Books Ltd.
7. Fletcher, B. (1924). *A history of architecture on the comparative method for the student, craftsman, and amateur*. Batsford.
8. Frampton, K. (1985). *Modern architecture*. Thames and Hudson.
9. Giedion, S. (1967). *Space, time, and architecture: The growth of a new tradition*. Harvard University Press.
10. Grady, J. 1955. Nature and the Art Nouveau. *The Art Bulletin*, 37(3): p. 187–192.
11. Holzer, D. (2015). BIM and parametric design in academia and practice: The changing context of knowledge acquisition and application in the digital age. *International journal of architectural computing*, 13(1): p. 65-82.
12. Huemer, F. (1999). Borromini and Michelangelo: Some preliminary observations on the facade of S. Carlino. *Source: Notes in the History of Art*, 18(4): p. 19–29.
13. James-Chakraborty, K. (2014). Brunelleschi. In *Architecture since 1400*. University of Minnesota Press.
14. James-Chakraborty, K. (2014). Inventing the Avant-Garde. In *Architecture since 1400*. University of Minnesota Press.
15. Laugier, M. A. (1755). *Essai sur l'architecture*. chez Duchesne.
16. Levin, K. (1979). Farewell to Modernism. *Arts Magazine*. p. 90-91.
17. Lynn, G., & Kelly, T. (1999). *Animate form (Vol. 1)*. New York: Princeton Architectural Press.
18. Olgyay, V. (1963). *Design with climate: Bioclimatic Approach to Architectural Regionalism*. Princeton university press.
19. Palladio, Andrea, 1508-1580. (1738). *The four books of architecture*. London.
20. Tansey, R.G and Kleiner, F.S. (1996). *Gardner's Art Through the Ages*. Harcourt Brace Jovanovich.
21. Tzikopoulos, A. F., Karatza, M. C., Paravantis, J. A. (2005). Modeling energy efficiency of bioclimatic building. *Energy and Buildings*, 37: p. 529-544
22. Venturi, R., Brown, D. S., Izenour, S. (1977). *Learning from Las Vegas: The forgotten symbolism of architectural*. MIT press.
23. Viollet-le-Duc, E. E. (1881). *Lectures on architecture* (Vol. 1): Courier Corporation.
24. Yi, Yong-Kyu, and Yi, Y.K. (2010). Utilization of Scientific Method as a Tool of Architectural Design. *Journal of Architectural Research*, 12(2): p. 1-7.

PLEA SANTIAGO 2022
Will Cities Survive?

Responsive Brise-soleil
Design Concept and Performance Analysis

GABRIEL DE BEM[1 2 3] PABLO LA ROCHE[2] EDUARDO KRÜGER [1] ALEXANDRE A. A. M. DE ABREU[3]

[1] Federal University of Technology - Paraná, Curitiba, Brazil
[2] California State Polytechnic University – Pomona, United States of America
[3] Federal Institute of Education, Science, and Technology – Santa Catarina, Canoinhas, Brazil

ABSTRACT: Responsive systems are capable of providing comfort with energy savings using real-time environmental data. In this paper, we focus on a responsive system designed to control solar heat gains and indoor illuminance, using a set of movable parallel slats combined as a brise soleil in order to provide shading to a south-facing window. A low-cost microprocessor equipped with sensors commands the responsive behaviour according to a pre-programmed schedule, as follows: a) neutral and operative temperature parameters based on the Adaptive Comfort Model; and, b) indoor illuminance thresholds based on the Useful Daylight Illuminance (UDI) parameter. The test-cell study, conducted at the Lyle Center for Regenerative Studies of the California State Polytechnic University, located in Pomona, California, compared three conditions: unshaded window, shaded by brise soleil in a static position, and shaded dynamically by the responsive brise soleil. Results show the effectiveness of the system in adequately keeping indoor illuminance within recommended limits in comparison to the static brise soleil. The control of indoor operative temperature was also effective in a direct comparison with the static condition and evidently versus the configuration without any shading, albeit this last condition was evaluated on particularly hot days in February.
KEYWORDS: Responsive architecture; Responsive brise-soleil; Dynamic shading system; Intelligent façade; Building thermal performance.

1. INTRODUCTION

Responsive constructive systems can adapt their shape according to indoor or environmental conditions [1]. The building envelope has an essential role in regulating lighting and thermal exchanges between indoor and outdoor environments [2]. There are mainly three different approaches to façade development. The first one corresponds to mechanical shading devices where movable parts, operated by microprocessors, control solar heat gains and illuminance levels. The second approach entails chemical solutions associated with optical glass properties triggered by an electronic signal to adjust sunlight, heat gains, and transparency. Finally, smart materials can be adopted, which do not require energy supply to activate their dynamic response [2][3].

This article deals with the development of a climate-responsive brise-soleil prototype that should be able to control solar heat gains and indoor illuminance levels. A low-cost microprocessor equipped with sensors grants the system's the responsive behavior according to a pre-programmed schedule triggered by two conditions: neutral and operative temperature limits according to the Adaptive Comfort Model proposed by ANSI/ASHRAE 55 [4] and indoor illuminance minimum and maximum levels based on the Useful Daylight Illuminance (UDI) parameter [5]. The test-cell study compared three conditions: unshaded window, shaded by a fixed brise-soleil; and dynamically shaded by the responsive brise-soleil.

This paper has three sections. The first one introduces the field of study and summarizes the underlying concept. Section 2 presents the methodological approach, providing information about the sensors and the design criteria for the prototype development and control. In Section 3 we discuss results obtained.

2. METHODOLOGY
2.1 Test Cell and local climate

A test cell was used, with the dimensions of 1.35 m x 1.35 m x 1.35 m. It has a single glazed window 610 mm wide x 610 mm high, facing south.

According to ANSI/ASHRAE 55 [4], the climate analysis should be based on weather data from the nearest meteorological station. For the design concept study, the available data is from Chino airport weather station, at 34°N and 118° W, elevation 649 ft a.s.l.. Local climate is Köppen-Geiger's "Csb" (Mediterran Climate) [6]. The test cell is located at the John T. Lyle Center for Regenerative Studies in the California State Polytechnic University at Pomona, California.

2.2 Design Concept for the brise-soleil

The Adaptive Comfort Model proposed by ANSI/ASHRAE 55 [4] was used in the design process of the brise-soleil. The times when shaded or sun-lit conditions are needed were defined based on the monthly indoor Comfort Operative Temperature (Neutral Temperature), in an hourly basis.

2.2.1 Indoor Comfort Operative Temperature

The adaptive comfort model is aimed at naturally-ventilated indoor spaces and user adaptive behaviour. According to this concept, the definition of the thermal comfort range should be based on the Neutral Operative Temperature (T_n), considering the following assumptions [4]:

- the building relies only on natural ventilation for temperature control;
- occupants' metabolic rate should range from 1.0 to 1.5 met;
- occupants can adjust their clothing level from 0.5 to 1.0 *clo*;
- prevailing mean outdoor air temperature ($T_{pm(out)}$) ranges from 10ºC to 33.5ºC.

$T_{pm(out)}$ is the average outdoor temperature from 30 days before the current day of analysis. The range for 80% thermal acceptability is obtained from the neutral temperature T_n given by Equation 1. Lower and higher temperature thresholds are applied to T_n and correspond to +/- 3.5ºC around T_n. Fig. 1 and Fig. 2 show comfort ranges obtained for each month in Pomona.

$$T_n = (0.31 \times T_{pm(out)}) + 17.8ºC \qquad (1)$$

Figure 1:
Monthly comfort zone from January to June for 80% thermal acceptability (Pomona, CA).

Monthy comfort zone within 80% of acceptability						
Thresholds	Jan	Feb	Mar	Apr	May	Jun
To - 3.5	17,99	18,16	18,20	18,46	19,14	20,48
To	21,49	21,66	21,70	21,96	22,64	23,98
To + 3.5	24,99	25,16	25,20	25,46	26,14	27,48

Figure 2:
Monthly comfort zone from July to December for 80% thermal acceptability (Pomona, CA).

Monthy comfort zone within 80% of acceptability						
Thresholds	Jul	Aug	Sep	Oct	Nov	Dec
To - 3.5	21,23	21,68	21,67	20,63	19,07	17,95
To	24,73	25,18	25,17	24,13	22,57	21,45
To + 3.5	28,23	28,68	28,67	27,63	26,07	24,95

From the obtained adaptive comfort range, mean hourly temperatures from the weather file can be used to assess the need for shading to prevent overheating to occur. Fig. 3 and Fig. 4 show mean hourly temperatures for each month, below, within, and above the comfort range, highlighted in blue and white for unshaded windows, and in yellow-orange scale when shading is needed and in what intensity.

Figure 3:
Monthly mean hourly values from January to June for 80% thermal acceptability.

Mean monthly hourly values within 80% of acceptability						
Hour	Jan	Feb	Mar	Apr	May	Jun
6	6,08	8,23	8,36	7,85	11,62	14,03
7	5,81	8,16	8,41	8,23	12,70	15,40
8	5,62	8,14	9,27	10,80	14,68	17,16
9	7,39	9,88	11,43	12,85	16,85	18,97
10	10,60	12,34	13,42	14,54	18,80	21,46
11	13,52	14,43	15,14	16,45	20,96	23,75
12	16,20	16,16	16,93	18,11	22,82	26,27
13	17,85	17,33	18,38	19,31	24,26	27,82
14	18,89	18,02	19,41	19,91	25,10	29,50
15	19,34	18,23	19,85	19,91	25,29	29,44
16	19,07	18,12	19,71	19,62	24,83	28,68
17	17,97	17,69	19,13	18,97	23,91	27,76
18	16,34	16,80	18,14	18,09	22,78	26,77

Figure 4:
Monthly mean hourly values from July to December for 80% thermal acceptability.

Mean monthly hourly values within 80% of acceptability						
Hour	Jul	Aug	Sep	Oct	Nov	Dec
6	16,14	15,86	14,95	12,09	7,72	6,81
7	17,46	16,83	15,09	12,17	7,74	6,69
8	19,16	18,93	18,09	13,71	8,33	7,18
9	21,22	21,18	21,02	16,82	10,90	9,15
10	23,85	24,17	23,90	19,28	12,88	11,95
11	26,80	27,33	26,99	21,37	15,12	14,43
12	29,38	30,08	29,90	23,60	16,85	16,32
13	31,38	31,95	31,87	24,93	17,94	17,53
14	32,36	32,61	32,52	25,59	18,80	18,30
15	32,34	32,84	32,46	25,68	19,23	18,65
16	31,52	32,17	31,78	25,10	18,77	18,17
17	30,49	31,24	30,55	24,05	17,51	17,09
18	29,39	30,09	29,03	22,46	15,86	15,73

Shading is required to avoid overheating in the afternoon in July, August, and September.

A solar-shading system consisting of horizontal slats could provide adequate shading. The shading device could comprise of six slats, 95 cm in length and 7 cm in depth, not centralized to the window opening to allow sunlight during morning hours.

As a responsive brise-soleil should be able to rotate its slats blocking or allowing in various intensities direct sunlight, the prototype dimensions are somewhat increased in length and depth. The current design is thus based on variations of the solar angle to determine the responsive behavior of the set of slats.

2.3 Slats rotation versus solar angle

In a responsive system, the slats, each with a width of 11 cm, could assume different tilt angles to provide total or partial shading depending on solar angles. For an adequate management of indoor temperature and illuminance levels, the rotation of the slats was set to provide three shading conditions: 0% (no shading), 50%, and 100% shading. Equations 2, 3, and 4 provide desired rotations (θ) for a south façade at noon. Hence, the prediction of the obtained shading is more accurate for the times when solar azimuth is near 180° or at noon hours.

For 0% shading:

$$\Theta = \alpha \qquad (2)$$

For 50% shading:

$$\Theta = \arcsin \frac{\cos \alpha}{2} - \alpha \qquad (3)$$

For 100% shading:

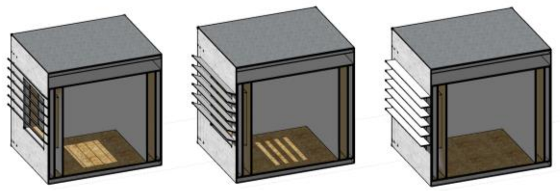
$$\Theta = 90^{\circ} - 2.\alpha \qquad (4)$$

Where,

α = solar elevation angle
Θ = slat rotation angle to the horizontal plane

Fig. 3 presents a shading simulation using the Sketch-Up Software for the three shading patterns on February 22nd at noon, with 0% shade, 50%, and 100% shading, respectively.

Figure 3:
Shading patterns at noon on February 22nd, with 0%, 50% and 100% shading



Due to the narrow gap between the brise-soleil structure and the roof, the rotation of the servomotor arm and, thus, of the slats is limited to about 50° up and down, respectively. Therefore, the system cannot provide adequate shading when the solar angle is too low.

2.4 Shading system functionality criteria

The satisfactory operation of the system for either shading or allowing sunlight is meant to ensure the maintenance of indoor operative temperature (T_o) within the thermal comfort zone and with adequate illuminance levels.

2.4.1 Operative Temperature:

According to ANSI/ASHRAE Standard 55 [4], office activities with a metabolic rate of 1.0 and 1.2 met (writing, filing, seated), not exposed to direct sunlight, and for a maximum air velocity of 0.10 m/s, the Operative Temperature (T_o) can be obtained with equation 5.

$$T_o = \frac{T_a + T_{mr}}{2} \qquad (5)$$

where T_o = Operative Temperature (°C);
T_a = indoor temperature (°C);
T_{mr} = indoor mean radiant temperature (°C).

The parameter used here for promoting shading or allowing solar radiation is given by operative temperature thresholds for 80% thermal acceptability.

2.4.2 Illuminance level:

The illuminance levels required for an office area are usually defined by the office activity. We considered the Useful Daylight Illuminance (UDI) [5] as the relevant metric for controlling the amount of daylight within the range 100 to 2000 lx. The real-time sensor employed allows indoor illuminance control even on cloudy days.

2.4.3 Responsive rules

The responsive behavior of the system starts with the calculation of the operative temperature from sensor readings (from air temperature (S3), globe temperature readings (S2), assuming a low airspeed of 0.03 m/s). If T_o is below the comfort zone (T_n – 3.5°C), the system operates under Condition 1. As solar heat gain is desirable, this condition allows the choice of one of the three possible shading patterns (0%, 50%, and 100%) according to illuminance levels (S1). If the operative temperature is within the comfort zone ($T_n - 3.5°C \leq T_o < T_n + 3.5°C$), Condition 2 is activated. As no solar heat gain is required, the quantity of direct solar radiation corresponds to a shading profile of either 50% or 100%. If the operative temperature is above the comfort zone ($T_o \geq T_n + 3{,}5°C$), Condition 3 applies. When the indoor operative temperature is above the limit, no direct sunlight is permitted, so the system operates to keep a 100% shading level. If even with 100% shading the illuminance level is still above the upper UDI threshold (2000lx), the brise-slats rotates to the maximum angle (50°) to reduce the amount of diffuse solar radiation.

The microprocessor runs the programming code every 10 minutes updating all variables involved: calculated solar angle (based on Pysolar script [8]), measured indoor temperature (S3), globe temperature (S2), outdoor temperature (S4), and indoor illuminance (S1), calculated mean radiant temperature, operative temperature, and rotation slat angles. The neutral temperature is updated daily based on data from 21 days prior to the current day (S4).

2.5 Fabrication process

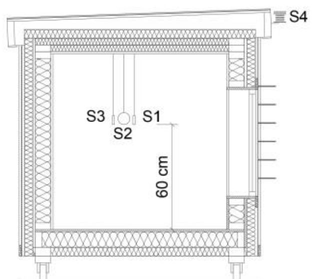
The brise-soleil is made of wood sheets 6 mm thick, with the core made of foamboard. To reduce the total weight of the brise, the final brise slat is made of foamboard. The rotation elements were designed with Sketch-up software and printed in a Low Force Stereolithography™ (LFS) 3D printer. The rotation movement is controlled by a rotation arm attached to a servomotor. The brise slats are connected to each other and on the rotation arm by steel cables (Fig. 4).

Figure 4:
Brise soleil

2.6 Sensors distribution

As the 50% shading produces a striped pattern, the location of the illuminance sensor (S1) in terms of height corresponds to 60 cm from the floor to avoid direct sunlight, as, even when a partly shaded condition is reached (50%), the sensor could show illuminance levels as if it were not shaded. The globe (S2) and the indoor temperature sensor (S3) are located next to S1 at 60 cm from the floor. The outdoor temperature sensor (S4) is protected by a 3D printed solar shield (Fig. 5).

Figure 5:
Sensor locations



2.7 Responsive system

A low-cost microprocessor controls the responsive system. Python programming language allows the management of four sensors and one servomotor. It is possible to access real-time data using an online datasheet. In this work, we used a Raspberry Pi 3 microcomputer and three DS18B20 type temperature sensors (S2, S3, S4), an Adafruit TSL2591 High Dynamic Range Digital Light Sensor (S1), and a high-torque metal gear servomotor manufactured by ZOSKAY.

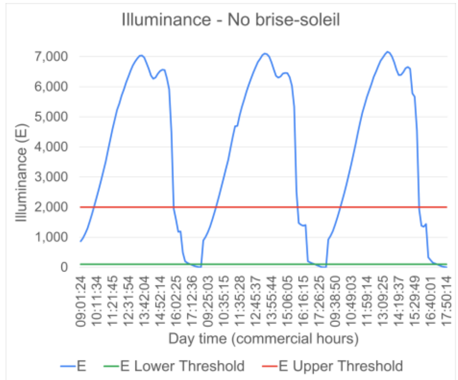
3. RESULTS

To evaluate the functionality of the responsive brise-soleil, the data analysis includes 3 sets of 3-day measurements. As we didn't have a control test cell available, data were collected in distinct periods though not much apart from each other. As the illuminance parameter refers to daylight periods, we focused on the daytime period between 09:00 and 18:00.

3.1 No shading device

Data collected from this series with no shading device refer to 10-12 February 2022. Fig. 6 shows indoor illuminance (E, in lx) in blue and both lower and upper E thresholds based on the UDI concept, in red and green lines, respectively.

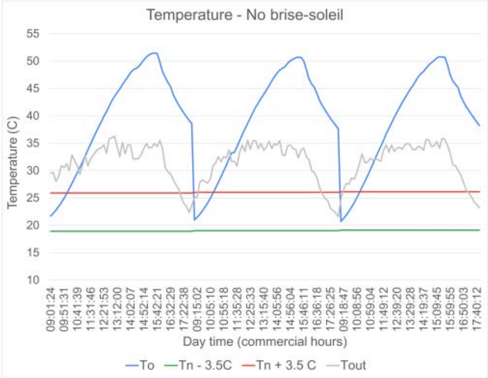
Figure 6:
Indoor Illuminance – no brise-soleil



During the three days of measurement indoor illuminanced enormously exceeded the upper threshold of 2000 lx in the morning from 10:00 until 16:00. To prevent this amount of illuminance in a real building, the use of internal shading might be needed, which would yet block the view to the outside. Results indicate the strong need for controlling excessive daylight.

As for the indoor temperatures with respect to the comfort zone, Fig. 7 presents lower and upper temperature thresholds, in red and green lines, respectively, and the operative temperature in blue against the outdoor temperature in gray.

Figure 7:
Temperature – no brise-soleil

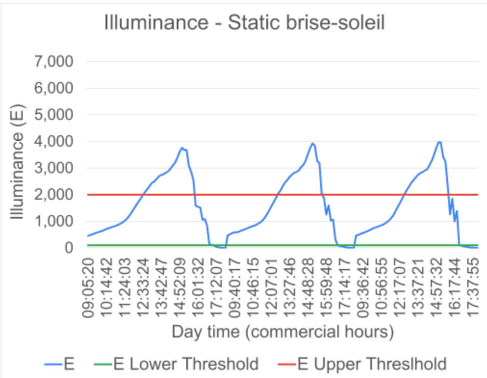


The operative temperature exceeds the upper limit from 10:00 to 18:00 reaching over 50ºC. This reinforces the need for shading and/or cooling the indoor space. A noticeable overheating effect is noticed with indoor operative temperatures reaching over 50°C against an ambient temperature of 35ºC outdoors.

3.2 Static brise soleil

This series of data refers to 3-5 February 2022. Fig. 8 shows illuminance data for that period.

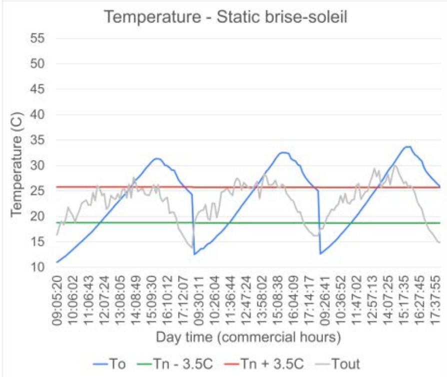
Figure 8:
Indoor Illuminance – static brise-soleil



Despite being shaded by a regular brise-soleil (static mode, with no slats rotation) indoor illuminance exceeds the upper threshold of 2000 lx from 12:00 to 16:00. The maximum level is reached in the afternoon at 15:00, with around 4000 lx. Again, there is a need for an internal shading device that would, additionally to the brise-soleil, reduce potential occupant discomfort caused by excessive illuminance and glare.

Indoor temperatures exceed the comfort limit ($T_o \geq T_n + 3{,}5$ºC) during the afternoon, from 13:00 to 17:00, also as a function of the outdoor temperature (Fig. 9). During this set of measurements, even with T_{out} in most cases within the comfort range, indoor indoor operative temperature exceeded the upper threshold up to 8 degrees (day 3).

Figure 9:
Temperature – static brise-soleil

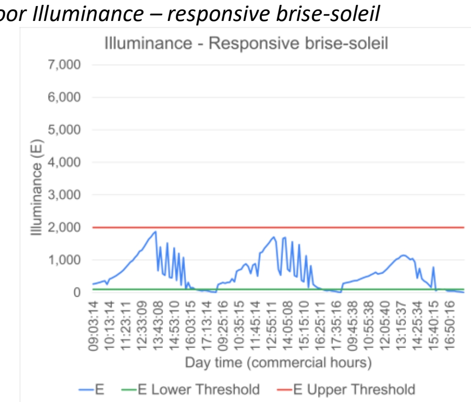


As the brise-soleil was designed to allow direct solar radiation during morning periods in winter, the comfort zone is reached in the morning period, around 11:00.

3.3 Responsive brise-soleil

The final series of measurements corresponds to the responsive brise-soleil, for the time frame 9-11 March 2022. Fig. 10 presents the illuminance control resulting from the system's behavior.

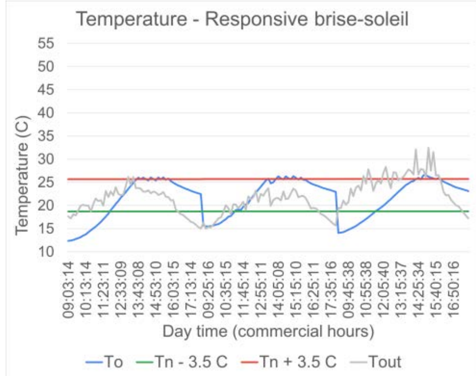
Figure 10:
Indoor Illuminance – responsive brise-soleil



The responsive behavior of the brise-soleil successfully controlled the amount of illuminance gained through direct and diffuse solar radiation. The illuminance level remained within the desired range according to UDI, from 100 to 2000 lx. The instability of measurements from 13:00 is explained by the alternance of Conditions 1 to 2 (see section with responsive rules). When the operative temperature reaches or surpass the comfort zone limit it increases the shading percentual, from 50% to 100%. As soon as the T_o drops, the shading pattern allows more direct sunlight, increasing daylight illuminance level. The reduction of indoor illuminance on the third day of measurements can be explained by the partly clouded sky on that particular day.

For the temperature analysis, Fig. 11 presents the distribution of operative temperature, neutral temperature thresholds, and outdoor temperature.

Figure 11:
Temperature – responsive brise-soleil



During the first two days, the operative temperature remained under control, slightly exceeding the upper threshold (T_n + 3,5ºC). Even when the T_{out} was above the comfort zone, the responsive system satisfactorly controlled the amount of solar heat gains (day 3). To avoid the surpassing of the comfort zone indoors, the reduction of the T_n thresholds from 3.5ºC to 2.5ºC might keep the T_o most of the time within 90% of thermal acceptability.

4. CONCLUSION

This prototype proves that a responsive brise-soleil can improve both the illuminance and thermal performance of the built environment being able to reduce energy demand for illumination and air conditioning. Besides this, responsive shading systems with flexible possibilities of providing shade throughout the year can be more efficient in locations with sudden weather changes than static shading systems.

Regarding the fabrication of the responsive brise-soleil we would like to highlight that:

- low-cost sensors were used for gathering and operating the system from measured environmental variables;
- production, customization, function, and resistance requirements were accomplished by means of 3D printing process;
- control of solar heat gains and illuminance levels indoors was possible by the autonomous and responsive control system;
- an improvement of indoor thermal and luminous performance was verified in the test cell at a prototype stage.

Further developments of this research will comprise other seasons and orientations. In addition, we intend to test different colours of the slats and check their interference in indoor illuminance. In the same way, it is possible to alternate the shape of the brise-soleil slats in order to reflect more sunlight to the ceiling improving both temperature and illuminance.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001 and Lyle Center for Regenerative Studies.

We want to thank prof. Ph.D. Leandro Fernandes from the Federal University of Paraná, Brazil, for supervising the design concept and the professional colleague Prof. Marlon Mülhbauer from Federal Institute of Education, Science and Technology - Santa Catarina, Canoinhas, Brazil, for generating shading equations. Finally, we are grateful for the opportunity to access Mountie MakerSpace (Mt. San Antonio College) and their helpful team for all support provided during the brise-soleil construction.

REFERENCES

1. Chang, T.; Huang, H; Datta, S., (2019). Design and fabrication of a responsive carrier component envelope. Buildings, Basel, v. 9, n. 84, Apr. MDPI. DOI: 10.3390/buildings9040084.
2.Ricci, A.; Ponzio, C.; Fabbri, K.; Gaspari, J.; Naboni, E, (2020). Development of a self-sufficient dynamic façade within the context of climate change. Architectural Science Review. DOI: 10.1080/00038628.2020.1713042
3. Barozzi, M.; Lienhard, J.; Zanelli, A.; Monticelli, C., (2016). The sustainability of adaptive envelopes: developments of kinetic architecture. Procedia Egineering, n. 155, p. 275-284. DOI: 10.1016/j.proeng.2016.08.029
4. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, (2020). ASHRAE Standard 55-2020 – Thermal Environmental Conditions for Human Occupancy. USA, Atlanta: 2020.
5. Nabil, A.; Mardaljevic, J., (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. Lighting Research and Technology, 37.
6. Weatherbase, (2021). Homepage, [Online], Available: https://www.weatherbase.com/weather/weather-summary.php3?s=50740&cityname=Pomona,+California,+United+States+of+America, last accessed 2021/09/29 [29 September 2021].
7. International Organization for Standardization, (1998). ISO 7726:1998 - Ergonomics of the thermal environment – Instrument for measuring physical quantities. Switzerland, Geneva: 1998.
8. Pysolar, (2014). Homepage, [Online], Available: https://pysolar.readthedocs.io/en/latest/, last accessed 2022/02/04 [04 February 2022].

PLEA SANTIAGO 2022
Will Cities Survive?

Proposal of climatic zoning for buildings in Mozambique

MARIANA NAVARRO BENEVIDES[1] DAVID BRUNO DE SOUSA TEIXEIRA[2] JOYCE CORRENA CARLO[1]

[1] Department of Architecture and Urban Planning, Federal University of Viçosa, Brazil
[2] Department of Agricultural Engineering, Federal University of Viçosa, Brazil

ABSTRACT: This study aimed to propose climate zones for Mozambique using multivariate statistical techniques, in addition to establishing the most appropriate thermal conditioning strategies for each zone. Principal component analysis (PCA) was used to select the most relevant variables. From this selection, the hierarchical clustering analysis (HCA) was used to define spatially homogeneous climatic zones considering Ward's method as a hierarchical agglomerative technique and the Euclidean distance as a measure of similarity. For each established zone, the most suitable constructive strategies for thermal conditioning were defined. The PCA enabled the reduction of the initial database from 104 to 47 variables, among which the climatic and bioclimatic variables related to temperature and vapor pressure stand out. From the HCA, three climatic zones were defined for the Mozambican territory. For all zones, there was a high demand for constructive conditioning strategies, among which the adoption of daytime ventilation and thermal inertia with solar heating demonstrate greater potential for increasing the annual hours of comfort. The proposed zoning has great application potential for construction planning more adapted to the climatic aspects of Mozambique, contributing to increasing the energy efficiency of buildings in that country.
KEYWORDS: Energy efficiency, Dwellings, Climate, Constructive strategies.

1. INTRODUCTION

Climate zoning is an important tool that makes it possible to identify and mitigate adverse climate impacts on buildings and define basic requirements for construction in different zones [1-2] in addition to providing the rational use of climate resources [3].

Different climate zoning methods have been adopted by different countries. Among these methods, multivariate statistical techniques such as principal component analysis (PCA) and cluster analysis are widely used for climate data processing [4-6]. While clustering is used for the spatial definition of zones [5–7], PCA is used for data pre-processing to reduce the number of variables from the identification of the most relevant ones [4].

In addition to the definition of zones, the identification of thermal conditioning strategies for buildings can provide an increase in thermal comfort conditions. In this context, Mozambique is a country with limited availability of climate data [8] and does not have climatic zoning for buildings, evidencing a gap in the building performance field. Based on the definition of these zones, it becomes possible to identify the basic requirements for construction in this country, which can help enhance the energy efficiency of buildings.

This study aimed to propose climatic zones for buildings and to identify the most suitable constructive thermal conditioning strategies for Mozambique.

2. MATERIALS AND METHODS

2.1 Study area

Mozambique is located in southeast Africa (Fig. 1a) and has a territorial area of 801,590 km², with altitudes ranging from 4 to 1471 m. According to the Köppen-Geiger climatic classification [9], the country has seven distinct climates, varying between tropical, subtropical, and semiarid climates (Fig. 1b).

In agreement with the characterization of residential buildings presented in UN-Habitat's Housing Profile Report [10], 93.9% of Mozambique's population resides in their own dwellings, that is, they are not rented. In addition, most of these buildings were self-built, which is not specific to the country's rural regions but for the whole country.

Regarding the types of dwellings, three different models are observed (Fig.2). The northern region comprises the provinces of Niassa, Cabo Delgado, and Nampula, where quadrangular and rectangular constructions with internal partitions and more than one exit to the external area are characterized, in addition to the use of typical construction materials of the region, such as adobe and bamboo. In the center of the country are the provinces of Zambezia, Tete, Manica, and Sofala, which have the same building format as the northern region, however, these residences do not have well-defined internal divisions. Finally, in the regions declared as urban, formed by Gaza, Inhambane, and Maputo, the typologies are quadrangular and rectangular as in other regions, however, they present many internal divisions, in addition to the use of constructive materials more familiar to the constructions of the 20th century, such as fiber cement sheets, soil-cement block, and others [10].

Figure 1: (a) Location of Mozambique and (b) its climatic classification of Köppen-Geiger [9].

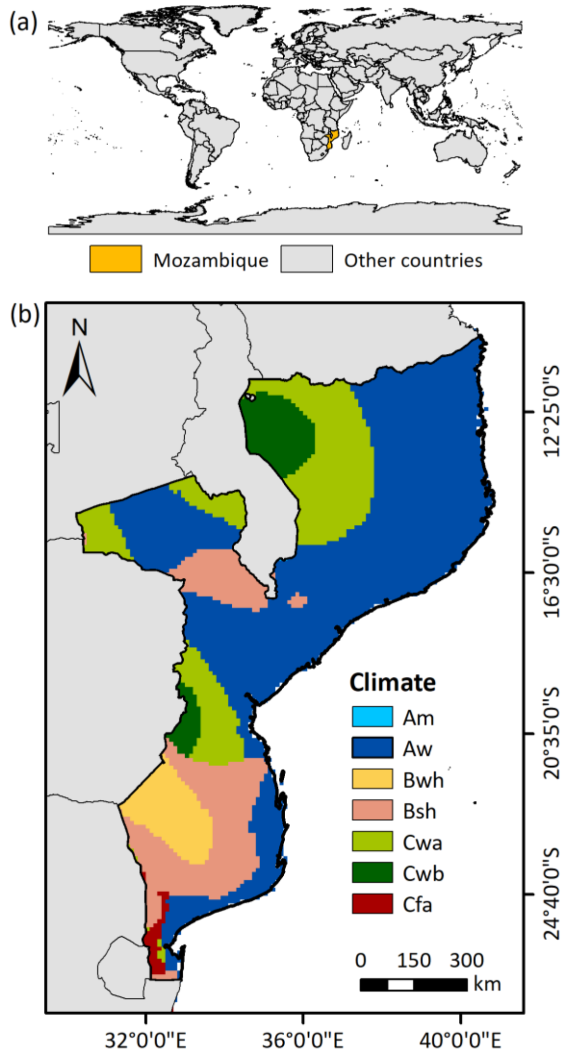
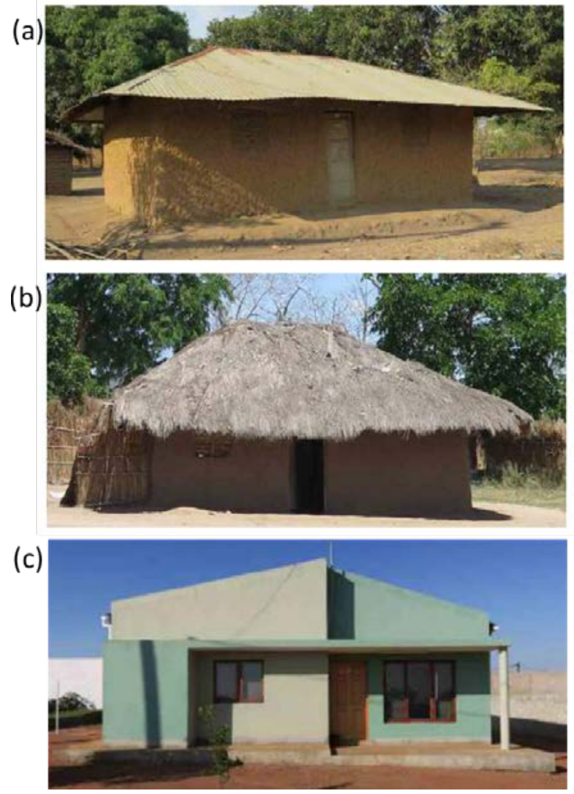


Figure 2: Typical dwellings of the (a) northern region, (b) central region, and (c) urban areas in Mozambique [10].



2.2 Definition of the climatic zones

Data from 104 variables in pixel format, obtained from the WorldClim 2 Data Portal database [11], was the adopted source to define the climatic zones. This database includes climatic variables (e.g., monthly average, maximum and minimum temperatures) and variables called bioclimatic (e.g., thermal amplitude, annual precipitation), in addition to altitude values. In total, 9682 pixels covered the whole country area (Fig. 3).

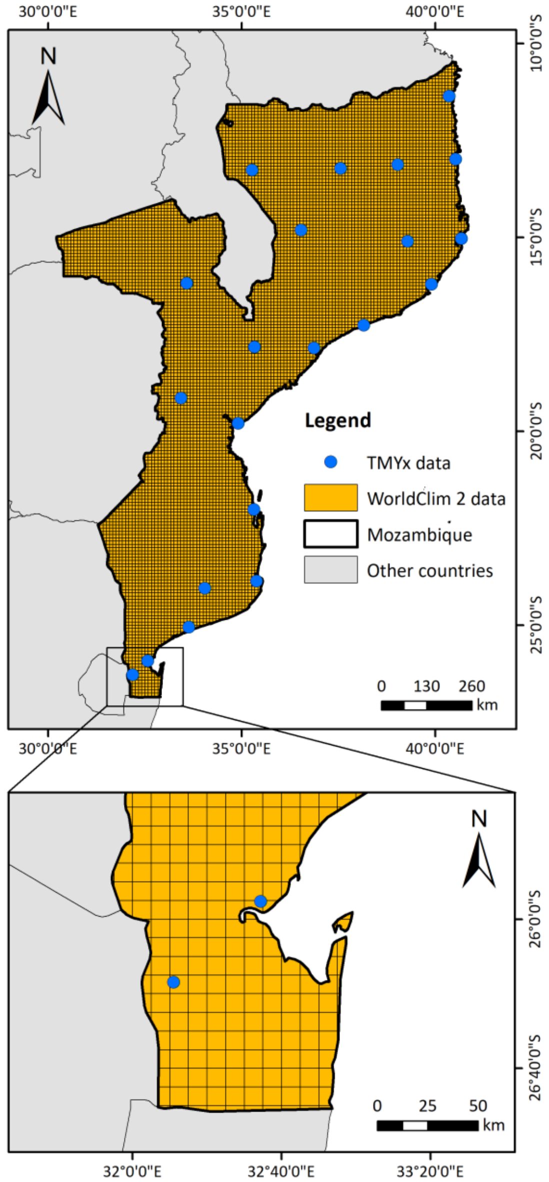
Principal component analysis (PCA) was the adopted method for the selection of the variables of most practical relevance in defining the zones. PCA is a statistical procedure used to extract relevant information from a multivariate dataset from the conversion of correlated variables into linearly uncorrelated variables, called principal components (PCs).

In the present study, we considered that the number of PCs to be used should explain at least 90% of the total variance of the data. Furthermore, as a criterion for the selection of variables, only those that presented a correlation (positive or negative) equal to, or greater than, 0.80 were suitable for selection.

From the climatic variables selected by the PCA, the pixels were grouped based on the hierarchical clustering analysis (HCA) to define the climatic zones. In addition to these variables, the central latitudes and longitudes of each pixel were included in the analysis. Ward's method [12] was used as a hierarchical agglomerative technique. As a measure of proximity, the Euclidean distance was used [7].

These procedures were performed using the R software, version 4.0.2 [13]. A voting scheme with 23 different indices identified the ideal number of climatic zones (clusters) through NbClust package [13], also in the R environment.

Figure 3: Spatial distribution of the WorldClim 2 data pixels and the TMYx data used for Mozambique.

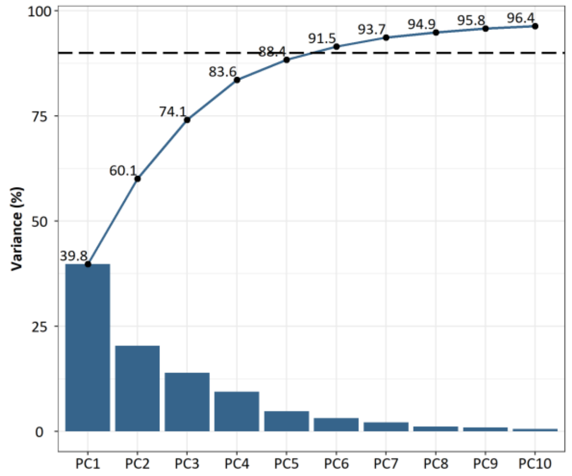


3. RESULTS AND DISCUSSION

3.1 Definition of the climatic zones

The PCA technique allowed the reduction of the dimensionality of the initial database and the definition of the variables of greater influence on the proposed climate zoning for Mozambique. Based on the defined number of main components selection criteria, only the first six main components were selected for the analysis of variables, totaling 91.50% of the variance (Fig. 4).

Figure 4: Percentage of explained variance and accumulated variance for the first ten principal components (PCs).

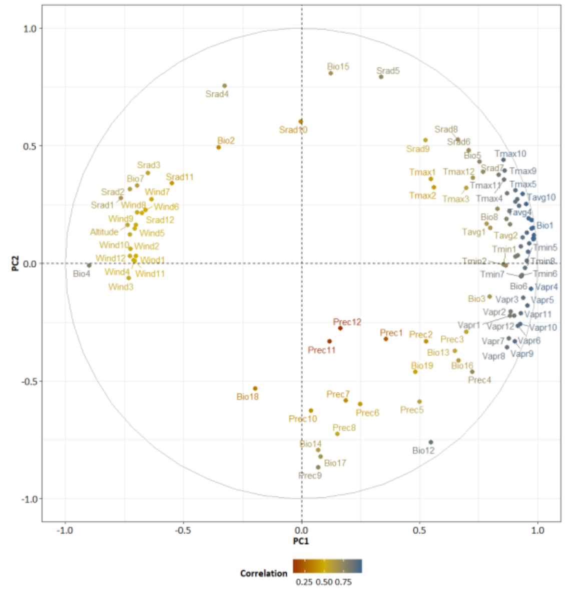


Although the first six principal components were considered for the choice of the most important variables, it was noticed that correlation values considered significant (≥|0.8|) occurred only in the first two PCs. From the total set of 104 variables, we found that 41 showed a significant correlation with PC1, while 6 variables were significant for PC2. Fig. 5 shows the correlation values between the two most relevant principal components, PC1 and PC2, and the 104 variables analyzed. In this figure, the variables located adjacent to the circumference delimitation have a positive or negative correlation close to unity and present a greater correlation with each other when contiguous to each other.

Therefore, PCA allowed the reduction of the dimensionality of the initial database from 104 to 47 variables. Among these, there is the relevance of mean, maximum, and minimum temperatures for most months, in addition to bioclimatic variables also related to temperature, confirming the importance of this variable. Furthermore, the variable vapor pressure was also important, since all months were selected.

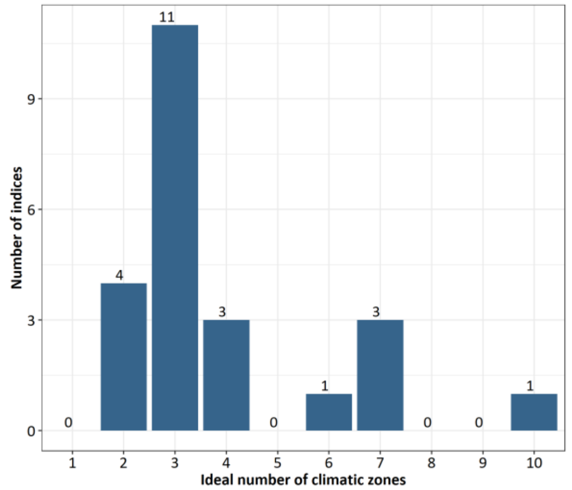
From the use of these variables, HCA enabled the grouping of pixels in order to define climatically homogeneous zones. Based on the voting scheme regarding the use of 23 indices (Fig. 6), it was found that the ideal number of climate zones for Mozambique is three.

Figure 5: Biplot graph of the correlation values between the principal components 1 and 2 and the 104 variables analyzed.



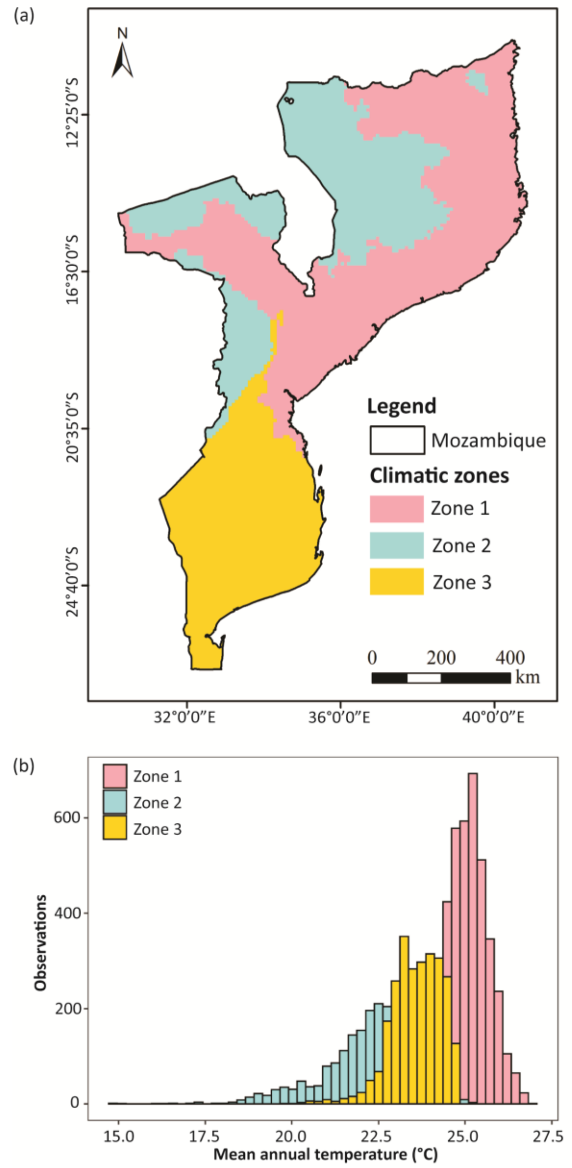
Note: Tmean: monthly mean temperature (1, 2, 3 .... 12 = January, February, March, ... December), Tmin: monthly minimum temperature, Tmax: monthly maximum temperature, Prec: monthly rainfall precipitation, Srad: monthly solar radiation, Wind: monthly wind speed, Vapr: monthly water vapor pressure.

Figure 6: Ideal number of clusters suggested by the 23 indices used.



As presented in Fig. 7a, Zone 1 is the largest defined zone, occupying about 45% of the total country area, and it is located on the coast, with high temperatures (Fig. 7b). On the other hand, Zones 2 and 3 are smaller, with areas of 28.3 and 26.7%, respectively. The reader must notice that Zone 2 has the highest altitudes (maximum of 1471 meters) [11] and, consequently, the lowest temperatures when compared to other zones.

Figure 7: (a) Spatial distribution of the climate zones defined for Mozambique and (b) histogram of the mean annual temperature values for each zone.

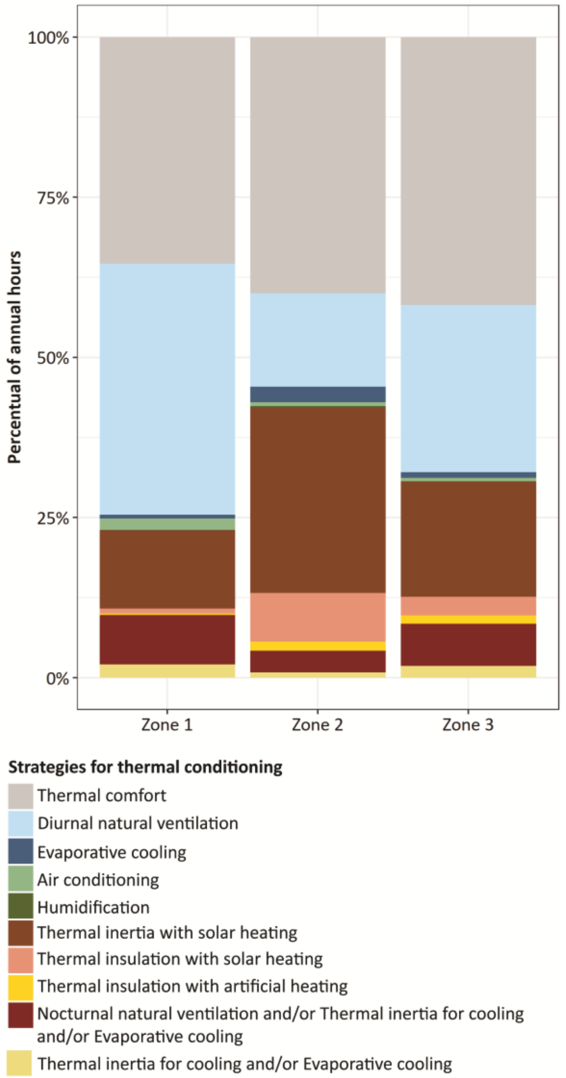


3.2 Definition of the constructive strategies

There was a high demand for thermal conditioning strategies in all climatic zones defined for Mozambique. The three established zones demanded the daytime natural ventilation strategy, with emphasis on Zones 1 and 3, required in 39.0 and 26.0% of the annual hours, respectively (Fig. 8). As explained by Aflaki et al. [16] and Zheng et al. [17], the use of natural ventilation consists of a passive strategy that relies on pressure differences to move air through buildings (convective cooling), which promotes the renewal of indoor air. Aflaki et al. [16] and Chen et al. [18] also highlight that natural ventilation has great potential for reducing the energy required for cooling building components, with a lower operating cost when compared to the use of mechanical ventilation Zheng et al. [17].

Zone 2 presented a demand for the thermal inertia strategy with solar heating expressively higher than the others, required in 28.9% of the annual hours. According to Nikolić et al. [19], thermal inertia with solar heating consists of the use of constructive components that retain the heat absorbed, slowly releasing it to the interior of the environment when the internal temperatures become lower than the external ones. The fact that this zone presents the greatest demands for the strategy of thermal insulation with solar heating corroborates the need for heating.

Figure 8: Percentual of annual hours of thermal comfort occurrence and demands for thermal conditioning strategies for each zone.



Demands for artificial cooling (air conditioning) and artificial heating (with thermal insulation) showed low annual percentages for all zones (<2% of annual hours). As shown by Kashyap et al. [20], the use of passive strategies has an advantage over artificial ones since they do not require the use of electricity.

In addition to the aforementioned strategies, shading is recommended for all established zones once the dry bulb temperature values are higher than 20°C [21].

4. CONCLUSION

PCA and HCA multivariate statistical techniques enabled the definition of three zones with distinct climatic characteristics and constructive particularities in Mozambique. For all zones, there was a high demand for constructive conditioning strategies. Daytime ventilation and thermal inertia with solar heating had the greatest potential for increasing the annual hours of comfort. The proposed zoning has great application potential for construction planning more adapted to the climatic aspects of Mozambique, contributing to the enhancement of energy efficiency building measures in this country.

ACKNOWLEDGEMENTS

This study was supported by the Coordination for the Improvement of Higher Education Personnel, Brazil (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES, grant number 001).

REFERENCES

1. Chen, X., & Yang, H. (2018). Integrated energy performance optimization of a passively designed high-rise residential building in different climatic zones of China. *Applied Energy*, *215*(January), 145–158. https://doi.org/10.1016/j.apenergy.2018.01.099
2. Walsh, A., Cóstola, D., & Labaki, L. C. (2019). Validation of the climatic zoning defined by ASHRAE standard 169-2013. *Energy Policy*, *135*(October). https://doi.org/10.1016/j.enpol.2019.111016
3. Khambadkone, N. K., & Jain, R. (2017). A bioclimatic analysis tool for investigation of the potential of passive cooling and heating strategies in a composite Indian climate. *Building and Environment*, *123*, 469–493. https://doi.org/10.1016/j.buildenv.2017.07.023
4. Praene, J. P., Malet-Damour, B., Radanielina, M. H., Fontaine, L., & Rivière, G. (2019). GIS-based approach to identify climatic zoning: A hierarchical clustering on principal component analysis. *Building and Environment*, *164*. https://doi.org/10.1016/j.buildenv.2019.106330
5. Xiong, J., Yao, R., Grimmond, S., Zhang, Q., & Li, B. (2019). A hierarchical climatic zoning method for energy efficient building design applied in the region with diverse climate characteristics. *Energy and Buildings*, *186*, 355–367. https://doi.org/10.1016/j.enbuild.2019.01.005
6. Hao, Z., Zhang, X., Xie, J., Wang, J., & Liu, J. (2020). Building climate zones of major marine islands in China defined using two-stage zoning method and clustering analysis. *Frontiers of Architectural Research*, *xxxx*. https://doi.org/10.1016/j.foar.2020.07.004
7. Bai, L., Yang, L., Song, B., & Liu, N. (2020). A new approach to develop a climate classification for building energy efficiency addressing Chinese climate characteristics. *Energy*, *195*, 116982. https://doi.org/10.1016/j.energy.2020.116982
8. Gelcer, E., Fraisse, C. W., Zotarelli, L., Stevens, F. R., Perondi, D., Barreto, D. D., Malia, H. A., Ecole, C. C., Montone, V., & Southworth, J. (2018). Influence of El Niño-Southern oscillation (ENSO) on agroclimatic zoning for tomato in Mozambique. *Agricultural and Forest Meteorology*, *248*(June 2017), 316–328. https://doi.org/10.1016/j.agrformet.2017.10.002
9. M. C. Peel, B. L. Finlayson2, and T. A. M. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, *11*, 1633–1644.
10. UN-Habitat. (2018). *Moçambique - Housing Profile Report*. https://unhabitat.org/sites/default/files/documents/2019-05/housing_profile_mozambique_pt.pdf
11. Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086
12. Ward Jr, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association*, *58*(301), 236–244. https://doi.org/https://doi.org/10.1080/01621459.1963.10500845
13. R Core Team. (2020). *The R Project for Statistical Computing 4.0.2*. https://www.r-project.org/
14. Charrad, M., Ghazzali, N., Boiteau, V., & Niknafs, A. (2014). NbClust: An R Package for Determining the Relevant Number of Clusters in a Data Set. *J. Stat. Softw. 61*. https://doi.org/https://doi.org/10.18637/jss.v061.i06
15. Charrad, M., Ghazzali, N., Boiteau, V., & Niknafs, A. (2015). *NbClust: Determining the Best Number of Clusters in a Data Set. R package version 3.0*. https://cran.r-project.org/web/packages/NbClust/index.html.
16. Aflaki, A., Mahyuddin, N., Al-Cheikh Mahmoud, Z., & Baharum, M. R. (2015). A review on natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy and Buildings*, *101*, 153–162. https://doi.org/10.1016/j.enbuild.2015.04.033
17. Zheng, X., Shi, Z., Xuan, Z., & Qian, H. (2018). Handbook of Energy Systems in Green Buildings. In R. Wang & X. Zhai (Eds.), *Handbook of Energy Systems in Green Buildings* (pp. 1227–1270). Springer Nature. https://doi.org/10.1007/978-3-662-49120-1_8
18. Chen, Y., Tong, Z., & Malkawi, A. (2017). Investigating natural ventilation potentials across the globe: Regional and climatic variations. *Building and Environment*, *122*, 386–396. https://doi.org/10.1016/j.buildenv.2017.06.026
19. Nikolić, D., Skerlić, J., Cvetković, D., Radulović, J., & Jovanović, S. (2018). Basic principles of passive solar heating. *3rd International Conference on Quality of Life*, 9.
20. Kashyap, S., Kumar Gaba, V., & Kumar Tiwari, A. (2019). Enhancing Passive Cooling and Natural Ventilation for Houses of Various Climatic Zones of India. *2019 IEEE 2nd International Conference on Power and Energy Applications, ICPEA 2019*, 183–187. https://doi.org/10.1109/ICPEA.2019.8818531
21. Lamberts, R., Dutra, L., & Pereira, F. O. R. (2014). *Eficiência Energética na Arquitetura* (3rd ed.). Eletrobrás/Procel.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA SANTIAGO 2022
Will Cities Survive?

Influence of urban morphology on thermal gain
Brazilian Context

RENATA MANSUELO ALVES DOMINGOS [1] EMELI LALESCA APARECIDA GUARDA [1] FERNANDO OSCAR RUTTKAY PEREIRA [1]

[1] Universidade Federal de Santa Catarina

ABSTRACT: The shape of cities can influence the thermal gain generated by radiation, which can be positive or negative. In Brazil, which has a predominantly tropical climate, this gain tends to be avoided. This research aims to evaluate the influence of urban form on the solar thermal gain for the cities of Cuiabá and Florianópolis. The method is divided into the definition of urban scenarios, simulation in EnergyPlus, and analysis of thermal loads for cooling. The results show that when comparing the cities, the thermal load needed to achieve comfort in Cuiabá is much higher, being more than double. The best scenario for the surroundings is C, where the shadow projection is more expressive and influences the central model being evaluated more. This change ranged from 3% to 10% in the decrease in the thermal load gained by the building. The more significant the radiation that the city is exposed to, the greater the influence of shading and, consequently, the thermal load that the city is subject to. This is the first step in an optimization process for the use of solar energy according to urban morphology in Brazilian cities.
KEYWORDS: Urban Design, Cooling thermal load, Solar Energy

1. INTRODUCTION

Among academics and practitioners working in urban planning and design, there has been an ongoing discussion about the relationships between urban morphology and environmental sustainability. From a sustainable urban development perspective, built morphology has played a central role in determining overall energy consumption in cities. [1]

Currently, 75% of global energy consumption takes place in cities. On climate change, adapting urban settlements to meet this growing demand is a priority issue, especially for fast-growing cities in developing countries like Brazil. Planning the urban morphology of the built environment is a crucial issue for moving to a climate-adapted urban environment [2].

Holmes e Hacker [3] showed that the current challenge for construction professionals is to design low-consumption buildings while still providing environmental comfort. These buildings rely on passive strategies, thus reducing the demand for cooling, lighting, heating, and equipment, consequently reducing consumption and achieving thermal comfort inside the buildings suitable for the occupants [4, 5].

The shape of cities and neighborhoods can influence energy efficiency. The thermal gain generated by radiation can be positive or negative, depending on the climate. Although many efforts have recently been made to promote energy efficiency in the built environment, they are mainly applied to individual building units. However, few studies have attempted to quantify the effect of urban density and layouts on building energy consumption. [6].

A set of factors is considered to assess the influence of urban morphology in terms of the radiation balance (incoming solar radiation, outgoing thermal radiation, and daylight level) as renewable sources of energy, heat, and light on building surfaces. representative about geometry and orientation [2].

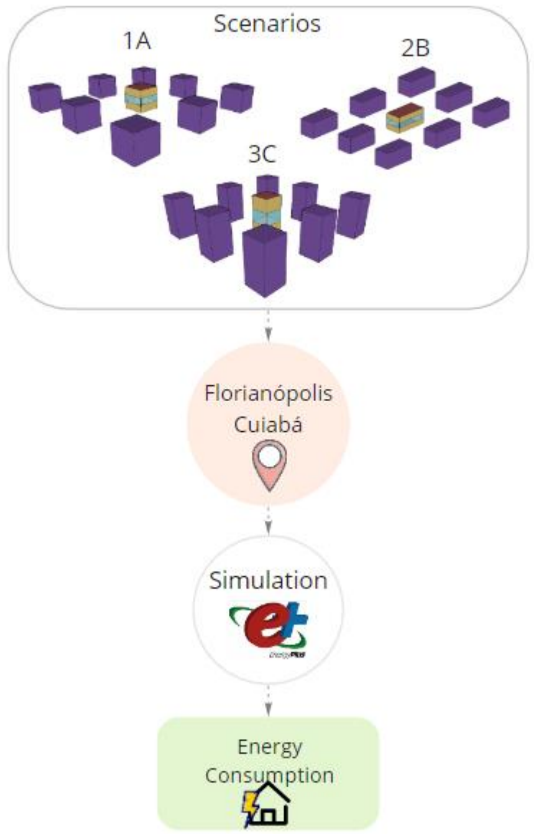
In the case of Brazil, which has a predominantly tropical climate, this gain tends to be avoided in warmer places. In tropical climates, the solar resource offers enormous potential for different applications. In addition to daylight indoors, solar energy can be converted to local thermal and electrical energy production. However, in these sunny regions, solar heat gains from the building envelope can also produce highly undesirable thermal comfort conditions for users, consequently increasing the demand for electricity for cooling the environment [6].

Thus, this research aims to evaluate the influence of urban form on the thermal solar gain of a building in Brazil.

2. METHODOLY

The method is divided into the definition of urban scenarios (blocks), simulation and analysis of the results. According to the Figure 1.

Figure 1:
Research Flowchart



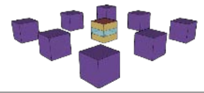
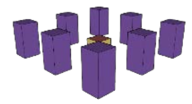
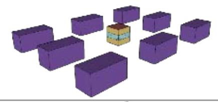
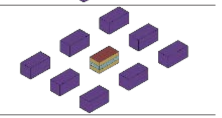
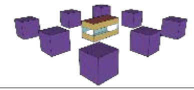
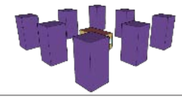
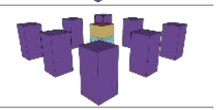
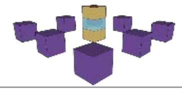
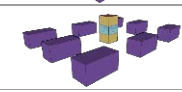
2.1 Definition of urban scenarios

The survey contains nine different scenarios. Three models were defined for the evaluations. The first is square and has the dimensions of 3x3x3 (Model 1 for the evaluation and A for the surroundings); the second is twice the size on the x-axis (Model 2 for the assessment and B for the surroundings), and the third is twice the size on the y-axis (Model 3 for the assessment and C for the surroundings). The central building is what is evaluated, and the surroundings undergo variation (Table 1).

The models were defined according to the most familiar buildings in the two cities presented below, and the master plans considered the building in isolation. There is a variation in the heights of the buildings in the same block. As this is an initial study, this variation was simplified.

The cities defined are Cuiabá and Florianopolis. Cuiabá has a warmer climate (savannah) with an average annual temperature of 26.3ºC, and Florianopolis has a milder climate (subtropical) and an average annual temperature of 20.8ºC.

Table 1:
Dimensions of the analyzed scenarios

ID	Module (m)	Surroundings (m)	
1A	3x3x3	3x3x3	
1B	3x3x3	3x3x6	
1C	3x3x3	3x6x3	
2A	3x6x3	3x6x3	
2B	3x6x3	3x3x3	
2C	3x6x3	3x3x6	
3A	3x3x6	3x3x6	
3B	3x3x6	3x3x3	
3C	3x3x6	3x6x3	

2.2 Simulation

The simulation was performed in the EnergyPlus software. EnergyPlus is software that has already been validated in previous research [7, 8]. The building considered is a commercial building, and the inputs for occupation, lighting, equipment, and air conditioning set point were added following the Brazilian energy efficiency normative instruction [9]. The power density of lighting and equipment is 14.1W/m² and 15W/m². The occupancy density is 10m²/person, 10 hours, and 260 occupancy days. The modules were considered in the naturally ventilated condition and with the windows open according to the occupancy schedule.

The Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Service, and Public Buildings (INI-C) [9] was taken to insert the constructive characteristics and pattern of use of the module under analysis. Thus, he considered the module as an office building, with internal and external mortar walls (2.5cm), ceramic brick (9cm) and fiber cement tile roof (1cm), attic with resistance >5cm, and solid concrete slab

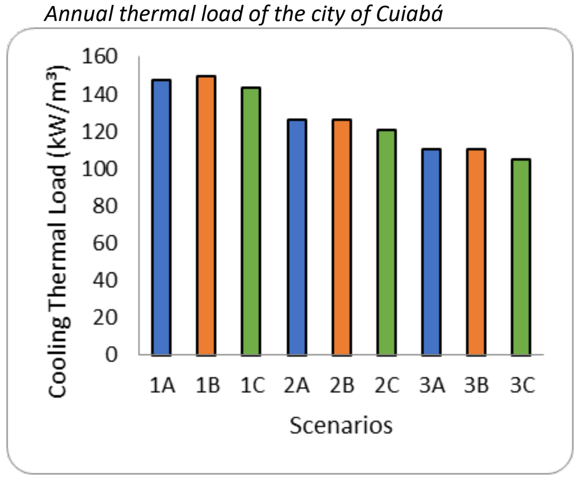
(10cm) as lining. The walls and roof have an absorbance of 0.5 and 0.8, respectively. The openings were considered the width and length of the module, with a sill and height of 1.0m. The single colorless glass of 6mm was used, with a solar factor of 0.82 and transmittance of 5.7W/m².K.

The consumption value analyzed considers the thermal load necessary for cooling the hours of operation with a temperature above 24ºC. Heating is not considered in the city of Florianopolis because it was null.

3. RESULTS

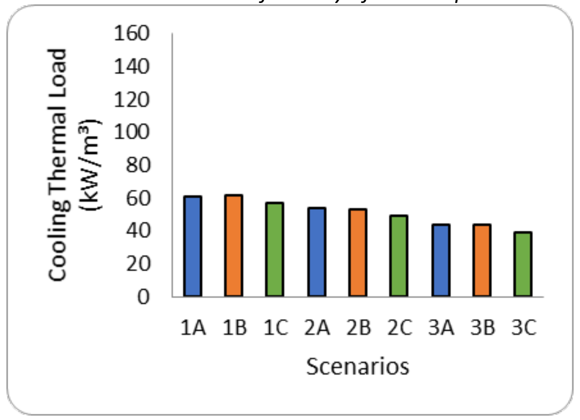
The thermal load was calculated considering the thermal load per cubic meter for comparison to be made. Figure 2 shows the annual results for Cuiabá, and Figure 3 shows the results for Florianopolis. At first, when comparing the cities with each other, it is noticed how the thermal load needed to achieve comfort in Cuiabá is much greater, being more than double. The models showed the same behavior in both cities when analyzing the annual scenario.

Figure 2:
Annual thermal load of the city of Cuiabá



It is noted that the building format that had the most gain in thermal load was model 1, regardless of the surroundings. The same goes for model 3, which had better performance in all environments considered. The best environment independent of the scenario is C, where the shadow projection is more expressive and influences the central model being evaluated more. This change varied from 3% to 10% in the decrease in the thermal load gained by the building.

Figure 3:
Annual thermal load of the city of Florianopolis



The monthly analysis shows how the impact of the thermal load, directly linked to radiation, should pay more attention to the hottest regions. The city of Cuiabá has a significant savings potential in absolute numbers, and this difference can be seen in months such as August, September, and October (Figure 4), where the thermal load reaches 27% when comparing the same surroundings and different models. When we compare the same model and different scenarios, this economy tends to remain constant throughout the year, being around 6%. (Figure 5)

Figure 4:
Thermal load of August, September and October of the city of Cuiabá

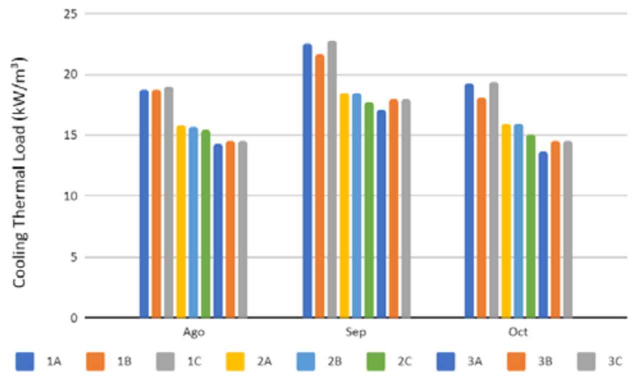
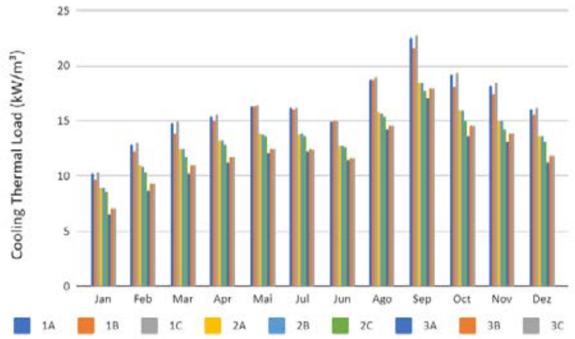


Figure 5:
Monthly thermal load of the city of Cuiabá



The city of Florianopolis has a climate with four well-defined seasons. This means a very different behavior from what was seen before (Figure 6). The most significant difference between the scenarios in January, February, and March, reaching 33% more load when comparing different models. The comparison between scenarios has a load of up to 12% difference (Figure 7). In June, July, and August, the load is small in absolute numbers, and therefore the percentage difference is more significant, reaching almost 50% in the comparison between the models and between the scenarios (Figure 8). This is because as the climate is predominantly cold, exposure to solar radiation has a more significant influence in these months.

Figure 6:
Monthly thermal load of the city of Florianópolis

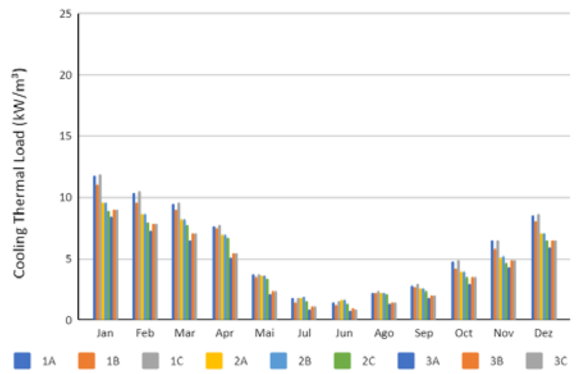


Figure 7:
Thermal load of January, February and March of the city of Florianopolis

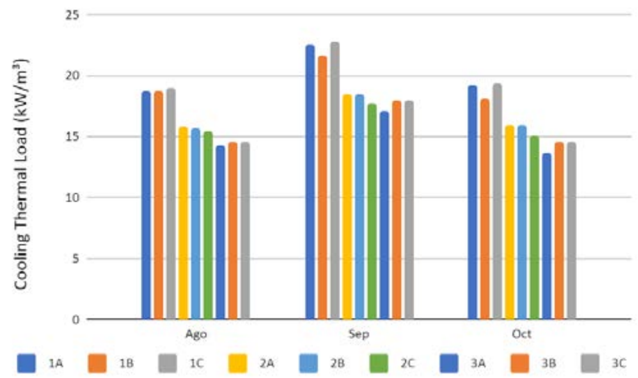
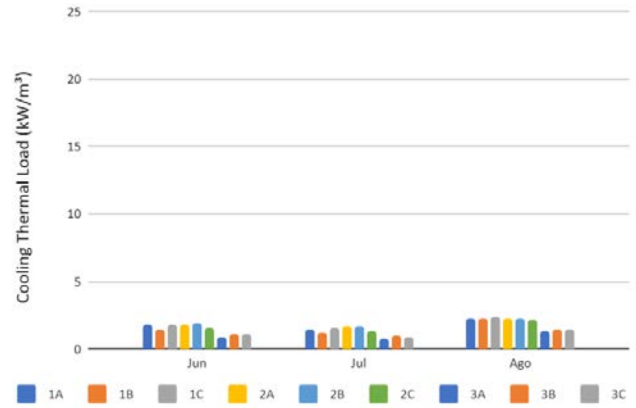


Figure 8:
Thermal load of June, July and August of the city of Florianopolis



4. CONCLUSION

Considering urban morphology is complex when thought of in architectural terms. However, with this research, it is possible to demonstrate how the surroundings considerably influence the thermal load gained by the building. Simulating buildings in isolation can generate a significant error when measures reduce consumption, especially if these measures are less than 10% of the difference.

This paper brings simplified scenarios for cities with different climates, a factor that should also be considered. The greater the radiation that the city is exposed to, the greater the influence of shading and, consequently, the thermal load that the city is subjected to.

This is the first step of an optimization process for the use of solar energy according to urban morphology in Brazilian cities.

REFERENCES

1.SARRALDE, J. J. et al. Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. Renewable Energy, v. 73, p. 10–17, 2015.

2. MARTINS, T. A. DE L. et al. Sensitivity analysis of urban morphology factors regarding solar energy potential of buildings in a Brazilian tropical context. Solar Energy, v. 137, p. 11–24, 2016.
3. HOLMES, M. J.; HACKER, J. N. Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century. Energy and Buildings, v. 39, n. 7, p. 802–814, 2007.
4. KAYNAKLI, O. A review of the economical and optimum thermal insulation thickness for building applications. Renewable and Sustainable Energy Reviews, v. 16, n. 1, p. 415–425, 2012.
5. RODRIGUEZ-UBINAS, E. et al. Energy efficiency evaluation of zero energy houses. Energy & Buildings, v. 83, p. 23–35, 2014.
6. MARTINS, A.L., ADOLPHE, T. & BASTOS, E.G. L. From solar constraints to urban design opportunities: Optimization of built form typologies in a Brazilian tropical city. Energy and Buildings, v. 76, p. 43–56, 2014.
7. DOMINGOS, R. M. A., AND PEREIRA, F. O. R. Comparative cost-benefit analysis of the energy efficiency measures and photovoltaic generation in houses of social interest in Brazil. Energy and Buildings, 243, 2021.
8. GUARDA, E.L.A. DE; et al. The influence of climate change on renewable energy systems designed to achieve zero energy buildings in the present: A case study in the Brazilian Savannah. Sustainable Cities and Society, v. 52, 101843, 2020.
9. BRASIL. Instituto Nacional de Metrologia, Qualidade e Tecnologia, Inmetro. Portaria n° 42, de 24 de fevereiro de 2021. Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas (INI-C). Diário Oficial da União, Brasília - DF, 2021.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 03
09:00 — 10:30

CHAIR
HECTOR ALTAMIRANO

PAPERS
1441 / 1280 / 1366 / 1646 / 1546

31TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022

Will Cities Survive?

What interior temperatures can be expected in Irish nZEB dwellings?

An analysis of recorded interior temperatures in a scheme of Irish nZEB dwellings built to the Passive House standard

SHANE COLCLOUGH[1,2,3], RICHARD O HEGARTY[1], MATHIEU LEBLANC[4], TOM DESBERTRAND[4], NEIL HEWITT[2], OLIVER KINNANE[1]

[1]University College Dublin, Dublin, Ireland
[2]Ulster University, Newtownabbey, BT370QB, UK
[3]Energy Expertise Ltd., Naas, Ireland
[4]EPF Engineering School, 34000 Montpellier, France
Corresponding Author s.colclough@ulster.ac.uk

ABSTRACT: This paper reports on the recorded interior temperatures in a scheme of 12 houses built to the passive house standard, and which are compliant with the Irish newbuild near Zero Energy Buildings (nZEB) implementation of the EU Energy Performance of Buildings Directive. The interior temperatures were found to be substantially higher than the assumptions inherent in the national energy rating software "DEAP". In addition, the interior temperatures were consistently high over the 24 hour period i.e. they did not follow the pattern of heating assumed in the DEAP software of two hours in the morning and six hours in the evening. The paper quantifies the corresponding additional space heating related energy consumption and finds it to be in the order of 29%. The findings are in line with other Post Occupancy Evaluation (POE) studies of nZEB dwellings and has implications for the accuracy of the Building Energy Rating (BER) assigned to dwellings.

KEYWORDS: nZEB, Passive House, Post Occupancy Analysis, POE, Dwelling Energy consumption

1. INTRODUCTION

The near Zero Energy Building Standard (nZEB) is required for all new dwellings constructed in the European Union from 1 January 2021 (EU, 2016a).

The objective of the nZEB101 project (*NZEB101*, n.d.) is to uncover the key nZEB design, construction and operations lessons as the Republic of Ireland embarks on the construction of 550,000 of these low-energy buildings by 2040 (Anon, 2018).

Previous papers on the indoor environmental quality (IEQ) of nZEB compliant deep energy retrofit dwellings occupied by retirees indicated prolonged high interior temperatures (Colclough et al., 2022) as did a small sample size of social housing dwellings built to the passive house (PH) standard and the nZEB standard (Colclough et al., 2018).

This paper looks at the interior temperatures recorded across a homogeneous scheme of 12 three-bedroom semi detached dwellings with a mixed-use profile. The aim is to determine if the temperature profiles previously identified for individual dwellings and deep energy retrofit dwellings occupied by retirees are experienced in a mixed-use development. By obtaining mean temperature profiles across the scheme of homogeneous dwellings, the influence of individual usage profiles is reduced and general conclusions can be drawn.

The areas covered in this paper include analysis of:

1. The recorded interior temperatures for the living room, main bedroom and kitchen.
2. A comparison with the predicted values for interior temperatures inherent in the National energy rating software, DEAP (*DEAP 4.2.0 Software*, n.d.).
3. Interior living room and rest of dwelling temperatures including comparison with assumed heating set temperatures.
4. Analysis of additional heating energy required to meet recorded temperatures compared with predicted temperatures.

2. METHOD

The nZEB101 project gathers data on indoor environmental quality (temperature, relative humidity, carbon dioxide concentrations) and the outdoor temperature and relative humidity at five-minute intervals. In addition, energy consumption has been recorded at half hourly intervals.

As part of the project, 12 PH dwellings have been monitored and are reported on here. An in-depth individual Post Occupancy Evaluation paper has previously reported on the occupant satisfaction, temperature profiles, carbon dioxide readings, energy consumption of three dwellings (Colclough et al., 2018). Previous findings included higher-than-expected temperatures during the heating season, in addition to longer than expected diurnal and seasonal heating periods.

This paper presents and analyses interior temperature data across the larger sample size of dwellings in order to gauge if the individual findings to date are replicated across the larger dataset, enabling conclusions from a more holistic perspective and the temperatures are compared with those inherent in the Dwelling Energy Assessment Procedure (DEAP) national energy rating software.

The 102m^2 three bedroomed two storey dwellings have an A2 BER and are certified passive houses.

The development is a mix of social housing and privately owned dwellings. All 9 of the social housing dwellings are occupied by families, with two of the privately owned being owner occupied dwellings (single occupancy), with the remaining privately owned unit rented to a family.

The houses studied are newly constructed two-storey timber framed semi-detached dwellings with triple glazed windows and Mechanical Ventilation with Heat Recovery (MVHR) systems and for which full details are available (Colclough et al., 2018).

The exhaust air MVHR recovers heat from the expelled air, and also uses an integrated heat pump to provide Domestic Hot Water (DHW) and space heating (Nilan, n.d.). Auxiliary and instantaneous space heating demand is met with two wall mounted 550 W electric radiators. The houses are almost identical in size and encompass a kitchen, living room and utility room on the ground floor and three-bedrooms (one en suite) and a bathroom on the first floor.

Nine of the houses were monitored over a full year and good data integrity was achieved. In any cases where less than 50% of the data for the season was available, box plots were not produced - e.g. nZEB17 withdrew from the monitoring after a number of months, so box plots were only produced for the winter season, despite some data being available for two other seasons.

3. RESULTS

3.1 Overview

The interior temperatures for all dwellings have been plotted using box plots which show not only the median and the mean readings obtained for each dwelling, but also provide information on the range of temperatures experienced.

The Dwelling Energy Assessment Procedure (DEAP) software which produces the BER assumes that the heating system has a set temperature of 21°C in the living room, and 18°C in all other rooms for two hours in the morning and six hours in the evening. This equates to an average heating system set temperature of 19.1°C for eight hours of the day for a typical dwelling, and a lower temperature for the remaining period given that the heating will be off and external temperatures will influence the heat loss from the building. The DEAP software calculates that mean temperatures will be 17.7°C (winter), 17.8°C (spring), 18.3°C (summer) and 18.0°C (autumn).

An investigation has been carried out into the recorded temperatures in the living room, kitchen and main bedroom in order to compare the actual temperatures with those expected by the DEAP software.

Figures 1, 2 and 3 respectively show the available recorded temperatures for the dwellings for each of the four seasons for living room, bedroom and kitchen.

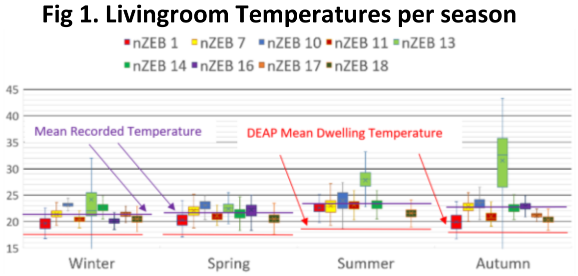
In the diagrams below, the mean recorded seasonal temperatures across all dwellings for the living rooms, kitchens and bedrooms are presented in purple lines, and the DEAP-estimated mean dwelling seasonal temperatures are presented in red.

3.2 Living room temperatures

The mean of the recorded temperatures for each season are seen to be higher than the mean temperatures expected by the DEAP software by significant margins: 3.5°C (winter), 3.7°C (spring), 4.3°C (summer) and 4.7°C (autumn).

The living room in nZEB 14 is seen to have the highest temperatures, with average temperatures of 24.4°C, 22.4°C 26.9°C and 31.5°C for winter through to autumn respectively. However, this is an outlier as the living room is used as a bedroom/computer room by the tenant's son.

Fig 1. Livingroom Temperatures per season

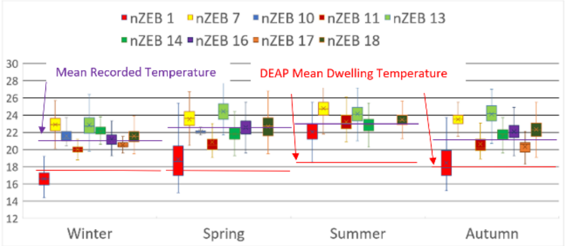


For all but one of the dwellings (nZEB 1), figure 1 shows that the living room temperatures experienced were above approximately 20°C for 75% of the time (apart for winter in nZEB 16 where the temperature was greater than 20°C for 50% of the time).

3.3 Bedroom temperatures

The box plots for the bedroom exhibits similar temperatures per season (fig 2) to those seen in the living room. Given that the DEAP assumed setpoint for the heating system is 18°C outside of the living room, the mean temperature differential is significantly higher than for the living room, ranging from 3.1°C (autumn) to 4.8°C (spring). nZEB1 exhibits the lowest temperatures, due to the relatively low occupancy rate reported by the owner occupier, and a preference for cooler bedroom temperatures.

Fig 2. Bedroom Temperatures per season



The remainder of the bedrooms range in temperature from a low of 18°C (nZEB 17, Autumn) to a high of 28°C (nZEB 13, Spring).

In the summer, the lowest mean temperature is 22°C (NZEB 1), while the other mean temperatures range from 23°C (nZEB14) to 25°C (nZEB7). This corresponds with the relatively high temperatures reported by the occupants.

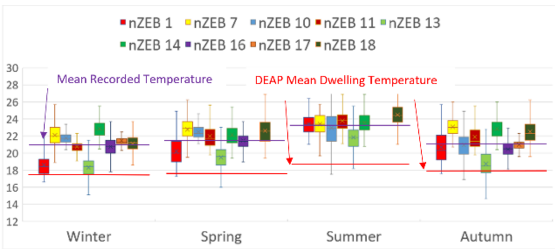
3.4 Kitchen temperatures

The mean kitchen temperatures are similar to the living room temperatures but again, similar to the bedroom, show a significantly higher mean temperature differential Vs the DEAP profile given that the expected heating system set temperature is 18°C (compared with 21°C for the living room).

The majority of the individual dwelling temperatures range from 17°C to 26°C. Mean summer temperatures range from 22°C (NZEB 13), to 24.6°C (nZEB18).

nZEB 10 and 17 are seen to have a relatively low range of temperatures across seasons for all rooms, indicating that there is good temperature control and a consistent setpoint for the heating system.

Fig 3. Kitchen Temperatures per season



This is in contrast to the relatively large range experienced in NZEB 1 (due to varying occupancy) and the living room of nZEB 13 (due to the particular usage profile). It is noted that the temperature profiles of the remaining rooms are relatively stable across seasons for NZEB 14.

4. INTERIOR TEMPERATURE PROFILES COMPARED WITH DEAP ASSUMPTIONS Overview

Section 3 indicates that on average, interior temperatures are significantly higher than those expected in the DEAP software. This section looks at whether the interior temperatures follow the heating pattern assumed by the DEAP software.

DEAP assumes that the living room is heated to 21°C for two periods i.e. 7 AM to 9 AM and 5 PM to 11 PM, and that the rest of the dwelling is heated to 18°C for the same periods. Therefore analysis has been carried out for all dwellings for which data was available to determine temperatures:

1. For the two daily heating periods.
2. Outside of the daily heating periods.

It was found that the temperatures were significantly different from those assumed by the DEAP software during the heating periods, and that the temperatures remained high outside of the heating period. This is a significant finding given that the divergence could have significant impact on the actual energy consumption of the dwelling compared with that predicted.

See Figs 4, 5 and 6. The red lines between 5 PM and 11 PM and between 7 AM and 9 AM indicate the expected heating set temperatures (i.e. 21°C in the living room, and 18°C in the bedroom). For the periods 9 AM to 5 PM and 11 PM to 7 AM, the heating is assumed not to be operational, with the interior temperatures expected to decline over those periods.

The box plots give the range of temperatures for each dwelling for the living room (Fig 4), bedroom (Fig 5) and kitchen (Fig 6) over the winter period (December 2019 to February 2020) for each of the four time periods (two heating periods, and two non-heating periods). It is noted that the period for the analysis predates the Covid pandemic restrictions ("Coronavirus," 2020).

4.1 Livingroom

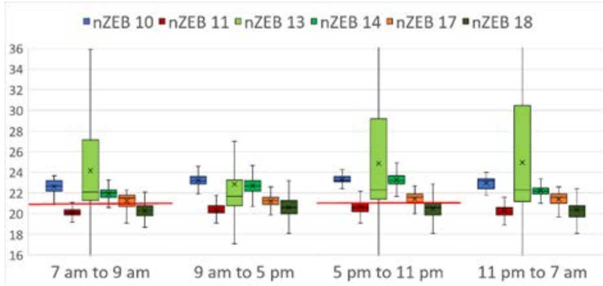
The living room nZEB interior temperatures are higher than the 21°C expected by the energy rating software, for all of the properties apart from the living room of nZEB 11 and 18 (Fig 4).

In some cases the temperatures are significantly higher than those expected – e.g. nZEB13, although this as previously stated is an outlier.

Between 7 AM and 9 AM and between 5PM and 11PM, the remaining three dwellings exceed the expected set temperature at least 75% of the time.

Outside of the heating periods, all the dwellings retain a similar temperature profile, indicating that the set temperature does not vary during the 24-hour period. Again apart from nZEB 11 and 18 (which are seen to have the lowest temperature), the majority of the dwellings continue to exceed 21°C.

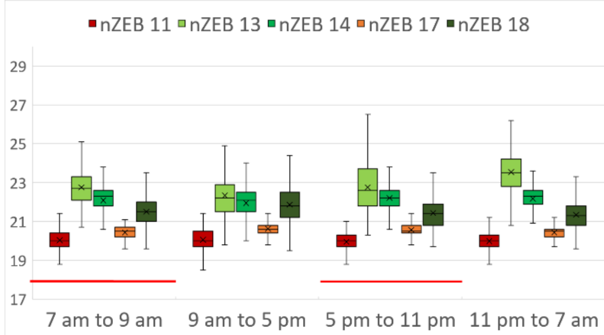
Fig 4. Winter Living room temperatures



4.2 Bedroom

The temperatures experienced in the bedroom over the winter (fig 5) are similar to those experienced in the living room. Again the temperature profiles are stable, within individual properties. As can be seen all the dwellings experience mean temperatures during the heating periods which are significantly higher than that expected by the DEAP software. The software underestimates the mean heating setpoint by between 2.1°C (nZEB11) and 4.5°C (nZEB14), (excluding the outlier nZEB13).

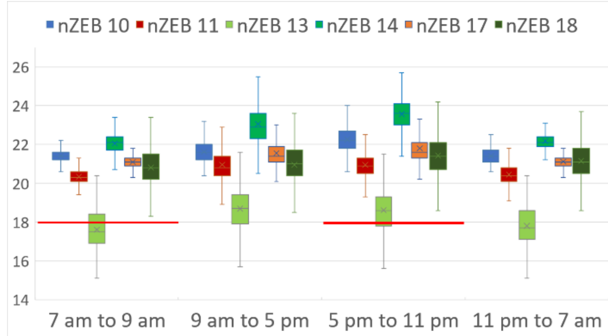
Fig 5. Winter Bedroom temperatures



4.3 Kitchen

Figure 6 shows that the temperatures again remain stable within the individual dwellings and that again the temperatures exceed the expected set temperature by significant margins ranging from 2.1°C (nZEB1) to .56°C for nZEB14. It is noted that nZEB13 has mean temperatures within +/-0.5°C of the 18°C setpoint assumed by the DEAP software.

Fig 6. Winter Kitchen temperatures



5. ADDITIONAL ENERGY CONSUMPTION DUE TO ELEVATED INTERIOR TEMPERATURES

The higher-than-expected temperatures can potentially have a significant impact on the energy consumption for the buildings, due to 2 factors – (i) the higher-than-expected temperatures during the heating period and also (ii) the consistently high temperatures during the hours (and months) when DEAP assumes no heating is taking place. In both respects the DEAP software underestimates the actual heating load by significant amounts. This section calculates the additional delivered space heat required (i.e. excluding consideration of internal heat gains, the coefficient of performance of the heat pump or the primary energy conversion factor).

nZEB 7 is seen (fig 1) to have mean interior temperatures which have the greatest match with the mean of the mean interior temperatures across the four seasons during which heating takes place. It is noted that other dwellings e.g. nZEB10 would have higher heat losses, but even the dwelling with the lowest recorded internal temperatures (nZEB1) would experience higher space heating losses than those predicted by DEAP.

A simple heat balance equation is used to estimate the additional delivered heat $Q_{AD'L}$ that is required to maintain the higher internal temperatures to those assumed in the DEAP software (equation 1)

$$Q_{AD'L} = L \cdot \Delta T \cdot H \quad \{kWh\} \quad (1)$$

The mean temperature differential between the mean dwelling temperature assumed in DEAP and the mean recorded dwelling temperature is represented by ΔT {°C}, *L* is the (DEAP) heat loss coefficient {W/K}, *H* is the number of heating hours {hrs}. This calculation is computed for the heating months assumed in DEAP (i.e. excluding June, July August and September) and the results are presented in Table 1. Data is presented for each season of the year.

The increase in space heating energy consumption ranges from 20% (during the winter) to an additional 42% (during the two heating months in autumn). The additional heat losses amount to a total of 1427kWh delivered energy, and when expressed as a percentage of the total annual delivered energy (4980kWh), equate to 29% additional space heating load.

Table 1 Expected (DEAP) and Measured Temperatures and resultant potential additional heat loss for dwelling nZEB7

nZEB 7	Season			
	Winter	Spring	Summer	Autumn
Liv Room (recorded)	21.6	21.9	23.6	22.9
Kitchen (recorded)	20.9	21.6	23.3	21.3
Bedroom (recorded)	21.1	22.4	23.1	21.3
Mean Dwelling (recorded)	21.1	22.0	23.3	21.6
DEAP Mean (est.)	17.7	17.8	18.3	18
ΔT (°C)	3.4	4.2	5.0	3.6
Additional Ht loss {kWh}	485	599		343
DEAP Heat Loss {kWh}	2374	1790		816
Additional Heat loss {%}	20%	33%		42%

The heat loss of the passive house dwelling is exceptionally low at 66 W/K - equivalent to a specific heat loss of 0.65W/(m^2K). Therefore, in absolute terms the additional heat loss due to higher internal temperatures than the DEAP software assumptions are low.

In addition, the percentage losses are lower than the additional 65% space heat loss reported over the same heating period for a scheme of nZEB compliant Deep Energy Retrofit dwellings in a previous paper from the nZEB101 project (Colclough et al., 2022). It is noted that the specific heat loss for the retrofit dwellings is 2.76 W/(m^2K). This is over four times the heat loss of the new passive house dwellings in this study.

Further analysis is required to determine the overall regulated load energy consumption and to compare it with the measured regulated load energy consumption. This would enable a comparison of the actual running costs for operational energy with the theoretical. Such an analysis would not only include the effects of the increased interior temperatures, but also include the actual heat loss (rather than the theoretical) and the actual coefficient of performance of the heat pump.

6. DISCUSSION AND CONCLUSION

The nZEB compliant PH dwellings demonstrate a significant disparity with the assumptions inherent in the National energy rating software. At the same time, it is clear that the buildings are performing in line with the requirements of the occupants as indicated by the high occupant satisfaction levels reported in individual Building Use Survey results.

The trend of prolonged high interior temperatures is consistent with other studies – the setpoint temperatures for the heating system embedded in the DEAP software are substantially lower than those recorded in the nZEB dwellings, and the recorded temperatures also indicate that the heating system is operating for substantially more than the eight hours assumed in the DEAP software.

The DEAP software calculates that the temperature ranges from 17.7°C (winter) to 18.3°C (summer) for the dwellings under consideration.

These temperatures are significantly below the temperatures experienced in the monitored rooms. The mean of the recorded heating season mean temperatures range from 20.8°C (bedroom in the autumn) to 22.8°C (living room in the autumn).

Table 1 shows that the mean dwelling temperatures of a typical dwelling exceeds the DEAP predictions by 3.4°C (winter), 4.2°C (spring), 5.0°C (summer), and 3.6°C (autumn).

Not only are average room temperatures significantly higher than DEAP expectations but they also do not vary by the assumed 3°C (21°C in the living room and 18 °C for the rest of the dwelling). Rather they exhibited temperature differentials of no more than 1.6°C (in the case of the temperature differential between the living room 22.9°C and the kitchen and bedroom (both 21.3°C) during the autumn.

Dwelling temperatures do not exhibit synchronisation with the assumed heating periods and are much higher than the assumed set temperatures of 21°C for the living room and 18°C for the rest of dwelling.

Given that the same trend has been seen in other monitored Irish nZEB compliant dwellings, this is emerging as an established pattern, although further POE would be valuable across more typologies and usage profiles.

While higher temperatures are expected for category I occupants (including the elderly in the previous study), it does not explain the reason for the high temperatures experienced in the mixed-use development under study here.

One potential factor which could influence the consistently high temperatures is that these nZEB dwellings are constructed to the passive house standard – a standard known for its exceptionally low space heating demand. This could influence occupants' behaviour given the low cost of high interior temperatures (consistent with other findings with respect to "comfort taking").

However, low heating demand is a key driver in the nZEB standard and the findings here may well indicate future trends which policymakers should be cognisant of.

Due to the higher-than-expected interior temperatures, and longer than expected heating periods, space heating energy consumption is 29% higher than expected over the heating season. The higher temperatures result in additional heat losses during the winter of 20%, the spring of 33% and the of autumn 42% for the sample dwelling (nZEB7).

The author has been engaged to investigate high energy consumption in other A rated developments, given occupant dissatisfaction with heating costs being substantially higher than expected. There is a concern that occupants may become distrusting of BER ratings, and that they disregard the primary objective of BER ratings being as an asset management tool, enabling a comparison between relative energy efficiency performance.

A similar situation occurred in the transport sector, leading the EU to embrace the WLTP (Worldwide Harmonised Light vehicle Test Procedure) energy efficiency standards which more accurately reflect the performance under typical operating conditions rather than the previously laboratory-based operating conditions (New European Driving Cycle - NEDC) in existence in the 1980s (*From NEDC to WLTP*, 2019). The stated reason for the replacement of the energy efficiency standards was that they had become outdated due to several evolutions in technology and operating conditions - conditions very similar to those experienced in dwellings over the same period.

Such an approach could be adopted for modern buildings given the real-world usage profile of dwellings evident from the research undertaken to date.

Another finding is of high interior temperatures during the summer in the dwellings, leading to a concern of overheating. Despite the houses meeting the passive house overheating criteria of temperatures of 25°C or less for 10% of the year, further study will be carried out in this area.

Overall, the findings have implications for national strategy in relation to energy consumption and related climate change commitments.

They also have significant implications for individual households and highlights the need to educate occupants on how best to extract the best performance from the low-energy dwellings that they are now inhabiting.

Finally, it also has implications for industry, and highlights the need for Post Occupancy Evaluation to be carried in addition to comparison of expected and recorded IEQ and energy consumption (in alignment with compliance with The Energy Performance of Buildings Directive).

ACKNOWLEDGEMENTS

This project is supported by the Sustainable Energy Authority of Ireland under Grant Agreement 18/RDD/358. The authors would also like to acknowledge the assistance of Wexford County Council and the occupants of the dwellings without whose assistance, this study would not have been possible.

REFERENCES

nZEB101 project. http://www.nzeb101.ie/

Anon. (2018). National Development Plan 2018—2027.

BS EN 16798-1:2019 Energy performance of buildings. Ventilation for buildings. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. M. (n.d.). Retrieved June 16, 2021, from https://shop.bsigroup.com/ProductDetail?pid=000000000030297474

Colclough, S., Hegarty, R. O., Murray, M., Lennon, D., Rieux, E., Colclough, M., & Kinnane, O. (2022). Post occupancy evaluation of 12 retrofit nZEB dwellings: The impact of occupants and high in-use interior temperatures on the predictive accuracy of the nZEB energy standard. Energy and Buildings, 254, 111563. https://doi.org/10.1016/j.enbuild.2021.111563

Colclough, S., Kinnane, O., Hewitt, N., & Griffiths, P. (2018). Investigation of nZEB social housing built to the Passive House standard. Energy and Buildings, 179, 344–359. https://doi.org/10.1016/j.enbuild.2018.06.069

Coronavirus: First case confirmed in Republic of Ireland. (2020, February 29). BBC News. https://www.bbc.com/news/world-europe-51693259

DEAP 4.2.0 Software. (n.d.). Sustainable Energy Authority Of Ireland. Retrieved May 12, 2020, from https://www.seai.ie/home-energy/building-energy-rating-ber/support-for-ber-assessors/domestic-ber-resources/deap4-software/

EU. (2016a). European CommissionDirective 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Off. J. Eur. Communities, L 153 (2010), pp. 13-35. European CommissionDirective 2016 Annex 1 COM 860 Final.

From NEDC to WLTP: What will change? (n.d.). WLTPfacts.Eu. Retrieved March 5, 2022, from https://www.wltpfacts.eu/from-nedc-to-wltp-change/

Nilan. (n.d.). Compact P (CTS 700) Product data. Retrieved December 2, 2019, from http://reader.livedition.dk/nilan/571344807/html5/

NZEB101. (n.d.). NZEB101.i e. Retrieved August 12, 2019, from http://www.nzeb101.ie/

PLEA 2022 SANTIAGO
Will Cities Survive?

Rethinking the work environment
An analytical design applicability to office buildings in Santiago, Chile

TOMÁS SWETT AMENÁBAR[1], JOANA CARLA SOARES GONCALVES[2], KLAUS BODE[3]

[1] Triangular Arquitectos, Santiago
[2] Architectural Association School of Architecture, London; Bartlett School of Architecture – UCL, London; School of Architecture and Cities, University of Westminster, London
[3] Urban Systems Design (USD), London

ABSTRACT: Following almost five decades of the air-conditioning supremacy, in the 1990s the acknowledgement of the positive effects of more flexible and informal environments upon the productivity and satisfaction of occupants led to the design of buildings more opened to the outdoors. In this context, advanced analytical procedures are essential to the understanding of the complex energy balance of buildings and, consequently, of the architectural possibilities to reduce energy demand for space cooling and heating. With the ultimate objective of challenging the oversimplified design of the artificially conditioned glass office-building typology, this research project puts forward a Research Pro-Design Methodology including a sequence of analytical procedures for the evaluation of the environmental response of architectural solutions. The guidelines were applied on a Design Proposal of an office building in the continental Mediterranean climate of the city of Santiago, in Chile. Following the lessons learnt from the analytical studies, among the key design concepts was space and environmental diversity to accommodate contemporary office activities. The analytical studies at the pre-design concept stage proved to effectively inform the main architectural decisions, whilst the analytical assessment of the final design solution indicated that natural ventilation is office environments in Santiago is possible for over 85% of the occupational hours.
KEYWORDS: Work-Environment, Daylight, Passive Architecture, Analytical Study, Design Methodology.

1. INTRODUCTION

The supremacy of the air-conditioned glass box that was instated in the 2nd half of the 20th century suppressed the evolution of the so-called bioclimatic architecture around the world. It was only in the 1990s that the acknowledgement of the positive effects of more flexible and informal environments upon the productivity and satisfaction of the occupants resulted to the re-introduction more natural conditions in the design of office buildings in key commercial centres of the world, leading to new design solutions for buildings more opened to the outdoor environment [3]. Some of these key features were: atriums and open spaces (such as terraces and balconies), external shading and operable windows, exposed structure and other building components (adding thermal inertia to the internal spaces). By creating bringing daylight and ventilation into the office buildings, together, these basic passive strategies created more attractive and energy efficient alternatives to the sealed glass-box office building [3].

As widely discussed by specialists from the field of environmental design [9], advanced analytical procedures are essential to the understanding of the complex energy balance of buildings and, consequently, of the architectural possibilities to reduce cooling loads, taking into consideration form and orientation, thermal performance of the building fabric, openings for daylight and ventilation, shading and other aspects of the building design, coupled with occupational patterns and the understanding about challenges the potentials of the local climate.

With the ultimate objective of challenging the oversimplified design of the glass building typology, this research project proposes a redefinition of the office environment, evolving from the concept of *workspaces* to *work-environments* and exploring the environmental potential of architectural design to achieve low-energy buildings with environmental quality. For this purpose, a Research Pro-Design Methodology was developed including a sequence of analytical procedures for the evaluation of the environmental response of architectural solutions (looking at performance and quality parameters). In a second moment of the work, the related guidelines were applied on an Design Proposal exercise of an office building in the continental Mediterranean climate of the city of Santigo, in Chile [7].

2. CLIMATE

Santiago *de Chile* is in a valley between the Andes and other mountains (33°50´S; 70°70´W). The city is 120 km far from the Pacific Ocean and has a Continental Mediterranean climate (Csb), according to the Köppen–Geiger climate classification [5]. The mean daily air temperature (MDT) fluctuates from 8.4°C to 21°C, offering a clear potential to natural ventilation. The highest temperatures occur between December and February, and the coldest between June and August. The year can be divided in three clear seasons: Warm - with MDT between 17.4 and 21°C (November to March), when the mean daily maximum temperature rises to 33.5°C; Mild - with MDT of 14.5°C (April and October); and Cold - with MDT between 8.4 and 11.7°C (May to September) (Fig.1).

In general, the coldest hours are between 6:00 and 7:00 hrs and the warmest between 14:00 and 16:00 hrs. Overlapping the climate data with the occupational hours of a typical office building, a need of heating was identified for 54.5% of the time, versus almost 33% of hours in comfort and only 12.8% of hours above the comfort zone (ASHRAE 55 [1]) (Fig.2). According to principles of environmental design [8], the hours in comfort could be maintained if shading and ventilation are provided to avoid solar gains and remove excessive internal gains from the occupation. In addition, the internal gains from the typical office activities, coupled with minimum ventilation, can raise temperatures during the cooler hours, whilst shading, thermal mass and night-time ventilation, together, can be beneficial during the overheating period.

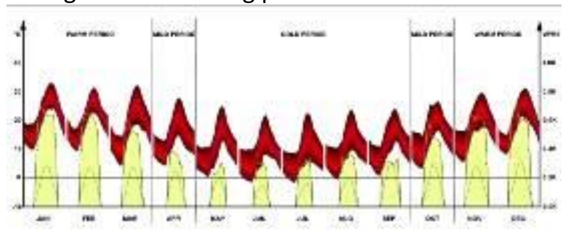


Figure 1: Diurnal temperature averages - Santiago, Chile. Source: Meteonorm.

Figure 2: Percentage of annual hours in comfort, of heating and cooling deficit, according to outdoor temperature (based on the adaptive comfort model of ASHARE 55 [1]).

3. RESEARCH PRO-DESIGN METHODOLOGY

The proposed Research Pro-Design Methodology included the critical examination of the impact of architectural parameters on daylight and thermal response of the building design by means of analytical procedures, looking at: form and orientation; size, design and positioning of openings; façade treatment and transitional spaces. Drawing from the understanding of the climatic conditions, a sequence of alternative scenarios (variations of a base-case named" shoe-box") were tested in the phase of initial analytical explorations, by means of advanced computer simulations to inform a parametric optimization process. With regards to the thermal studies, a set of sensitive analysis of individual strategies were analysed and followed by the evaluation of combined strategies.

On a second moment, the impact of urban morphology was also verified within the analytical environmental studies of the research project on which this paper is based [7]. Three hypothetical urban scenarios were created following the main contemporary office´s development areas in Santiago, taking into account urban canyons and building regulations. Output of solar radiation upon the façade were extracted from the outputs of thermodynamic simulations, for different days of the year, along the height of the 4 orientations of the base-case model. The urban studies showed that in the north orientation (the most exposed to solar radiation), the variation of solar radiation along the height is higher in winter (maximum of 130 Wh/m^2) than in summer and the difference between both periods is greater than in other orientations. During winter, urban contexts affect mainly up to level 14, whereas in the summer, the impact is minimum. Given the minimum impact of the urban form on the impinging solar radiation during the warm period of the year, further analytical explorations did not include the urban context, focusing mainly on the climatic conditions. The diagram in Figure 3 summarises the research process towards the *Analytical Design Concept.*

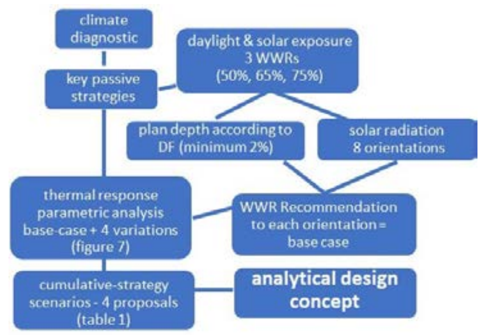


Figure 3: Diagram of the research process towards the Analytical Design Concept.

3.1. Analytical Explorations

Daylight and Solar Exposure:

Computer simulations of daylight and solar radiation were carried out with the software DIVA [6]. Starting the study of facades, the initial analytical explorations addressed the impact of different window wall ratios (WWR) on two aspects of buildings' environmental performance: 1. Daylight conditions, by simulating Daylight Factors (DF) for a typical overcast sky condition in Santiago and; 2. Exposure to solar radiation to 8 orientations, adding the effect of an "ideal" shading to block the penetration of direct solar radiation during the mild and warm periods (Fig.4). The aim was to identify the depth of minimum DF = 2% achieved with a range of WWRs, varying from 50 to 75% and compare with the consequential solar gains (Figs.5 & 6).

In addition, the heat gains associated with lighting, equipment and occupation of a typical office environment are presented to put in context the relative impact of the solar gains to the total heat gains [4]. The 75% WWR resulted in a 9m deep passive daylight zone, followed by 7.5m with the WWR of 66% and 6m with 50%. (Fig.5). Looking for a balance between minimum solar gains in the warm period of the year and maximum daylight access, initial guidelines were stablished: the maximum WWR = 75% to the South and Southeast orientations, WWR = 66% to North, East and Southeast and WWR = 50% to West, Northwest, and Northeast (Fig.6).

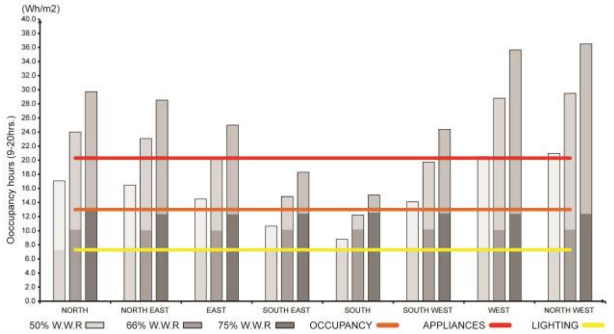


Figure 4: Reduction of solar gains on 8 orientations as a combined effect of different WWRs (75%, 66%, 50%) and an "ideal" shading, in perspective to the contribution of internal gains associated with the occupation.

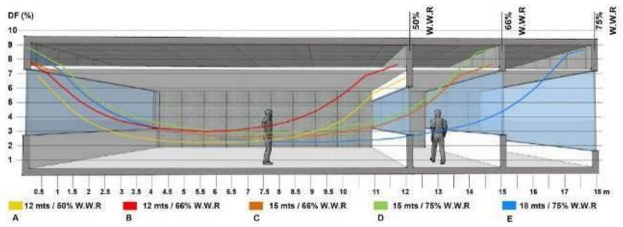


Figure 5: DF values across a double-aspect typical floor for 3 different WWRs (75%, 66% and 50%).

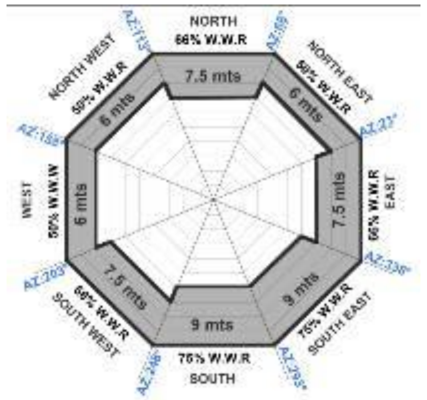


Figure 6: Recommendation of floor depth and WWRs for 8 orientations as a result of maximum daylight.

Thermal Response:

The thermal dynamic simulations were carried out with the software TAS [2]. The thermal assessment of the base-case tested in the previous simulations was carried out with thermodynamic simulations (considering minimum ventilation rates for fresh-air requirements only), to re-evaluate the impact of 3 WWR, now looking at the heating and cooling loads (Fig.7). The results showed that the West and Northwest pose the higher cooling loads, almost 50% higher than in the South, to which the lower loads were found. Also, in both orientations the increase of the WWR from 50 to 75% had the most significant impact in the rise of solar gains (by 10 KWh/m^{2}yr). Different from that, the lower cooling loads on the South and Southeast, confirmed the opportunity to WWR of 75%.

Continuing with the thermal assessments, as heating loads were close to zero in all cases, focus was put on reducing the cooling loads, taking a typical North-facing office room as reference. For this, a sensitivity analysis of the effectiveness of night-time ventilation, thermal mass, different glazing properties and solar control (varying different degrees) was firstly performed. From the simulation results is clear to see that day-time ventilation at 10 air-changes (ach) have a very similar contribution than the night-time ventilation at 7.5 ach, pushing cooling loads down to 40 KWh/m^{2}yr, approximately, almost 50% less than in the base-case. Regarding the shading, the insertion of 3 horizontal elements of 30cm each has the most effective response, as it blocks almost the totality of direct solar radiation impinging on the North orientation.

Single glazing windows are significantly better than the double-glazing alternative, resulting in 50 KWh/m^{2}yr against 70 KWh/m^{2}yr, due to the higher heat losses through conduction when the internal conditions get warmer than the outside (common phenomenon in office environments).

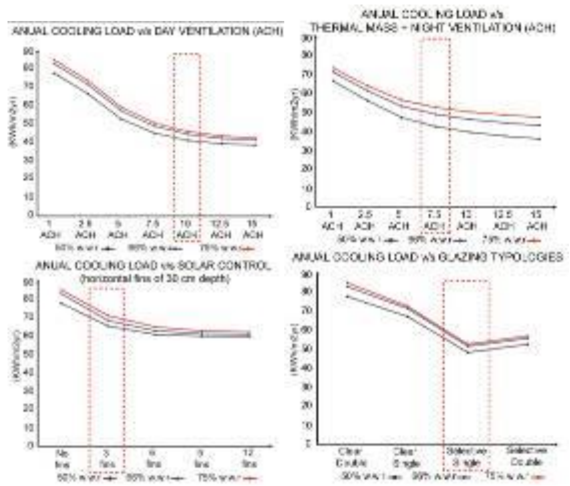


Figure 7: Sensitive analysis of the effectiveness of day-time and night-time ventilation, thermal mass and shading, with 3 different WWRs, applied to a North-facing base-case office.

Following up, four proposals were created combining different scenarios for the previously examined passive strategies, as described in Table 1. Here, day-time ventilation was not included to avoid potential issues associated with urban noise and pollution in the work environment. The second proposal was the most effective in terms of improvement, with cooling loads dropping from 90 KWh/m^{2}yr in the base-case to values between 20 and 30 KWh/m^{2}yr, depending on the WWR (Fig.8).

Table 1: Four Proposals to reduce cooling loads.

	VENTILATION	MATERIAL	GLAZING
Base case	NO	light	Clear Double Glazed
Proposal 1	Night ventilation 7.5 ACH	Thermal mass	Clear Double Glazed
Proposal 2	Night ventilation 7.5 ACH	Thermal mass	Selective Single Glazed
Proposal 3	Night ventilation 15 ACH	Thermal mass	Selective Single Glazed
Proposal 4	Night ventilation 15 ACH	Thermal mass	Selective Single Glazed

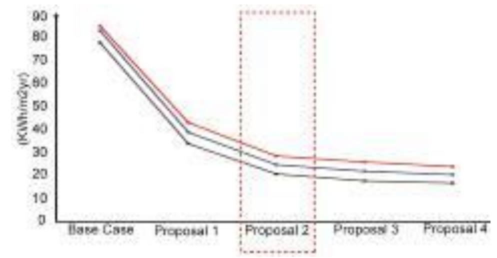


Figure 8: Annual cooling loads for the 4 proposals.

Following the assessment of thermal performance, an in-depth analysis of internal gains related to common office activities and occupational patterns had a central role to inform environmentally efficient strategies with respects to the orientation and key spatial configurations for distinctive areas of the office building. The pattern of internal gains shows a clear distinction between types of spaces and activities, with relatively lower and constant loads in the cellular office versus significantly higher (10x) and a more variant profile in the meeting rooms and teamwork areas. Informal meeting and hot-desk areas stay in between the two and oscillate more (Fig.9).

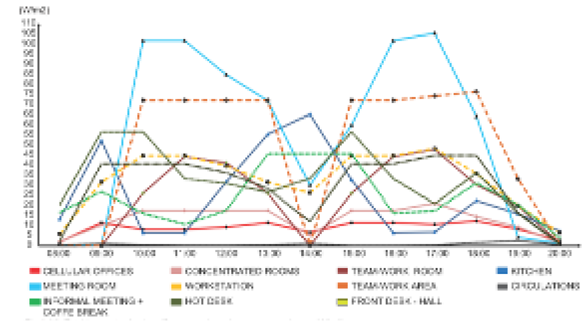


Figure 9: Distribution of internal gains of common office activities along a typical week-day.

These observations point out to the advantage of positioning open-plan areas, where there are higher internal gains, on the orientations with less solar exposure (S and SE, in this case), and those spaces with less intense heating loads towards the more exposed orientations (N, W and NW).

4. APPLICABILITY: DESIGN PROPOSAL

Following the lessons learnt from the analytical studies, the key concepts that drove the design solutions were: maximization of envelope area to benefit views, daylight and natural ventilation, when needed and appropriate - according to the air-quality and noise conditions of the external environment); space and environmental diversity to contemporary office activities; and variation in the façade treatment across orientations and height responding to different solar exposures. The research process towards the *Architectural Design Concept* and the subsequent *Design Proposal* is shown in Figure 10.

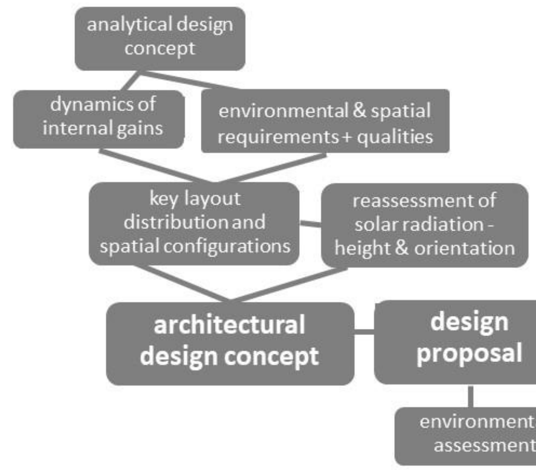


Figure 10: Diagram of the research process to Architectural Design Concept and the Design Proposal.

In addition to that, the several office spaces were organized in the shape of vertical "villages", around four storey-high atriums, with the cellular offices facing North and the double-height open-plan areas (with the higher internal gains) towards the South, therefore, being less exposed to solar gains (Figs. 11 - 12). The higher floor-to-ceiling height facilitate the dissipation of the internal gains generated by the occupation and improve the daylight distribution along deeper floor plans. Openings created on the North, East and West sides allowed daylight into the atrium (Fig. 11).

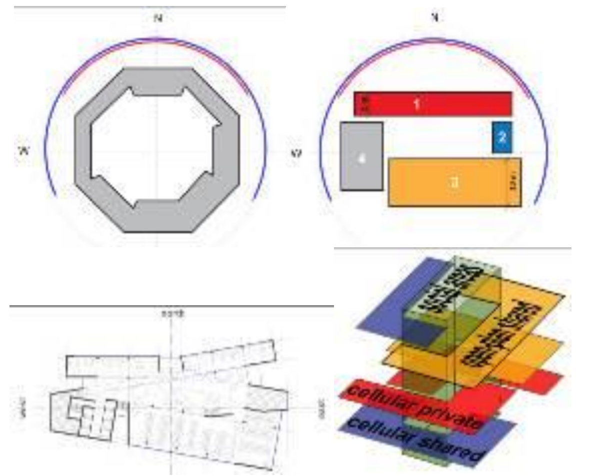


Figure 11: Top - Diagrame of plan depths in relation to the guidelines in response to orientation, with the distribution of main spaces (celular offices-1, service area-2, open-plan offices-3, area of social interaction-4). Bottom – Typical floor plan and diagramme of the "office village".

Moving to the façade design, the distribution of solar radiation identified in the computer simulations was used as a guideline to a refined determination of the level of transparency (given by the combination between the previously recommended WWR and the light transmittance of the iluminating panels - glass), determining the U Values of the building components (although the entire building only has single-glazed panels) and the light-transmitance of the modulated glass component (Fig. 14). Looking at the North face (with the highest solar exposure), the outcomes of the thermodynamic simulations showed the benefit of having in the first seven floors (plus the ground-floor) an average light transmittance = 54% and U Value = 2.07 W/m^2.K. For the remaining eight floors, the light transmittance dropped to 48% and the U Value to 1.86 W/m^2, in order to minimize solar gains. In the most exposed area of the North façade (top west corner), light transmittance was further reduced to 42% and U Values to 1.88 W/m^2. These average values were achieved per floor/space adjusting the amount of three types of glass panels: opaque, semi-translucid and clear, where external light-weight external horizontal shading devices were attached to the operable windows (Figs. 14 & 15). The design outcome is a façade opaquer than the conventional glass-box.

Figure 12: Section of the design proposal with the cellular offices (single height) at the North and open-plan offices (double-height) at the South.

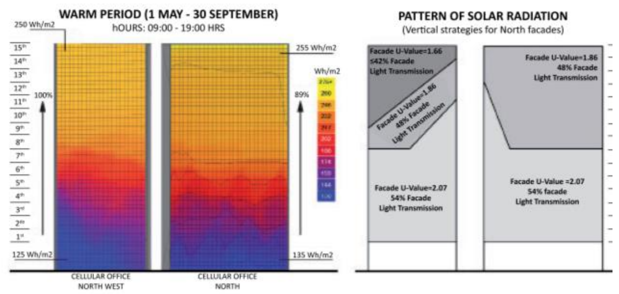


Figure 13: Left – simulation of solar radiation values for a typical day in the warm period showing cummulative daily values. Right – Diagramme with the general strategic strategies for the façade treatment including U Values, recalculated WWRs and Light Transmitance.

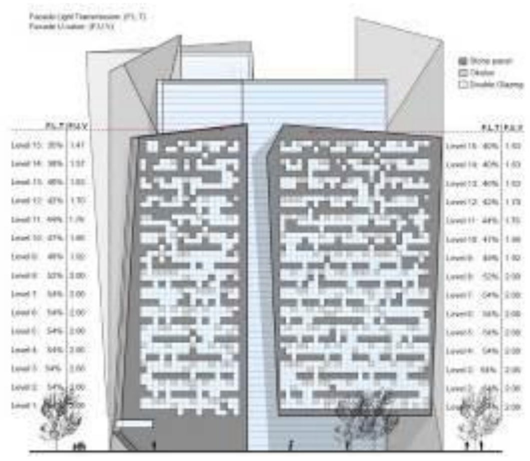


Figure 14: View of the south façade, showing an increase in opacity in the higher floors (due to higher solar exposure).

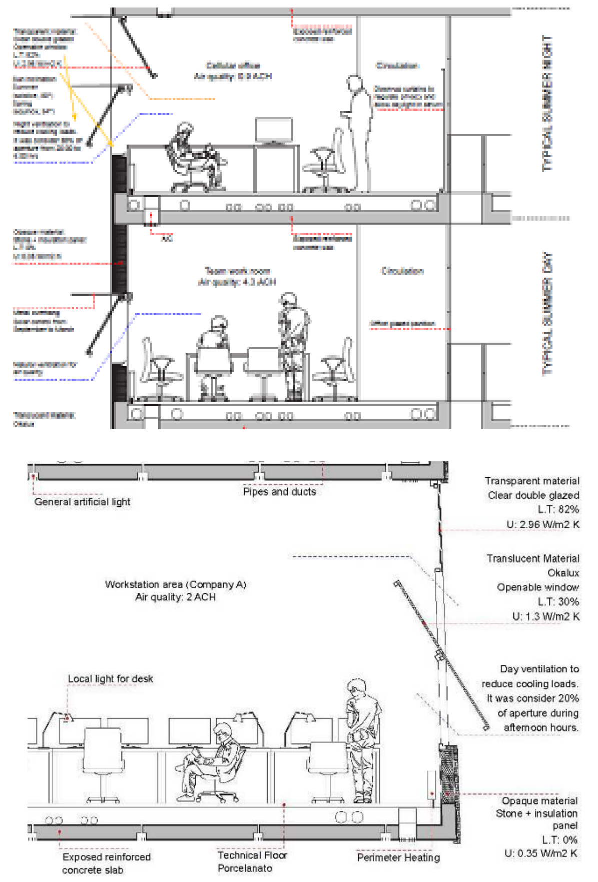


Figure 15: Top - Section of the south-facing cellular offices. Bottom - Section of the north-facing open-plan offices.

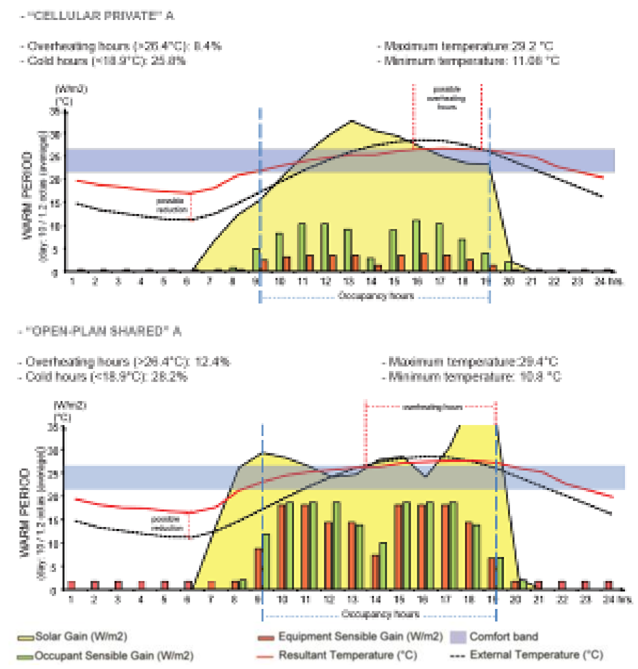


Figure 16: Temperature profile of a cellular office, an open-plan office and the atrium space in a typical warm day.

The thermal performance of the final design proposal was verified in terms of annual hours in comfort with the use of natural ventilation and temperature profiles in typical days of the year (Fig. 16). In a typical warm day, maximum temperatures in the main spaces (cellular and open-plan offices) oscillate around 29ºC (surpassing by a small margin the upper limit of the comfort zone), being the lowest peak in the cellular offices.

5. FINAL CONSIDERATIONS

The initial analytical studies proved to be possible to naturally ventilate office buildings in the Mediterranean climate of Santiago for over 85% of the occupational hours, in addition to satisfactory daylight conditions throughout the floor plan. The central atrium space, coupled with the north-south zoning of offices were key design strategies to bring daylight and natural ventilation into the building, whilst positioning the activities of higher internal gains (the open-plan offices) towards the "cooler" orientation and vice-versa. In sum, simplified analytical studies that define the Research Pro-Design Methodology at pre-design concept stage, developed here, is an effective measure to environmentally inform the main architectural design decisions.

ACKNOWLEDGEMENTS

Thanks to the AA School of Architecture and the SED Master Course (SED), at the AA Graduate School, for supporting this research project.

REFERENCES

1. ASHRAE (2013). ASHRAE 55-2013: Thermal Environmental Conditions for Human Occupancy. Atlanta: ASHRAE.
2.EDSL (2013). TAS Engineering. Available at: https://www.edsl.net/tas-engineering.
3. Gonçalves, J.C.S. (2019). The New Working Environment: Environmental Diversity and Flexibility of Space. In: *PÓS*, v.26, p.e161676.
4. Johnson, Counsell and Strachan. (2011). Trends in Office Internal gains and the Impact on space Heating and Cooling. CIBSE Technical Symposium, Leicester, UK.
5. Peel, M. C.; Finlayson, B. L.; Mcmahon, T. A., (2007). Updated world map of the Köppen–Geiger climate classification. In: *Hydrol. Earth Syst. Sci.* 11, p 1633-1644.
6. Reinhart, C.F., et al (2011). DIVA for Rhino Version 2.0. SOLEMMA LLC (USA). Available at: http://www.diva-for-rhino.com/
7.Swett, T. (2013). *Rethinking the Office Building Typology in Continental Mediterranean Climate* (March. Dissertation). SED, AA School of Architecture. London.
8. Szokolay, S. (2007). Introduction to architectural Science. 2nd ed. Architectural Press Books an imprint of Routledge. Taylor & Francis Group. London and New York.
9. Yannas, S. (2008). Reconceiving the built environments of the gulf region, challenging the supremacy of air conditioning. *2A Architecture and Art, Golf Research Project in Sustainable Design*, Dubai, n. 7, p. 20-43, 2008.

Influence of cost-benefit of different construction systems for envelopment on energy consumption in a Housing of Social Interest

RENATA MANSUELO ALVES DOMINGOS [1] FERNANDO OSCAR RUTTKAY PEREIRA [1]

[1] Universidade Federal de Santa Catarina

ABSTRACT: In Brazil, buildings in the residential sector consume about a quarter of the electricity. Due to the low energy efficiency of these buildings, much electricity is wasted, whether this loss is related to the building systems of the envelope or other factors. It is known that there is a significant gain and loss of heat in the envelope. The use of Insulating materials has also changed this phenomenon, but it has added value, so the best way to analyse the cost benefits of different types of building systems is to use life cycle costs. Therefore, the objective here is to analyse the cost-benefit of different materials used in walls and roofing through life cycle costs. The method used is a simulation, in which EnergyPlus calculates the consumption and use of able of price compositions for budgets to determine the costs of the house and the different types of building systems. The results show that the lowest consumption model does not have the lowest life cycle cost, but the relationship is not linear, and the initial cost has the most significant impact. He highlighted the importance of life cycle cost as a cost-benefit parameter, including the initial input cost and the cost of electricity.
KEYWORDS: Building materials, energy savings, life cycle cost, energy efficiency, simulation.

1. INTRODUCTION

As people pay more and more attention to the energy crisis and environmental pollution, research on new technologies has emerged to optimize energy use and reduce the spread of polluting waste. The energy consumed by buildings is responsible for about 40% of the world's primary energy [1]. According to the National Energy Balance [2], in Brazil, the energy consumed by the residential sector represents about 25% of the country's total energy consumption.

In the residential sector, energy demand is mainly related to climate, building design, energy system, occupant usage, and economic level. Generally speaking, households in developed countries use more energy than emerging economies and, due to the installation of new equipment, especially air conditioning (AC) equipment, energy consumption is expected to continue to grow [3]. Buildings with poor thermal performance will cause discomfort to users, and as income increases, occupants choose to make manual adjustments, which increases building operating costs and carbon dioxide emissions. The increased use of air conditioning across the country means expanding its energy infrastructure [4].

Although the use of air conditioning systems for refrigeration is restricted in Brazil, the use of air conditioning systems is responsible for approximately 20% of domestic electricity consumption [5]. Rising incomes and improving living standards are expected to increase its use as it will be within the economic range. Brazil's most used conditioning system is the electrical air conditioning system, which significantly affects energy costs. Therefore, homes with low purchasing power can suffer significant discomfort. This can affect productivity, happiness, learning skills, etc., thus affecting daily activities. For all these factors, especially for these low-income families, it is necessary to provide thermal comfort houses with lower energy consumption to achieve thermal comfort [5]. In this case, it is crucial to invest in buildings to improve the quality of the environment, improving users' quality of life. In addition, it is essential to benefit low-income families at affordable prices. Combining these premises constitutes a proposal for sustainable development, where the environment, society, and economy are integrated [6].

According to Almeida et al. [7] and Ghisi et al. [8], the total consumption of electricity gradually increased due to the use of air conditioners. According to Mazzaferro [9], the building envelope is responsible for the heat exchange between the internal and external environments and mainly determines the internal temperature of the building. In this way, the energy consumption attributed to air conditioning can be reduced by suitable construction elements, which provide better energy efficiency and thermal performance.

According to Moldovan et al. [10], buildings must use architectural features (envelope) with good thermal properties, geometry, and orientation. In many cases, the importance of dynamic thermal performance is often ignored or underestimated, and adequate heat capacity is not correctly considered as one of the design parameters, as described by Aste et al. [11]. Gagliano et al. [12] proved the importance of evaluating the thermal behaviour of the building according to each direction of the facade to delay heat transfer so that measures can be taken to ensure adequate comfort and reduce the cooling demand of the system. Giordano et al. [13] emphasized that adequate envelope structure is essential for buildings.

However, a significant question often raised by construction professionals is the extent to which energy-saving measures are adopted in terms of cost-effectiveness [14]. To carry out an economic analysis, not only the thermal condition of the building must be considered, but also the weather condition, energy price, location, available resources, and other factors must be considered. The challenge is to find a strategy that achieves the best building performance at the lowest cost.

Therefore, there must be a balance and proper simulation to apply the best strategy for each specific situation. Deng et al. [15] pointed out that most projects cannot be shared due to climatic and cultural characteristics. It also emphasizes that most projects did not analyse economic viability. It is known that there is a significant increase and loss of heat in walls and roofs. Using Insulating materials changed this phenomenon, but added value, so the best way to analyse the cost benefits of these different scenarios is to use lifecycle costs.

The basic premise of financial viability is that the investment cost is less than or equal to the net economic value [16]. Most people are unaware of the renovation measures that can be used to improve the energy performance of buildings and the other benefits that these measures can bring [17]. Of course, all efficiency measures (such as increasing insulation and using more efficient light bulbs) will incur financial costs, but the electricity savings after renovation can be equal to or greater than the initial cost after several years of operation. Thus, in the life cycle cost (LCC) method, calculating the cost of each initial and relative maintenance measure and its financial benefits is used. This method decides whether to implement them to obtain energy savings [18].

In this scenario, this article has the general objective to analyse the influence of the cost-benefit relationship with the energy consumption of different constructive systems for the envelope in a Housing of Social Interest.

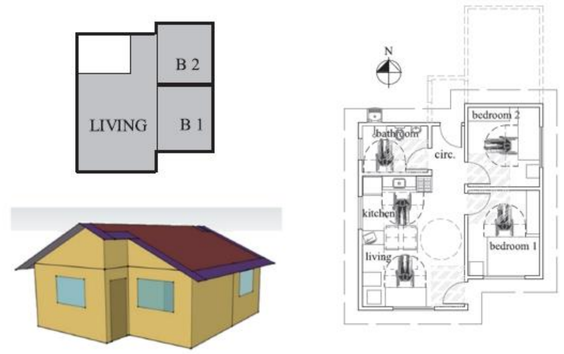
2. METHODOLOGY

The methodological procedures were separated into three stages: the characterization and definition of the object of study, thermo-energetic simulation, and the life cycle cost calculation.
Study object

2.1 Study object

Focusing on single-family housing, a representative project of one-story residential housing was used, which is located in the bioclimatic zone 3 of Florianópolis (SC), which has the highest frequency of occurrence and was determined by Triana et al. (2015) [19]. The floor plan and volume used are shown in Figure 1.

Figure 1:
Architectural Project [19]



The main features of the project for the one-story single-family house are described below:

– Cross ventilation; Eaves: 50 cm; Ceiling height: 2.50 m; Electric shower for water heating, considering equipment power > 4,600W;

– Floor: ceramic floor 0.75 cm + 2 cm subfloor + 15 cm concrete slab;

– Walls: 13 cm (ceramic brick with 6 holes 9x14x24 cm with internal and external plaster) with U=2.39W/m²K and thermal capacity=150kJ/m²K and α of 0.3;

– Coverage: 2 waters, tile (changes) + attic ceiling (changes). Inclination of 23, 6º. Tile with α of 0.3;

– External doors: 2 of 0.80x2.10 m, wood with U =1.49 W/m²K; Internal doors: 0.80x2.10 m, wood with U =1.49 W/m²K;

– Windows: living room and bedrooms: 1.50 m2, 2 sliding leaves, sill=1.10 m; kitchen: 1.20 m2, 2 sliding leaves; bathroom: 0.48 m2, tilting window with a frame, sill=1.50 m; Windows without shutters; Glass: 4 mm transparent; Aluminum frames;

– Installed lighting power density: Living Room and Bedrooms=5 W/m².

There are several ways to apply energy-saving strategies in buildings. This article focuses on heat transfer through the envelope. Addressing the roof first, three types of ceilings (PVC, plaster, and slab) and two tiles (ceramic and fiber cement) were selected to form six roof models. Its thermophysical properties are shown in Table 1.

Table 1:
Thermal properties of the building systems of the roofing models

Model	Element	Thermal transmittance (W/m².°C)	Thermal capacity (kJ/m².°C)
1	Ceramic tile and PVC	1.75	21
2	Fiber cement tile and PVC	1.76	16
3	Ceramic tile and plaster	1.94	37
4	Fiber cement tile and plaster	1.95	32
5	Ceramic tile and slab	2.05	238
6	Fiber cement tile and slab	2.06	233

For the walls, two types of blocks (ceramic and concrete) and two Insulating materials (EPS and rock wool) were selected, forming six models described in Table 2.

Table 2:
Thermal properties of the building systems of the walls models

Model	Element	Thermal transmittance (W/m².°C)	Thermal capacity (kJ/m².°C)
10	Ceramic block - 6 holes 9x14x24	2.39	150
20	Concrete block - 2 holes 9x19x39	2.79	209
30	Ceramic block - 6 holes 9x14x24 + EPS (8cm)	0.41	125
40	Ceramic block - 6 holes 9x14x24 + Rock wool (4cm)	0.77	195
50	Concrete block - 2 holes 9x19x39 + EPS (8cm)	0.43	228
60	Concrete block - 2 holes 9x19x39 + Rock wool (4cm)	0.81	329

The parametric evaluation combines all systems, resulting in 36 housing models. The ten house (10) represents the wall, and the unit house the roof (1); for example: in model 11, we have an envelope composed of a ceramic block wall and a ceramic tile roof with PVC lining.

2.2 Thermoenergetic Simulation

Consumption analysis is based on the physical description of buildings, heating or cooling systems, and internal loads. The program chosen for this study is EnergyPlus, which is distributed free of charge by the US Department of Energy and is widely used in energy simulation studies. The software uses IDF and EPW input files. Basically, a software interface inputs data about the building and the weather entered. The IDF files contain technical data on the building envelope, materials, the HVAC system, and other parameters, while the EPW contains meteorological data. The GroundDomain: Slab object is used to model heat transfer with the ground in the simulation model.

To calculate the thermal load of the rooms in the house, according to the “Inmetro Residential Building Code” - INI-R [20], each room defines two people, so there are four people in total. The COP used to convert this payload is 2.86. The air conditioning system only works when there are people in the room. To avoid discomfort caused by heat, start the cooling system after the temperature reaches 26ºC. For cold discomfort, the system heating method is used from 16ºC. It may not be common to use air conditioning in social housing, but as the cost of discomfort cannot be measured, it is assumed that air conditioning is used in both bedrooms.

2.3 Life Cycle Cost of Housing

Considering the life cycle cost of the building, the cost is divided into three groups: initial investment, maintenance, and energy. For the calculation, the online TCPO tables (Tables of Composition of Prices for Budgets) are used as references for these values, and these tables are constantly updated. Also, the initial investment depends on the construction cost, and these cost changes are based on the materials present in the model [21].

The maintenance of the system depends on the value related to maintenance and installation of the components of the energy supply system and other characteristics necessary for the proper functioning of the building and the comfort of its users. The life expectancy considered for housing is 50 years.

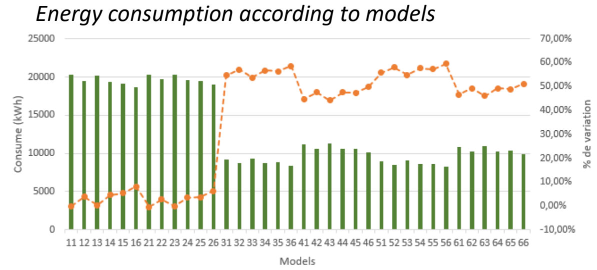
3. RESULTS

The results were analyzed in three parts, the first being the consumption, then the initial cost, and finally the life cycle cost where consumption and initial cost are considered together.

3.1 Consume

The most significant influence on consumption is the addition of Insulating material in the construction systems of the walls. In Figure 2, the variation system "10" and "20" can see others, and there is a saving of around 45% in energy consumption. The combination with the lowest performance (21) and the best performance (56) has a difference of approximately 60% of the amount of energy spent; o shows the great potential of using suitable materials in civil construction to save energy.

Figure 2:
Energy consumption according to models



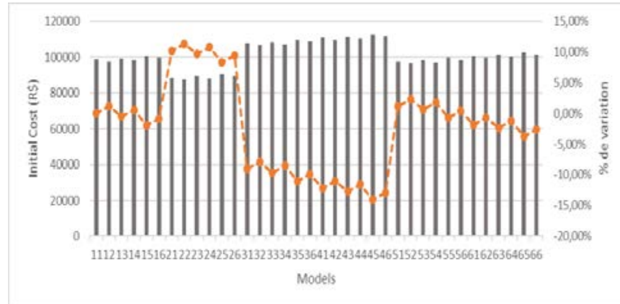
The variation between the different types of roofing was less expressive than that of the walls. However, the even models with fiber cement tiles perform better than those with ceramic tiles, the difference is around 3%, but it reached 4 .3%. The difference between the use of PVC and Plaster ceilings was minimal, less than 1%, the slab, when compared to both PVC and Plaster, had a more significant impact, around 5%.

3.2 Life Cycle Cost (LCC)

It is known the importance of energy-saving measures and how they affect the energy consumption of buildings. Changing the construction system will entail costs, in which case the calculation of energy consumption is the starting point for calculating the cost of the energy efficiency measure. With this data, it is possible to calculate the cost of the building's life cycle and compare the benefits generated or not generated by implementing the measures.

Figure 3 shows the initial costs, the percentage increases or decreases in the cost of the base model (11). There is a more expressive impact on the walls again, and there is also a lower investment in models with ceramic brick when compared to those with concrete blocks. Among the coverage systems, the variation was low, around 1%.

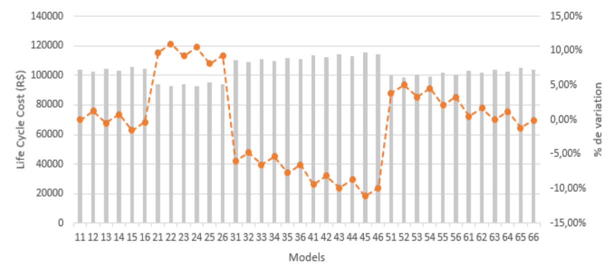
Figure 3:
Initial cost of models



When the life cycle is taken into account, the cost of the operation is also calculated. In this case, energy consumption is added to the initial cost of each housing model. The cost-benefit analysis considers the entire building cycle, hence the use of life cycle cost. In Figure 4 are these data, it is noted that the behavior of the LCC graph is similar to that of initial costs, which leads to the conclusion that in these cases the initial cost has a more expressive impact over the life of the building than the costs generated by consumption in that period.

The models with the best cost-benefit are models 21 – 26; models 31 to 36 and 41 to 46 even having a good performance in terms of consumption, but the worst about LCC having the highest values accumulated in the life cycle; however, it is essential to note that this variation is around 5% to 10%, then an assessment of benefits beyond the financial can be done. Models 51 to 56 and 61 to 66 have a better performance than the initial models in terms of consumption, but being in the middle about LCC can lead to a choice for the energy issue but still having cost benefits.

Figure 4:
Life Cycle Cost of Models



4. CONCLUSION

This research seeks to evaluate certain types of construction systems for wrapping from the point of view of life cycle cost. It can be seen from the results that consumption by itself is not enough to assess the benefits as a whole. When the life cycle cost is used as a cost-benefit parameter, it includes the initial investment cost and the cost of electricity.

This article evaluated different building systems. However, in other evaluations, changes made to the building design such as orientation, layout, geometry, and others can result in significant energy savings without additional costs. That is why this primary care from the professional is always necessary. The research shows the importance of these assessments considering the entire building lifecycle.

REFERENCES

1. International Energy Agency; Organisation For Economic Cooperation And Development. (2009) World Energy Outlook2009. Paris: IEA International Energy Agency; OECD.
2. Balanço Energético Nacional. (2018) Relatório final 2018: Ano base 2017. Rio de Janeiro: EPE.
3. Pérez-Lombard, L.; Ortiz, J.; Pout, C. (2008) A review on buildings energy consumption information. *Energy and Buildings*, v. 40, n. 3, p. 394–398.
4. Triana, M. A.; Lamberts, R.; Sassi, P. (2018) Should we consider climate change for Brazilian social housing? Assessment of energy efficiency adaptation measures. *Energy and Buildings*, v. 158, p. 1379–1392.
5. TUBELO, R. et al. (2018) Cost-effective envelope optimisation for social housing in Brazil's moderate climates zones. *Building and Environment*, v. 133, n. November 2017, p. 213–227.
6. Jensen, P. A. et al. (2018) 10 Questions Concerning Sustainable Building Renovation. *Building and Environment*, v. 143, n. May, p. 130–137.
7. Almeida, M. A.; Schaeffer, R.; La Rovere, E. L. (2001) The potential for energy conservation and peak load reduction in the residential sector of Brazil. *Energy and Buildings*, v. 26, p. 413-429.
8. Ghisi, E.; Gosch, S.; Lamberts, R. (2007) Electricity end-uses in the residential sector of Brazil. *Energy Policy*, v. 35, p. 4107-4120.
9. Mazzaferro, L. (2013) Influência de elementos construtivos do envelope no desempenho térmico de edificações unifamiliares. 93 f. TCC (Graduação) - Curso de Engenharia Civil, Engenharia Civil, Universidade Federal de Santa Catarina, Florianópolis.
10. Moldovan, M.D.; Visa, I.; Neagoe, M.; Burduhos, B. G. (2014) Solar heating & cooling energy mixes to transform low energy buildings in nearly zero energy buildings. *Energy Procedia* 48: 924 – 937.
11. Aste, N.; Leoforte, F.; Manfren, M.; Mazzon, M. (2015) Thermal inertia and energy efficiency – Parametric simulation assessment on a calibrated case study. *Applied Energy* 145: 111-123.
12. Gagliano, A.; Patania, F.; Nocera F.; Signorello, C. (2014) Assessment of the dynamic thermal performance of massive buildings. *Energy and Buildings* 72: 361-370.
13. Giordano, R.; Serra, V.; Tortalla, E.; Valentini, V.; Aghemo, C. (2015) Embodied Energy and Operational Energy assessment in the framework of Nearly Zero Energy Building and Building Energy Rating. *Energy Procedia* 78: 3204 – 3209.
14. Marszal, A. J.; Heiselberg, P. (2011) Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark. *Energy* 36: 5600-5609.
15. Deng, S.; Dalibard, A.; Martin, M.; Dai, Y.J.; Eicker, U.; Wang, R.Z. (2011) Energy supply concepts for zero energy residential buildings in humid and dry climate. *Energy Conversion and Management* 52: 2455–2460.
16. Dodoo, A.; Gustavsson, L.; Tettey, U. Y. A. (2017) Final energy savings and cost-effectiveness of deep energy renovation of a multi-storey residential building. *Energy*, v. 135, p. 563–576.
17. Ferreira, M.; Almeida, M.; Rodrigues, A. (2016) Cost-optimal energy efficiency levels are the first step in achieving cost effective renovation in residential buildings with a nearly-zero energy target. *Energy and Buildings*, v. 133, n. November 2014, p. 724–737.
18. Ouyang, J.; Ge, J.; Hokao, K. (2009) Economic analysis of energy-saving renovation measures for urban existing residential buildings in China based on thermal simulation and site investigation. *Energy Policy*, v. 37, n. 1, p. 140–149.
19. Triana, M. A.; Lamberts, R.; Sassi, P. (2015) Characterisation of representative building typologies for social housing projects in Brazil and its energy performance. *Energy Policy*, v. 87, n. December 2014, p. 524–541.
20. Centro Brasileiro De Eficiência Energética Em Edificações – Cb3e.
Proposta de Instrução Normativa Inmetro para a Classe de Eficiência Energética de Edificações Residenciais. 2018.
21. Domingos, R. M. A., and Pereira, F. O. R. (2021). Comparative cost-benefit analysis of the energy efficiency measures and photovoltaic generation in houses of social interest in Brazil. *Energy and Buildings*, 243.

One-stop-shops as a model to manage housing energy retrofit

A General Approach to Europe and Spain

CARLOS MARMOLEJO-DUARTE [1], ROLANDO BIERE-ARENAS [1], SILVIA SPAIRANI-BERRIO [2], YOLANDA SPAIRANI-BERRIO [2], CARLOS PÉREZ-LAMAS [1]

[1] Centre for Land Policy and Valuations (CPSV), Universitat Politècnica de Catalunya (UPC), Spain
[2] Research Group in Architectural Restoration (GIRAUA-CICOP), University of Alicante (UA), Spain

ABSTRACT: Energy renovation of buildings in the European Union would lead to important energy savings and a 26% reduction in consumption. But, despite these relevant benefits and the programs implemented to promote energy retrofit, in Europe and Spain, the housing renovation rate is low. The barriers faced by contractors, homes, and finance companies are impassable. So, in the international arena, and promoted by European directives, have appeared One-Stop-Shops (OSS), as integrated management entities to promote the energy renovation of dwellings, which seems a central element in the development of future strategies. This paper analyses the implemented experiences of OSSs in Europe, trying to identify the main elements, and proposes lines of action to strengthen OSS operation in the long term. To do it, documents, regulations, and data on the context were studied. Also explores the Spanish pioneering experiences through in-depth interviews. The results suggested that a lack of structural funding is one reason why activities were finished and that the most successful cases applied an 'all inclusive' model and supported families in the entire process. It is highlighted the relevant role played by European projects as a source of funding and specialist knowledge; as well as the pending solution barriers.
KEYWORDS: European and Spanish housing renovation policies, residential energy efficiency, barriers to home renovation, renovation of buildings and housing, energy performance

1. INTRODUCTION

Building stock in Europe is responsible for 40% of energy consumption, and 36% of greenhouse gas emissions. Around 35% of the buildings are over 50 years old, almost 75% of these are inefficient from an energy perspective, and only between 0.4% and 1.2% of the housing stock is renovated [1]. The situation is similar in Spain: buildings represent 30% of energy consumption (being the most relevant the residential sector), and 50% were built before the NBE-CT-79 rule of minimum criteria for thermal insulation in homes.

Since 2002, the European Union has developed a legislative framework to promote the rehabilitation of this obsolete building stock, and processes for improving the energy efficiency of buildings, with the enactment of the Energy Performance of Buildings Directive 2002/91/EC [2], and the Energy Efficiency Directive 2012/27/EU [3] that established that each member state must design a building renovation strategy, through specific actions, to achieve efficient, decarbonised building stock prior to 2050 [4].

Additionally, the EU promotes policies that help to create a stable framework for investment decisions and help the involved actors to make informed decisions to save energy and money. Also, the European Green Deal [5] defines energy renovation of public and private buildings as an essential measure to ensure that Europe is climate neutral by 2050. The set of European regulations obliges member states to define the minimum energy efficiency requirements for new buildings, and existing buildings that required a renovation. Each member state must decide the requirements and the calculation methods to be applied. In consequence the member states have implemented different models for transposing EPBD regulations [6]. However, despite the implemented programs to promote the housing energy retrofit, and important efforts made, the adoption of extensive renovation at European level is still very limited. The European annual rate of relevant renovations in the residential sector is about 1%, basically due to the barriers that families must face to perform the actions to rehabilitate.

Important renovations must be defined as those that reduce a building's final energy demand for heating by between 50% and 80% [7]. In this context, the energy renovation of these buildings would imply a 26% reduction in energy consumption.

So, the One-Stop-Shops (OSS) have appeared in Europe, provided by the EU as integral management entities to promote residential renovation.

The main aim of this work is to analyse the OSS experiences in the European context, and deeply the pioneer experiences in Spain. This analysis is aimed to understand the organisational models of OSS, the services they offer, and overall the barriers it has overcome, and those that are still to be resolved. In addition, to propose strategies for future actions.

2. METHODOLOGY

The research develops a qualitative analysis of 31 implemented OSS European cases study, excluding Spain (Table 1), and an in deep qualitative analysis of 3 Spanish cases (Table 2) to generate a comparison and define the most relevant topics in both contexts.

Table 1: European OSS cases studied

OSS Name	Leader type	Country	Beginning
RenoBooster	PPP	Austria	2019
Huisdokter	PPP	Belgium	2005
HomeGrade	Pub	Belgium	2017
EERSF	PPP	Bulgaria	2005
Aradippou OSS	Pub. PPP	Cyprus	2018
ProjectZero [1]	Pub	Denmark	2009
BedreBolig	Pub	Denmark	2013
PKA – Sust. Sol.	PPP	Denmark	2015
Frederikshavn	Pub	Denmark	2017
Ecofurb	Pr.	England (UK)	2009
Parity Projects [2]	Pr., Coo	England (UK)	2013
KredEx	Pub	Estonia	2009
Energies POSIT'IF [3]	Pub, Coo	France	2013
Pass Rénovation [4]	Pub, Coo	France	2013
ARTÉÉ	Pub	France	2015
OKTAVE	Pub	France	2017
RenoHub	PPP	Hungary	2019
SuperHomes	Pr.	Ireland	2015
Mantova	Pub	Italy	2020
Leeuwarden [5]	Pr.	Netherlands	2013
Woon Wijzer Winkel	Pr.	Netherlands	2015
Huizenaanpak	Pr., Coo	Netherlands	2014
Stroomversnelling	Pr., Coo	Netherlands	2015
Reinmarkt	Pub	Netherlands	2014
Bolig Enøk	Pr.	Norway	2009
Tighean Innse Gall	Pr.	Scotland (UK)	2014
ALIEnergy	Pub	Scotland (UK)	2011
MunSEFF	Pub	Slovak Repub.	2011
Slovseff	Pub	Slovak Repub.	2014
Energiesprong	Pr.	UK, Fr., Germ.	2013
FinEERGo	Pub	Various *	2019

Notes: a) Complementary, additional or optional names; [1] Zero Home, [2] Retrofit Works, [3] Île-de-France Énergies, [4] SPEE Picardie, [5] Slim Wonen Met Energie, b) Type of leader entities; PPP: Public-Private Partnership, Pub.: Public, P.: Private, Coo.: Cooperative.

Table 2: Spanish OSS cases studied

OSS Name	Region	Leader type	Type
GarrotxaDomus	Catalonia	Foundation	Coordination
OSIR	Extremadura	Administration	Coordination
OPENGELA	Euskadi	Administration	Coordination

The European analysis has been developed between April and September 2021 into the following stages: 1) identification of OSS using official reports and studies [5, 6, & others], research projects (Eracobuild, INNOVATE, COHERENO, and Refurb), scientific papers, and institutional websites of OSS focused on energy renovation in multi-family and single-family housing; 2) elaboration of a database with selected variables organized in the next groups of contents: a) general OSS data (leader entity, country, operating since, program/project, European plan, National plan, Regional plan, website), b) type of dwelling (single or multi-family), c) macroeconomic & environmental variables (GDP, CO2PC, Renewable Energy %), d) mass media (internet, showroom, office, to the door…), e) passive improvements (isolation, ventilation, enclosures, solar protection devices, water recycling), f) active improvements (photovoltaic plates, boilers, heat pumps, heat recovery), g) other improvements (functional, aesthetic, accessibility), g) responsibility for the works, h) offered services (green marketing, energy audit, project redaction, financing, grant management, permission management, search of suppliers, bidding for works, supervision of works, set up, monitoring of works, post evaluation), i) customers (private owners, co-owners, companies, tenants), and j) partners (providers, manufacturers, specialised advisers, financial entities); 3) selection of cases, according to defined criteria, and 4) analysis of documentary information and the database. The variables have been analysed individually, within each group, detecting the most relevant in percentages.

For Spanish case, once identified four operative OSS, in-depth interviews were made to promoters of the three in the most advanced stage. The structure of the used forms is: general data, background, barriers addressed, offered improvements & Services, structure and operation, and obstacles overcome to implement it. The steps have been: 1) identification of OSS, 2) collecting information through public documents (webpages and audio-visual material), 3) contrasting and complementing them through a form applied to their promoters, and 4) deepen certain aspects through an in-depth interview.

To establish similarities and the most important topics, an analysis & discussion between European and Spanish cases has been developed, and final comments have been developed.

3. SOME BARRIERS TO ENERGY RENOVATION

The processes of renovating the housing stock are limited by a series of barriers that affect families (economic, lack of knowledge and information, lack of capacity to implement renovations, etc.)

Frequently, the decision of housing energy renovation is affected by negative experiences of owners, and the consequence lack of trust regarding advisors and contractors [8], also supported by the "do it yourself" culture [9]. Based on the review of the literature, we organize them as follows:

- *Barriers and market failures:* a) informational asymmetry based on that some of the actors involved in the residential renovation process do not have the necessary knowledge of energy efficiency [10]; b) economic factors: conditioned by the necessary capital, and the facts that its recovery is uncertain and long-term. The empirical evidence indicates considerable penalisation of future savings, and divided incentives [11]; c) behaviourism, considering that the decision of homeowners to develop renovations is influenced by personal (awareness, attitudes, experiences, beliefs, and skills), contextual and external factors [12], and e) legal framework and management, considering also that studies suggest that some national energy efficiency action plans of some members states might not be adequate, and new policies are necessaries [13].
- *Determinants:* a) inconveniences in the decision process is a widespread problem for confused and asymmetric information [14], and that is not a dichotomous process, but a complex with specific problems in each stage [15]; b) social factors, for example habits, which induce actions regardless of the context, or the reluctance to invest in residential improvements [16]; c) understand rehabilitation as a housing adaptation process [17], or as gradual on time [18]; d) EE lack of knowledge and fragmented supply [19], & e) demand disaggregation [20].

In this scenario of difficulties in rehabilitation, the OSSs have gradually emerged, mainly in Europe and USA, in national, regional, and local settings, with a range of regulatory frameworks, adapted to these, with difficulties that this implies.

4. EUROPEAN OSS ANALYSIS

Some studies, such as Boza-Kiss and Bertoldi [21], Cicmanova et al. [8], or Krosse, L., *et al.* [22], review implemented OSSs, many of which promoted by European initiatives. These enable measures to be adopted that improve dwellings' energy efficiency, at the same time as they offer a renovated dwelling that meets the homeowner's real needs [18].

To overcome the barriers of lack of information and knowledge, a One-Stop-Shop should consider, in accordance with the model and considering its scope, the active participation of the owners of dwellings to be renovated. Also, is essential the identification of a market segment. According INNOVATE classification [23], based on the degree of support offered and in the context of energy renovation of dwellings, four OSS operation models are identified: a) Facilitation: offers a first approach of the client to the benefits of energy retrofit, provides information at no cost that is oriented towards the customer, and acts as a facilitator of the processes, b) coordination: contacts customer with a suppliers, previously endorsed and carry out energy renovation works, and with financial entities if is required. They can control the process but do not take responsibility for the results, c) all-inclusive: acts as a contractor, offering packages of services: information, coordination with suppliers, contractors & financing. It is responsible for the process and, sometimes, guarantee energy saving after works, and d) ESCO: similar to all-inclusive in services, but also guarantees energy savings after the works. The cost of the investment is paid to the company through generated energy savings.

4.1 Some outstanding cases

- *Retrofit Works (U.K.)* started in 2013 as part of the Green Deal. It is based on a cooperative of SMEs of contractors, local suppliers (including technicians) qualified in energy, social agents, and the energy consultancy Parity Projects (PP). They have formed since 2017 an OSS. The process starts with a web tool provided that families can use to find out about possible improvements and necessary investment. Those who are interested contact PP and, if is necessary, one technical coordinator visit the home to carry out an onsite assessment. Then, the three proposals of RW cooperative members are sent and a service contract is signed with PP, which carries out the technical monitoring of the works with the selected RW contractor. The operating costs of PP are covered by commission paid by the contractors.
- *OKTAVE (France*) is led by town and city councils and promoted by the agency for ecological transition ADEME and the Gran Este region. It brings together two financial companies, one of a social nature. The OSS provides a service that includes customised assistance on technical, financial, and administrative aspects under a model of a single point of contact. It draws up a financial plan that combines subsidies, tax credits, and zero interest loans for up to 15 years, and it seeks an ESCO to recover the investment with energy savings. The contractors and suppliers are local and trained, and accredited by OKTAVE, included in a register of qualified suppliers. The process starts with a free energy audit to assess the solutions and draw up a quote and an estimation of financing possibilities. It continues with the signing of a payment agreement for the provision of services, the search for suppliers and contractors, and an analysis of the suitability of the technical and financial proposal. With the fees, the management of subsidies (whose amount is paid in advance through a revolving fund), licences, and loans begins. The works are monitored, accepted, and put into operation.
- *BetterHome (Denmark)* offers diverse predefined renovation packages for private home-owners. Through automated, customised services and a web application, the potential customer first informs the installers and preselects the measures. Then, the homeowner through direct contact with the technical team can adapt the package and the technical and financial terms to their specific needs. The OSS works with local craftspeople, who receive training and tools to guarantee quality services. Better-Home carries out the promotion, quality control, monitoring, and customer care. In 2016, it completed over 200 projects and it has gradually expanded.

A different scheme is that implemented in France by the Ile de France region. A new, semi-public company was created and an ESCO was developed to offer a complete value chain for renovation [9].

5. SPANISH CASE STUDIES

The OSS concept in Spain appears in 2014 ERESEE as "local rehabilitation agencies." Although the local rehabilitation offices existed previously, linked to the rehabilitation of the public housing stock and within the framework of the integral rehabilitation of degraded neighbourhoods. Unlike these offices, the concept of OSS: a) is not necessarily linked to an integral rehabilitation, b) nor is it aimed at areas of vulnerable population, & c) nor is in public housing. In this context three local operational OSS experiences are studied, all derived from European projects.

5.1 GarrotxaDomus (GD)

Is the evolution of HolaDomus (HD), pilot project in the framework of the EuroPACE Project, managed by EuroPACE Foundation, a non-profit entity with public-private participation: GNE Finance and Olot City Council, which has supported it and intends to extend it on the province through GiDomus. The pilot test had an agreement with GNE Finance. The owners had the possibility of financing with 5.5% APR rates, 1.5% commission, without cancellation or refinancing commission, within a period of 5 to 15 years.

The OSS model GD simplified interaction between owners and the other involved actors. The process begins by offering services of an energy office aimed at providing advice to reduce consumption through information on habits and housing improvements by effective messages based on people's needs. Subsidies are also managed and information is provided on affordable financing lines; the building license, the IBI and ICIO bonuses are processed and the owner is assisted to request budgets, within a portfolio of 70 validated professionals. To speed up the process, GD has, in addition to the physical office, a website with all the necessary information and each procedure is optimized to contain precise information to, for example, report a license or grant a subsidy.

Some 430 middle-income households and single-family homes have benefited, 95 assisted in drafting energy projects; a third part executed, another third part in execution and the rest in the previous phases. The most measures applied have been: insulation, air conditioning with photovoltaic support, enclosures... In general, the demand comes with a certain level of awareness, that increases as receive advice. The best valued services are support, centralized dialogue and assistance in obtaining subsidies. On the other hand, it can be seen that in the case of multi-family housing, the lack of affordable financing and, above all, the need for the agreement of the Homeowners' Meeting, makes it difficult to deploy renovations.

5.2 OSIR

The Office of Integral Services for the Energy Rehabilitation of Housing (OSIR) is an initiative of the Extremadura Government and Extremadura Energy Agency (AGENEX), with the support of the European projects H2020: HoseEnvest and INNOVATE. It is aimed at multi-family homes. The office is in Badajoz, and is studied new openings in Mérida and Caceres.

Previously, a diagnosis and rehabilitation potential study was carried out in the Interreg FINERPOL project framework, and training for the construction sector through the REHABILITE project. Then appear OSIR and the Extremadura Housing Energy Efficiency Guarantee Fund (GEEVE). The fund is nourished by public resources (ERDF included), is managed by Extremadura Avante and seeks to mitigate the risk of participating financial entities. Thus, the entities offer loans to owners with special conditions; return terms of 15 years, reduced rates (less than 4.5% APR), without commissions (except opening). In order to the fund to accredits guarantee, renovations must affect the envelope, include an active system, and improve one step in the EPC energy class.

OSIR identifies buildings with a high rehabilitation potential due to lack of insulation and inefficient central boilers (previous to 1980). In parallel, contact and inform via web. Then, contact the administration of buildings and the presidency of the community. A technician visits the building, identifies shortcomings and opportunities for intervention. Then, with the improvement proposals, its energy savings, estimate cost and the subsidy and financing options, OSIR summons the neighbors, who can agree to undertake them all, prioritize them by cost or reject them. OSIR does not assume the direction, but accompanies the homes in the execution and reception of works. Parallel to project drafting, uploads its characteristics, its cost and compliance with the parameters required by GEEVE to cover the credit to a computer platform of the financial entities. This overcomes the barrier of ignorance of the financial sector of the implications of energy rehabilitation. AGENEX technicians provide support and advice, although they have contracted staff to provide their services.

Ten months after its opening, 200 buildings have been visited and 170 diagnostic and improvement reports have been issued. 3 have agreed to undertake the improvements and 2 have completed the selection of the contractor that will implement them.

5.3 Opengela (OG)

OG was born with the support of the H2020 Hiross4all project, to promote the creation of OSS in vulnerable neighborhoods. The first two OG offices operate in Otxarkoaga (Bilbao) and Txonta (Eibar). It aims is to extend the initiative, opening new offices across Basque country. GNE Finance also participates with its knowledge in rehabilitation financing.

It promotes multi-family buildings rehabilitation, empowering the owners to become protagonists in decisions, and leading the actions. The rehabilitation focuses on energy efficiency (reaching “C” EPC class, improving one or two letters), including health, habitability, comfort and accessibility improvement. Almost 50% of the rehabilitation cost is covered by subsidies and the rest by owners. Also, owners can apply for an additional aid or credits, and the spills can be prorated (up 36 months). OG is working with GNE Finance, assisting on economic needs of owners with difficult access to conventional banking. Also, is designing a line of aid, so that communities of owners can assume payments, in case of late payment.

OG seeks to increase the household’s confidence whit a regulated, competitive and transparent action. In the process, through an agreement with owners, is managed a contract, including technical conditions, & contracting pool. Otxarkoaga *(Viviendas Municipales)*, is still the owner of some houses, and is part of the owner’s communities, thus this procedure is easy. In the case of Txonta, with private homes, OG has the support of City Council's Urban Planning Department, & regional Urban Rehabilitation Society (DEBEGESA).

The OG Otxarkoaga office has three technical professionals, specialized in energy rehabilitation, one with social communication skills. 25% of the personnel cost is covered by Hiross4all, the rest by aid from the Department of Territorial Planning…, of Basque Government. For its part, Municipal Housing covers the costs of premises, material and services. OG Txonta has a technician, depending to Eibar Town Planning Department, assisted on technical, legal, economic, and administrative services by DEBEGESA.

In OG Otxarkoaga, the OSS's reception has been so good, due to a previous intervention in envelopes of some buildings, that help to shows renovations, cost, and the “word of mouth” communication on benefits. The process begins with the information of the problems to the owners, including improvements, based on the available aid, preferences and economic possibilities. Then, an agreement is requested for the administrative contracting process that begins with the drafting of the technical conditions, continues with the public call, with the contracting table, the review of the offers and its interpretation.

In Otxarkoaga, action is being taken in 5 buildings (16 portals & 240 homes). In Txonta, the action is being taken on 17 portals (221 homes) with an emphasis on energy and accessibility aspects.

5. ANALYSIS AND DISCUSSION

In addition to initial Nordic countries experiences, operating OSSs are mainly in the Netherlands (5), France (4), and the U.K. (4). Of these, four OSSs have been operating since 2009 (ProjectZero in Denmark, Ecofurb in England, KredEx in Estonia, and Bolig Enøk in Norway). These are the longest running OSSs after the two that have been in operation since 2005 (Huisdokter in Belgium and EERSF in Bulgaria).

Regarding *Nature and Initiative*, highlights public initiatives (16 cases, 51.61%), two collaborating with a cooperative and one case through a PPP. In general, public entities are town councils, with support of regional or national energy agencies. Almost half the OSS use all-inclusive model (optimum), 26% a facilitating model, and 24% a coordination model.

About *Financing for operation*, most (28 cases, 90.32%) have received public financing of European programmes or projects, mainly to cover it operating costs. Many of these start as pilot test in the project framework. Of these, the ones that are not operating, generally shut down, if it functioned as a pilot test, without future funding. In relation to the model, the ESCO type use private financing as they act as agencies that use energy savings to finance customers and make it profit.

About *Communication Channels*, the most used to attract clients are Internet (webs) and mass media. Customer service offices also play a relevant role. The next most common means of communication is local meetings. The showroom option was only observed in all-inclusive and consultancy models and the ‘door-to-door’ method only in all-inclusive.

Regarding *Offered Improvements*, In the passive ones, there is a tendency to more integrated. In the buildings, the main passive improvements are focused on insulation (30 cases, 96.77%), types of doors-windows (26 cases, 83.87%), and ventilation (25 cases, 80.65%). In active ones, there is a clear predominance of photovoltaic panels incorporation (26 cases, 83.87%) in multi-family housing, and heat pumps (23 cases, 74.19%), followed by boilers.

Regrading *Provided Services*, the main ones are: energy audit (27 cases, 87.10%), project (23 cases, 74.19%). Those that are least frequently offered are: acceptance of the works, and other improvements.

About *Customer Target*, in some cases, OSSs focus on a local office but act in different regions or internationally, particularly when they form part of a programme that involves many cities: Bolig Enøk, Energiesprong, FinEERGo, or Reinmarkt…

Is important to highlight the cases with a model addressed both single-and multi-family buildings market, as successful building renovation business models: EnergieSprong, Oktave, and BetterHome.

In Spain, despite its diverse nature, OSS share the impulse of public administrations, which distinguishes it in relation to those of other European countries, mostly private. Although the responsibility of the administrations in promoting energy rehabilitation is clear, its participation in the OSS (with public funds) entails difficulties. For example, the limitation in contract services, based on supplier records.

Another distinctive feature is that it is aimed to multi-family housing, with a set of added challenges: a) complexity of obtaining an agreement from the owner`s community, b) financing for the community and coverage of non-payments, and c) in deprived areas, organizational problems and lack of daily management. For this reason, the participation of multi-family building management professionals is crucial. Also, is important to act as a link between the neighbourhood communities and the OSS, as in OSIR.

The third characteristic is its “facilitation” type. This is understandable, considering the role of the administrations. But in a context of fragmentary information regarding benefits, possible measures, cost/benefit ratio, financial aid and assistance, this model represents a very significant evolution.

Also noteworthy are the international initiatives of consulting companies, installers or organized

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

distributors, which make it possible to group together a fragmented service market. Spanish cases integrate these services and try to prioritize professionals with technical, economic and administrative solvency. It also highlights the efforts to unite professional, industrial and financial associations. Thus, these experiences respond to the OSS model desired by the EC, beyond that the provision of integrated services.

6. FINAL COMMENTS

The preliminary results suggest at the European level that the lack of structural financing is a cause of the closure of its activities and that the most successful ones respond to the all-inclusive model, assisting families throughout the process. Likewise, the important role that European administrations and projects play as a source of funding and, of specific knowledge, is highlighted; as well as the obstacles that have been overcome to implement them and those pending resolution.

In Spain, OSS are emerging in a critical moment; the imminent arrival of EU NextGeneration fund, which management can be assisted by these, especially when there are resources and initiatives from the EC and the EIB to finance technical assistance in efficiency of public and private entities, as well as studies for the establishment of OSS.

In sum, a point of no return has been reached in which OSS appear as a relevant actor in meeting the challenges associated with the climate emergency.

ACKNOWLEDGEMENTS

This work is carried out within the framework of the project *Beyond the EPC Requirements, potential and risks of energy efficient mortgages in the promotion of efficient homes, EnerValor2*, funded by the Spanish Ministry of Science, Innovation and Universities (Ref. PID2019-104561RB-I00).

REFERENCES

1. European Parliament (2020). Draft Report on maximising the energy efficiency potential of the EU building stock (2020/2070(INI), Committee on Industry, Research and Energy. Available: https://www.europarl.eu/648631.pdf
2. EUROPEAN PARLIAMENT AND OF THE EU COUNCIL (2002). DIRECTIVE 2002/91/CE, of 16 December 2002 on the energy performance of buildings (OJEC L 1 de 65. 4.1.2003). Available: https://eur-lex.eu.eu/3A32002L0091
3. EUROPEAN PARLIAMENT AND OF THE EU COUNCIL (2012). DIRECTIVE 2012/27/UE, of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC & 2006/32 /EC. Available: https://eur-lex.eu.eu/3A32012L0027
4. De Santiago, E. (2014). La estrategia para la rehabilitación energética en el sector de la edificación residencial en España: método y principales resultados. *Ciudad y Territorio. Est. Territ.*, 46(182): p. 773-788. DOI: 10.3989/ic.63735
5. European Commission. A European Green Deal. 2019. Available: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal [21 August 2021].
6. García-Hooghuis, A.; Neila, J. Modelos de transposición de las Directivas 2002/91/CE y 2010/31/UE "Energy Performance Building Directive" en los Estados miembros de la UE. Consecuencias e implicaciones. Informes de la Construcción 2013, 65, p. 289-300.
7. ENERDATA. ZEBRA2020-Data Tool. 2015. Available: https://zebra-monitoring.enerdata.net/ES/ [16 July 2021].
8. Cicmanova, J; Eisermann, M; & Maraquin, T. - E.C. (2020). How to set up a One-stop-shops for integrated home energy renovation? A step-by-step guide for local authorities and other actors. INNOVATE Project. *Energy Cities*. Available https://e-c.eu/wp-content/INNOVATE.pdf
9. Boza-Kiss, B. & Bertoldi, P. (2018). *One-stop-shops for energy renovations of buildings. Case studies.* European Commission. *JRC Science for Policy Report,* [JRC113301]. Available: https://e3p.jrc.ec.europa.eu/one-stop-shops
10. Hunkin, S.; Krell, K. (2019). Supporting energy renovation of private households through One-Stop-Shops. A Policy Brief. From the Policy Learning Platform on Low-Carbon Economy. Interreg Europe. Available: https://www.interreu.eu/20190210_oss.pdf [27 July 2021].
11. Gillingham, K. & Palmer, K. (2014). Bridging the Energy Efficiency Gap: Policy Insights from Economic Theory and Empirical Evidence. *Review of Environmental Economics and Policy*, 8(1), 18-38. DOI: 10.1093/reep/ret021
12. Ebrahimigharehbagh, S.; Qian, Q. K.; Meijer, F. M., & Visscher, H. J. (2019). Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making? *Energy Policy*, 129, 0301-4215. DOI: 10.1016/j.enpol.2019.02.046
13. Rosenow, J.; Fawcett, T.; Eyre, N.; Oikonomou, V. Energy efficiency and the policy mix. Build. Res. Inf. 2016, 44, 562–574, DOI: 10.1080/09613218.2016.1138803
14. Arkeloff, G.A. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism. The *Quarterly Journal of Econom.*, 84(3), 488-500. DOI: 10.2307/1879431
15. De Vries, G.; Rietkerk, M. & Kooger, R. (2019). The Hassle Factor as a Psychological Barrier to a Green Home. *Journal of Cons. Policy*. DOI: 10.1007/S10603-019-09410-7
16. Rana, A. *et al.* (2021). Evaluation of financial incentives for green buildings in Canadian landscape. *Renew & Sust. En. Reviews*, 135, 110199. DOI: 10.1016/j.rser.2020.110199
17. Salom, J. & Pascual, J. (2018). Ed. *Residential Retrofits at district scale. Business Models under Pub. Private Partnerships.*
18. Pardalis, G., Mahapatra, K., Bravo, G., & Mainali, B. (2019). Swedish House Owners' Intentions Towards Renovations: Is there a Market for One-Stop-Shop? *Buildings*, 9(7), 164. DOI: 10.3390/buildings9070164
19. Thøgersen, J. (2017). Housing-related lifestyle and energy saving: A multi-level approach. *Energy Policy*, 102, 73-87. DOI: 10.1016/j.enpol.2016.12.015
20. Risholt, B. & Berker, T. (2013). Success for energy efficient renovation of Dwellings-Learning from private homeowners. *Energy Policy*, 61, 1022-1030. DOI: 10.1016/j.enpol.2013.06.011
21. Boza-Kiss, B. & Bertoldi, P. (2018). *One-stop-shops for energy renovations of buildings. Case studies.* European Commission. *JRC Science for Policy Report,* [JRC113301]. Available: https://e3p.jrc.ec.europa.eu/oss-erb
22. Krosse, L.; Monclus, M.; Nijrolder, A. (2021). Building Refurbishment Initiatives and Business Models. A Global Benchmark. Available: https://www.fundnaturgy.org/77630
23. INNOVATE. Integrated solutioNs for Ambitious Energy Refurbishment of priVATE Housing Project. Available: https://cordis.europa.eu/project/754112 [9 July 2021].

Assessment of a retrofit proposal for workspace in a Brazilian public university

ADRIANA PETITO CASTRO[1] ELISABETI BARBOSA[2] CAMILA DE FREITAS ALBERTIN[2] LUCILA CHEBEL LABAKI[2]

[1] Paulista University (UNIP), Brazil
[2] University of Campinas (UNICAMP), Brazil

ABSTRACT: The edification labeling program from PBE Edifica has been mandatory in Brazil since 2014 for new constructions and retrofitting in federal public buildings. The Normative Instruction nº2 made many institutions seek to foster actions not only to attend legislation, but also improve their energetic performance and try to save public resources which have limited budget. Based on the labeling edification diagnosis, it was selected a building The buildings labeling program from PBE Edifica has been mandatory in Brazil since 2014 for new constructions and retrofitting in federal public buildings. The Normative Instruction nº2 caused many institutions to look for foster actions not only to attend legislation, but also to improve their energetic performance and try to save public resources with limited budget. Based on the labeling buildings diagnosis, it was selected a building in the campus of the University of Campinas, with an office typology to put forward retrofitting ideas and analyze through labeling comparison the influence of lighting, air conditioning, and roof characteristics parameters. It was observed that changing the lighting, from conventional to LED ones, reduced the energy consumption by 50.54%. The air conditioning substitution brought an energy saving of about 40% on the edification. A roof change in the building represented a more comfortable setting for users and might influence as well on the operation of the acclimatizing equipment which represents about 48% of a building consumption. This paper emphasizes through its labeling results that for the studied scenarios not only the envelope, but also air conditioning are the most relevant parameters as compared to the lighting system. However, the latter contributes a lot to energy-consuming reduction.
KEYWORDS: labeling program, energy efficiency, retrofit, thermal performance

1. INTRODUCTION

According to the Brazilian Energy Balance [1], buildings in Brazil consume about 52% of available electricity, where households represent 26.1%, the commercial sector corresponds to 17.4%, and the public sector represents 8.5% of it. In this context, medium to long-term solutions that reduce costs and increase energy efficiency are urgent in a scenario that demands technological and scientific development on serious energy efficiency planning [2]. Additionally, saving energy costs in buildings presumes its optimization and rational use. In this sense, public services in-use buildings that present a limited budget compared to the private sector are living laboratories for studies on how to apply energy-efficient concepts.

The potential benefit of this energy efficiency relies on the consumption reduction of natural resources since the hydraulic source represents 64.9% of the Brazilian power grid [1], inferring an urgent need to save public expenses in buildings that provide essential services to the population. Hence, the Brazilian labeling energy program on public buildings projected for the National Energy Efficiency Plan (PNEf, in Portuguese) constantly fosters improvement in the general building's context and enables efficiency patterns and standard excellences to be followed [3]. Besides, this policy encourages the use of mechanisms that provide constant assessments, retrofits, and energy production systems according to performance regulations.

The Brazilian Labeling Program (PBE) aims to reduce energy waste and encourage the rational use of energy in buildings.

The labeling process in Brazil started as a voluntary program. It evolved to become an imminent mandatory program for federal public buildings since 2014 for buildings throughout the national territory, with the maximum classification (level "A"). However, to achieve effective energy efficiency at level A, changes in occupants' behavior are necessary, both individual and collective [4].

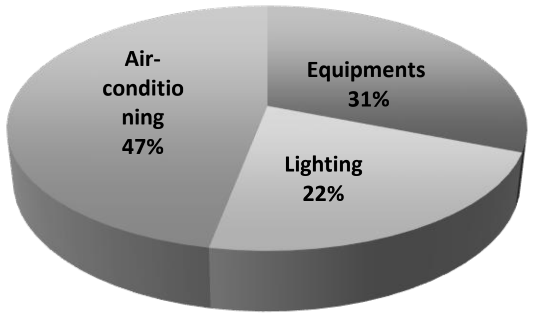
Even with strong growth, the application of Labeling still lacks studies, dissemination of good practices, training, and dissemination of knowledge in the most diverse social classes further to leverage the process in an acceptable, safe, and sustainable way.

Based on instruments that allow the assessment of energy performance, both of the buildings themselves, and the actions to bring or expand energy efficiency, public management can be established with more alignment with the needs of today's society. Those tools allow prioritization of public investments, consolidate the justifications for them, and promote greater awareness of the users of these buildings [2].

Architecture solutions related to energy efficiency present a high potential to be implemented on the design stage and available possibilities of interventions in the construction. According to Procel data [5], the potential energy saving is about 50% on new buildings and 30% on existing ones. Consequently, retrofitting is an instrument boost to sustainability since it can improve energy sources utilization, reduce environmental impact, and optimize waste resources in civil construction.

Air conditioning systems are responsible for almost half of the total energy consumption in commercial buildings [5], as shown in Fig.1, and their performance is related to the envelope's energy efficiency. This work presents a retrofit proposal in a (public) service building for the lighting and air conditioning systems, demonstrating the potential reduction of its energy consumption through simulation in the Webprescriptive method [6].

Figure 1:
Distribution of consumption by final use in public buildings [5, adapted]



2. OBJECTIVE

This work compares how interventions on lighting, air conditioning, envelope can influence on the final labelling. It reports that the building might positively impact the energy efficiency label in a standard building in a public university, bearing in mind restrictions on design modifications for public buildings. Also, the work focuses on a simulation of external interventions to improve thermal performance and compare it with other buildings of the same type. So, this work aims to assess the influence of a retrofit mechanism on a higher education building to improve its energy efficiency label.

3. METHODOLOGY

The study case is a public higher education building located in the city of Campinas, Brazil. To assess the influence of a retrofit on these constructions, it was chosen a standard building for office work. Initially, it was performed a label draft on the selected building. At this phase, the prescriptive method was applied. After that, assessments were conducted on some reference variables such as lighting, air conditioner, and changes in roofing systems which could impact the building envelope label to assure better energy efficiency.

3.1 Analyzed Building

The Faculty of Mechanical Engineering (Fig. 2) contains ten buildings with three floors, with the blocks interconnected by corridors with or without halls.

Block B was selected for applying the WebPrescritivo [6] method since it mostly corresponds to an office environment. The prescriptive process is relatively fast to apply and can be used in most buildings for a preliminary analysis.

Figure 2:
Orientation according with to Geographic North of FEM buildings, with highlight to the analyzed block B [7, adapted]

3.2 Assessment of energy performance

An initial evaluation on the energy efficiency level was conducted by using the prescriptive method described in the Technical Regulation on Commercial, Services and Public Buildings Quality (RTQ-C, in Portuguese, 2017) [8]. The online instrument WebPrescritivo, available on the LabEEE website [6], was used for filling the data buildings. This tool facilitates the application of equations, features pre-requirements validations, and provides the global level of label efficiency of the building.

The study case is a public higher education building located in the City of Campinas, Brazil. To assess the influence of a mechanism of retrofit on these buildings, it was chosen a standard building for office activities. The prescriptive method was applied in all scenarios. Initially, it was analyzed the building with real use. After that, assessments were conducted by changing some reference variables such as lighting, air conditioner, and changes in roofing systems which could impact the building envelope label to assure better energy efficiency.

Therefore, the Labeling process was applied by keeping the original design parameters and the existing equipment without any building intervention. After that, four scenarios were established to compare new parameters to a new labeling procedure.
Thus, the established scenarios were:
I. Revision only of the lighting parameter for the whole block.
II. Revision only of the air conditioner parameter for the whole block.
III. Joint adjustment of lighting and air conditioning parameters for the building.
IV. Joint adjustment of lighting and air conditioning parameters and interventions on the roofing system of the building.

4. RESULTS

The four scenarios were analyzed by simulating with the new variables. The objective was to establish the achieved improvement in each scenario and the changing in the final labeling.
Table 1 shows the results for each scenario simulation and the benefits to the building

Table 1:
Summary of results

Simulation	Intervention	Action type	Benefit for building
Scenario 1	lighting	Replacement of fluorescent tubes for LED	Energy saving. There was no change in the general label.
Scenario 2	air conditioning	Replacement of old equipment for new one level A of Energy Efficiency	Reduction of energy costs in the order of 40%
Scenario 3	lighting and air conditioning	Replacement of lighting and air conditioning systems	Improvement in the overall quality and efficiency of the building. User comfort limited to these two parameters, as the envelope is still underperforming.
Scenario 4	lighting, air conditioning, envelope	Replacement of lighting, air conditioning and roofing systems	Reduction in heat exchange between the external and internal environment with the replacement of the covering material (Fiber cement tile for Metal tile with polyurethane). The reduction in thermal transmittance and absorbance results in improved thermal comfort and reduced energy consumption with air conditioning.

4.1. Energy performance assessment of the original project – no intervention

Considering the original project, the proposal for labeling the block (envelope) and the rooms (lighting and air conditioning) was conducted, generating the results shown in Table 2.

Table 2:
Results of the Webprescriptive method applied to the building (original design)

BLOCK B	Envelope	Lighting	Air conditioner	FINAL
Labelling	C	B	C	C

Through the data obtained with the labeling procedure, it was noted that the worst performance of this building fell on the parameters of the envelope and air conditioning, which reflected in the result for the final label of the building. As regarding to the envelope, this is due to the constructive design typology of the building: structural blocks, tilting windows that limit natural cross-ventilation in the rooms as well as the roofing type of the building, composed of fiber cement tile. As for air conditioning data, the low level of efficiency can be explained by the existence of technologically outdated equipment in the building, since window equipment with low aggregate energy efficiency was planned, which did not even have a label of efficiency. Although the lighting has achieved a satisfactory level of efficiency, it should be noted that the building's original lamps corresponded to the tubular fluorescent models, which have higher energy consumption when compared to LED lamps widely available on the market today. The main appeal of this technology is due to its low energy consumption, although it still has a higher initial cost than fluorescent ones [9].

4.2. Energy performance assessment based on the replacement of parameters from the original project

By considering the initial results for the building, the assessment of its energy efficiency, modifications presented in the following subsections and the evaluation of the individual results are proposed.

Four scenarios were established, as described below.

4.2.1. Scenario 1 – Intervention only in lighting system

From the replacement of the original lighting (tubular fluorescent lamps - 32W) by highly efficient (label A) tubular LED lamps (16W), the building label is proposed for each item as well as the final label.

Based on the obtained results, it is worth mentioning two points: the first one corresponds to the fact that even by changing the lamps so that a lighting power density (DPI) equivalent to level A was reached, due to the prerequisites of the existing system, the lighting label reaches most level B. The second point concerns the fact that, with the replacement, the monthly energy consumption in the building decreases by about 50.54%, considering the building operation for 12h/day and twenty-two working days in a month.

The result also shows that lighting alone was not able to change the general label in view of maintaining the other parameters with a significant weight in the composition of the available label.

4.2.2. Scenario 2 – Intervention only in air conditioning

The replacement of the 41 existing air conditioners with different ratings (A, B, and E) for appliances with efficiency levels classified as A, the proposal for labeling the building was made.

The significant importance of air conditioning in the final building labeling as well as the replacement of all the appliances in the building resulted in an improvement in the general label, from C to B. In addition, it is important to emphasize the fact that the air conditioning system label moved from C to A. In addition, energy costs were significantly reduced, as can be seen in Table 2, since the equipment was of better efficiency and brought less consumption to the energy bill of the place, about 40%.

4.2.3. Scenario 3 - Intervention in lighting and air conditioning

Combining the substitutions made in sub-items 4.2.1 and 4.2.2, the proposal for labeling the building was made.

In this scenario, the replacement of existing lighting and air conditioning systems for new, more efficient ones showed an improvement in the overall efficiency quality of the building. However, it should be noted that the comfort of building users is limited to these two parameters since the envelope still shows low performance, and there was no retrofit evaluation for this system. Although there are energy savings by equipment with greater efficiency, they are used for a longer time to ensure the comfort and well-being of the occupants. The option for standardized construction techniques, materials, and projects, for distinct locations, without considering each region's specific climatic conditions and implementation negatively affects the performance of buildings and environmental comfort for users, resulting in environments not suitable for the proposed activities [10].

4.2.4. Scenario 4 – Intervention in lighting, air conditioning, and envelope

With the combination of sub-item 4.2.3 associated with the change in coverage, a label can be proposed for the whole building.

The efficiency of the bioclimatic strategy is directly related to the type of material used in its facade and roof [11].

By analyzing the project, it was verified that the type of roofing used in fiber cement structure, with high solar absorbance (74.5%) and high thermal transmittance (2.06 W/m2K), confers high heat gain to the building. Therefore, an improvement in the performance of the structure is suggested by replacing the roofing system with a sandwich tile with an air chamber larger than 5 cm (which allows changing the of 2.06 W/m²K thermal transmittance to 0.63 W/m²K), which reduces the solar absorbance of the roof to 37.2%. This tile uses insulating materials with low thermal conductivity, which means a decrease in heat exchange between the external and internal environment by up to 90%. This type of roof is extremely functional, with thermal properties that allow greater insulation from the external to the indoor environment and therefore more thermally comfortable. This is due to the higher thermal capacity of this component, favoring thermal inertia [12].

4.3 Results obtained for each scenario

Table 3 illustrates the results obtained for each proposed change.

Table 3:
Results from the proposed changes

BLOCK B	Envelope	Lightning	Air conditioner	FINAL
Scenario 1	C	B	C	C
Scenario 2	C	B	A	B
Scenario 3	C	B	A	B
Scenario 4	B	B	A	B

By changing the three systems parameters, lighting, air conditioning, and envelope, for analyses of the thermal transmittance and solar absorbance of the roof, there was no alteration on the final label. Nonetheless, it was observed that only by changing air conditioning equipment it was possible to influence the final label. Furthermore, the combined alterations proved to be very effective in improving the last building label. Modifications in the envelope (roofing system) were able to promote, in combination, a significant change in the envelope label and, consequently, in the general one.

It was observed that the replacement of conventional lamps for LED lamps reduced lighting energy consumption up to 50.54%.

By changing the air conditioning units, the energy savings was approximately 40%. In addition, modifications in the building roofing type increased the user's comfort and influenced their operation of the air conditioning system, which represents 48% of consumption.

When changing the three systems parameters, lighting, air conditioning, and envelope, for analyses of the thermal transmittance and solar absorptance of the roof, there was no alteration on the final label. Nonetheless, it was observed that only by changing air conditioning equipment it was possible to influence the final label. Furthermore, the combined alterations proved to be very effective in terms of improving the last building label.

Modifications in the envelope (roofing system) were able to promote, in combination, a significant change in the envelope label and, consequently, in the general one.

It was observed that the replacement of conventional lamps for LED lamps reduced lighting energy consumption by 50.54%.

By changing the air conditioning units, the energy-saving was approximately 40%. In addition, the modifications in the building roofing type not only increased the user's comfort but also influenced their operation of the air conditioning system, which represents 48% of consumption.

5. CONCLUSION

Given the results, it was observed that the retrofit practice for energy efficiency focusing on artificial lighting and air conditioning systems, besides being an environmentally acceptable path, remains as an option to obtain economic and energy savings. Distinctly of a simple recovering, which restores the building to its original condition, retrofit technique intends also to introduce an enhancement to the building.

Therefore, retrofitting to reduce envelope gains/loss is a conservation strategy to pursue, at first to reduce the demanded equipment for air conditioning and lighting

Due to economic restrictions and limitations for design changes in public buildings, the proposed adjustments were restricted to the roofing type and some interventions in the façades and limited to surface properties, such as solar reflectance.

A possibility to be explored by further studies could be the evaluation of vegetation around the building to improve the performance of the envelope concerning insolation in the building and improvement in the thermal comfort of users.

The rational use of energy is crucial to guarantee future demands and avoid waste. The bioclimatic context (sustainable) in architecture must ensure a good performance of the building, beginning from the design stage, prioritizing passive strategies and minimizing the use of energy for lighting and air conditioning. This means maximizing the use of natural resources saving energy throughout use.

It is worth noting that by adapting a building to energy efficiency standards it is possible, in most cases, to increase construction costs. The concern with the insertion of the building in the environment must be constant, both in the phase of its conception and construction and on the part of the future users of the building, for whom it is important to provide the necessary environmental education. Hence, by applying retrofitting in a study case, it is shown the possibility to provide background to put forward benchmarking techniques for similar building types.

The present study concludes that when changing the three systems parameters, lighting, air conditioning, and envelope, (for analyses of the thermal transmittance and solar absorptance of the roof) there was no alteration on the final label. Nonetheless, it was observed that only by changing air conditioning equipment it was possible to influence the final label. Furthermore, the combined alterations proved to be very effective in terms of improving the final building label.

Modifications in the envelope (roofing system) were able to promote, in combination, a significant change in the envelope label and, consequently, in the general one.

ACKNOWLEDGEMENTS

This work was developed under the Electricity Sector Research and Development Program PD-00063-3032 /2017 - PA3032: "Sustainable campus model at the University of Campinas - Brazil: An integrated living lab for renewable energy, electric mobility, energy efficiency, monitoring and energy demand management", regulated by the National Electricity Agency (ANEEL in Portuguese), in partnership with CPFL Brazil (Local Electricity Distributor).

Acknowledgement is due to the School of Mechanical Engineering for supporting the research with field study.

REFERENCES

1. Brazilian Energy Balance 2020 Year 2019 / *Empresa de Pesquisa Energética* – Rio de Janeiro: EPE, 2020.

2. Associação Brasileira das Empresas de Serviços de Conservação de Energia (ABESCO). Available: http://www.abesco.com.br/pt/ [21 March 2021].

3. SORGATO, M.J.; MELO, A.P.; LAMBERTS, R. Análise do método de simulação de desempenho térmico da norma NBR 15575. In: *Encontro Nacional de Conforto no Ambiente Construído*, v. 12, 2013.

4. LABAKI et al. Diagnóstico de etiquetagem de eficiência energética em edificações da Unicamp. In: Campus

Sustentável: um modelo de inovação em gestão energética para a América Latina e o Caribe. Synergia Editora, 2021.

5. ELETROBRÁS. Pesquisa de posse de equipamentos e hábitos de uso – Ano Base 2005. Rio de Janeiro: *ELETROBRÁS, 2008.* Available: http://www.procelinfo.com.br/main.asp?View=%7B4A5E324F-A3B0-482A-B1CD-F75A2A150480%7D [10 April 2021].

6. WEBPRESCRITIVO. Ferramenta de Avaliação de Eficiência Energética de Edificações Comerciais pelo Método Prescritivo do RTQ-C. Projeto S3E. Convênio FINEP 01.09.0440.00/CT-Energia/Ref.:0509/08. 2010. Available: http://www.labeee.ufsc.br/sites/default/files/webprescritivo/index.html [14 June 2021].

7. GOOGLE MAPS. Available: https://www.google.com.br/maps/place/Faculdade+de+Engenharia+Mec%C3%A2nica/@-22.8194056,-47.0665919,199m/data=!3m1!1e3!4m5!3m4!1s0x94c8c6ac3564aee5:0x3fa32a727555a765!8m2!3d-22.8188644!4d-47.0654201 [03 April 2021].

8. BRASIL. MINISTÉRIO DO DESENVOLVIMENTO, INDÚSTRIA E COMÉRCIO EXTERIOR – MDIC. INSTITUTO NACIONAL DE METROLOGIA, QUALIDADE E TECNOLOGIA – INMETRO. Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas (RTQ-C), v.4, 2017.

9. SCALCO, V. A. et al. Retrofit do Sistema de Iluminação em Edificações de Escritórios: potencial de economia de energia de acordo com método da Etiqueta PBE Edifica. Lumiere Eletrics, p. 13, 2015.

10. KOWALTOWSKI, D. O processo de projeto em arquitetura: da teoria à tecnologia. Oficina de Textos, 2011.

11. CORBELLA, O.; CORNER, V. Manual da Arquitetura Bioclimática Tropical para a Redução do Consumo Energético. Rio de Janeiro, 2012

12. CANEPPELE, L.B.; NOGUEIRA, M. C. J. A.; VASCONCELLOS, A. B. Avaliação da eficiência energética e custo-benefício no uso de coberturas metálicas em supermercados empregando o software Energy Plus. *Revista eletrônica em gestão, educação e tecnologia ambiental*, v. 9, p. 1971-1979, 2013.

PLEA STGO 2022

WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE URBAN DEVELOPMENT

DAY 03
09:00 — 10:30

CHAIR
CARLOS ESPARZA

PAPERS
1364 / 1196 / 1267 / 1670 / 1269

32TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA 2022 SANTIAGO
Will Cities Survive?

How climate trends with urban morphology impact the thermal performance of buildings

EMELI LALESCA APARECIDA DA GUARDA [1] RENATA MANSUELO ALVES DOMINGOS [1] RAYNER MAURÍCIO E SILVA MACHADO[2] MARTIN ÓRDENES MIZGIER[2] FERNANDO OSCAR RUTTKAY PEREIRA[1]

[1] Federal University of Santa Catarina, Environmental Comfort Laboratory (LabCON)
[2] Federal University of Santa Catarina, Energy Efficiency in Buildings Laboratory (LabEEE)

ABSTRACT: Climate change is a critical global challenge in the 21st century, and urban design can increase these impacts. Thus, this work aims to evaluate through simulations, the influence of climate change on the internal thermal conditions of office buildings, considering different urban morphologies. The methodological process consists of: i) structuring and defining nine urban scenarios; ii) climate files Generation, using as a basis the RCP4.5 and climate projection of 2035 and iii) definition of the limits of thermal comfort and discomfort through the adaptive model. The results show that climate change will impact the internal conditions of buildings, mainly in terms of thermal acceptability for users. Urban scenarios 1, 2, and 3 exceed the upper limit in September, presenting discomfort due to heat in Cuiabá in the historical period and 2035. In Florianópolis, the month of May, which was below the lower limit in the historical period, in 2035 falls within the comfort range, i.e., becoming warmer. It is noteworthy that the influence of shading, as in scenarios 1A, 2C, and 3A of the surroundings, reduces heat discomfort and increases the hours of thermal comfort in the module.
KEYWORDS: Climate Change, Adaptive Comfort, Urban Scenarios.

1. INTRODUCTION

In our cities, resilience, livability, and well-being are influenced by continuous urban densification, global and local climate change, and extreme heatwaves. The high temperatures in the future will lead to an increase in the energy demand of cooling in the buildings to maintain the comfort conditions in the buildings [1]. Thus, these changes impose new impacts on buildings and cities due to the increase in the average global temperature and changes in other microscale climatological variables, which consequently increase the internal temperature of buildings.

The Intergovernmental Panel on Climate Change (IPCC) publishes reports in order to investigate the impact of climate change on energy resources, human activities, and extreme events, such as the last fully released, namely the Fifth Climate Change Assessment Report (AR5) [2]. Four scenarios of GHG emissions, air pollutant emission, and land use are described: one stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.6 and RCP6.0), and one scenario considering high-emissions (RCP8.5).

Furthermore, cities are the main contributors to climate change, but at the same time, urban areas are also among the most vulnerable places in the world [3]. Because of this, in Brazil, more than two-thirds of the population is urban, and this number is expected to increase in the coming years, enhancing the impacts of climate change.

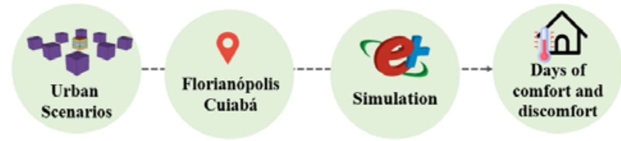
Urban design can have a significant impact on climate change [3]. Furthermore, Mavrogianni et al. [4] stated that the shape of a building has a considerable effect on the variation of the indoor air temperature of buildings, especially when they are in an urban context. Thus, planning the urban morphology of the built environment on an urban scale is a fundamental issue for climate adaptation [5]. In the coming decades, sustainable urban planning must face two significant challenges: promoting adaptation measures to mitigate the local effects of climate change and moving towards a new energy paradigm.

In this context, this work aims to evaluate the influence of climate change on the internal thermal conditions of buildings, considering different urban morphologies.

2. METHODOLOGY

The methodological process consists of: i) structuring and defining urban scenarios; ii) climate files generations iii) definition of the limits of thermal comfort and discomfort and iv) simulation of the thermal performance of the building in the naturally ventilated condition, considering the urban morphology (Figure 1).

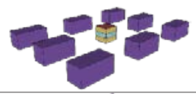
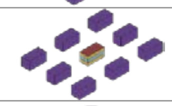
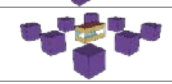
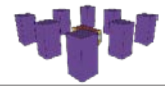
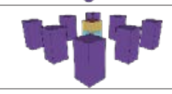
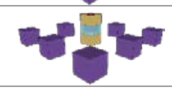
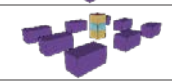
Figure 1:
methodological process



2.1 Scenarios

Modules defined the scenarios, and their dimensions are described in table 1, considering nine-block configurations in this research.

Table 1:
Dimensions of the analyzed scenarios

ID	Module (m)	Urban environment (m)	
1A	3x3x3	3x3x3	
1B	3x3x3	3x3x6	
1C	3x3x3	3x6x3	
2A	3x6x3	3x6x3	
2B	3x6x3	3x3x3	
2C	3x6x3	3x3x6	
3A	3x3x6	3x3x6	
3B	3x3x6	3x3x3	
3C	3x3x6	3x6x3	

2.3 Climate files generation

The Morphing methodology [6] has been widely used in current literature to generate future climate files. This methodology modifies a set of historical climate variables of 8,760 hours per year and incorporates the effects of global warming in the climate files, allowing the projection of the climate. However, to optimize and consolidate this process of generating future weather files, the research group Arup North America and Argos Analytics developed the WeatherShift™ tool. This tool is based on the combination of 14 General Circulation Models (GCMs).

The tool provides the use of two emission scenarios, RCP 4.5 and RCP 8.5 from the Fifth Report (AR5) of the IPCC and three future climate projections, divided into 20-year time slices, as follows: 2035 (period 2026-2045), 2065 (period 2056-2075) and 2090 (period 2080-2099) and presents as results future climate files in EPW format, widely used in simulations of thermal and energy performance of buildings and cities. For this research, the 50% probability level represented climate change and the RCP4.5 emission scenario for the 2035 climate projection.

2.2 Characterization of regions and study module

The cities of Cuiabá-MT, located in the Brazilian savanna (central region), and Florianópolis-SC, located in the south of the country in the Atlantic Forest biome, were taken as the object of study. The climate profiles of these cities are classified as Tropical (Aw) and Tropical Humid (Cfa), respectively, in the Koppen-Geiger classification.

The Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Service, and Public Buildings (INI-C) [7] was taken as a reference for the insertion of constructive characteristics and pattern of use of the module under analysis. Thus, he considered the module as an office building, with internal and external mortar walls (2.5cm), ceramic brick (9cm) and fiber cement tile roof (1cm), attic with resistance > 5cm, and solid concrete slab (10cm) as lining. The walls and roof have an absorbance of 0.5 and 0.8, respectively. The openings were considered the width and length of the module, with a sill and height of 1.0m. A single colorless glass of 6mm was used, with a solar factor of 0.82 and transmittance of 5.7W/m².K.

2.2 Computer simulation

EnergyPlus, version 9.3, was used, considering occupancy patterns, lighting power densities, and equipment according to (INI-C) [7]. The power density of lighting and equipment is 14.1W/m² and 15W/m². The occupancy density is 10m²/person, 10 hours, and 260 occupancy days. The modules were considered naturally ventilated and with the windows open according to the occupancy schedule.

2.4 Indicator of thermal comfort and discomfort

The limits of comfort and thermal discomfort by heat by cold, on the criteria described by Dear and Brager and presented in Standard 55 [8], were used as comfort and thermal discomfort indicators for naturally ventilated buildings.

Thus, the hours of comfort and discomfort were computed considering the monthly average of external temperature (30 days) for Cuiabá and Florianópolis in the historical period and climate projection of 2035. The comfort levels are given by the neutral temperature (Tn) are defined in Equation 1. Moreover, the thermal acceptability limit adopted in this research is 80% described in Equations 2 and 3.

$$T_n = 17.8 + 0.31 \times T_{Emed} \quad (1)$$

$$T_{upper} = T_n + 3.5 \quad (2)$$

$$T_{lowr} = T_n - 3.5 \quad (3)$$

Where: T_C – Neutral temperature (◦C);
T_{Emed} – Prevailing mean outdoor temperature (◦C);
T_{upper} – Upper limite (◦C);
T_{lower} – Lower limite (◦C).

3. RESULTS

3.1 Analysis of the internal thermal conditions of the modules in the historical and future scenario

Neutral temperatures will increase in the future scenario of climate change, with an increase of 0.42°C in Cuiabá and 0.80°C in Florianópolis (Table 2).

Table 2:
Temperature and neutral and adaptive comfort limits

Cuiabá		
RCP 4.5	Current	2035
Tn (°C)	26.01	26.43
Upper	28.51	29.93
Lower	23.51	22.93
Florianópolis		
RCP 4.5	Current	2035
Tn (°C)	21.00	21.80
Upper	27.82	28.07
Lower	20.82	21.07

In Cuiabá, in the historical period, it is observed that in all urban scenarios, they are within the range of comfort limits, except for September, which exceeds the upper limit, presenting thermal discomfort due to heat (Figure 2). Scenarios 1, 2, and 3 cross the upper limit in September with average indoor temperatures above 29.1°C, 29.05°C, and 28.9°C, respectively.

Considering the impacts of climate change, there is an increase in internal temperatures in all months of the year, consequently making September warmer. However, it should be noted that the upper limits increase by +1.42°C, while the lower limits decrease by -0.58°C. However, they fall within the comfort ranges in all months, except September (Figure 3).

Figure 2:
Monthly average temperatures and upper and lower limits in Cuiabá in the historical period

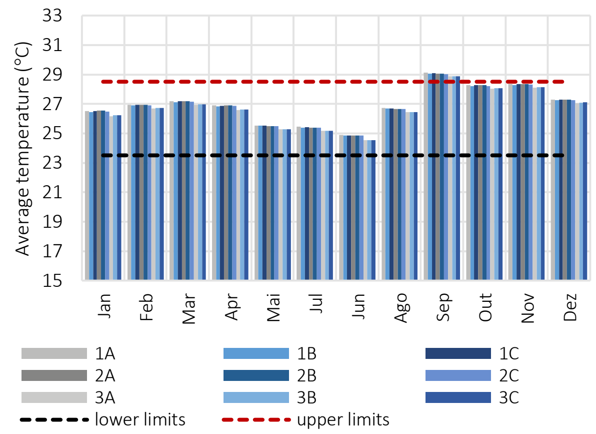
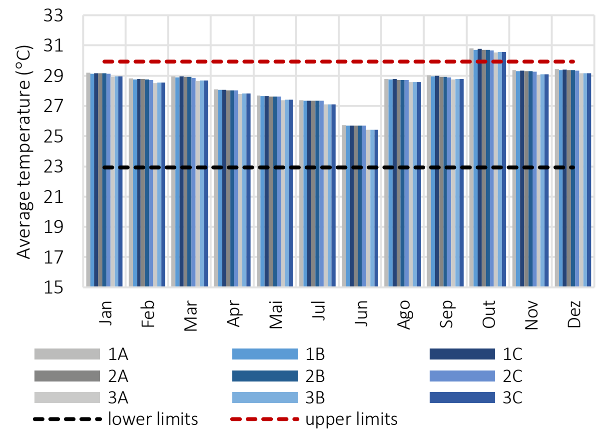


Figure 3:
Monthly average temperatures and upper and lower limits in Cuiabá in RCP 4.5 in the period 2035



In Florianópolis, in the historical period, in all urban scenarios, it experienced cold discomfort from May to September, with average monthly indoor temperatures below 20.7°C (Figure 4). In the other months, the scenarios were within the range of thermal comfort.

In future climate projections, internal temperatures become warmer, reducing the months in which the scenarios are below the upper limit; with the impacts of climate change, the month of May becomes warmer, staying within the comfort range. Thus, the months of July to September are below the lower limit, with average monthly internal temperatures below 21.07°C (Figure 5). In addition, it is observed that February and December showed an average increase of around 1°C.

Figure 4:
Monthly average temperatures and upper and lower limits in Florianópolis in the historical period

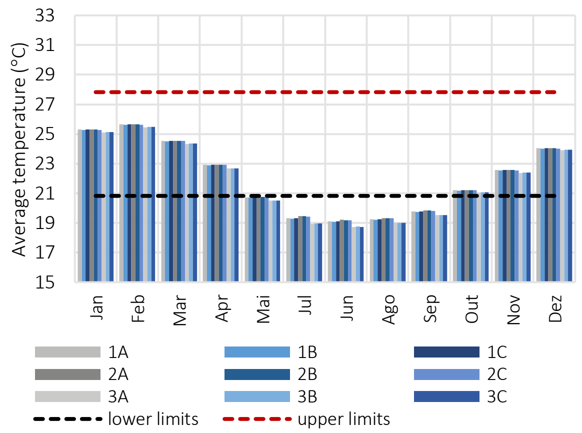
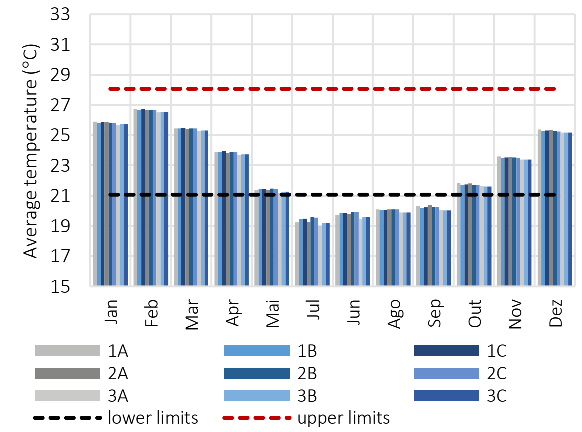


Figure 5:
Monthly average temperatures and upper and lower limits in Florianópolis in the RCP 4.5 in the period 2035



In this context, it is observed that the impacts of climate change will influence the internal temperatures of buildings, increasing the months that are at risk of thermal discomfort. In Cuiabá, this risk occurred in December, January, and February, which increased by around two °C in RCP4.5 in 2035. In Florianópolis, this risk occurred in December and February.

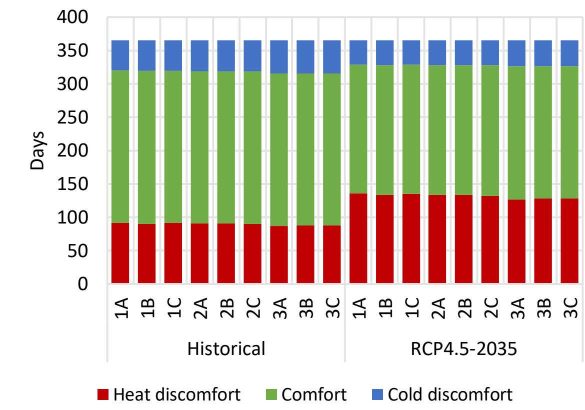
In addition, it is noteworthy that the urban scenarios presented internal temperatures with minimal differences; however, scenario 3A presented lower internal temperature values, which can be justified by the fact that the module is more shaded by the surroundings. Scenarios 1A, 1C and 2A, and 2B present higher values of internal temperature in all analyses, as they present facades exposed to radiation and little influence of the surrounding shading.

3.2 Analysis of the comfort and discomfort conditions of the modules in the historical and future scenario

They are analyzing the conditions of thermal comfort and discomfort through the internal temperatures of the modules and their formats of urban scenarios.

Scenario 1A, in Cuiabá, had the highest days in heat discomfort, from 92 days in the historical period to 136 days in 2035, increasing by 32%. Consequently, hours in comfort decreased by -18% compared to the historical period, in scenario 1A (Figure 6). In addition, it is noteworthy that in all scenarios, the hours of heat discomfort increased in future climate projections, especially for the scenarios that present larger areas of facade and openings exposed to radiation, such as 1A, 2B, 3B, and 3C.

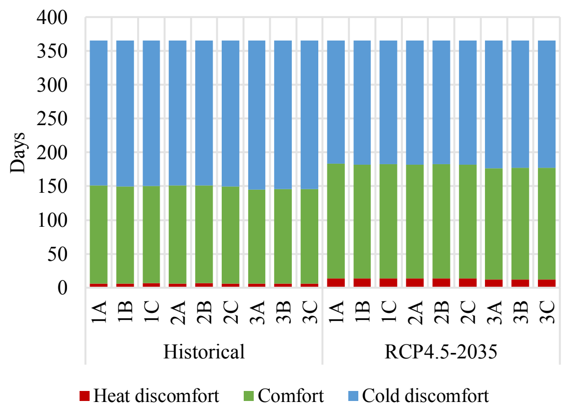
Figure 6:
Days in comfort and thermal discomfort in Cuiabá



In Florianópolis, urban scenarios 1 and 2 had the longest days in cold discomfort, with an average of 152 days in the historical period (Figure 7). This fact may have occurred because the ceiling height of the module is 3.0m, while modules 3 A, B, and C have a ceiling height of 6.0m. It is noteworthy that they did not exceed six days in heat discomfort in all scenarios in the historical period.

Considering climate changes, hours in comfort increase by around 14% in scenarios 1 and 2 and by 15% in scenarios 3 (Figure 7). The days in discomfort due to cold decrease and, consequently, the days in discomfort due to heat increase about the historical period. Scenarios 1 and 2 had longer days in heat discomfort, with an average of 14 days.

Figure 7:
Days in comfort and thermal discomfort in Florianópolis



In this context, it is observed that in hot climates, such as Cuiabá, the days in thermal discomfort increase and the days in comfort decrease, in both urban scenarios. Moreover, in climates where the predominance in the historical period was discomfort from cold, with the influence of climate change, this is reduced, increasing discomfort from heat, as in Florianópolis.

4. CONCLUSION

Climate change will impact the internal conditions of buildings, mainly on issues of thermal acceptability for users. Thus, it is observed that the limits of acceptability increase in future climate projections; however, even considering that the user adapts, urban scenarios 1, 2, and 3 exceed the upper limit in September, presenting discomfort due to heat, in Cuiabá in the historical period and 2035.

In Florianópolis, the impacts of climate change increase external temperatures, influencing internal temperatures and, consequently, reducing discomfort due to cold. Thus, the month of May, which was below the lower limit in the historical period, in 2035 falls within the comfort range, that is, becoming warmer.

It is noteworthy that the influence of shading, as in scenarios 1A, 2C, and 3A of the surroundings, reduces the hours of discomfort due to heat and increases hours in thermal comfort in the module. Well, as the influence of the ceiling height as in scenarios 3. Thus, the influence of the urban environment can be substantial for the mitigation of these effects through the increase of shading and reduction of exposed areas.

ACKNOWLEDGEMENTS

To the collaborative project of Arup North America Ltd and Argos Analytics, for making the Weathrshift tool and future weather files used in this research available.

REFERENCES

1. T. Van Hoof; et al. (2016). Analysis of the predicted effect of passive climate adaptation measures on energy demand for cooling and heating in a residential building. Energy, 94, p.811-820.
2. IPCC (2014) IPCC Fifth Assessment Report.
3. M. Vukmirovic; et al. (2019). The Improvement of the Comfort of Public Spaces as a Local Initiative in Coping with Climate Change. Sustainability, 11.
4. A. Mavrogiani; et al. (2014). The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. Building Enviroment, 78, p.183-198.
5. T. A. L. Martins; et al. (2016). Sensitivity analysis of urban morphology factors regarding solar energy potential in a Brazil tropical context. Solar Energy, 137, p.11-24
6. S. E. Belchr. J. N. Hacker; D. S. Powell (2005). Constructing design weather data for future climates. *Building Services Engineering Research and Technology*, 26, p. 49–61
7. INI-C (2021). Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas. Brazil.
8. ASHRAE (2013). ASHRAE Standard 55: Thermal Envir. Conditions for Human Occupancy. 2013.

Understanding informal production of public spaces for a new, sustainable urban planning strategy

Case study of community gardens in Piura, Peru

STELLA SCHROEDER [1]

[1] University of Bío-Bío, Architecture School, Faculty of Architecture, Construction and Design. University of Piura, Architecture School, Faculty of Engineering

ABSTRACT: Unauthorised activities, sometimes called 'informal' activities, have long been part of urban life. They routinely occupy or appropriate urban spaces, revealing new functions of these places. This study aims to explain what factors motivate residents to recover existing public spaces for gardening and development processes, uses and responsibilities. Additionally, this work develops detailed knowledge of the determinants of space production to identify the role the temporal use of public space can play in sustainable urban planning strategies. Drawing on empirical evidence from Piura, Peru, this multi-method approach uses interviews, observations and documentary materials or mediated data to yield a description of multiple processes at this research site. Furthermore, a field analysis shows why people transform such spaces, confirming that a major potential benefit lies in enhancing the ecological knowledge of urbanites. The latter process includes cultivating an appreciation of the role that urban gardens can play in promoting sustainability and life qualities. These findings contribute to a deeper understanding of the role that the informal use of public space can have in urban planning and development strategies. Thus, social justice-oriented planners in Piura can use these processes as a guide to build a more inclusive, responsive and equitable city.
KEYWORDS: Informal practices, Public space, Urban gardening

1. INTRODUCTION

The emergence of informal production has become one of the critical challenges of urbanization in recent decades. Informal or self-constructed spaces are largely the product of local self-management processes, which play an important role in the physical dynamics of the city. Informality is often associated with procedures that occur outside formal processes and regulations (Roy, 2005). Today in many cities around the world, these activities are integral parts of everyday urban landscapes and everyday life systems (Hou, 2020; Iveson, 2013). With regard to informal activities, Marx and Kelling's (2019) do not focused on the formal-informal differentiation, but on the activities of residents. They introduce a focus on social and spatial organization and how people make the city. In this context, it is recognized that some activities that may be considered informal have a significant social effect on urban life.

This research focuses on how such spaces are produced through a variety of processes and activities, allowing residents to become the main social actors in the development of a city. According to studies on space and place Tuan (1977), Soja (1999), or Massey (1994), argue that a basic entity, becomes a place when meaning is attributed to it. The physical and social production of public space validate that there is a close relationship between people and urban space, and this relationship contributes to spatial transformation.

Although inhabitants are often disadvantaged and in conflict with urban plans or land occupation laws, they express their claims in ways that challenge the official uses of urban space (Shortell and Krase, 2011). However, the use of the informal spaces is rarely included in governmental policy papers and is often described as an ad hoc or temporary activity. In this context, reference is made to the concept of insurgent citizenship to characterise the claims of members of the subaltern society (Devlin, 2018). This movement equates urbanism with the physical realm, asserting that small-scale intervention in material form can positively impact the everyday lives of urban residents. 'The settlers transform their urban spaces with daily, functional and symbolic use', according to Hernández García (2014, p. 172). This author argues that the social construction of space relates to the interaction of individuals with a space. Thus, public space involves a complex confluence of actors who display active citizenship through various forms of appropriation (García-Arias and Hernández-Pilgarín, 2019).

In developed countries, studies on the practice of urban gardens have a long history. Currently, this practice is considered community gardening, the use of vacant lots or city land for small-scale agriculture and community space. This work owes much to the pattern of abandonment of urban spaces and a concomitant increase in civil and environmental rights activism in neighbourhoods (Eizenberg, 2012; Hou, 2014). Guitart et al. defined community gardens as 'open spaces which are managed and operated by members of the local community in which food or flowers are cultivated' (2012, p. 2). In this context, Mares and Peña (2010) affirmed that 'urban gardens often embody a pattern of resistant uses and the recodification of space wherein local neighbourhoods and communities assert control of places for communal uses that lie outside the purview or control of the market' (p. 253f.). Research on communitarian gardening explores this practice's role as an alternative method for fostering a good environmental and social balance. The concept of sustainability is crucial in this process, as it has been used to build more inclusive and resilient cities and neighbourhoods (Ioannou et al., 2018). In this vein, the model of the potential contributions of urban agriculture to sustainability objectives defined by Vásquez-Moreno and Córdova (2013), links three dimensions (environmental, economic, social-cultural) with a broad range of topics, such as social equality and community building, health, visual quality and provision of urban green, and ecosystem services. This framework has increased interest in the emergence of informal gardens across the developed and developing world (Hardman et al., 2018).

For instance, this practice has occurred in Piura, Peru, where many informal urban gardens have been created in recent years by communities to transform public spaces and the city. Neighbours in the area care for these spaces using their own financial resources and add elements such as benches or vegetation. Notably, during the COVID-19 pandemic, the use of small urban spaces and the implementation of urban gardens has increased.

Piura has experienced accelerated urban growth in the last 60 years, also a trend at the national level, driven by the need for housing and the occupation of urban land (through invasions or illegal land markets). However, mechanisms established by the law gave certain legality to these process (e.g., one must obtain a certificate of possession of the lot or be registered) (Cockburn, 2019). This is not recognised by official planning committees, but it is considered a marginal urbanisation process.

Based on previous research on typologies of produced public spaces, this study aims to illustrate what factors motivate residents to recover existing open public spaces for gardening and plant cultivation and their development processes, uses and maintenance requirements. Thus, this research seeks to develop a detailed explanation of the determinants of space production and related barriers to reveal pertinent forms of intervention to improve the quality of life of a community. Additionally, this work evaluates the potential value of the community gardens for the urban realm and identifies ways that such bottom-up movements can be supported and how the temporal use of public space can enhance sustainable urban planning and development strategies.

Notably, the results of this study are linked to those of a study within the project MGI Morgenstadt Global Smart Cities Initiative, which, among other things, analysed citizens' perceptions of and implications for public space planning.

2. METHODOLOGY

This study's approach involved selecting and studying one initiative of the production of informal community gardens. The site selection of the initiative in the Human Settlement of Santa Rosa in the city of Piura was based on the presence of an informal gardening initiative began by the neighbours without municipal support. The latter was confirmed by fieldwork prior to the investigation, which showed the location in the central city, where urban gardens are less common, as opposed to the outer suburbs. Santa Rosa was one of the first areas of the city occupied by migrants from the rural areas of the region. The first houses were auto-constructed between 1960 and 1980. From this time on, both constant improvement and incremental changes have been observed. Since its formalisation, the settlement has remained in a continuing process characterised by the co-evolution of architecture and urban design.

Figure 1:
Site selection. Human Settlement Santa Rosa, Piura. Illustration: author.

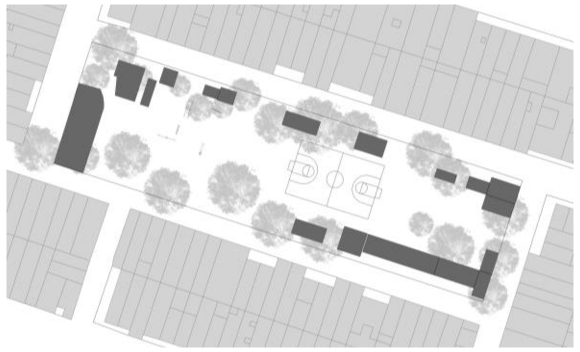


Figure 1 shows the site of the case study with a range of gardens implemented around an empty park area that is used as a community space. The size and individual location of each garden relate to the plot of the resident taking caring for that space.

The field work was conducted from July to September 2021. A multi-method approach using interviews, observations and documentary materials or mediated data yielded a description of multiple processes at the research site. Observations covered the activities and those in charge in these areas at different times during the week. A questionnaire was applied with residents and users to understand the quality, the impact of the gardens and external support needed. Additionally, due to the current situation, the field of interest was included if the pandemic changed the uses and maintenance of the space.

3. RESULTS

Most of these areas are clearly delimited with a fence, and the materials used in these places have included wood, bamboo and recycled materials like corrugated sheet iron or tires, as illustrated in Figure 2. Other gardens show clear delimitation through vegetation as natural fences. Moreover, some areas are used as storage rooms, parking areas, places to dry laundry or other domestic uses not necessarily related to gardening.

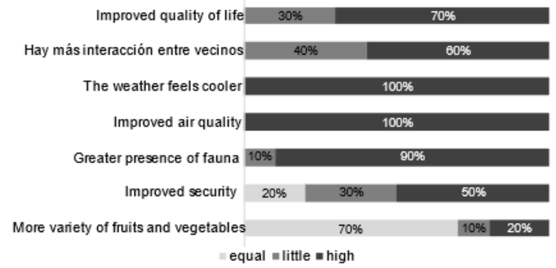
Figure 2:
Photo of a sample garden. Photo: author

The field analysis confirmed that before the construction of the urban gardens, many aspects of the design and maintenance of the city's public spaces had been unsatisfactory, which helps to explain the informal production behaviours of the inhabitants. In this work, the questionnaire obtained responses from 20 local gardeners, all of them homeowners. Of these respondents, 80% had lived longer than 20 years in the sector, 50% were between 41 and 60 years of age, and 25% were between 25 and 40 or over 60 years of age.

According to this questionnaire, the main reasons that people transformed the space into gardens. were to have a green space or a garden of their own (28%) and to improve their neighbourhood environments (32%). Another 16% were seeking spaces to grow products such as fruits, vegetables or medicinal plants. Additionally, most residents said that planting was their personal hobby and indicated this activity was an effective way to use one's free time when living in urban communities. Many residents were migrants from the mountain parts of the region, where everyone has a garden and grows fruits and vegetables. Therefore, these people brought this custom to the city of Piura. Others had seen the green spaces and decided to create similar spaces for themselves.

Figure 3 confirms that a major potential benefit lies in enhancing the ecological knowledge of urbanites, including an appreciation of the role that urban gardens can play in enhancing both sustainability and quality of life. In this vein, 100% of the interviewees indicated that the intervention had notably improved the urban climate, and 96% confirmed that air quality had improved. Another 80% of those interviewed observed a greater presence of local fauna.

Figure 3:
Evaluation of positive impact of the urban garden. Illustration: author.



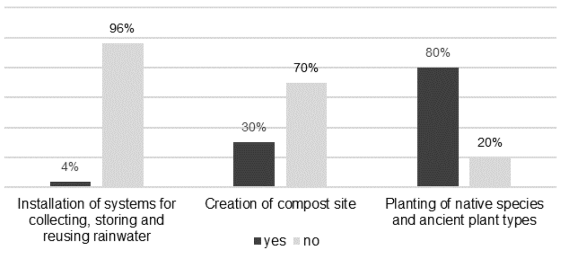
However, regarding maintaining the gardens under sustainable aspects, Figure 4 shows that most of the respondents had not installed systems allowing the collection, storage and reuse of rainwater for irrigation purposes. Furthermore, barely 30% of the respondents had created composting sites to support fertilisation and soil health. In terms of species selection, the results indicated that most of the neighbours had planted native plant species in the area and ancient vegetables to maintain the region's natural and cultural heritage.

These gardens present a dynamic living space. In these spaces, informal production began at the initiative of certain neighbours. After this point, the gardens were slowly constructed. The spaces were not definitive or finished but constantly being improved, an incremental transformation. This process began with a small space with few plants and continued with the construction of pergolas, furniture or fences or the cultivation of medicinal

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

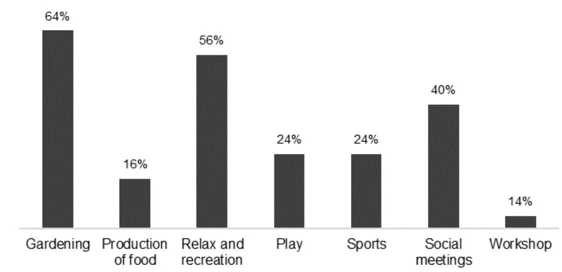
plants or vegetables. With time and transformation, these spaces even adopted new functions.

Figure 4:
Implementation of sustainable systems and use of native vegetation. Illustration: author.



These gardens offer the possibility of activities that are generally rare in the public realm (but not particularly unusual in private spaces), such as gardening, painting, grilling and planting trees. These activities are usually restricted to private settings, such as back gardens. For many, gardening has become an important activity, but various activities go far beyond gardening, as demonstrated in Figure 5. Additionally, depending on the time of day, the use of these spaces could change. Many residents confirmed that they use these areas for relaxing and in summer neighbours appreciate the green garden outside of their house. More than half of the interviewees stated that they use the space every day. In this sense, such spaces have the clear function of creating social networks and thus creating a community.

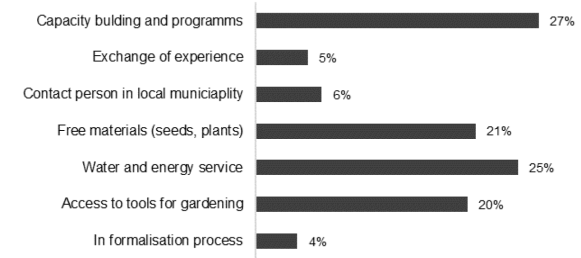
Figure 5:
Activities related to the community gardens. Illustration: author.



Notably, the pandemic changed the respondents' behaviours regarding the use and maintenance of these spaces, and 92% of the interviewees said that space had become more important to them than it was before. Most agreed that they were now spending more time in the space cultivating fruits and vegetables. Additionally, the garden space now serves as a space for social gatherings and community meals.

The interest shown by the population in the initiative has been necessary to encourage public and private institutions to cooperate and support local actions taken in the neighbourhoods. Furthermore, the questionnaire asked how the public and private sectors could support community garden initiatives to make their implementation easier and more sustainable over time. Figure 6 demonstrates that the main needs in this process include water and energy supplies; education and training programs (related to gardening techniques, local plant species and construction); access to tools; and subsidies for elements such as seeds, plants and construction materials.

Figure 6:
Support needed by the community to maintain and improve their gardens. Illustration: author.



4. DISCUSSION

In studies on urbanism, informality is a form of fluid, resilient and flexible urbanisation that fills the gaps left by the incapacity or indifference of the State (Fawaz, 2017; Marx and Kelling, 2019). In this empirical study, the absence of a formal process is a significant condition that influences the production of the public space. The lack of formal ownership of such areas facilitates residents to act in a relatively unprecedented way in an urban public space. This action is different from that of a formal public space, where local parks and open spaces do not require any action from their users because production and maintenance are conducted by government institutions. Acting outside of the formal some other dilemmas might occur as well. For example, residents reported damage of vegetable plots or theft of plants and trees.

The case of Santa Rosa describes how a space was slowly transformed into a community garden. Gardening, as an informal production, takes place with a lack of public management, neglected public infrastructure and disregard for the living needs of residents, such as their personal sentiments, social activities and green areas.

Studies like one by Reynolds (2007) supported the idea of adopting an informal route in cities to add character and diversity to the local landscape. Crane (2013) highlighted the creativity and innovation of the gardeners transforming unused land for urban agricultural action. Furthermore, vegetable plots can enhance community vitality (Poulsen et al., 2014) bringing people together to maintain physical health, and to learn new practical organic gardening skills (He and Zhu, 2018).

Municipalities and local authorities can embrace and enable such activities across the city, and more residents can engage in informal activities and feel empowered to revitalise the urban environment. Furthermore, as argued by Hardman et al. in the case of Salfort, UK, 'This in turn has enabled the local authority to entice those practising informal action onto a more legitimate path, through offering land to enable their action to grow and have a wider impact on the city's inhabitants' (2018, p. 7). However, as seen in the study of He and Zuh (2018), many people are still against informal community gardening, primarily because they see them as the invasion of public resources that planting vegetables on public green spaces could lower their standard of living.

Currently, the community discussed in this study does not have adequate guidance to sustain their gardens over time to generate a cycle of learning for future generations. As stated by Costa et al. (2016) community gardens provide great benefits at a very local level, however, many times represent a disconnected experience and, therefore, a dysfunctional resource regarding connectivity to other green elements of the city and deliver fewer public benefits than they have the potential for.

As presented in this study, the demand for capacity building is a crucial factor for local initiatives. Especially in the face of a changing climate, it is essential to raise awareness in communities about ecological and sustainability issues. The lack of knowledge regarding these aspects influences the conservation and maintenance of urban gardens, and this study identified a crucial factor that limits the capacity of local initiatives in futureproofing these people's neighbourhood. Three important factors must be considered by residents that influence the improvement of the gardens and thus the regeneration of a city that is resilient to climate change. These residents must consider these factors: first, the management of organic waste and soil recovery (composting); second, the management of wastewater; and third, general knowledge about sustainable urban agriculture.

Furthermore, regarding the urban sustainability objectives of Vásquez-Moreno and Córdova (2013) mentioned earlier, certain aspects should be highlighted and included in further planning studies on this subject. For instance, an area's residents should improve water availability and the installation of systems and infrastructure to properly treat wastewater and make it available for the irrigation of public green space. The latter process can reduce the stress of available freshwater resources. Capacity building and the use of organic waste can be used in this type of urban intervention to obtain organic fertiliser. The latter increases the productive capacity of the soil; is economical; and avoids the use of artificial fertilisers, thus reducing pollution. Moreover, the importance of planting species native to the area helps these species grow properly because they are adapted to local conditions, use fewer resources for their development and preserve the balance of ecosystems. Therefore, the continuous improvement and adaptation of such management practices is crucial to maintain sustainable and climate-resilient urban green spaces. In this vein, neighbourhood associations can play an important role in this process as a link between residents and local governments.

5. CONCLUSION

In rapidly growing cities, such as Piura, especially in developing and transitional countries, green areas, environmental quality and the capacity to provide ecosystem services are increasingly under pressure. The study of informal community gardens within the Human Settlement of Santa Rosa proves the need of the residents to claim urban land by cultivating open spaces, in unbuilt and undeveloped green areas on the level of the neighbourhood.

The objective of this paper was to illustrate what factors motivate residents to recover existing open public spaces for gardening and plant cultivation and their development processes, uses and maintenance requirements. It evaluated the potential value of the community gardens for the cities regarding climate change and identifies ways that such bottom-up movements can be supported sustainable urban planning and development strategies which largely correspond to the needs, expectations, possibilities and symbolic constructions of its inhabitants. Recognizing the determinants of the genesis of the space and, consequently, raising awareness about this concept in the city, together with the adoption of the appropriate regulations, would be of immense relevance for greater flexibility and timely change.

In this vein, the findings contribute to a deeper understanding of the role that the temporary and informal uses of public spaces (in this case, urban community gardening), can play in urban planning. Social justice-oriented planners can learn and use these processes to develop more inclusive, responsive and sustainable cities. However, actions prevent a certain security and stability.

Finally, the definition of synergy allows one to interpret how informal production in a public space influences that space's built environment. In this study, this definition has enhanced the planification of new urban gardening projects in Piura, using citizen engagement as important pillar. The more actors involved in climate change adaptation and mitigation processes, the greater the impact will be on society and, above all, the environment. Nevertheless, it underscores the importance of establishing a municipal program and supporting a governance system for urban gardening initiatives and informal land use.

ACKNOWLEDGEMENTS

The author is a PhD candidate at the University of Bío-Bio, Chile, and is a recipient of the Chilean National PhD scholarship ANID BECAS/DOCTORADO NACIONAL 21200196.

The MGI is a project funded by the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety (BMU).

REFERENCES

1. Cockburn, J. C., (2019). El Estado y la informalidad urbana. Perú en el siglo xxi. *PLURIVERSIDAD*, 3: p. 45–64.
2. Costa, S., Fox-Kämper, R., Good, R., Sentić, I., Treija, S., Atanasovska, J. R. and H. Bonnavaud, (2016). The position of urban allotment gardens within the urban fabric. In R. Fox-Kämper, S. Bell, N. Keshavarz, M. Benson, S. Caputo, S. Noori, and A. Voigt (Eds.), Urban Allotment Gardens in Europe (p. 201–228). Routledge.
3. Crane, A., Viswanathan, L. and G. Whitelaw, (2013). Sustainability through intervention: A case study of guerrilla gardening in Kingston, Ontario. *Local Environment,* 18(1): p. 71–90.
4. Devlin, R. T., (2018). Asking 'Third World questions' of First World informality: Using Southern theory to parse needs from desires in an analysis of informal urbanism of the global North. *Planning Theory*, 17(4): p. 568–587.
5. Eizenberg, E., (2012). Actually Existing Commons: Three Moments of Space of Community Gardens in New York City. *Antipode,* 44(3): p. 764–782.
6. Fawaz, M., (2017). Planning and the refugee crisis: Informality as a framework of analysis and reflection. *Planning Theory*, 16(1): p. 99–115.
7. García-Arias, M. F. G. and Hernández-Pilgarín, (2019). Obsolescencia y revitalización de un parque. acción colectiva, cognición y ciudadanía en la apropiación del espacio público. *Revista Eleuthera,* 20: p. 55–72.
8. Guitart, D., Pickering, C. and J. Byrne, (2012). Past results and future directions in urban community gardens research. *Urban Forestry and Urban Greening,* 11(4): p. 364–373.
9. Hardman, M., Chipungu, L., Magidimisha, H., Larkham, P. J., Scott, A. J. and R. P. Armitage, (2018). Guerrilla gardening and green activism: Rethinking the informal urban growing movement. *Landscape and Urban Planning,* 170: p. 6–14.
10. He, B. and J. Zhu, (2018). Constructing community gardens? Residents' attitude and behaviour towards edible landscapes in emerging urban communities of China. *Urban Forestry and Urban Greening,* 34: p. 154–165.
11. Hernández-García, J., (2014). Construcción Social de Espacio Público en Barrios Populares de Bogotá. *Revista INVI*, 28(78): p. 143–178.
12. Hou, J., (2014). Making and Supporting Community Gardens as Informal Urban Landscapes. In A. Loukaitou-Sideris and V. Mukhija (Eds.), The Informal American City: Beyond Taco Trucks and Day Labor. (p. 39–57). MIT Press.
13. Hou, J., (2020). Guerrilla urbanism: urban design and the practices of resistance. Urban Design International.
14. Ioannou, B., Morán, N. and C. Certomà, (2018). Grassroots Gardening Movements: Towards Cooperative Forms of Green Urban Development? In S. Bell, R. Fox-Kamper, N. Keshavarz, M. Benson, S. Caputo, S. Noori, and A. Voigt (Eds.), Urban Allotment Gardens in Europe (p. 62–89). Routledge.
15. Iveson, K., (2013). Cities within the City: Do-It-Yourself Urbanism and the Right to the City. *International Journal of Urban and Regional Research,* 37(3): p. 941–956.
16. Mares, T. M. and D. G. Peña, (2010). Urban agriculture in the making of insurgent spaces in. In J. Hou (Ed.), Insurgent Public Space: Guerilla Urbanism and the Remaking of Contemporary Cities. (p. 241–254). Routledge.
17. Marx, C. and E. Kelling, (2019). Knowing urban informalities. *Urban Studies,* 56(3): p. 494–509.
18. Massey, D., (1994). Space, Place, and Gender. University of Minnesota Press.
19. Poulsen, M. N., Hulland, K. R. S., Gulas, C. A., Pham, H., Dalglish, S. L., Wilkinson, R. K. and P. J. Winch, (2014). Growing an urban oasis: A qualitative study of the perceived benefits of community gardening in Baltimore, Maryland. *Culture, Agriculture, Food and Environment,* 36(2): p. 69–82.
20. Reynolds, R., (2007). On Guerrilla Gardening: A Handbook for Gardening without Boundaries. Bloomsbury.
21. Roy, A., (2005). Urban informality: Toward an epistemology of planning. *Journal of the American Planning Association,* 71(2): p. 147–158.
22. Shortell, T. and J. J. Krase, (2010). Place, Space, Identity: A Spatial Semiotics of the Urban Vernacular in Global Cities. ESA Research Network Sociology of Culture Midterm Conference: Culture and the Making of Worlds, October 2010, [Online], Available: https://ssrn.com/abstract=1693110 [15 July 2022].
23. Soja, E. W., (1999). Thirdspace: Expanding the Scope of the Geographical Imagination. In D. Massey, J. Allen, and P. Sarre (Eds.), Human Geography Today. Polity Press.
24. Tuan, Y., (1977). Space and place: the perspective of experience. University of Minnesota Press.
25. Vásquez-Moreno, L. and A. Córdova, (2013). A conceptual framework to assess urban agriculture's potential contributions to urban sustainability: An application to San Cristobal de Las Casas, Mexico. In International Journal of Urban Sustainable Development (Vol. 5, Issue 2, p. 200–224).

Brazilian coastal cities

A case study related to the impact of rising sea level

VICTOR MOURA BUSSOLOTTI[1] IZABELA ULIANA PELLEGRINI[1] CRISTINA ENGEL DE ALVAREZ[1]

[1] Universidade Federal do Espírito Santo

ABSTRACT: Climate changes resulting from human activities after the Industrial Revolution lead to several consequences, such as sea level rise (SLR). The most pessimistic estimates of greenhouse gas emissions (GHG) in the atmosphere indicate that the oceans can rise almost 1 meter and Brazilian coastal cities should suffer from this phenomenon. The city of Vila Velha was chosen as a case study, with the objective of evaluating the risks of SLR caused by climate change and verifying whether the strategies for land occupation, zoning and construction of buildings provided in the municipal master plan of Vila Velha take into account the predicted effects of global warming. As a methodology, 3 steps were carried out, which consisted of preparing maps of future sea level in the city, classifying the different degrees of impact and systematizing the data in a table. The results show that, even in optimistic scenarios, a portion of the city tends to be submerged and, in the worst heating scenarios, only 0.3% of the population won't be directly impacted. It is possible to observe gaps in the municipal masterplan that must be corrected in its future versions to contemplate climate change and reduce the vulnerability of the population.
KEYWORDS: Climate change; Sea level; Masterplan.

1. INTRODUCTION

It is known that after the Industrial Revolution of the 19th century, human activities generated climate changes that caused global warming [1], leading to several consequences, such as the increase in the frequency of weather extremes, extinction of some species and the sea level rise (SLR).

The Intergovernment Panel on Climate Change (IPCC) [2], in its fifth report, entitled AR5, argues that the magnitude of the consequences of global warming will depend on the mitigating actions that will be taken to reduce greenhouse gas emissions (GHG). Thus, four scenarios were proposed based on trajectories of concentration of GHG in the atmosphere, the RCPs. The RCP2.6 scenario considers low emissions and is the most optimistic, the RCP4.5 and RCP6.0 scenarios consider intermediate emissions and the worst scenario, with high emissions, is called RCP8.5.

It is expected that even the scenario of RCP2.6 can already lead to a minimum increase in temperature of 1.5°C, which is the maximum value intended by the signatory countries of the Paris Agreement in 2015. If no action is taken towards a reduction of greenhouse gas emissions, going in the direction of RCP8.5, the planet can exceed a 4°C increase in temperature.

Coastal areas are among the regions most affected by global warming, as a result of the rise in sea level, with expectations of flooding. According to the different scenarios proposed by the IPCC report, there is an expectation that the different RCPs scenarios will lead to different values of global sea level rise. As can be seen in Figure 1, even the RCP2.6 scenario would already allow an elevation of about 60 centimetres at the sea level. The most extreme scenario in the report, RCP8.5, already contemplates the possibility of a rise in sea level close to 1 meter compared to the current level of the ocean.

Figure 1 (to be continued):
Sea level rise projection [3]

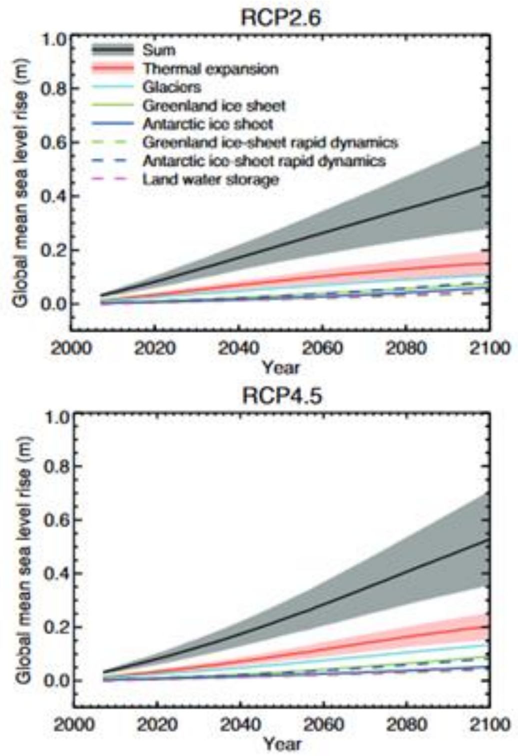
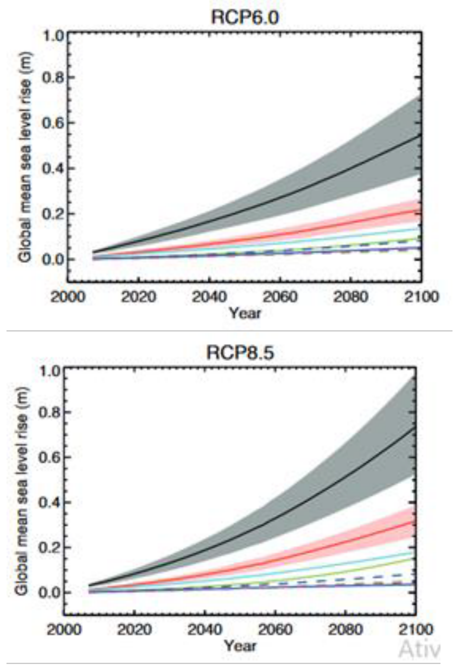


Figure 1 (finish):
Sea level rise projection [3]



In view of these future estimates, it is important to map the areas with the greatest vulnerability to this threat, that tend to be flooded, so that measures can be taken to prevent and adapt the city to the effects of climate change that must be included in public policies related to the planning of cities.

One of the ways to do this is through municipal masterplans (PDMs or Planos Diretores Municipais, in portuguese), which are laws that guide the use and occupation of land in urban areas, dividing the city's territory into different zones with specific characteristics. Among the aspects considered in the elaboration of municipal zoning, there are different interests, such as preserving nature, places of historical importance and promoting the quality of life of the citizens. This legislation constitutes, therefore, an instrument to ally municipal interests in the economic, physical and social aspects [4].

It is also necessary to take into account the large number of dwellings in situation of poverty and irregularly built in Brazil, often in places of high risk of suffering disasters, such as the slopes, which become even more vulnerable with climate change, including floodings [5].

In Brazil, a legislation called Estatuto da Cidade [6] determines that the PDMs are mandatory for cities with more than 20,000 inhabitants and constitute the basic instrument of the policy of development and expansion of the urban area of a city, covering its entire territory. The law also states that the masterplans must be reviewed continuously, with a maximum interval of 10 years between each of them.

The Brazilian coast is composed by 274 municipalities, across 17 states and more than eight thousand kilometers in length [7], being one of the biggest coastal zones on the planet and being directly influenced by the effects of sea level rise resulting from climate change.

One of the cities that is part of the Brazilian coastal zone is Vila Velha, located in the Southeast region of the country, neighbouring the city of Vitória, which is the capital of the state of Espírito Santo, and with an estimated number of 414.586 inhabitants [8]. Vila Velha, due to its geographic and population characteristics, was chosen as a case study which makes it an example of fragility in relation to the Brazilian coast.

Vila Velha's urbanization process is relatively recent, dated around half of the 20th century. The population growth is not followed by an organization of land use that preserves areas of inundation. Even today there is a lack of efficient solutions that combat the flooding in urban areas. Otherwise, the municipal administration wants to limit the excessive occupation on the seafront [9], what helps to minimize the damages caused by sea level rise.

The current Municipal Masterplan of Vila Velha (PDM) was launched in 2018, and should be reviewed in the next 6 years, according to the Estatuto da Cidade. In it, there is a division of the municipal territory in zones with different characteristics, such as environmental or social interest, priority occupation, and others.

Among these zones, the Priority Occupancy Zones *(Zonas de Ocupação Prioritária*, ZOPs), which correspond to the part of the city's territory with the best infrastructure or with the potential for great improvement, where the encouragement of urban densification and renewal must occur, and the Zone of Special Interest (*Zonas de Especial Interesse,* ZEIs), which comprise areas that require differentiated treatment for the purpose of applying the parameters and instruments of urban policy and for inducing urban development, can be highlighted [10].

However, it must be verified if the zones are in accordance with future climate projections, especially regarding to sea level rise, given that the city already suffers from flooding. In addition, it can be mentioned that the master plan also regulates the architectural characteristics of new constructions, having the power to impose constructive requirements compatible with the new expected climatic reality.

Thus, the objective of the research was to assess the risks of rising sea levels caused by climate change through a case study in the city of Vila Velha in the state of Espírito Santo (Brazil) in order to provide data for the definition of coping strategies to be used, adopted by the municipal government, and verifying if the strategies of land occupation, zoning and construction of the buildings foreseen in the PDM take into account the predicted climate changes.

It is noteworthy that the results obtained in the research can be replicated for other similar conditions in Brazilian coastal cities, since Vila Velha has characteristics in common with the others, being a typical example of a Brazilian municipality bathed by the sea. In this way, the study can serve as a basis to be replicated in other scenarios, indicating possible gaps and paths to be followed by other coastal municipalities.

2. METHODOLOGY

The methodological procedures for the elaboration of the analysis of the areas affected by the sea level rise (SLR) in Vila Velha were divided into 3 stages.

The first step consisted of obtaining the file in .KML format, compatible with the Google Earth software, available on the ClimateCentral website [11], containing estimates of sea level rise which may occur as early as this century or as late as the year 2200, depending on the level of pollution, compatible with different greenhouse gas emission scenarios, the RCPs, contained in the IPCC AR5 [2]. The file was prepared from previously published studies [12].

Then, the file obtained was superimposed on the map of the administrative division of Vila Velha, in order to observe the impact of each scenario on the neighbourhoods. Five levels of impact were established, which received scores from 0 (zero) to 5 (five), in the following order: 0: unaffected neighbourhood; 1: little impacted neighbourhood (less than 30% of the area); 2: medium impacted neighbourhood (less than 50% of the area); 3: impacted neighbourhood (about 50% of the area); 4: heavily impacted neighbourhood (more than 50% of the area); 5: fully impacted neighbourhood (all impacted area). Analyses were visually estimated using .KMZ files.

The data obtained were systematized in tables with the objective of generating graphs for future analyses. For better visibility of the results, the neighbourhoods were grouped into 5 regions (called *regiões administrativas*), according to the division of the Municipality of Vila Velha available in .KMZ format [13]. Each region has its own characteristics in terms of economic, social and developmental aspects. Using the data provided by the city hall, were also computed the data on the affected population, households and percentage in relation to the total of each region, for each heating scenario and taking into account the current population data available.

After this process, data was sought in the Municipal Masterplan of the city of Vila Velha [10], on the zoning profile of the municipality to generate qualitative analyses. Also, it was sought in other legislation referring to some public initiative to increase Urban Resilience. In addition, literature reviews were carried out to better understand the needs and solutions to combat and respond to floods caused by possible scenarios of sea level rise caused by climate change.

3. RESULTS

As a coastal city, Vila Velha will have direct impacts with the rise in sea level. However, this effect will not be homogeneous across the territory and could have serious consequences for the dynamics of the municipality. Correlating with the local reality and with the occupation forecasts marked by the masterplan, many of the affected areas are potential places for development and accommodation of population growth.

Currently, Vila Velha already suffers from the effects generated by pluvial floods, since the use and occupation of the soil, historically, has not proved to be efficient for the preservation of fragile and floodable areas, such as the banks of rivers and streams. This demonstrates that sea level rise should be considered as it directly impacts hydrological systems and drainage, in addition to the direct consequences of sea level rise mentioned in this article.

The results of the total number of affected neighbourhoods in each region can be seen in Figure 2. In scenario 01, the most optimistic, it is already possible to see neighbourhoods totally affected in regions 01 and 02, where, according to the PDM, there are axes of municipal growth.

In the following scenarios, there is an increase in the number of neighbourhoods totally affected in all regions, consequently decreasing the neighbourhoods that will have a smaller part of their territory flooded.

Figure 2:
Affected neighbourhoods.

		Affected neighborhoods				
	Impact level	scenario 01	scenario 02	scenario 03	scenario 04	
REGION 01	0	5	2	0	0	
	1	7	4	3	1	
	2	1	2	2	0	
	3	1	3	3	1	
	4	3	3	4	8	total
	5	1	4	6	8	18
REGION 02	0	8	3	0	0	
	1	8	4	4	0	
	2	0	3	2	1	
	3	2	4	4	2	
	4	2	2	3	3	total
	5	1	5	8	15	21
REGION 03	0	9	6	4	1	
	1	2	3	2	5	
	2	3	1	2	1	
	3	2	3	2	1	
	4	1	2	4	2	total
	5	0	2	3	7	17
REGION 04	0	4	3	1	1	
	1	4	2	2	1	
	2	6	2	2	1	
	3	0	3	5	3	
	4	0	3	0	3	total
	5	0	1	4	5	14
REGION 05	0	8	2	1	0	
	1	4	4	2	2	
	2	4	3	2	3	
	3	4	2	0	0	
	4	1	6	8	4	total
	5	0	4	8	12	21

Only regions 3 and 4 have neighbourhoods that will not suffer any flooding, even in the worst scenario (04), as they are in higher altitude regions. Bearing in mind, however, that access to these places tends to be compromised due to the flooding of lower level areas in the surroundings.

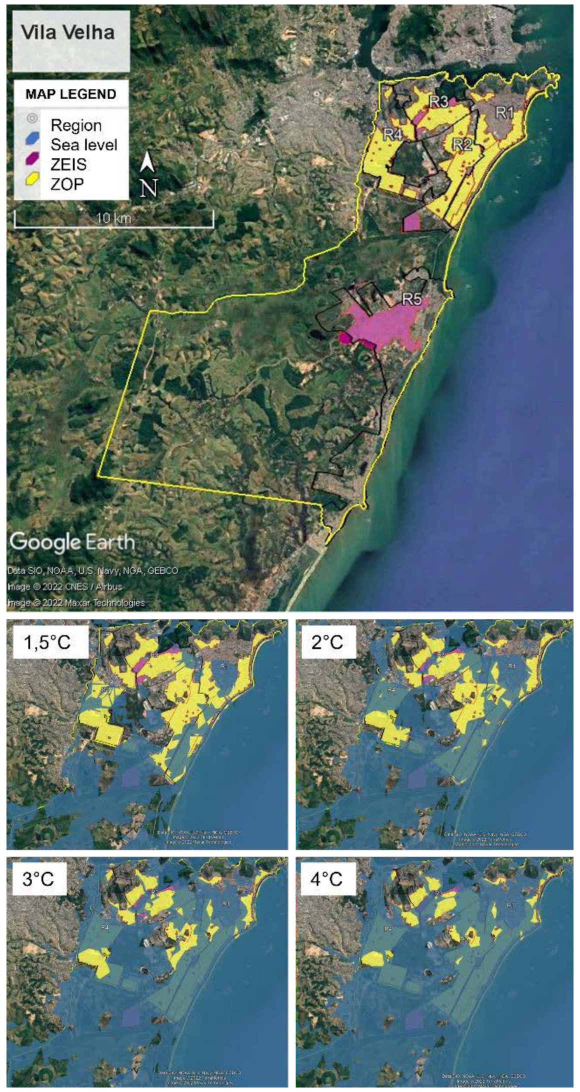
It is possible to notice that, in the most critical scenario, region 2 presents the worst forecasts, given that of its 21 neighbourhoods, 15 will be totally affected. Region 1 will also be heavily affected, as 16 of its 18 neighbourhoods fall under impact levels 4 and 5.

The two regions are home to most of the areas described by the PDM as priority occupation zones, that is, the spaces in the city with more infrastructure designed to accommodate population growth, called ZOPs (Figure 03).

The regions highlighted in yellow on the map represent the Priority Occupancy Zones (ZOP) and the ones marked in pink are the Special Zones of Social Interest (ZEIS). When applied to the zoning of the Flood Shapefile, it can be noted that the priority occupation areas will be less affected in the best scenario (1.5°C), but as the increase in the planet's temperature intensifies, the function of accommodating the growth population will be compromised.

The Region 5, which houses most of the areas intended for social housing, is practically all flooded with an increase of 3°C.

Figure 3:
Administrative regions of the municipality of Vila Velha and priority occupation zones.

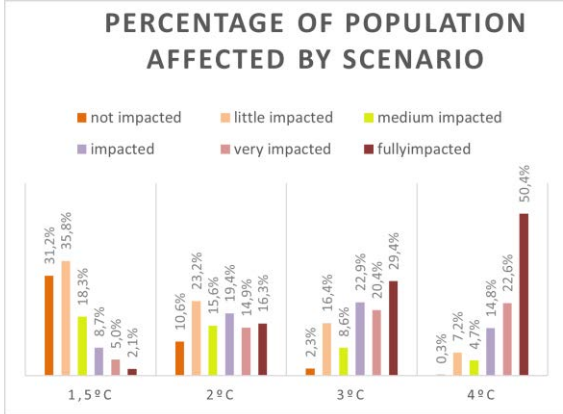


From Figure 4, it can be noted that, in relation to the total population affected, even in the low-emissions scenario, with only 1.5°C of increase in global temperature, only 31.2% of the population would be in unaffected neighbourhoods. As emissions intensify, it is visible that the degree of impact on neighbourhoods becomes greater and covers more and more the population of the municipality.

In the scenario of a 4°C increase in temperature, it is expected that only 0.3% of the population will not suffer any impact, with more than 50% of the inhabitants currently living in neighbourhoods that are predicted to be completely submerged.

Considering the population of the neighbourhoods indicated by the base data, about 400 thousand people (99.7% of the population), considering the current number of inhabitants of the city, in approximately 134 thousand residences would be affected by the floods if nothing is done to control the emissions.

Figure 4:
Affected population in each scenario.



The 10 most populous neighbourhoods in the municipality, mostly located in the areas described in the masterplan as able to accommodate population growth, will be mildly affected in the most optimistic scenario, but from the 2°C increase scenario, there will already be neighbourhoods severely affected, mainly those located on the coast or with low level quotas because they are close to existent water courses.

It should be remembered here that the neighbourhood considered with the highest population has areas of accentuated relief, which will be free from floods, even in the face of an increase of 4°C. However, most residents do not live in these higher altitude places, which are mostly in places of environmental preservation and areas of cultural interest of the municipality. Thus, in most of these mentioned places, their construction is even prohibited.

Another point to be highlighted is that this study does not consider, in principle, the effect of the increase in level quota on mobility and access to unaffected areas, and therefore, it is possible that the sea level rise may make the occupation of even more territories impracticable.

The results of this research clearly demonstrate the fragility of the municipality in the face of rising sea levels, which indicates the need to take measures to increase the local resilience of Vila Velha.

The term Resilience finds several meanings in the literature, however, in this article it is understood as the ability to resist, adapt and respond to events of slow and chronic processes (stresses) or to abrupt changes and extreme events (shocks), maintaining its functioning now and in the medium and long term future [14].

Based on this, it is necessary to understand what is already proposed within the land use and occupation control plans to face climate change and what is configured as a lack. The clear effects, even in the long term, also demonstrate the urgency of the issue.

Even without making direct reference to climate change, the masterplan of Vila Velha provides guidelines for the preservation of natural assets, including fragile and wetland areas among the priority action places. For this purpose, ZEIAs are created, that is, Zones of Environmental Interest (Zona Especial de Interesse Ambiental) and the definition of wetlands where you cannot create subdivisions of land for construction.

The plan also suggests the creation of a Drainage Plan to combat flooding. Another important point present in the legislation is the incentive to the Creative Economy, of which architecture is a part. Thus, there is a concern to encourage public policies aimed at innovative solutions to the local problems [10].

Additionally, a notable consideration is that the highest permeability rates present in the PDM of Vila Velha (35% and 30%) coincide with the areas most prone to flooding due to sea level rise. However, there is a strong lack of urban planning instruments or construction guidelines in Building Codes that point out effective solutions for dealing with the floods or for encouraging constructions with good efficiency to reduce their level of carbon emissions in the atmosphere.

4. CONCLUSION

Although the effects of climate change can already be perceived in the present days, when analysing the effects predicted for future periods, the projections point to catastrophic scenarios, which demonstrate the need to mitigate greenhouse gas emissions and to adopt strategies for the adaptation of coastal cities, at the risk of being submerged.

The results of the projections for the city of Vila Velha show that region 1, composed of the coastal neighbourhoods with the largest population and with greater density and economic potential, together with region 2, composed of neighbourhoods included in the development axis proposed by the municipality in the Master Plan, will be affected most.

This fact indicates that the economic losses derived from the rise in sea level will be significant in

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

the city if no preventive action is taken by the municipal administration when proposing the future PDMs.

It is concluded that the current masterplan for Vila Velha is correct when defining ZOPs in places that will suffer less from the rise in sea level, directing the occupation of the territory in these areas.

However, it is observed that the ZEIs, which serve a portion of the most economically vulnerable population, are located in places that will be more affected by the SLR, tending to increase the vulnerability of the population living in these areas, which constitutes a lack present in the current masterplan.

There is also a lack of concern for efficient solutions that are capable of dealing with the problems in a resilient way in the long term and in extreme scenarios of global warming caused by the climate changes.

It is important as well that the city's Masterplan takes into account the effects of climate change, since the axes of development are in areas that may be submerged in the future.

The present study, being carried out in the city of Vila Velha, uses it as an example of a place with characteristics commonly found in other different municipalities present around the entire Brazilian coastal zone. In this way, it points out reflection questions about water and floods which should be reviewed in the preparation of their future masterplans.

The results obtained allow us to affirm that the research objective of evaluating the risk of sea level rise for coastal cities was achieved, highlighting that the adopted methodology can be replicated in the other similar situations mentioned before in the paper.

It is also possible to be observed that the graphical representation of the simulations can still be considered as an important instrument for discussion and decision-making in the formulation of the public policies aimed at more resilient cities, that are capable to deal with the predicted climate changes.

REFERENCES

1. Nobre, C.A., Sampaio, G., Salazar, L. (2007). Mudanças climáticas e Amazônia. Ciência e Cultura, v. 59, p. 22-27. ISSN: 2317-6660.

2. IPCC. Intergovernmental Panel On Climate Change (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2014. Available: http://ar5-syr.ipcc.ch/ [06 July 2021].

3. Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan (2013). Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available :https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf. [07 Augus 2021].

4. Prefeitura de Vila Velha (2018). Plano Diretor Municipal (PDM). Available: https://www.vilavelha.es.gov.br/paginas/desenvolvimento-urbano-e-mobilidade-plano-diretor-municipal-pdm [24 March 2022]

5. PBMC. Painel Brasileiro de Mudanças Climáticas (2016). PBMC, 2016: Mudanças Climáticas e Cidades. Relatório Especial do Painel Brasileiro de Mudanças Climáticas [Ribeiro, S.K., Santos, A.S. (Eds.)]. PBMC, COPPE – UFRJ. Rio de Janeiro, Brasil. 116p.

6. BRASIL (2001). Lei nº 10.527, de 10 de julho de 2001. Regulamenta os arts. 182 e 183 da Constituição Federal, estabelece diretrizes gerais da política urbana e dá outras providências. Brasília, DF. Available: http://www.planalto.gov.br/ccivil_03/leis/leis_2001/l10257.htm [24 March 2022].

7. Ministério do Meio Ambiente (2018). MMA divulga municípios da zona costeira. Available: https://www.gov.br/mma/pt-br/noticias/definidos-municipios-da-zona-costeira. [04 May 2021].

8. IBGE (2022). Vila Velha. Available: https://cidades.ibge.gov.br/brasil/es/vila-velha/panorama [04 May 2021].

9. Gurgel, A. de P. (2010). História Política e Econômica de Vila Velha. Pro Texto Comunicação e Cultura. p. 147. 1ª edição.

10. Vila Velha (2018). Lei complementar Nº 65, de 09 de novembro de 2018. Institui a revisão decenal da lei municipal nº 4575/2007 que trata do plano diretor municipal no âmbito do município de vila velha e dá outras providências, 2018. Available: https://www.vilavelha.es.gov.br/legislacao/Arquivo/Documents/legislacao/html/C652018.html [24 March 2022]

11. Climate Central (2021). Surging Seas Extreme Scenario 2100. Available: http://xs3d.climatecentral.org/ [07 August 2021].

12. Strauss, Benjamin H., Scott Kulp, and Anders Levermann (2015). "Carbon choices determine US cities committed to futures below sea level." Proceedings of the National Academy of Sciences 112.44.

13.Prefeitura de Vila Velha (2015). Arquivos de Georreferenciamento. Available: https://www.vilavelha.es.gov.br/paginas/desenvolvimento-urbano-e-mobilidade-arquivos-de-georreferenciamento [17 September 2021].

14. LU, Xianfu (2019). Building Resilient Infrastructure for the Future: Background paper for the G20 Climate Sustainability Working Group. *Adb sustainable development working paper series*. 2019. Avaliable: http://dx.doi.org/10.22617/WPS190340-2> [28 Outubre 2021].

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE URBAN DEVELOPMENT

Urban Climate Model for Valparaiso, Chile

Adaptation of the urban climate model of the Eixample area of Barcelona city

Claudio Carrasco[1 2], Massimo Palme[1], Antonio Isalgué[3]

[1] Departamento de Arquitectura, Universidad Técnica Federico Santa María, Chile.
[2] Escuela de Construcción Civil, Universidad de Valparaíso, Chile.
[3] Architecture, Energy and Environment, School of Architecture, Polytechnic University of Catalonia, Spain.

ABSTRACT: One of the effects of human activity on planet performance is the urban climate. Its characteristics have been studied during the last decades and both morphological and buildings materials (buildings and streets), activity and transit have been declared, all associated with anthropic factors. Various models have been developed to adequately define the behaviour of the urban climate according to these variables. In this paper, the urban climate of the sector with the highest activity into buildings and transit in the city of Valparaiso, Chile, is evaluated. It is evaluated using the Urban Climate Model developed for the Eixample area of Barcelona by Isalgué et. al. [1]. New factors are defined that would affect the climate behaviour of this zone in this city of coastal characteristics and Mediterranean climate and then calibrate the model. The results show a high correlation between the measurements in the field and the results of applying this adjusted model.
KEYWORDS: Urban Climate Model, Mediterranean climate, urban morphology, urban activity, urban materials.

1. INTRODUCTION

Urban climate phenomenon and the urban heat island (UHI) are evidence of human influence on climate change. Currently 55% of the world's population resides in cities and its urban environments; the United Nations projected to increase it to 68% by 2050 [2]. The rising rates of urbanization have led to an increase in impervious areas that affect or modulate the local surface energy balance [3]. As a result, urban areas have developed their own climate performance. For example, they present a difference in air temperature and moisture when compared to surrounding rural areas to mitigate the climate effect in cities and the global warming [4], [5], [6]. Knowing the factors that define urban climate performance is necessary to carry out actions and policies to mitigate the climate effect in cities and global warming.

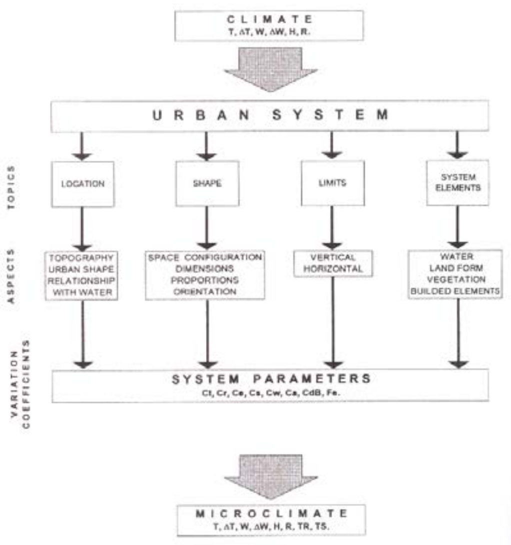
The design of cities and their regulations vary. Within them there are various forms of tissue that have been classified studies. Stewart and Oke [7] have defined these characteristics and determined that in one city there are several Urban Climatic Zones. On the microscale, inside each fabric, we find a variety of shapes and materials, but the most widely used model for its study is the urban Canon, defining itself as the unit of study. On the other hand, cities determine their global climate variations by their relationship to the mesoscale and the surrounding landscape and topography.

The most important cause of the temperature increase is the modification of land surfaces; the second is the waste heat from an urban human activity [8]. The thermal behavior of the cities and its different neighborhoods depends on urban variables such as the morphology of urban spaces, Sky View Factor, Relative Elevation Factor, the change in landscape roughness, shape and use of buildings, vegetation and bodies of water, the transit activity increase, among others [9], [10], [11]. Its impact in the heat storage, the trapping of radiation and less evaporation are among the reasons for climate change caused by urbanization [12].

In the face of climate change and combating the negative effects associated with the urban climate, we must evaluate the incidence of urban and design elements in the variables that define the climate, at each necessary urban scale. Including the microclimatic scale, which is where regulatory standards can act punctually and favor global improvements. We must determine the incidence of these elements in the air temperature, the variation of the air temperature, the relative humidity, the direction and speed of wind and the radiation on the urban canyon. Successful urban planning strategies are needed to mitigate the (excessive) increases in urban air temperature and to reduce future heat loads that there are inside the canyon [13]. These strategies can increase resilience in urban areas.

On the other hand, urban climate simulation software, considers the relationship of both spatial and temporal phenomenon in mesoscale and microscale with urban elements of the city. However, they are not entirely designer or urban planner friendly. In recent decades, different simulators have been developed, such as the Local Circulation Model lcm2d [14]; [15], single layer urban canopy model [16] Hotmac [17], LM: local model; FVM: Finite Volume Model; Bubble (Basel Urban Boundary Layer Experiment) and Urbvent [18].
In recent times ENVI-met [19] is one of the most used software in the simulation of microclimatic urban scenarios. The Urban Weather Generator (UWG) is a tool developed at the Massachusetts Institute of Technology (MIT) [20], which generates an urban weather file instead of a rural weather file, with modified temperatures in the urban canyon.
Ochoa and Serra [21] developed an urban climatic system (Fig. 1) to explain how the climate behaviour is conditioned by the city. They correlated four city topics: Location, Shape, Limits and system elements. They defined the aspect of these topics and finally the urban microclimate parameters.

Figure 1:
Urban climatic system. Ochoa & Serra, 1998.



Isalgué et. al. [1] developed an urban climate model for the Eixample area of Barcelona (Mediterranean climate), Spain, located in the Mediterranean Sea. The model presents three urban climate scales: the city scale, the neighbourhood scale and the urban canyon scale. These scales are successively related. This model highlights elements of urban space design, use of buildings and traffic: Typical elements using in building regulations and urban planning. In this research, this model is adapted to predict the microclimatic performances on Valparaíso (Mediterranean semi-arid climate), Chile, located on the Pacific Ocean of South America. Different both climatic and urban parameters were measured within the area of study to define the adapted Eixample model.
The model present different equations for each urban climate parameter.

2. METHODOLOGY

2.1 MODEL VARIABLES

According to the evaluation model, three urban scales that define the procedure are determined.
1 Start data:
Corresponds to the information of climate status variables delivered by the weather station:
Radiation (R); Temperature (T); Temperature fluctuation (ΔT); Relative Humidity (RH); Wind intensity (V); Predominant wind direction (dV); Sound background level(N).
2 Zonal Scale Model description:
For the determination of the zonal characteristics from an area or region, the following urban factors of the study area are considered (zone) and then the canyon of study in next microclimatic scale:

Table 1:
Parameters

SIMBOLOGY	URBANO ZONAL / INTO CANYON
ha	Weather station height (in meters above sea level)
haz (m)	Average height of the study area (in meters, respect to sea level)
altz(°)	General slope of soil in the area (in degrees)
aztz(°)	Slope orientation in the study area (in degrees respect north)
fhrz(-1,1)= arc tg(altura/distancia)/90°	Zonal Relative Height with respect to the environment (between -1, 1)
faig	Percentage of water in the weather station (from 0 to 1)
faigz (0,1)= (entre desierto y mar)	Percentage of water in the study area (from 0 to 1)
fveg	Percentage of vegetation in the weather station (from 0 to 1)
fvegz (0,1)= (entre desierto y selva)	Percentage of vegetation in the study area (from 0 to 1)
Dact	Density of "static" activity (relates energy consumption / inhabited m2) in the weather station (from 0 to 1).
Dactz (0,…)	Density of "static" activity (relates energy consumption / inhabited m2) (from 0 to 1). Presence of anthropic activity.
Dtr	Traffic density at the weather station (from 0 to 1).
Dtrz(0,…)	Traffic density in the area (number of vehicles per hour) (from 0 to 1). Presence of human activity
factz= (Dactz-Dact)/ (Dactz+Dact)	Zonal Activity Factor (relates zonal activity density and activity density at the weather station)
ftrz= (Dtrz-Dtr)/ (Dtrz+Dtr)	Zonal traffic factor (relates zonal traffic density and traffic density at the weather station)

These factored and interrelated characteristics, according to their incidence or not in the determination of a climatic state parameter, determine the following zonal data of the study area (for winter, spring, summer and autumn):
Radiation in the vertical plane to the south Rz (w)
Temperature Tz (°C)
Temperature fluctuation ΔTz (°C)
Relative humidity HRz (%)
Wind intensity
Wind direction dVz (azimuth to north in °)
Sound Nz (dBA)

According to the urban structure of the Eixample of Barcelona, "area" is considered, in the model, as a surface of the fabric, of 2 x 2 km2 domain.
In this research, we will study the behavior of the T° of the air and the variation of the T° of the air.

The next equation defines Air Temperature inside the study area (Tz):

$$Tz= T + 7\ factz + 4\ ftrz + ((ha-haz)/180) - 4 \cos aztz \times \sin altz + 4\ fhrz \times \exp(-Vz) + (T-Tmedia\ anual) \times (0{,}5(faig-faigz) + (0{,}2(fveg-fvegz))) \quad (1)$$

T	Temperature measured by the city's weather station
factz	Zonal Activity Factor
ftrz	Zonal traffic factor
ha	Station height above sea level
haz	Zone height
aztz	Slope orientation
altz	General slope of the terrain
fhrz	Relative height Factor
Vz	Zonal wind
Tmedia	Average annual temperature
faig	Factor Percentage of urban water
faigz	Factor Percentage of water in the area
fveg	Factor Percentage of urban vegetation
fvegz	Factor Percentage of vegetation in the area

And this equation define Air Temperature into the canyons within the area of study (Tp):

$$Tp= Tz + (\Delta Thr + \Delta Tveg + \Delta Tdens + \Delta Taig) \times \exp(-0{,}5Vp) + 3\,((Rp - Rz)/Rz) \times \exp(-Vp) \quad (2)$$

Tz	Zonal temperature
ΔThr	Relative elevation Factor (fhr)
ΔTveg	Vegetation Percentage Factor (fveg) Canyon Relative Humidity (RH)
ΔTdens	Canyon Traffic Density Factor (ftrp) Density Factor of canyon activity (factp) Canyon wind (Vp)
ΔTaig	Canyon water factor (fair) Canyon relative humidity (RH)
Vp	Canyon wind speed
Rp	Canyon radiation
Rz	Zonal radiation

Increment by relative height factor: *$\Delta Thr = 0.5\ fhr$ (= 0 if height > 0)*
Increase due to vegetation (without shade): *$\Delta Tveg = -2 \times fveg \times (100 - HR) / 100$*
Increment by density factor: *$\Delta Tdens = (ftrp + 2\ factp) \times (\exp(-Vp) + 1) / 2$*
Increase by water factor: $\Delta Taig = -6 \times faig \times (100- HR) / 100$

Finally, the results of the application of the model in the scale of the urban canyon define:

$$Tp= Tz + (\Delta Thr + \Delta Tveg + \Delta Tdens + \Delta Taig) \times \exp(-0{,}5Vp) + 3\,((Rp - Rz)/Rz) \times \exp(-Vp)$$

Relative height increment:
$\Delta Thr = 0{,}5\ fhr$(= 0 si alcaria > 0)
Relative height factor
Increase by vegetation (without shadow): $\Delta Tveg = -2 \times fveg \times (100 - HR)/ 100$
Factor vegetation percentage
Canyon moisture
Increase by density:
$\Delta Tdens = (ftrp + 2\ factp) \times (\exp(-Vp) + 1)/2$
Canyon traffic density factor
Canyon Activity Density Factor
Canyon wind
Increase by water:

$\Delta Taig = -6 \times faig \times (100 - HR)/100$
Canyon water factor
Canyon moisture

CANYON TEMPERATURE VARIATION
According to the model, the determination is influenced by:

ΔTz	Zone temperature oscillation
fveg	Factor Percentage of vegetation
Vp	Canyonl wind speed
Rp	Point Radiation
Rz	Zonal Radiation
ΔTdens	Canyon Traffic Density Factor (ftrp)
	Canyon Activity Density Factor (factp)
	Canyon wind (Vp)

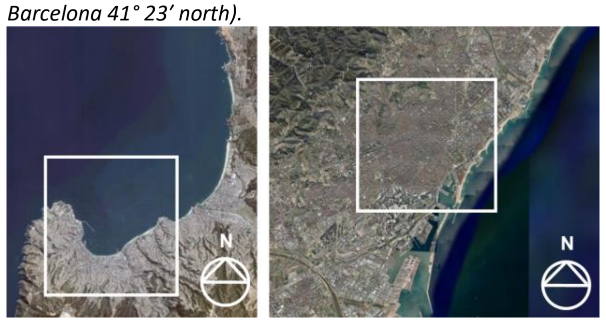
$\Delta Tp = \Delta Tz \times (1 - 0{,}1 \times fveg) \times (1 + 0{,}5 \times \exp(-Vp)) \times (Rp - Rz)/Rz + 0{,}6 \times \Delta Tdens)$

The model identifies three principal factors in the urban climate formation: anthropogenic heat generation, impervious materials and urban geometry.

2.2 DELIMITATION OF THE STUDY AREA

The present investigation was developed in the city of Valparaíso, which is located in the central zone of Chile. It is a coastal city with a mediterranean climate and around 295,000 inhabitants.
The chosen model is proposed for an urban fabric with a coastal Mediterranean climate (Eixample, Barcelona), which is similar to that of Valparaíso (Figure 2). Therefore, an attempt is made to validate its structure for a climate of these characteristics.
The central area of Valparaíso recognized as the financial district of the city was studied. It also corresponds to the area of the city that presents the highest rates of heat island.
This area is a sector of the city recognized as world heritage and whose morphology has not changed for at least 20 years.

Figure 2:
Urban situation. Left, Valparaiso (33° 3'south). Right, Barcelona 41° 23' north).



2.3 MAP OF THE MORPHOLOGY AND ACTIVITY OF THE STUDY AREA

The Valparaiso geomorphological situation (figure 3) the building situation of study area (Figure 4 - 5, different heights of the buildings in the area are observed on the map), the SVF and HRF factors are defined (Figure 6). Information on traffic activity (traffic density), activity inside buildings (zonal activity density) water situation and vegetation situation NDVI (Figure 7) is also surveyed.

Figure 3:
Valparaiso geomorphological situation

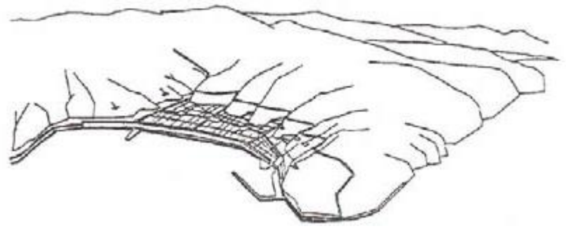


Figure 4:
Building situation shape

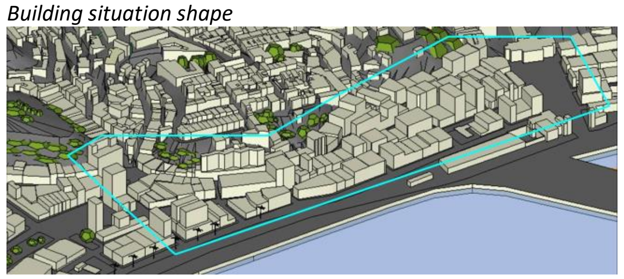


Figure 5:
Buildings heights

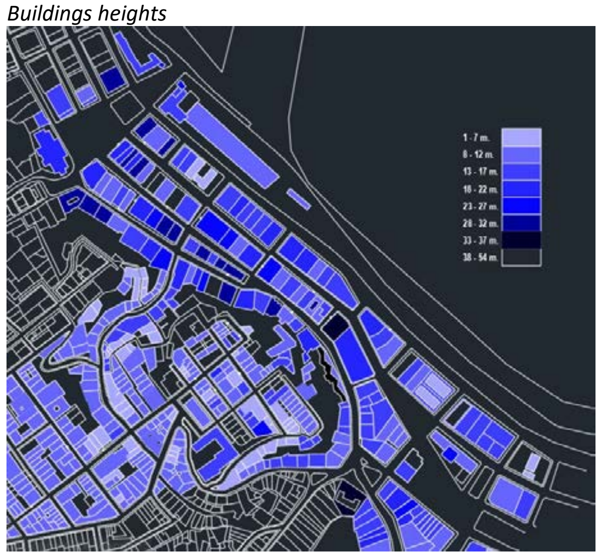


Figure 6:
Sky view factor (SVF) and Relative height factor (RHF) of canyons in study area.

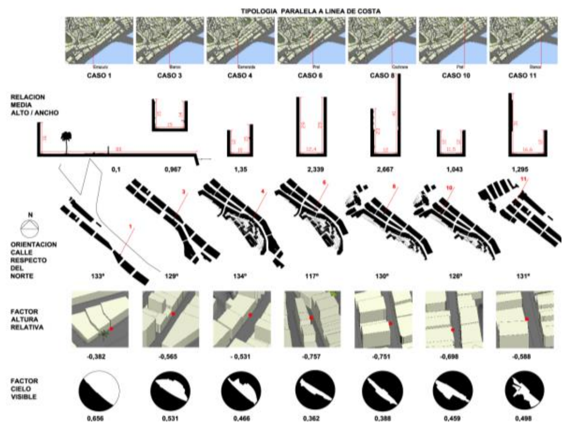
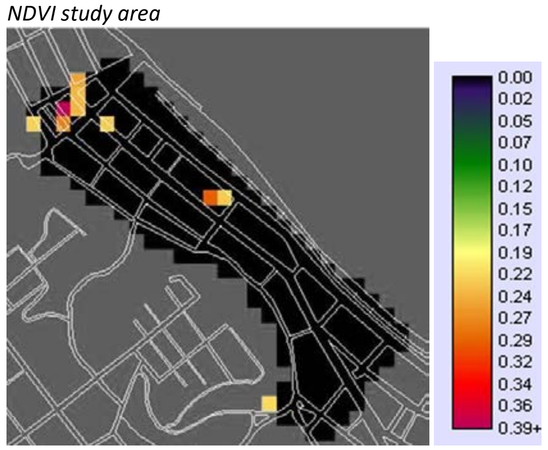


Figure 7:
NDVI study area



MESUREMENT AND SIMULATION
A variety of recording points were defined in order to measurement the variables defined by the Eixample urban climate model [1].
Measurement campaigns were carried out in winter on a clear day and between the hours of 10:30 am and 2 pm. and 8 p.m.
Then a survey of measurements of Temperature (°C) and Temperature Oscillation (°C) were made in the specific places of study in the area.
Then, the records of the urban factors that the model defines were raised.
With the survey of the urban factors, the results of T° t variation of the T° in the Eixample model are simulated and compared with the field records.

3. RESULTS

The results shown a R^2 0.81 and a correlation coefficient 0.9 between the values of the adapted model and those measured in the urban canyon in the variable air temperature (Fig. 8).
And a R^2 0.84 and a correlation coefficient 0.92 were obtained between the values resulting from applying the model and those measured in the urban canyon, for the variable Variation in Air Temperature, in sunny days in winter (Fig. 9).

Figure 8:
Comparison of the measured and simulated Air temperature within the area of study

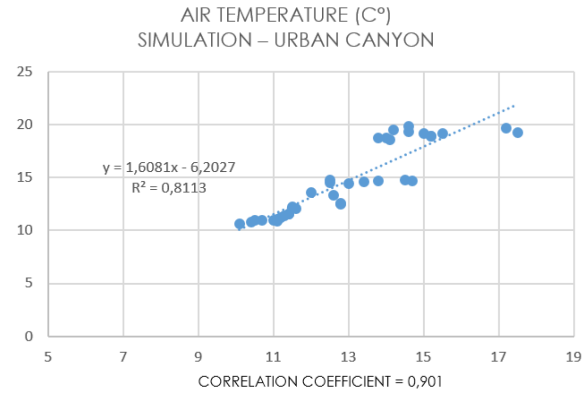
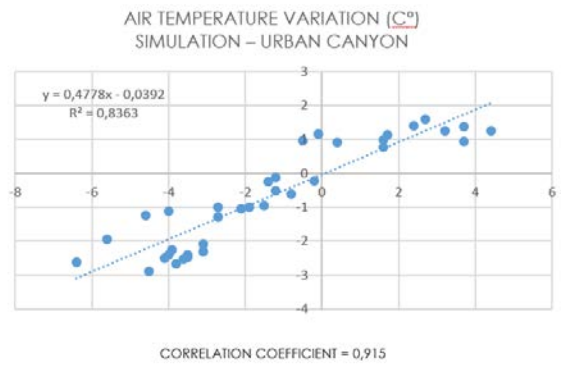


Figure 9:
Comparison of the measured and simulated Air temperature variation within the area of study



4. CONCLUSION

This paper corresponds to the results of the climatic modeling of the financial district of the city of Valparaíso using the Eixample Urban Climate Model and adapted to the local conditions of a city. This model is considered suitable for fabrics located in a coastal Mediterranean climate. Consider morphological and energetic elements, water and vegetation, all the characteristic elements of its urban spaces and existing in climates of these characteristics.
Although the model used is presented as a model of climatic averages, its structure is very appropriate for built spaces in coastal climatic conditions. The incorporation of both the Zonal Density Descriptor and Zonal Frontal Descriptor adjust the model respect to

the behavior of Radiation and Wind Speed. Neither were described in this document.

The incorporation of the Zonal Frontal Density descriptor Densfz = 0.88, characterizes how permeable the fabric is to horizontal wind. Allows you to fit the model to ground measurements of wind speed.

The incidence of the sea breeze makes it necessary to adapt the model to the edge fabrics, especially to the incidence of the Humboldt current. This could be made explicit by incorporating the Zonal Front Density descriptor not described in this document.

In the particular case of the city of Valparaíso, the elements of vegetation are mainly confined to public squares with no presence in canyons, as can be seen in the NDVI image.

The correlations determined between the morphological descriptors and the global climatic behavior of the area fit the model with numerical factors appropriate to the characteristics of the study area. The proposed model for the fabrics of the Eixample in Barcelona is useful for geometric fabrics such as the one analyzed and modeled in Valparaíso, considering urban design variables that urban planners use in the regulation of their urban design plans.

ACKNOWLEDGEMENTS

This work was done with the support of Fondecyt Project 1200275 awarded in Chile by ANID.

REFERENCES

[1] Isalgué, A. J. Roset and H. Coch, (2000). Environmental Evaluation of an Urban Sector. *Proceedings International Building Physics Conference*. Eindhoven, Netherlands. p. 429-436.

[2] UN, 2018. World Urbanization Prospects. United Nations, [Online], Available: https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts. pdf [21 May 2019].

[3] Oswald, SM; B. Hollosi, M. Zuvela-Aloise, L. See, S. Guggenberger, W. Hafner, G. Prokop, A. Storch, W. Schieder, (2020). Using urban climate modelling and improved land use classifications to support climate change adaptation in urban environments: A case study for the city of Klagenfurt, Austria. *Urban Clim*ate. 31, 100582.

[4] Oke, T. R., (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*. 108 (455): 1-24.

[5] Carrasco, C., (2009). Morfología y microclima urbano análisis de la forma espacial y materiales como modeladores del microclima de tejidos urbanos mediterráneos costeros: el caso de la ciudad de Valparaíso. Doctoral dissertation Barcelona. http://www.tdx.cat/handle/10803/51572.

[6] Palme, M., L. Inostroza, G. Villacreses, A. Lobato, C. Carrasco, (2017). From urban climate to energy consumption: Enhancing building performance simulation by including the urban heat island effect. *Energy and Buildings* 145 (5), 107- 6.

[7] Stewart, I.D. and T. R. Oke, (2010) Thermal Differentiation of "Local Climate Zones" Using Temperature Observations from Urban and Rural Field Sites. *9th Symposium on Urban Environment*, Keystone, CO, 1-6, American Meteorological Society.

[8] Oropeza-Perez I., (2020). Simplified Numerical Model for Analyzing the Effects of the Urban Heat Island upon Low-Rise Buildings by Using a Free-License Thermal Simulation Program. *Urban Sci*., 4, 30.

[9] Roset J., R. Serra, A. Isalgué, H. Coch, (1999). Energetic analysis for an urban sector of Barcelona. *REBUILD 3rd International Conference: Rebuilding the Cities of Tomorrow*, Barcelona, p. 206-209.

[10] Tsitoura, M., M. Michailidou, T. Tsoutsos, (2016). Achieving sustainability through the management of microclimate parameters in Mediterranean urban environments during summer. *Sustainable Cities and Society* 26. 48–64.

[11] Carrasco C., M. Palme (2020). Urban form and urban materials as controller of urban climate in Valparaiso, Chile. *IOP Conf. Series: Earth and Environmental Science* 503.

[12] Katzschner, L. (2010). Urban climate in dense cities. In: NG, E. (Ed.). Designing high-density cities for social and environmental sustainability. *London: Earthscan*, cap. 7, p. 71-78.

[13] Orehounig, K., A. Mahdavi, E.-M. Doppelbauer, W. Loibl, T. Tötzer, (2014). Projections of design implications on energy performance of future cities: a case study from Vienna. *Sustainable Cities and Society,* 12, 92–101

[14] Kimura F., P. Manins, (1988). Blocking in periodic valleys. *Boundary-Layer Meteorology*, 44, 137–169.

[15] Lee, S. H. and F. Kimura, (2001). Comparative studies in the local circulations induced by land-use and by topography. *Boundary-Layer Meteorology*, 101, 157-182.

[16] Kusaka, H., H. Kondo, Y. Kikegawa, F. Kimura, (2001). A Simple Single-Layer Urban Canopy Model for Atmospheric Models: Comparison with Multi-Layer and Slab Models *Boundary-Layer Meteorology*, 101, 329-358.

[17] Yamada T., (2004) Merging CFD and atmospheric modeling capabilities to simulate airflow and dispersion in urban areas. *Fourth Asian Workshop on Computational Fluid Dinamics. Univerity of Tokio. Computational Fluid Dynamics journal 13*. pp. 329-341.

[18] Germano M., (2006). Qualitative modelling of the natural ventilation potential in urban context. *Tesis Doctoral. Faculté environnement naturel, architectural et construit. Laboratoire d'énergie solaire et physique du bâtiment. Section d'architecture.* Lausanne, EPFL Ecole Polytechnique Federale de Lausanne.

[19] M. Bruse, M. Nikolopoulou, (2004). Tools for planning and Design at Micro-Scale; *Conference paper: Urban Green Space in Europe: New Approaches and Future Challenges*, 15-16.

[20]Bueno, B., L. Norford, J. Hidalgo, G. Pigeon, G. (2012). The urban weather generator. *Journal of Building Performance Simulation* 6 (4), 1-13.

[21] Ochoa J.M., R. Serra, (1998). Microclimatic analysis of some urban scenarios, *Environmental Friendly Cities, Proceedings of PLEA'98.* Lisbon. Ed. James2 & James, London, U.K.

Climate Change and Megacities

South Asian Mega-cities are in extreme heat stress

KUMAR BISWAJIT DEBNATH[1]; DAVID JENKINS[2]; SANDHYA PATIDAR[2]; ANDREW D PEACOCK[2]; BEN BRIDGENS[1]; HELEN MITRANI[1]

[1]Hub for Biotechnology in the Built Environment (HBBE), School of Architecture, Planning & Landscape, Newcastle University, UK

[2]School of Energy, Geoscience, Infrastructure and Society (EGIS), Heriot-Watt University, UK

ABSTRACT: Of 33 Global Megacities, ten are situated in South Asia. Extreme heatwaves are becoming an annual phenomenon due to climate change in South Asian megacities. In this study, we evaluated 29 years (1990-2019) of historical data on heat stress in ten selected megacities (existing and prospected) —New Delhi, Dhaka, Mumbai, Kolkata, Ahmedabad, Chennai, Bengaluru, Hyderabad, Chittagong, and Pune—predominantly in India and Bangladesh. We used Heat Index (HI) and Environmental Stress Index (ESI) analysis to evaluate stress and vulnerability. Our results showed that most megacities are already experiencing 'Extreme caution' and 'Danger' levels of heat stress which may lead to heat cramps, exhaustion, stroke, and even death. Furthermore, the frequency of 'Danger' level of heat stress and vulnerable level of ESI has increased significantly since 2011 in the selected megacities, which elevated the heat-related vulnerability among the millions of inhabitants.

KEYWORDS: Extreme heat, Megacities, South Asia, Climate change, vulnerability.

1. INTRODUCTION

Of 33 Global Megacities (UN, 2018)— with a population of more than 10 million — ten are situated in South Asia. According to the UN, New Delhi will be the largest megacity globally, with Dhaka and Mumbai in the top ten megacities by 2030 (a predicted total of 43) (UN, 2018). Also, extreme heatwaves are increasing due to climate change in South Asia (IPCC, 2022), becoming an annual phenomenon. Therefore, billions of people will live with the adverse effects of extreme heat.

Extreme heat exposure may cause severe health issues ranging from heat exhaustion, cramps, and heatstroke to even death (NIH, 2022). Furthermore, to live with extreme heat, people are inclined to use air conditioning which causes elevated electricity demand for cooling, which is projected to grow rapidly (Debnath, Jenkins, Patidar, & Peacock, 2020). For example, India will have 240 million A/C units by 2030, reaching 1144 million by 2050 (IEA, 2019), from 21.8 million in 2017 (GoI, 2015).

In this study, we evaluated 29 years (1990-2019) of historical data on Heat Stress and associated vulnerability in ten selected megacities (existing and prospected) —Dhaka, Chittagong, New Delhi, Mumbai, Kolkata, Ahmedabad, Chennai, Hyderabad, Pune, and Bengaluru— predominantly in India and Bangladesh.

2. METHODOLOGY

We obtained 29 years of weather data (1990-2019) from the Meteoblue database (www.meteoblue.com) for the Heat Index (HI) and Environmental Stress Index (ESI) analysis of 10 megacity's climate. The ambient temperature and relative humidity data were used to calculate the hourly heat index (HI) with the following Equation 1 adopted from (Rothfusz & Headquarters, 1990):

$$HI = -42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783 \times 10^{-3}T^2 - 5.481717 \times 10^{-2}R^2 + 1.22874 \times 10^{-3}T^2R + 8.5282 \times 10^{-4}TR^2 - 1.99 \times 10^{-6}T^2R^2 \quad \ldots\ldots(1)$$

Where, T - Ambient dry bulb temperature (°F)

R - Relative humidity (integer percentage)

HI was selected for the study as it has been widely used in several studies to analyse the adverse effect of heat stress, such as (Luo & Lau, 2019; Modarres, Ghadami, Naderi, & Naderi, 2018; Choi & Lee, 2020; Opitz-Stapleton, et al., 2016). For the analysis in this study, we converted the ambient dry bulb temperature into °C with the following Equation 2 adopted from (Fay & Hardie, 2003):

$$C = 5/9\,(F - 32) \quad \ldots\ldots(2)$$

Where C- Ambient dry bulb temperature (°C)

F- Ambient dry bulb temperature (°F)

Furthermore, we used the Heat Stress Index scale (**Table 1**) developed by National Oceanic and

Atmospheric Administration (NOAA) (NWS, 2020) to evaluate the HI for different megacities.

Table 1: *Heat index and corresponding health impacts* (NWS, 2020)

Heat Stress Index (°C)	Category	Dangers
27-32	Caution	Fatigue
32-41	Extreme caution	Sunstroke, heat cramps and heat exhaustion
41-54	Danger	Sunstroke, heat cramps and heat exhaustion, and even heat stroke
54+	Extreme danger	Heat/sunstroke

Rather than only analysing temperature and Relative Humidity as parameters to show the climate change effect in the selected cities, we also adopted the methodology of the Environmental Stress Index (ESI) as a measure for climate analysis because ESI considers the effect of climatic parameters such as ambient temperature (Ta), relative humidity (RH) and solar radiation (SR). The basic methodology of ESI was described in (Moran, et al., 2001), and Equation 3 is as follows:

$$ESI = 0.63T_a - 0.03RH + 0.002SR + 0.0054(T_a \times RH) - 0.073(0.1 + SR)^{-1} \ldots\ldots (3)$$

Where, T_a was the ambient temperature (°C), RH the relative humidity (%), and SR the solar radiation (Wm^{-2}), and the output unit for ESI is °C.

For analysing the vulnerability to extreme heat, the work schedule reduction linked to Heat Index (HI) was used as described in **Table 2**.

Table 2: *Work schedule reduction recommendations* (NIOSH, 2016)

Adjusted Temperature or Heat Index (°F(°C))	Work/Rest Minutes Per Hour; Moderate Workloads (% Hourly Reduction)	Work/Rest Minutes Per Hour; Light Workloads (% Hourly Reduction)
90 (32.2)	Normal (0%)	Normal (0%)
100 (37.8)	45/15 (25%)	Normal (0%)
104 (40.0)	30/30 (50%)	Normal (0%)
105 (40.6)	25/35 (58.3%)	Normal (0%)
106 (41.1)	20/40 (66.6%)	45/15 (25%)
108+ (42.2+)	0/60 (100%)	35/25 (41.6%)
111+ (43.9+)	0/60 (100%)	0/60 (100%)

Based on the Work/Rest Minutes Per Hour in **Table 2**, we used the following Equation 4 (Moderate workload) and 5 (Light workload) for the estimate of the total annual per person-hours lost due to heat stress:

$$H_{Mw} = (a \times 100\%) + (b \times 100\%) + (c \times 66.6\%) + (d \times 58.3\%) + (e \times 50\%) + (f \times 25\%) \ldots\ldots (4)$$

$$H_{Ml} = (a \times 100\%) + (b \times 41.6\%) + (c \times 25\%) + (d \times 0\%) + (e \times 0\%) + (f \times 0\%) \ldots\ldots (5)$$

Where, H_{Mw} was the hours reduced in moderate workload (h), H_{Ml} *was* the hours reduced in light workload (h), a is the hours with HI of 43.9°C (and higher), b is the hours with HI between 43.9-42.2°C, c is the hours with HI between 42.2-41.1°C, d is the hours with HI between 41.1-40.6°C, e is the hours with HI between 40.6-40.0°C, and f is the hours with HI between 40.0-37.8°C.

3. RESULTS AND DISCUSSION

3.1 Heat Stress Index (HI)

In the case of Dhaka (Bangladesh), the HI was 49.68°C in 2015. The maximum HI was 51.94°C in 2019, the highest in the past 29 years; 2.3°C and 3.37°C higher than the highest HI in 2015 and 2011. Dhaka's average HI was 30.36°C in 2019 and 29.53°C in 2015. Only 69 hours (h) in 2015 had HI in the danger level, which increased 3.39 times by 2019 (234h) (Figure 1A).

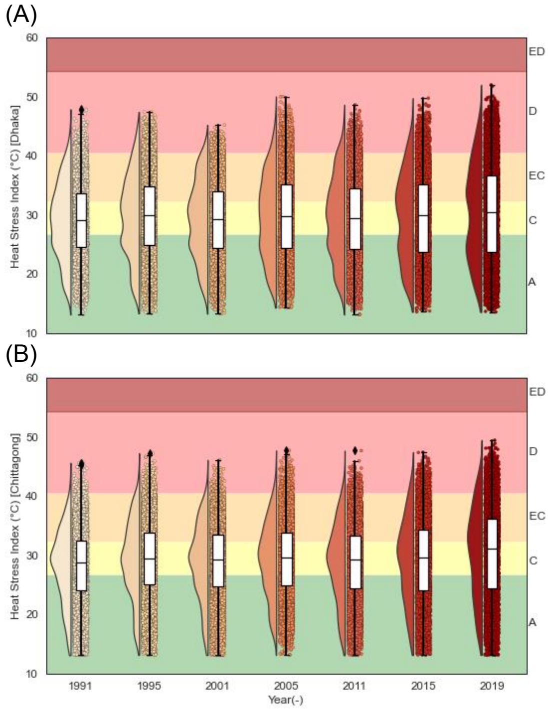


Figure 1: Heat Index (HI) for (A) Dhaka and (B) Chittagong, Bangladesh in 1991, 1995, 2001, 2005, 2011, 2015, and 2019. Here, ED= Extreme Danger, D= Danger, EC= Extreme Caution, C= Caution, and A= Acceptable.

For the port city of Chittagong (Bangladesh), the HI was at a danger level for 789h in 2019, which was 410h in 2015 and 235h in 2011 (Figure 1B). Therefore, the danger level exposure elevated 1.7 times in 2019 than in 2011. Similarly, the HI was at an extreme caution level for 3073h in 2019, 1.3 times higher than in 2011 (2444h). The highest HI was 49.40°C in 2019, about 2°C higher than in 2015 and 2011. Furthermore, the average HI increased to 30.33°C from 29.15°C in 2015 and 28.68°C in 2011.

In the case of the capital city New Delhi (India), the maximum HI was 51.92°C in 2019, the highest in the past 29 years; 1.8°C and 2°C higher than the highest HI in 2015 and 2011, respectively. New Delhi's average HI was 30.60°C in 2019 and 29.60°C in 2015 (Figure 2A). Only 58h in 2015 had HI in the danger level, which increased 4.43 times by 2019 (257h).

In Mumbai, the HI was at a danger level of 277h in 2019, only 86h in 2011 (Figure 2B). Therefore, HI at danger level in Mumbai elevated 3.22 times in 8 years. In 2015, the HI was 329h at the danger level. The highest HI was 48.11°C in 2019, about 2.3°C and 4°C higher than in 2015 and 2011. The average HI increased to 30.03°C in 2019 from 28.96°C in 2011.

The HI was at a danger level for 1342h in Kolkata in 2019, 1065h in 2015 and 619h in 2011 (Figure 2C). The danger level of HI exposure elevated 2.2 times by 2019 than that of 2011. The highest HI was 53.48°C in 2019, about 1.3°C and 4°C higher than in 2015 and 2011. The average HI increased to 31.62°C in 2019 from 30.18°C in 2011.

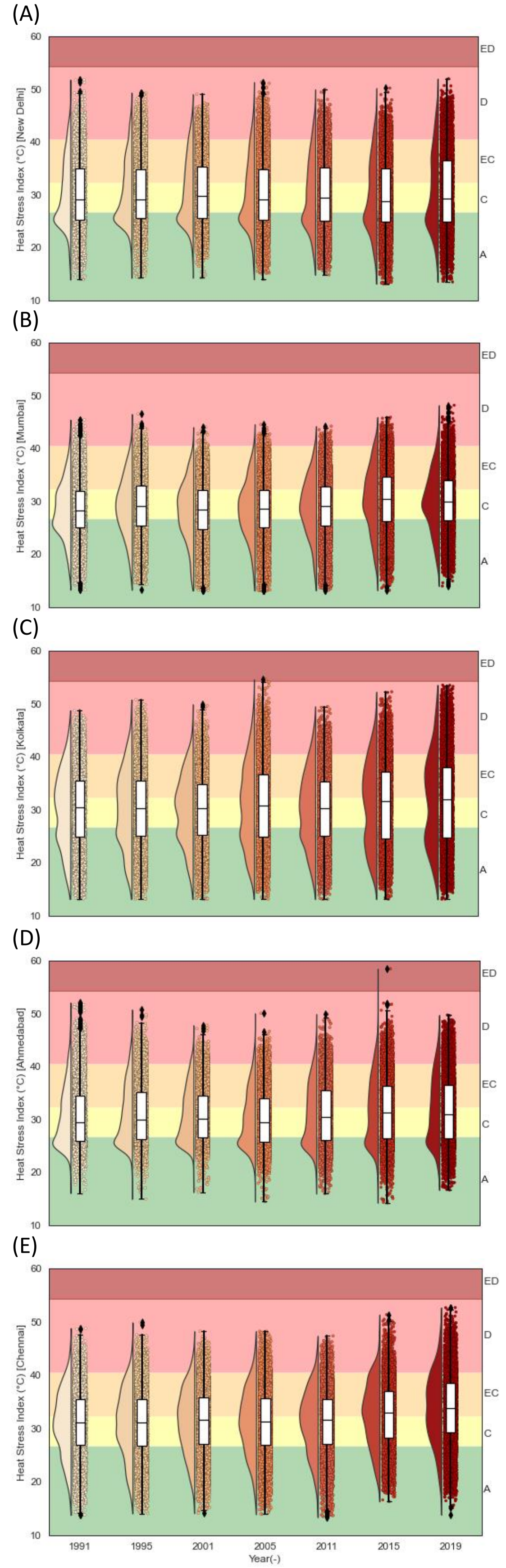
In the case of Ahmedabad, the danger level of HI exposure was 835h in 2019, 1.8 times that of 2011 (476h). In 2015, the highest HI was 58.41°C, 49.67°C and 49.83°C in 2019 and 2011, respectively (Figure 2D). The average HI increased to 31.65°C in 2019 from 31.02°C in 2011.

For Chennai, HI, the danger level experienced 1322h, which was 784h in 2015 and 369h in 2011 (Figure 2E). The HI exposure in danger level increased 3.6 times by 2019 than in 2011. The highest HI was 52.61°C in 2019, about 1.3°C and 5.31°C higher than in 2015 and 2011. The average HI increased to 33.71°C in 2019 from 32.63°C in 2015 and 31.16°C in 2011.

The HI reached the danger level of 162h in 2019, from 58h in 2015 to only 8 hours in 2011 in Hyderabad (Figure 2F). In 2011-19, the HI exposure to danger increased 20.25 times. The highest HI was 44.30°C in 2019, about 1.2°C and 2.24°C higher than in 2015 and 2011. The average HI increased to 27.77°C in 2019 from 27.30°C in 2011.

In the case of Pune, the danger level of HI exposure was 5h, 0h, and 4h in 2019, 2015, and 2011, respectively (Figure 2G). In contrast to most of the megacities in India, HI in Bengaluru never reached to danger level from 1991-2019 (Figure 2H).

Our results showed a 1.2-2.3°C and 2-5.31°C increase by 2019 in the HI since 2015 and 2011, respectively, in the megacities of Bangladesh (Dhaka and Chittagong) and India (New Delhi, Mumbai, Kolkata, Ahmedabad, Chennai, and Hyderabad). Only Pune and Bengaluru in India showed little to no exposure to the danger level of HI. Nevertheless, they also showed an increase in HI levels.



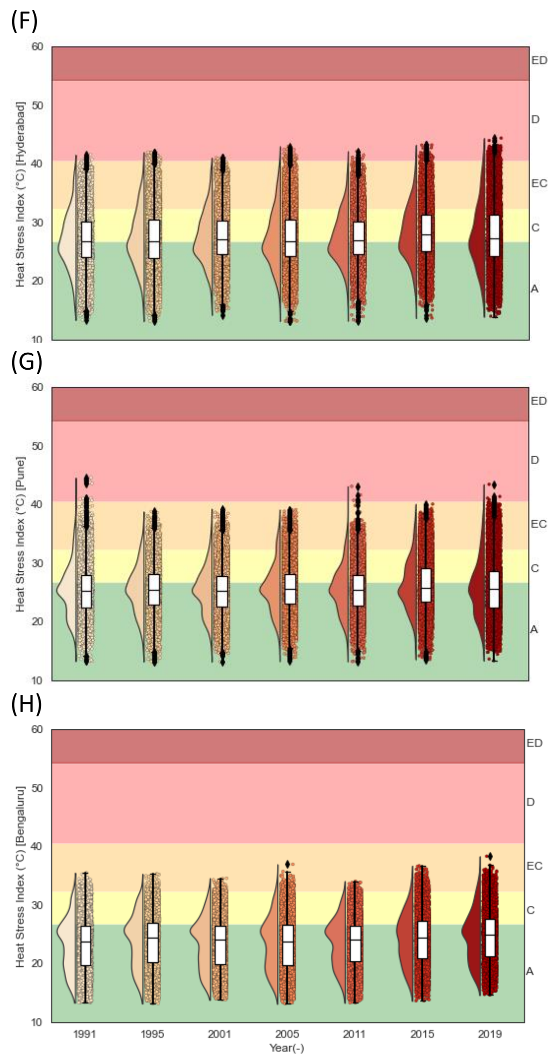
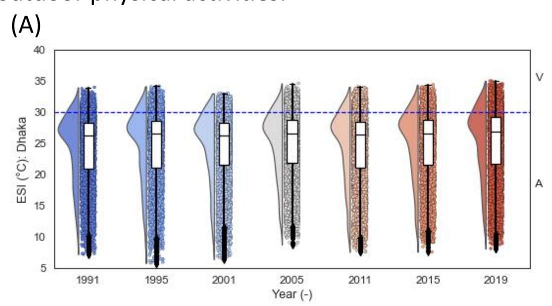


Figure 2: HI for (A) New Delhi, (B) Mumbai, (C) Kolkata, (D) Ahmadabad, (E) Chennai, (F) Hyderabad, (G) Pune, and (H) Bengaluru (also called Bangalore), India in 1991, 1995, 2001, 2005, 2011, 2015, and 2019. Here, ED= Extreme Danger, D= Danger, EC= Extreme Caution, C= Caution, and A= Acceptable.

3.2 Environmental Stress Index (ESI)

In the case of ESI, we considered 30°C — wet bulb globe temperature (WBGT) threshold was considered 28°C (The Lancet, 2021) and ESI can substitute WBGT (Moran, et al., 2001; ClimateCHIP, 2022)— as the threshold above which the hours were considered vulnerable for people to conduct outdoor physical activities.



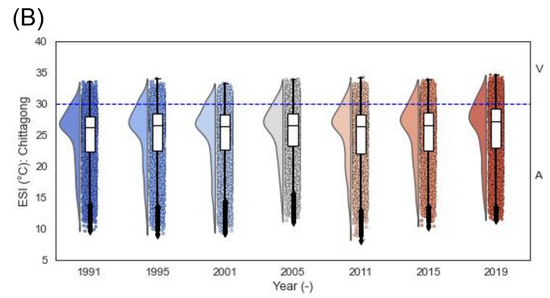


Figure 3: ESI for (A) Dhaka and (B) Chittagong, Bangladesh in 1991, 1995, 2001, 2005, 2011, 2015, and 2019. Here, V= vulnerable and A= Acceptable.

In Bangladesh, Dhaka and Chittagong showed elevated hours above the ESI vulnerability thresholds. The highest ESI was 34.95°C and 34.57°C in 2019 in Dhaka and Chittagong, respectively (Figure 3). The ESI for Dhaka was higher than the threshold for 1592h in 2019 and 1119h in 2011. For Chittagong, the ESI was higher than 30°C for 1559h in 2019, which was 882h in 2011; therefore, 1.77-time increase in 8 years.

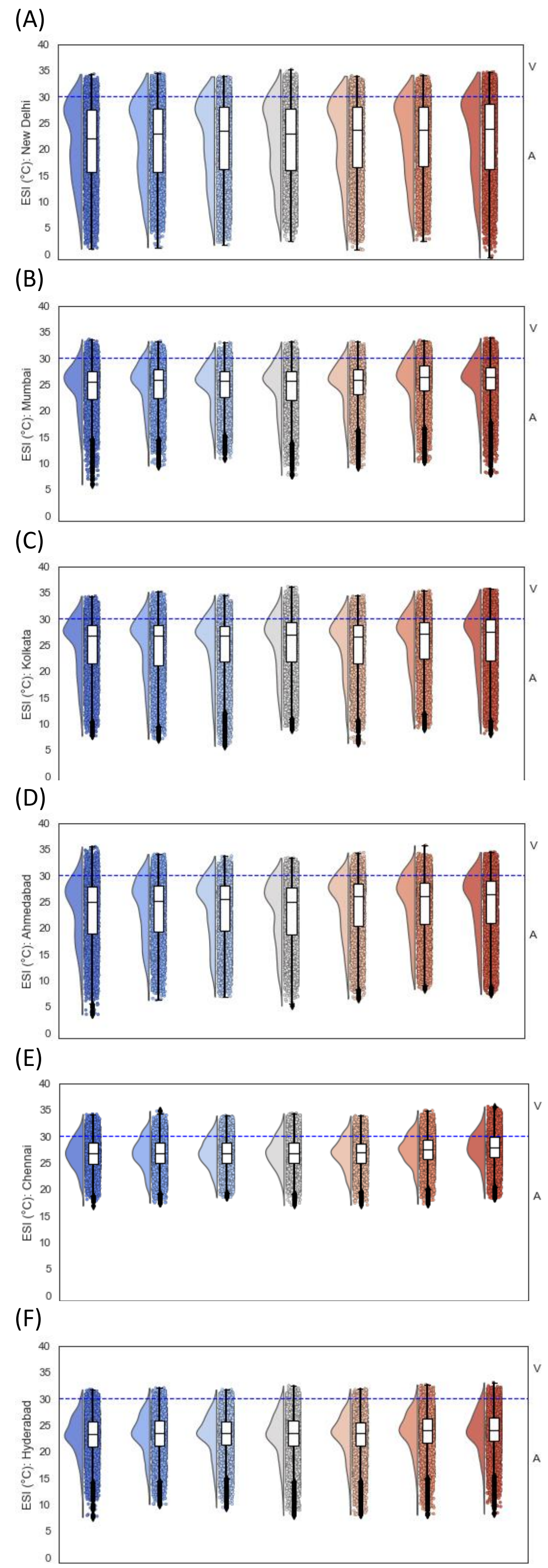
In India, apart from Bengaluru, all the megacities showed elevated exposure to vulnerable level ESI in 2019 compared to 2011. The highest ESI were 34.70°C, 33.83°C, 35.64°C, 34.43°C, 35.62°C, 33.07°C, and 31.47°C in New Delhi, Mumbai, Kolkata, Ahmedabad, Chennai, Hyderabad, and Pune, respectively, in 2019. In New Delhi, the ESI was higher than the threshold for 1299h in 2019, which was 1068h in 2011; therefore, 1.22 times increase. Higher than threshold ESI exposure hours elevated to 937h (from 564h in 2011), 2015h (from 1258h in 2011), 1378h (from 1016h in 2011), 2057h (from 1090h in 2011), 324h (from 117h in 2011) and 87h (from 1h in 2011) for Mumbai, Kolkata, Ahmedabad, Chennai, Hyderabad, and Pune, respectively, in 2019 (Figure 4).

3.3 Vulnerability

Considering the vulnerability to extreme heat from **Table 2** and Equations 4 & 5, the high number of hours exposed to danger level HI in most of the megacities in India and Bangladesh contributed to the reduction of massive work hours to cope with the heat stress-related health issues.

Due to heat stress annually in Dhaka, 454.6h (moderate workload) and 148.2h (Light workload) of work hours per person were reduced in 2019. The work hours per person were reduced annually by 469.3h (moderate workload) and 134.6h (Light workload) in Chittagong in 2019.

In the case of India, annually hours were reduced for moderate workload and light workload in megacities apart from Bengaluru (**Table 3**), which might be due to being a tropical savanna climate, which was different from the other studied megacities in India such as New Delhi (Sub-tropical), Mumbai (Tropical), Kolkata (Tropical wet-and-dry), Ahmedabad (semi-arid), Chennai (tropical wet and dry), Hyderabad (arid) and Pune (tropical wet and dry) in the Köppen climate classification (Arnfield, 2020). Furthermore, urban development devoid of sustainable contextual climate change adaptation and mitigation strategies exacerbated the heat stress linked to vulnerabilities in the megacities.



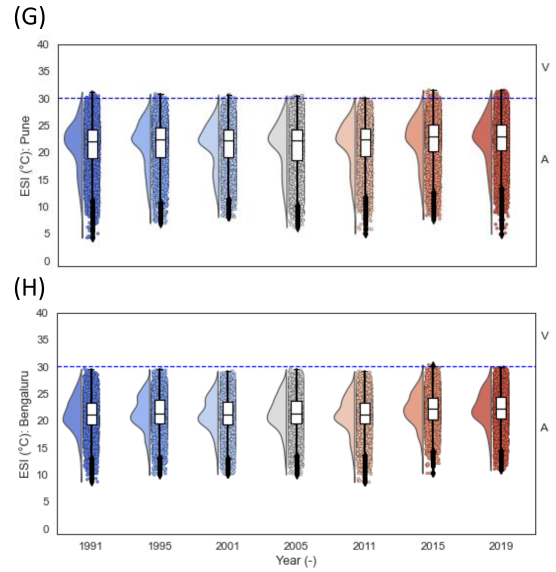


Figure 4: ESI for (A) New Delhi, (B) Mumbai, (C) Kolkata, (D) Ahmedabad, (E) Chennai, (F) Hyderabad, (G) Pune, and (H) Bengaluru (also called Bangalore), India in 1991, 1995, 2001, 2005, 2011, 2015, and 2019. Here, V= vulnerable and A= Acceptable.

Table 3: Annual hours reduced per person for moderate workload and light workload in Indian megacities

Megacity name	Moderate workload (Hours reduced)	Light workload (Hours reduced)
New Delhi	412.7	138.9
Mumbai	247.7	46
Kolkata	536.1	157
Ahmedabad	481.6	128.4
Chennai	687.4	184.7
Hyderabad	152.2	19.1
Pune	32.9	1.2

4. CONCLUSION

As ten megacities are situated in South Asia and extreme heatwaves are becoming an annual phenomenon due to climate change, in this study, we evaluated historical climate data for heat stress (HI and ESI) in those megacities in India and Bangladesh. We also estimated the vulnerability of the working population in terms of annually hours reduced for moderate and light workload in megacities due to heat stress.

Our results showed that most megacities are already experiencing 'Extreme caution' and 'Danger' levels of Heat Stress which may lead to heat cramps, exhaustion, stroke, and even death. We estimated a 1.2-2.3°C and 2-5.31°C increase by 2019 in the HI since 2015 and 2011, respectively, in the megacities of Bangladesh (Dhaka and Chittagong) and India (New Delhi, Mumbai, Kolkata, Ahmedabad, Chennai, and Hyderabad). The vulnerable population in the studied megacities might have to reduce annually 32.9-687.4h (moderate workloads) and 1.2-184.7h (light workloads) of work hours due to extreme heat in 2019. Furthermore, in India (apart from Bengaluru) and Bangladesh, all the megacities showed elevated exposure to vulnerable level ESI in 2019 compared to 2011. Also, the megacity's urban development devoid of sustainable contextual climate change adaptation and mitigation strategies exacerbated the heat stress-linked vulnerabilities. This study enhances our understanding of the effect of climate change on megacities in South Asian developing countries. It highlights hazardous futures that require action, as, by 2050, more people will be living in the cities than in rural areas.

ACKNOWLEDGEMENTS

This research was funded by the 'Decarbonisation of energy systems of South Asian developing economies through regional collaborations' project (Grant reference SENFC1-025), which was funded by First Flex Fund from the EPSRC Supergen Energy Networks Hub, CEDRI project (Grant reference EP/R008655/1), which was funded by the Engineering and Physical Sciences Research Council (EPSRC) and Indian Department of Science and Technology as part of the Newton-Bhabha program, and 'RESPIRE: Passive, Responsive, Variable Porosity Building Skins' project (ID/Ref: 91782) funded by Leverhulme Trust. We want to thank Meteoblue (www.meteoblue.com) for the climate data collaboration.

REFERENCES

Arnfield, A. J. (2020, November 11). *Köppen climate classification*. Retrieved March 27, 2022, from Encyclopedia Britannica: https://www.britannica.com/science/Koppen-climate-classification

Choi, G., & Lee, D. E. (2020). Changing human-sensible temperature in Korea under a warmer monsoon climate over the last 100 years. *International Journal of Biometeorology*, 1-10.

ClimateCHIP. (2022). *Heat Index Comparisons*. Retrieved from https://www.climatechip.org/heat_index_comparisons

Debnath, K. B., Jenkins, D. P., Patidar, S., & Peacock, A. D. (2020). Understanding residential occupant cooling behaviour through electricity consumption in warm-humid climate. *Buildings, 10*(4), 78. doi:https://doi.org/10.3390/buildings10040078

Fay, T. H., & Hardie, K. A. (2003). Fahrenheit to Celsius: An exploration in college algebra. *Mathematics and Computer Education, 37*(2), 207-209. Retrieved from https://search.proquest.com/docview/235936914?accountid=49696

GoI. (2015). *India Energy Security Scenarios 2047*. (Government of India) Retrieved from http://iess2047.gov.in

IEA. (2019). *Energy Efficiency: Cooling*. (International Energy Agency) Retrieved March 21, 2022, from https://www.iea.org/topics/energyefficiency/buildings/cooling/

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change . Cambridge University Press.

Luo, M., & Lau, N.-C. (2019). Characteristics of summer heat stress in China during 1979--2014: climatology and long-term trends. *Climate Dynamics, 53*(9-10), 5375-5388.

Modarres, R., Ghadami, M., Naderi, S., & Naderi, M. (2018). Future heat stress arising from climate change on Iran's population health. *International journal of biometeorology, 62*(7), 1275-1281.

Moran, D. S., Pandolf, K. B., Shapiro, Y., Heled, Y., Shani, Y., Mathew, W., & Gonzalez, R. (2001). An environmental stress index (ESI) as a substitute for the wet bulb globe temperature (WBGT). *Journal of thermal biology, 26*(4-5), 427-431. doi:https://doi.org/10.1016/S0306-4565(01)00055-9

NIH. (2022). *Effects of Heat*. (National Institute of Environmental Health Sciences) Retrieved March 21, 2022, from https://www.niehs.nih.gov/research/programs/climatechange/health_impacts/heat/index.cfm#:~:text=Prolonged%20exposure%20to%20extreme%20heat,%2C%20cerebral%2C%20and%20cardiovascular%20diseases.

NIOSH. (2016). *Criteria for a recommended standard: occupational exposure to heat and hot environments. By Jacklitsch B, Williams WJ, Musolin K, Coca A, Kim J-H, Turner N.* Centers for Disease Control and Prevention, U.S. Department of Health and Human Services. Cincinnati, OH: National Institute for Occupational Safety and Health (NIOSH). Retrieved from https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf?id=10.26616/NIOSHPUB2016106

NWS. (2020). *What is Heat Index?* (National Weather Service) Retrieved 2020, from https://www.weather.gov/ama/heatindex

Opitz-Stapleton, S., Sabbag, L., Hawley, K., Tran, P., Hoang, L., & Nguyen, P. H. (2016). Heat index trends and climate change implications for occupational heat exposure in Da Nang, Vietnam. *Climate Services, 2*, 41-51.

Rothfusz, L. P., & Headquarters, N. S. (1990). *The heat index equation (or, more than you ever wanted to know about heat index).* Scientific Services Division. Fort Worth, Texas: National Oceanic and Atmospheric Administration, National Weather Service, Office of Meteorology. Retrieved from https://www.weather.gov/media/ffc/ta_htindx.PDF

The Lancet. (2021, September). *HEAT AND PHYSICAL ACTIVITY*. Retrieved March 26, 2022, from EXPLORE OUR DATA: https://www.lancetcountdown.org/data-platform/climate-change-impacts-exposures-and-vulnerability/1-1-health-and-heat/1-1-3-exposure-of-vulnerable-populations-to-heatwaves

UN. (2018). *The World's Cities in 2018—Data Booklet.* Department of Economic and Social Affairs, Population Division. United Nations.

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE ARCHITECTURAL DESIGN

DAY 03
09:00 — 10:30

CHAIR
FELIPE VICTORERO

PAPERS
1271 / 1348 / 1361 / 1659 / 1184

33TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Recycling waste and its applications in building construction

Aseptic packaging as a thermal insulator for emergency housing

RAFAEL EDUARDO LÓPEZ-GUERRERO [1], KEVORK MICAEL NALBANDIAN [1], SCOTT GROMMETT O'NEILL BELLER [1], LEONARDO JAVIER CAAMAÑO [1], MANUEL CARPIO [1, 2, *]

[1] Department of Construction Engineering and Management, School of Engineering, Pontificia Universidad Católica de Chile.
[2] Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), Pontificia Universidad Católica de Chile, Santiago, Chile
*Corresponding author: manuel.carpio@ing.puc.cl; manuel.carpio@uc.cl

ABSTRACT: Worldwide, the construction industry is known for its high material consumption, waste and polluting gas emissions. To mitigate these issues, the recycling or reus e of waste is an available strategy, as in the case of long-lasting aseptic packaging (AP). This research aimed to evaluate AP feasibility as a thermal insulator, compared with other conventional insulating material, for applications in emergency housing in Valparaíso City, Chile. First, the different AP applications in construction were analysed through a literature review. Then, the commonly consumed AP in the Chilean market were examined. Finally, a specific building AP application and its thermal transmittance were evaluated by experimental analysis in relation to a conventional insulator. The results showed that the AP allows low transmittance values that contribute to complying with the mandatory minimum values established by the current national technical regulations for wall insulation. However, other important technical aspects, such as durability, fire resistance, interstitial condensation, etc., need to be evaluated to balance advantages and disadvantages throughout the life cycle. From the results, it can be inferred that the application studied is viable for temporary and non-definitive uses, such as emergency housing.

KEYWORDS: Sustainability, Construction, Recycling and Reuse of Waste, Aseptic Packaging, Thermal Insulation.

1. INTRODUCTION

The concept of sustainability has emerged in recent decades as one of the main demands of society for the environment. To achieve objectives in this regard, different strategies have been designed or adapted, especially in development sectors where the impacts are greater or more evident, as in the case of construction. This sector, specifically building construction, has been widely recognised for being responsible for consuming 40% of the world's material resources, 25% water, 40% energy and 12% soil, in addition to generating more than 25% of solid waste and emitting around 35% of total greenhouse gases (GHG) worldwide [1]–[3]. To reduce these impacts, recycling represents an important strategy once the energy or function of certain materials or products is recovered, avoiding their consequent inconvenience or final disposal. The main idea is to understand waste not as the end of the consumption cycle, but as the beginning or extension of a new one, eventually giving it an alternative use to its original function [4].

Every hour, globally, millions of tonnes of solid waste are discarded. Moreover, this process of waste degradation can be excessively slow, depending on its physical–chemical composition, leading to large environmental impacts [5]. Part of the waste produced is food and beverage containers, including globally produced and discarded long-lasting food containers such as aseptic packaging (AP). According to official data from the main AP production company, in 2020, 183 billion containers were sold [6], and according to the same source, worldwide, in the same year, barely 26% of such waste was recycled.

In recent decades, the recycling of AP has gained interest for subproduct purposes: first, because their raw material cannot be used to create new packaging, and second, because of its material composition, namely three layers of polyethylene (for waterproofing and bonding layers), cardboard (for rigidity and shape) and aluminium (which protects against light, air and bacteria). This makes a packaging mass of 74% cardboard, 22% polyethylene and 4% aluminium [7]. Thus, several proposals have emerged for its use as a thermal insulator in construction, due to its material composition of cardboard and aluminium [8], as an aggregate for concrete [9], fibres for asphalt mixtures [10] or as elements to lighten and insulate slabs [11].

The current research was aimed at studying the feasibility of AP as a construction material, thus finding a way to manage waste and contribute to the sustainable development of cities and communities.

The general objective of the research was to evaluate using AP as a thermal insulator, compared with other conventional insulating materials, through the analysis of product availability as discarded waste and by comparative evaluation of some thermal parameters for applications in emergency housing in Valparaiso, Chile.

2. METHODOLOGY

The present work adopted a qualitative approach through a bibliographic analysis, as well as a quantitative method by analysing the measurements of environmental impacts. A bibliographic review and a survey analysis were used as data collection instruments. Basic statistics and content analysis techniques were used as analysis methods, which allowed for the objective, systematic, qualitative and quantitative analyses of the bibliographic information [12]. The research was divided into four stages:

-Bibliographic review: A systematic review aimed at analysing the state of the art and identifying the potential uses of AP in the construction industry. In turn, this stage was divided into five substages: (i) the definition of the scientific databases, *Web of Science*, *Google Scholar* and *Scielo* were used specifically; (ii) keywords selection (in English, Spanish and Portuguese), namely *aseptic packaging*[1] *- building - construction - sustainability - recycling;* (iii) screening process, including scientific articles, theses or national and international official reports; (iv) elimination of repeated documents from different databases; (v) with the use of the 'snowball' technique through the bibliographic references of the revised documents, new publications were found, reviewed and selected.

-Survey analysis: A simplified analysis of supply and demand was conducted using survey analysis and basic statistics. The types of AP supply packaging on the market and the proportion of each type were examined. Likewise, the selection and typical demand for products with AP by common users were evaluated through structured questionnaires. In this way, through basic statistics, an average of the most consumed and discarded AP products could be defined.

-Experimental evaluation: It was aimed at performing a laboratory analysis of the AP application as isolation panels to obtain quantitative data missing from the literature. For this, thermal transmittance measurement tests were carried out by means of a simulation chamber of indoor/outdoor environmental conditions (*hot box*), which was maintained between 35–40 °C and separated by AP panels to an outdoor space at room temperature between 21–30°C. The dimensions of the ready-made AP panels were 88 × 76 cm; they had a density of 0.37 kg/m^2 and an average thickness of 0.4 mm. Three individual tests were performed: Test 1, with a single panel (one layer); Test 2, with two layers; and Test 3, with three layers. Thermal transmittance, other temperature and humidity data were monitored by a Testo 435-2 monitor.

-Comparative analysis and conclusions: Finally, a comparative analysis of the advantages and disadvantages of using AP as an insulator in relation to a conventional insulator was carried out, and conclusions were reached.

3. RESULTS

This section presents the general qualitative and quantitative results from the current work, presented in the same order as the methodological stages.

3.1 Bibliographic review

Based on the systematic review, 28 relevant publications from 2009 to 2021 were finally selected and analysed. These publications were grouped into five categories, mainly according to the use of AP in construction. Figure 1 shows the number of publications per year, and Fig. 2 shows the scope of the distribution of the studies analysed.

It is noted that the majority of the studies concentrated on AP as a thermal insulator application, while the other categories in Fig. 2 are studies evaluating other applications, for example, AP's mechanical properties or fire resistance of fibres elaborated from AP. In this sense, the categories in Fig. 2 are distributed by the following references: thermal insulator [13]–[21]; filling of slabs or walls [11], [22]; improving concrete or gypsum fibres [9], [23]–[27]; fibres for asphalt mixtures [10], [28]; and substitutes for other materials or components [29]–[34]. Considering the scope of this study, the following section delves into AP as a thermal insulation.

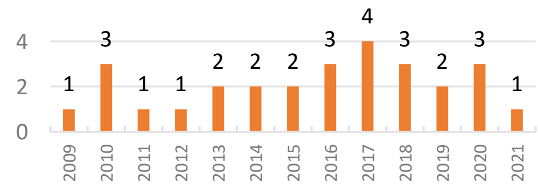


***Fig. 1**: Number of publications per year.*

[1] The keyword used was the exact trade name (Tetra Pak).

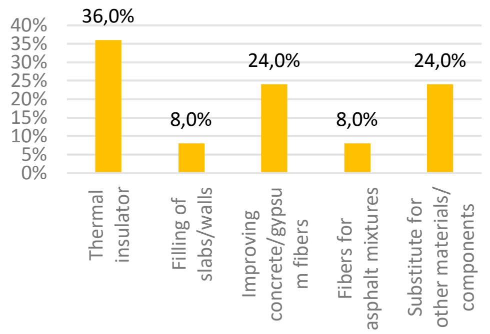


Fig. 2: *AP uses in the scientific literature.*

3.1.1 Thermal insulation

Thermal insulation is one of the biggest concerns in terms of reducing energy consumption in buildings during the operation phase and creating more comfortable conditions for users. This is crucial for the sustainability of construction, since buildings are responsible for more than a third of the world's energy consumption to maintain internal conditions of habitability [3]. To reach such building standards without increasing the associated costs or environmental impacts generated in the new insulation materials production, different AP applications have been proposed as thermal insulation, either with the use of containers in their original form or slightly modified or using the packaging as a raw material for other types of construction components.

In its original form, AP can be used directly as a thermal insulator, cutting and bending each unit to form plates or using slightly compressed containers to form air chambers and be placed into enclosures (ceiling or walls). Lefian (2014) analysed the hygrothermal performance of three different applications of AP: used with the container in its original and empty form, used in its original form and filled with plastic waste and used in its original form but compressed to create several air chambers of 2 cm inside the enclosure (multi-layered). The results indicated better performance for the latter. The study was carried out in several Chilean cities, with the multi-layered proposal even obtaining thermal transmittances below what is required by Chilean standards [14]. Fernandes et al. (2014) carried out a qualitative comfort evaluation in Brazil with AP panels cut and glued on the walls and ceilings of social housing and obtained positive results in the feeling of comfort, in addition to avoiding leaks and dirt ingress [15]. Similarly, Martini and da Trindade (2013) conducted a quantitative analysis of a similar element in residences applied in a louvre and in a false ceiling, obtaining a 17.5% reduction in indoor temperature [16].

With these same proposals of AP cut to form insulation tiles, Krüger et al. (2018) analysed this application as low emissivity sheets compared to aluminium and Expanded Polystyrene insulation (EPS) insulating materials in roofs of small safety cabins in Brazil. Their results indicated that the thermal resistance of the AP-coated face increased eight times [17]. Therefore, it is noted that the use of double sheets could be an interesting solution to improve the resistance value of surfaces and decrease heat gains, with the advantage of using twice as much cardboard. Some authors have presented certain thermal performance values that exemplify some of the quantitative advantages of AP applications. Some parameters stated have been summarised in Table 1.

However, despite the positive aspects previously reported, it is important to comment that the durability of these experiments has not been studied extensively and represents a fundamental factor in the sustainability of their application. In this sense, Sullivan et al. (2012) investigated solutions to extend the useful life of thermal insulation elements built with AP, since in their experimental studies, these presented serious problems of deterioration due to climatic causes once they were placed outside the building; thus, the authors proposed several solutions with other protection materials, such as recycled vinyl or wax [21]. Condensation is another important problem that must be taken into consideration, as reported by Lefian (2014) [14].

3.2 *Abrigando Valpo* project

Abrigando Valpo project (AVP) (Sheltering Valpo project) is a social project created by CEICC UC (The Student Coordination of the Department of Engineering and Construction Management of the Pontifical Catholic University of Chile), which addresses the problem of the poor thermal conditioning of low-income housing in Chile [35], specifically emergency housing, where a lack of thermal insulation in its envelope has decreased the quality of life of inhabitants. The AVP insulation system was proposed as a solution to improve the thermal resistance of these homes (Fig. 3).

Figure 3: *Thermally insulated emergency house with AP* [35].

Table 1*: Thermal parameters of some aseptic packaging applications and some conventional insulation materials (grey).*

Thermal conductivity λ (W/m.K)	Thermal resistance (m² K/W)	Thermal transmittance (W/m² K)	Characteristics of using aseptic packaging	Ref.
0.045	0.49	2.05	32 AP containers cut and glued together to form a layer	[19]
0.064	0.7	1.43	Wooden frame and cut AP (with air chambers)	[19]
		1.19	Tetra-brick (AP filled with plastic waste)	[14]
		0.92	Empty AP container as an insulator	[14]
		0.49	AP multi-layered, compressed containers with 2 cm air chamber	[14]
	0.7		Tectan (plate made with crushed AP glued and pressed)	[13]
0.03-0.05	1.51-1.08	0.922 (value conductance)	Plastic wood modular panels of composites with AP fibres (variation of results depends on density)	[20]
	1.95		80 mm cellulose fibre wool	[13]
0.048			Mineral wool	[20]
0.031			Styrofoam	[20]
0.027			Polyurethane foam	[20]
0.058			Vermiculite	[20]
0.032			Glass wool	[36]

AVP has worked with emergency houses sized 19 m² and 38 m² located in Valparaíso, Chile, which were insulated with AP panels as insulation against air and humidity. For emergency housing, approximately 1500 AP boxes are normally used for a house of 19 m^2 and 2500 units for a house of 38 m^2.

3.3 Analysis of AP for emergency housing

The current study analysed the technical feasibility of AP panels cut and glutted for emergency houses in Valparaiso City. First, a simple strategy for sample selection was carried out.

3.3.1 Sample selection

To identify the AP types most frequently found in Chile and to select a packaging type for the study, a survey analysis was carried out. Four commonly used supermarkets were surveyed in Santiago City, aiming to identify the types and quantities of consumer products that use AP containers. All AP packaging was characterised based on the information available on the packaging's websites. The survey campaign was then carried out. The results showed that the majority of long-lasting products (89% of the products) belonged to the AP of a specific trademark.

These AP products were divided into types of food containers, with 51% for dairy products, 33% juices, 8% alcoholic drinks and 7% for solid food. Similarly, the AP products were classified according to trademarks, which were counted in the five supermarkets surveyed, namely Tetra Brik Aseptic (TBA), Tetra Prisma Aseptic (TPA), Tetra Gemina Aseptic (TGA), Tetra Rex (TRX) and Tetra Recart (TR). TBA had the largest share with 81%, followed by TRA (3%), TGA (8%), TRX (2%) and TR (6%).

Additionally, a Google survey was conducted that aimed to describe the consumption habit of AP at home and confirm the decision of which type of AP to use. Thirty-five valid answers were obtained, confirming that the highest consumption of AP was TBA (78.5% of the answers). Finally, considering these results, the geometric regularity of the packaging, the facility to assemble the panels, the optimisation of the processes by the size of the open containers, as well as the possible waste of materials, the use of TBA packaging was considered for the laboratory test in this study. Due to their regular shape and easy modulation, AP containers of 1000 ml size were used.

3.3.2 Determination of AP thermal transmittance

In the results of the mean thermal transmittance (U) (Fig. 4), there was a significant difference between Tests 1 and 2, partly due to the small air chambers between the two panels produced by bent parts in the AP. Between Tests 2 and 3, the U difference was less significant, which could have been because a greater number of AP layers would not necessarily increase the insulation in a directly proportional way, and there may be an optimal amount of material to achieve a certain U value.

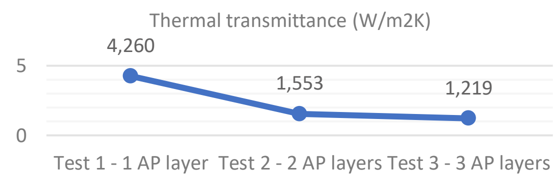


Figure 4*: Thermal transmittance of the three panels tested.*

3.3.3 Comparison of AP with conventional insulation

Table 2 shows that the optimal application of AP (thermal resistance) is even less thermally efficient than conventional insulation, despite presenting a high relative value. However, calculating the U values for the whole wall of an emergency house designed with two 15 cm-oriented strand board (OSB) panels thermally insulated with AP, this study stated that the six alternatives (Table 3) met the current mandatory national standard or General Urban Planning and Construction Ordinance (OGUC by its Spanish acronym), required for thermal zone 2 (Valparaíso City). Nevertheless, the AP walls did not meet the new recommended national standard, even though the AP panel (three layers) had values close to those recommended.

***Table 2**: AP thermal resistance compared with other research and conventional insulation materials (grey).*

AP panel tested	Thermal resistance (R) m²K/W	Ref.
AP panel (1 layer)	0.44	-
AP panel (2 layers)	0.64	-
AP panel (3 layers)	0.82	-
Cylindrical AP filled with plastic bags used as insulation 'blocks'	0.64	[14]
Empty AP used as insulation 'blocks'	0.82	[14]
40 mm glass wool	1.2	[36]

***Table 3**: Compliance of walls (same order as Table 1) with the current Chilean standard (W/m²K).*

U value of the wall	U value for Valparaíso ECS (recommended)	U value for Valparaíso OGUC (mandatory)
1.35	0.8	3
1.06	0.8	3
0.89	0.8	3
1.37	0.8	3
1.03	0.8	3
0.66	0.8	3

4. CONCLUSION

From the literature review carried out, it was concluded that there are at least five potential uses of AP in the construction industry: as a thermal insulator, filling slabs or walls, improving fibres in concrete, as fibres in asphalt mixtures and as a substitute for other materials or components. Some of these, such as insulating material, have mostly been explored by researchers for their intrinsic composition of insulating layers and the presence of aluminium. In addition, their use as fibres in asphalt mixtures has great potential to mitigate the final disposal of APs, as the consumption of AP waste for this purpose could reach very high volumes, absorbing a large amount of waste generated. Thus, it has been found that the use of recycled AP represents a promising option, depending on the socio-economic, technological or cultural context where it is to be applied. It will also depend on the supply and demand of the product, since it is necessary to connect the production chain, from the final disposal of the AP after its primary use in food to the correct discarding by society, as well as the correct selection and reuse in the extension of AP's embodied energy.

Regarding the applicability of AP reuse or recycling as insulation, the low thermal transmittance values show an essential benefit as a thermal insulator, as shown by the literature on different alternatives and the three types of uses assessed in the current study. Despite this, other critical technical aspects, such as durability, fire resistance, vulnerability to interstitial condensation and others, could be compromised. Furthermore, it is still necessary to conduct new research to prove AP as thermal insulation comply the standards recommended for some cities in Chile. Thus, without scientific studies that demonstrate compliance with these requirements, the application of AP as an insulator is restricted to temporary uses, such as in emergency housing.

ACKNOWLEDGEMENTS

This work was funded by the National Agency for Research and Development (ANID)/Scholarship Program/DOCTORADO BECAS CHILE/2020–21201032; ANID BASAL FB210015 CENAMAD; and ANID FONDECYT 1201052.

REFERENCES

[1] M. Yeheyis, K. Hewage, M. S. Alam, C. Eskicioglu, and R. Sadiq, "An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability," *Clean Technol. Environ. Policy*, vol. 15, no. 1, pp. 81–91, Feb. 2013.

[2] M. U. Hossain and S. T. Ng, "Critical consideration of buildings' environmental impact assessment towards adoption of circular economy: An analytical review," *J. Clean. Prod.*, vol. 205, pp. 763–780, Dec. 2018.

[3] UNEP, "Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector," Nairobi, 2020. [Online]. Available: https://wedocs.unep.org/bitstream/.

[4] C. N. P. Nunes *et al.*, "O Uso De Placas De Tetrapak Como Uma Alternativa Sustentável Na," pp. 64–69, 2009.

[5] C. Cimpan, A. Maul, M. Jansen, T. Pretz b, and H. Wenzel, "Central sorting and recovery of MSW recyclable materials: A review of technological state-of-the-art, cases, practice and implications for materials recycling," *J. Environ. Manage.*, vol. 156, pp. 181–199, Jun. 2015.

[6] TETRAPAK, "Acontecimientos y cifras de Tetra Pak, incluidos los resultados del desempeño financiero," 2019. https://www.tetrapak.com/ (accessed Sep. 08, 2019).

[7] S. A. Martínez, "Diseño conceptual de máquina generadora de bloques o ladrillos para construcción en base al reciclaje de Tetra Pak ®," UTFSM, 2016.

[8] E. L. Krüger, G. Suetake, and A. Matoski, "Evaluation of the thermal performance of insulation sheets in fiberglass security booths," *Build. Environ.*, vol. 136, no. February, pp. 1–10, 2018.

[9] G. Martínez-Barrera *et al.*, "Recycled cellulose from Tetra Pak packaging as reinforcement of polyester based composites," *Constr. Build. Mater.*, vol. 157, pp. 1018–1023, 2017.

[10] V. C. Andrés-Valeri, J. Rodriguez-Torres, M. A. Calzada-Perez, and J. Rodriguez-Hernandez, "Exploratory study of porous asphalt mixtures with additions of reclaimed tetra pak material," *Constr. Build. Mater.*, vol. 160, pp. 233–239, 2018.

[11] A. Vargas, B. V. Silva, M. R. Rocha, and F. Pelisser, "Precast slabs using recyclable packaging as flooring support elements," *J. Clean. Prod.*, vol. 66, pp. 92–100, 2014.

[12] P. B. Crowley and J. Delfico, *Content analysis: a methodology for structuring and analyzing written material*. Washington, D.C., 1996.

[13] M. A. Aguilar and M. Caucamán, "Materiales innovadores: Comportamiento térmico en la vivienda de Punta Arenas," Universiad de Magallanes, 2010.

[14] A. Lefian, "Aislamiento Termico Alternativo. Analisis del comportamiento tecnico e higrometrico de los ecoladrillos y tetraladrillos a la vivienda de emergencia en Chile," Universidad Politecnica de Cataluña, 2014.

[15] J. Fernandes, R. Jaqueline Danielewicz, and J. Secco, "Isolamento Térmico De Residências Através Da Reutilização De Embalagens Tetra Pak," *Rev. Bras. e Extensão Tecnológica*, vol. 2695, no. 2, pp. 77–80, 2014.

[16] D. Martini and T. Q. da Trindade, "Modelagem matemática da reflexão da radiação solar utilizando embalagens tetra pak® como isolante térmico," in *XXXII Congresso Nacional de Matemática Aplicada e Computacional*, 2013, vol. 214.

[17] E. L. Krüger *et al.*, "Evaluation of the thermal performance of insulation sheets in fiberglass security booths," *Build. Environ.*, vol. 136, no. February, pp. 1–10, 2018.

[18] F. C. Antico, M. J. Wiener, G. Araya-Letelier, and R. G. Retamal, "Eco-bricks: A sustainable substitute for construction materials," *Rev. la Constr.*, vol. 16, no. 3, pp. 518–526, 2017.

[19] G. Vieira and M. P. de P. Sousa Lima, "Thermal Performance of Tetra Pak Package as a Ceiling Material Thermal Performance of Tetra Pak Package as a Ceiling Material," no. July, 2018.

[20] S. Gao, Q. Y. Li, and Y. W. Zhang, "Experimental research on the thermal insulation and flame retardancy performance of WPC wallboard made of Paper-Aluminum-Plastics wastes," *Appl. Mech. Mater.*, vol. 34–35, pp. 1676–1680, 2010.

[21] D. Sullivan *et al.*, "Environmentally Friendly Roofing Materials in Chiang Mai," 2012. Accessed: Sep. 22, 2019. [Online]. Available: https://web.wpi.edu/Pubs/E-project/Available/E-project-022912-235710/unrestricted/Environmentally_Friendly_Roofing_Materials_in_Chiang_Mai.pdf.

[22] R. Jan and S. Mancik, "Environmental Assessment of Building Structures – Case Study," in *LEHM 2012, 6th International Conference on Building with Earth*, 2012, no. July.

[23] G. Barrera, J. B. Hernández Zaragoza, T. López Lara, and C. Menchaca Campos, *Materiales sustentables y reciclados en la construcción*. 2015.

[24] M. Quintero, P. Rodríguez, J. Rubio, and L. Jaramillo, "Bending and compression characterization of hollow structural elements made of recycled Tetra Pak ® - Based Boards (RTPBB) and an approximated calculation of the carbon footprint involved in their production," *Rev. Ing. Construcción*, vol. 32, pp. 131–148, 2017.

[25] T. Hamouda, A. H. Hassanin, N. Saba, M. Demirelli, A. Kilic, and Z. Candan, "Evaluation of Mechanical and Physical Properties of Hybrid Composites from Food Packaging and Textiles Wastes," *J. Polym. Environ.*, vol. 0, no. 0, p. 0, 2019.

[26] J. Wood *et al.*, "Microstructure and compressive strength of gypsum - bonded composites with papers, paperboards and Tetra Pak recycled materials," *J. Wood Sci.*, 2019.

[27] G. Martínez-barrera, J. José, M. Alonso-martínez, and M. Martínez-lópez, "Case Studies in Construction Materials Lamellae of waste beverage packaging (Tetra Pak) and gamma radiation as tools for improvement of concrete," vol. 12, 2020.

[28] H. K. K. Ajam, "Utilization of Shredded Tetra-Pak in Hot Mix Asphalt," *AL-Qadisiya J. Eng. Sci.*, vol. 6, no. 3, pp. 287–293, 2013.

[29] M. Cajas, "Propuesta De Desarrollo De Un Material Para Construcción Utilizando Empaque Tetra Pak Como Componente Principal Y Su Aplicación En El Diseño Para La Optimización De Espacios En Escuela Pública Tula Ortega," UNIVERSIDAD RAFAEL LANDIVAR, 2011.

[30] V. Ondrejka and N. F. Centre, "Sound absorption on board construction materials used in wood buildings," no. March 2021, 2020.

[31] S. Habibi, O. Pons, and T. Abt, "Evaluation of household waste materials for façade components in primary educational workshops . Degradation behavior and mechanical properties of aged samples," *J. Build. Eng.*, vol. 33, no. July 2020, p. 101573, 2021.

[32] D. C. Araújo, C. R. S. Morais, and M. E. D. Altides, "Avaliação mecânica e físico-química entre telhas convencionais e alternativas usadas em habitações populares," *Rev. Eletrônica Mater. e Process.*, vol. 2, pp. 50–56, 2008.

[33] L. Domínguez and D. Guemez-Pacheco, "Fabricación y evaluación de paneles aplicables a la industria de la construcción a partir del reciclaje de envases multicapa (tetra brik)," *Ingeniería*, vol. 14, no. 3, pp. 191–195, 2010.

[34] A. H. Hassanin and Z. Candan, "Novel bio-based composites panels from TetraPak waste," *Key Eng. Mater.*, vol. 689, pp. 138–142, 2016.

[35] CEICC, "Proyecto social 'Abrigando Valpo,'" *Proyecto Social 'Abrigando Valpo' (Alumnos UC)*, 2019. https://www.ing.uc.cl/ingenieria-y-gestion-construccion/proyecto-social-abrigando-valpo-alumnos-uc/ (accessed Aug. 11, 2019).

[36] ENVIRODEC, "DECLARACIÓN AMBIENTAL DE PRODUCTO Acustiver R," 2017. [Online]. Available: https://www.isover.com.ar/productos/acustiver-r.

PLEA SANTIAGO 2022
Will Cities Survive?

The potential of wall thermosiphon to reduce heat generated by internal charge density in residential bedrooms

FERNANDO DA SILVA ALMEIDA[1] MARIANE PINTO BRANDALISE[1] LUIS HERNÁN RODRÍGUEZ CISTERNA[2] MÁRCIA BARBOSA HENRIQUES MANTELLI[1] MARTIN ORDENES MIZGIER[1]

[1] Universidade Federal de Santa Catarina
[2] Universidad de Tarapacá

ABSTRACT: Thermosiphon and heat pipes are alternatives to passive air conditioning because of their heat transfer capability. Thus, this article has the objective is to evaluate through analytical simulations, using the MatLab software, different external and internal heat transfer coefficients (h), so that a wall thermosyphon this may be capable of passively to reduce heat generated by internal charge density in residential bedrooms in the city of Florianópolis-Brazil of climate humid subtropical (Cfa), for summer. In the results obtained, it was observed that the thermosyphon array showed to be capable of passively transferring heat between environments the internal and external, in housing applications, however, observations must be made. Where the array was simulated only with the tubes, in cases where Δt is equal to 1 and 4, there is difficulty in the proposed strategy, especially when the external convective coefficients are less than or equal to 25 W/(m²K), enlarging surfaces to transfer the heat generated would be an alternative. Already when the external heat transfer coefficients are greater than 100 W/(m²K), the internal coefficients are smaller what 10 W/(m²K), in this context, the use of water as a means of heat exchange proved to be the best alternative for the condenser.
KEYWORDS: Wall Thermosiphon, Passive solutions, Internal charge density, MatLab.

1. INTRODUCTION

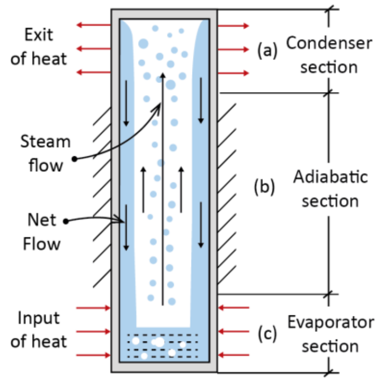
According to studies by the International Energy Agency (IEA) [1], around 40% of the energy consumed in the world is related to buildings. In Brazil, only the residential sector uses 27,6% of all electricity produced in the country [2]. Among the aspects that influence energy consumption, there are active air conditioning solutions (air conditioners, electric fans, exhaust fans, air exchangers, heating, among others), which are currently widely used in homes and non-domestic buildings. Thus, it is expected the development of more efficient projects, which can reduce the environmental impact associated with the construction and use of buildings, reducing energy demand, and improving the thermal comfort of occupants through the incorporation of passive architectural strategies [3].

Therefore, new passive solutions are increasingly being studied, an example of which can be the use of two-phase thermosyphons and heat tubes in walls [4], [5], [6], and [7]. Integrated into the seals, these systems have three main denominations: (1) Wall Implanted with Heat Pipes - WIHP; (2) Wall Thermosyphon - WT; e (3) Trombe Wall Implanted with Heat Pipes - TIHP. Such technology can contribute to minimize energy consumption by air conditioning and its consequences on environmental degradation and greenhouse gas emissions [8].

Thermosyphons are considered to be very efficient elements concerning heat transfer, transmitting a large amount of heat, without additional energy consumption, even when the temperature difference is low [9]. According to Alizadehdakhel *et al.* [10] (p. 312) "simplicity of design, high heat transfer rate, one-sided heat transfer (thermal diode), low cost, low weight, low maintenance cost, etc." make this equipment more promising for incorporation in buildings.

These devices are formed by three parts, the evaporator, adiabatic, and condenser sections. The evaporator is installed below the condenser to allow the condensed fluid to return to the gravity evaporation section. The heat exchanges of these devices are caused by the phase change of the liquid in the evaporating and condensing sections. In this sense, the working fluid is evaporated as it absorbs a given amount of heat equivalent to the latent heat of vaporization (Figure 1c), causing an increase in the vapor pressure inside the tube cavity. This difference in vapor pressure, present at the end of the evaporator and condenser, causes a pressure gradient in the vapor core that causes the vapor to transport upwards to the condenser. In this process, the vapor is converted into liquid, neglecting its latent heat of condensation, and raising the temperature of the condenser end (Figure 1a), in this way, the condensed liquid returns to the evaporation section as a thin film on the tube wall through of gravity [11] and [12].

Figure 1:
Gravity-assisted two-phase closed thermosiphon



Note: Adapted from Zhong and Ji, [12].

For this work, a wall thermosyphon (WT) is incorporated in a bedroom, with the evaporator inside the room, while the condenser is located outside. The objective is to evaluate through analytical simulations, using the MatLab software, different external and internal heat transfer coefficients (h), so that a wall thermosyphon may be capable of passively to reduce heat generated by internal charge density in residential bedrooms in the city of Florianópolis-Brazil of climate humid subtropical (Cfa), for summer.

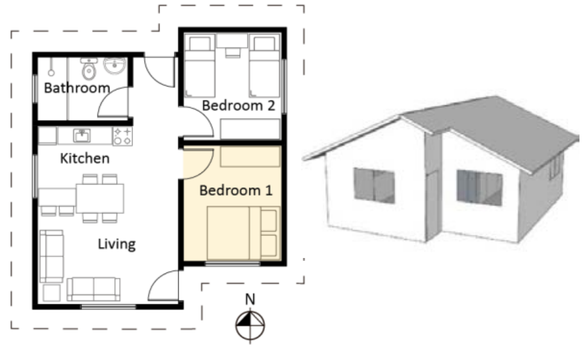
2. METHOD

The Methodology of this work is always in four stages: 2.1 The object of study, characterizing the study environment1; 2.2 Modeling presents a code developed from models defined from models, 2 Correlations of linear computing models, as well as linear adjustment parameters and employee variables, from modeling; 2.3 Criteria for determining wall thermosyphon; 2.4 Simulation processing, which concerns the method used in the simulations through the MATLAB software and offered for the results.

2.1 Study object

Florianópolis, the capital of the state of Santa Catarina, is located in the southern region of Brazil, has a latitude of 27.7 ° S, longitude 48.5° W and altitude 7m above sea level, its climate is determined as Cfa, according to the Köppen-Geiger classification. For this study, a long-term environment (bedroom 1), which has a ceiling height of 2.50 m, a width of 2.60 m and length of 3.10 m, totaling an area of 8.07 m², Figure 2. The chosen environment was defined from a base case obtained through studies carried out by Triana *et al.* [13]. This reference model concerns an isolated single-family house, which represented 35% of the sample for the family income level of 1 to three minimum wages in Brazil.

Figure 2:
Representative project for the detached house



Note: Adapted from Triana *et al.* [13].

From the sum of heat gain by occupation, artificial lighting and equipment, the internal charge density of the room was determined, obtaining 329.19W, such data were based on ISO 7730 [14] and NBR 16401-1 [15].

2.2 Computer modeling

A numerical modeling approach in steady-state is considered in this study, using MatLab software, such regime is also used by other authors to study the application of thermosyphons in the envelope [4], [16]. In modeling the device using the software, it is considered that the heat is transferred through the thermosyphon by two thermal resistances in series: boiling and condensation, which models are available in the literature [17].

The use of fins, which are extended, flat and annular surfaces externally connected to the thermosiphon tubes, to increase the natural convection heat transfer rate to the environment, is considered in the numerical code. The idea is to reduce the heat transferred from the external to the internal house environment, offering more thermal comfort and, for that, the heat transfer coefficients evaluated by the software, are needed [18], if the use of tubes alone is not enough to reduce heat.

In this context, the fixed parameters modeled in the Code are shown in Table 1, which follows:

Table 1:
Fixed parameters related to thermosyphon design

Symbol	Description	Value
k	Thermal conductivity of tubes and fins (copper)	380 W/(mK)
q_m	Maximum internal charge density	329,19 W

t_{int}	Constant module internal temperature	296,15K = 23°C
L_c	Condenser length	2,00 m
L_c	Evaporator length	2,50 m
d_i	Outside diameter of evaporator and condenser	$25{,}4 \times 10^{-3}$ m
d_o	Internal diameter of evaporator and condenser	$21{,}4 \times 10^{-3}$ m
	Evaporator fill factor	0,6
t	Flat fin thickness	2×10^{-3} m
w	Flat fin width	40×10^{-3} m
L_{tc}	Length lost in annular fin fabrication	15×10^{-3} m
t_{ae}	Annular fin thickness	3×10^{-4} m
d_{ac}	Annular fin diameter	60×10^{-3} m

The refrigerant R141b was selected for this study, as it was used in other studies that proposed wall thermosyphons for buildings [5] and [19]. The fluid has significant heat transfer capacity and needs a smaller tube wall thickness compared to other fluids, which means lower merit number and lower vapor pressure. In addition, the refrigerant is compatible with the material of the tubes and does not present flammability toxicity, fundamental parameters for incorporation in buildings.

Another fixed parameter established for the simulations concerns the temperature to be reached inside the model with the incorporation of the two-phase thermosiphon in the circuit. In this study, this variable was determined at 23 °C, because according to ASHREA 55 [20], this value is the recommended one to achieve acceptable thermal comfort for occupants of an indoor environment.

As for the variable parameters, it was decided to change: the number of tubes in the evaporator and condenser sections; the internal and external air temperature differences of the module (ΔT) in K; and the number of flat and annular fins. Among these parameters, the temperatures of the external air were determined taking into account the internal temperature to be reached in the module (23 °C), thus, as it is a passive system, values lower than tin were defined, namely: 22, 20, 18 and 16 °C.

2.3 Criteria for determination of WT

In order to define the number of tubes in the thermosiphon array and assess its applicability to passively reduce heat generated by the internal load density of the bedroom, the heat transferred by the device, between the internal and external environments, where it is inserted, is evaluated. Therefore, the natural convection heat transfer coefficients (h) are analyzed, using correlations presented by Incropera *et al*. [18], who show that, for gases (air) in natural convection, the heat transfer coefficient must range between 2 to 25 W/(m²K), while for liquids (water) it must vary between 50 to 1000 W/(m²K). In this scenario, for cases that obtain results with coefficients below 25 W/(m²K), the device's passive heat exchanges can occur from the use of air, while for results above 25 W/(m²K), water becomes up a design alternative.

Another key factor established was the maximum number of tubes to be implanted in the dormitory wall. For this study, it was decided to occupy the east wall, which is 3.10m long. In this context, considering the external diameter of the heat pipes and the minimum spacing of 50×10^{-3}m between them, the maximum number of pipes would be 40. In addition, the dimensions of the annular and flat fins were also considered in the determination of the set, since that, with the addition of these surfaces to the tubes, it is possible to install a maximum of 30 finned tubes, since the annular fins have a diameter of 60×10^{-3}m, in addition to respecting the spacing of 40×10^{-3}m between the pieces.

It is also added as a system implementation criterion, the maximum amount of fins installed in the tube, with regard to the annular ones, they are 3×10^{-4}m thick, in this way, 80 fins can be implemented, respecting a minimum spacing of 22×10^{-4}m between them in a length of 2,00m. Regarding the flat fins, for this research the maximum number considered in the evaporator section was 24, since a higher number of fins could interfere with the fabrication or adequate performance of the system.

2.4 Simulation processing

The simulation processing was divided into two main stages:

1. Number of tubes - 12 simulations were carried out, considering as parameters of variations (1) the number of tubes, 40, 35, and 30 tubes; and (2) the ΔT of 1, 3, 5, and 7, which correspond to the difference between the internal and external temperature, respectively, changing the temperature of the external air by 22, 20, 18, and 16 °C. Next, it was asked if the results provided in the 12 initial tests respected the criterion of ≤25 W/(m²K), which deals with the internal and external heat transfer coefficients, if the condition were respected, the process would move to the last phase, where the decrease in the number of tubes was established, considering the previous criterion. However, if the decision were not confirmed, the convergence of the simulations would proceed to the next step.

2. Addition of fins - at the end of the previous stage, annular and flat fins were added to the condenser and evaporator, respectively, to increase the heat transfer area and reduce the convective coefficients. For this purpose, 40 annular fins and 8 flat fins were fixed per tube and the number of tubes (20, 25, and 30) and the ΔT (1, 3, 5, and 7) were differentiated. If the situation were established and obeyed, the results would be stored refinements and the set would be conducted. However, if there are integrated, being more complex, 60 fins to the condenser and 16 to the evaporator. This process until it can define convective coefficients ≤ 25 W/(m²K), or up to the limit of the number of fins installed in the evaporator and condenser, which were 24 and 80, respectively.

3. RESULTS

Tables 2 to 5 present the results of the internal heat transfer coefficients (corresponding to the external coefficients (hext) of 5, 10, 20, 25, 50 and 100 W/(m²K). The tests presented in Table 2 represent the differences between the temperature of the indoor air, determined by the evaporator section (as a constant to be reached of 23°C) and the temperature of the outdoor air (assumed, for these simulations, at 22, 20, 18 and 16°C, which correspond to at ΔT of 7, 5, 3 and 1). In this scenario, the data in Table 2, that in only nine situations, the convective coefficients 25W/(m²K), for the interior and exterior of the environment occurred simultaneously, being these in situations with conditions with ΔT 7, for the tests with 30, 35 and 40 tubes and, ΔT 5, with 35 and 40 tubes. On other occasions, it was not possible to reach the objective that the internal heat reached a constant temperature of 23°C, using natural convective principles.

Table 2:
h_{int} results varying the ΔT (1, 3, 5 and 7) and number of tubes (30, 35 and 40)

	Case	External heat transfer coefficient W/(m²K) 5	10	20	25	50	100
30 tubes	C01-ΔT:1	-	-	-	-	-	243
	C02-ΔT:3	-	-	-	-	37,20	25,40
	C03-ΔT:5	-	-	41,10	27,00	15,90	13,30
	C04-ΔT:7	-	-	16,7	13,6	10,3	8,89
35 tubes	C05-ΔT:1	-	-	-	-	-	137
	C06-ΔT:3	-	-	-	94,40	27,80	20,20
	C07-ΔT:5	-	-	25,70	18,90	12,90	11,10
	C08-ΔT:7	-	57,40	12,50	10,70	8,53	7,64
40 tubes	C09-ΔT:1	-	-	-	-	-	93,30
	C10-ΔT:3	-	-	148	50,60	23,20	17,10
	C11-ΔT:5	-	-	14,90	18,40	10,80	9,15
	C12-ΔT:7	-	26,30	9,94	8,80	7,03	6,41

A factor to be considered in this evaluation is obtaining coefficients below 25W/(m²K) when the h_{ext} presents themselves with 50 and 100 W/(m²K), which shows the potential of the device. However, only with the installation of tubes, in most cases, the results are lower than established. That said, the next simulations were performed using surfaces extended to the tubes. In which, 40 annular fins were added to the condenser, and 8 flat fins to the evaporator, in order to increase the heat transfer areas of the set. However, considering the width of the flat fins and the diameter of the annular fins, the variations in the number of tubes were changed to 30, 25 and 20, while the ΔT variations were maintained.

From Table 3, it can be seen that with the addition of fins there was an improvement in relation to the previous results. In tests C16, C19, C20, C23 and C24, for example, results of internal and external convective coefficients lower than 25 W/(m²K) were collected.

Table 3:
h_{int} results by fixing 40 annular and 8 flat fins, and varying the ΔT (1, 3, 5 and 7) and number of tubes (20, 25 and 30)

	Case	External heat transfer coefficient W/(m²K) 5	10	20	25	50	100
20 tubes	C13-ΔT:1	-	-	-	-	31,40	15,50
	C14-ΔT:3	-	98,40	6,03	5,28	4.03	3.54
	C15-ΔT:5	-	4,34	2,63	2,44	2,14	1,94
	C16-ΔT:7	6,81	2,25	1,69	1,60	1,46	1,37
25 tubes	C17-ΔT:1	-	-	-	-	16,40	11,10
	C18-ΔT:3	-	10,08	4,13	3,65	2,96	2,71
	C19-ΔT:5	15,12	2,72	1,88	1,78	1,61	1,52
	C20-ΔT:7	2,95	1,61	1,29	1,24	1,14	1,09
30 tubes	C21-ΔT:1	-	-	-	38,40	11,20	8,32
	C22-ΔT:3	-	5,67	3,08	2,73	2,40	2,21
	C23-ΔT:5	4,95	1,97	1,47	1,46	1,33	1,28
	C24-ΔT:7	1,91	1,24	1,01	0,98	0,95	0,91

As for the simulations with ΔT 3, the external convective coefficients superior than 10 W/(m²K) were within the defined criteria. Another important aspect to be highlighted is that,

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

like the previous combinations, when the h_{ext} is presented with 50 and 100 W/(m²K), results lower than 25W/(m²K) are acquired in almost all the simulations performed.

For the next simulations, it was decided to discard the results within the established criteria. Therefore, the results are presented in Table 4, with the same variations performed in Table 3, however, 20 more annular fins were added to the condenser and 8 flat fins to the evaporator, totaling 60 and 16 fins, respectively. As in previous simulations, the results did not allow for what was determined; however, with external coefficient above 50 W/(m²K), the results were less than 25 W/(m²K), when 30 or 25 finned tubes were installed. In tests C31 and C27, all results had coefficients lower than 25 W/(m²K).

It is also noted that in the tests for ΔT 3, with 20 and 25 finned tubes, the definition was not reached only for the coefficient of 5 W/(m²K). In this scenario, it is important to highlight that authors present in the literature, such as Wang et al. [21] and Yu et al. [22] use 20 W/m²K) for external coefficients and 10 W/(m²K) for internal coefficients in heat transfer studies in environments that use natural convection, showing the passive potential of the system.

Table 4:
h_{int} results by fixing 60 annular and 16 flat fins, and varying the ΔT (1, 3 and 5) and number of tubes (20, 25 and 30)

		External heat transfer coefficient W/(m²K)					
	Case	5	10	20	25	50	100
20 tubes	C25-ΔT:1	-	-	-	86,80	9,30	6,13
	C26-ΔT:3	-	5,56	2,90	2,36	1,90	1,74
	C27-ΔT:5	1,01	1,07	1,19	1,26	1,72	5,61
25 tubes	C28-ΔT:1	-	-	45,4	15,5	6,61	4,94
	C29-ΔT:3	-	3,01	1,85	1,73	1,47	1,38
30 tubes	C30-ΔT:1	-	-	13,50	8,58	5,06	4,12
	C31-ΔT:3	13,40	1,98	1,42	1,39	1,23	1,17

Finally, in Table 5, the last 6 tests were performed, adding annular and flat fins to the tubes, which totaled 80 and 24 fins, respectively. With the addition of these extended surfaces, the simulations C34 and C34, corresponded to the coefficients indicated by Incropera et al. [18] by using natural convection. For simulations C33, C35 and C37, with external coefficients of 20 and 25 W/(m²K), coefficients ≤10 W/(m²K) can be obtained. While, once again, the results for ΔT 1, in all cases, do not correspond to the criteria defined for 5 and 10 W/(m²K).

Table 5:
h_{int} results by fixing 80 annular and 16 flat fins, and varying the ΔT (1, 3 and) and number of tubes (20, 25 and 30)

		External heat transfer coefficient W/(m²K)					
	Case	5	10	20	25	50	100
20 tubes	C32-ΔT:1	-	-	29,70	10,30	4,39	3,35
	C33-ΔT:3	-	1,92	1,52	1,14	0,98	0,95
	C34-ΔT:5	1,55	0,96	0,92	0,89	0,84	0,81
25 tubes	C35-ΔT:1	-	-	7,46	5,07	3,05	2.53
	C36-ΔT:3	5,17	1,22	0,95	0,92	0,90	0,87
30	C37-ΔT:1	-	-	4,28	3,36	2,36	2,04

Therefore, considering the results presented in this section, it can be determined that the thermosyphon set proved to be capable of extracting heat from an environment, using the defined criterion. It is worth mentioning that in situations where ΔT is equal to 1, the proposed strategy is difficult, requiring an increase in the number of finned tubes to achieve the objective, especially when the convective coefficients are less than or equal to 10 W/(m²K).

Furthermore, with the addition of the extended surfaces to the tubes, it can be seen that this was an important strategy to reduce the convective coefficients. Finally, mention that the results not achieved do not rule out the potential use of the thermosyphon set.

Thus, to indicate the implementation of the system in the architecture, in addition to allowing the device to operate with ΔT, close to or equal to 1, there are some deductions (evidence): (1) increase the external coefficients, from the use of liquids as convection Natural; (2) create a passive indoor air circulation system, so that the air does not become stagnant during the operating process, and improve the performance of the set for critical situations, such as ΔT of 1; and (3) allow alternatives for the condensation region, since this possibility has more arrangements and workability as it is located in the external environment of the building.

4. CONCLUSION

The main objective of this work is to evaluate the potential of a two-phase thermosif installed in a vertical fence in the interest of a dormitory in a social housing. From the results presented, it can be seen that the thermosyphon array showed to be capable of passively transferring heat between the internal and external environments, in housing applications, however, observations must be made. Where the array was simulated only with the tubes, in cases where Δt is equal to 1 and 4, there is difficulty in the proposed strategy, especially when the external convective coefficients are less than or equal to 25 W/(m²K), enlarging surfaces to transfer the heat generated would be an alternative.

Already when the external heat transfer coefficients are greater than 100 W/(m²K), the internal coefficients are smaller than 10 W/(m²K), in this context, the use of water as a means of heat exchange proved to be the best alternative for the condenser, in this context, it would be advisable to allow this section to be connected to a water tank to capture the generated heat more efficiently.

REFERENCES

1. International Energy Agency (2021). Global Status Report for Buildings and Construction. Available: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-601/topico-596/BEN2021.pdf [08 January de 2021].
2. Empresa de Pesquisa Energética (2020). Balanço Energético Nacional. Available: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2020 [15 January de 2021].
3. Bhamare, D. K. *et al.* (2019). Passive cooling techniques for building and their applicability in different climatic zones - The state of art. *Energy And Buildings*, 198: p. 467-490.
4. Zhang, Z. *et al.* (2014). A new type of passive solar energy utilization technology-The wall implanted with heat pipes. *Energy And Buildings*, 84: p. 111-116.
5. Fantozzi, F. *et al.* (2017) An Innovative Enhanced Wall to Reduce the Energy Demand in Buildings. *Journal Of Physics: Conference Series*: 796, p. 012043-012054.
6. Zhang, Z. *et al.* (2019). Dynamic heat transfer analysis of the wall implanted with heat pipes in summer. *Advances In Building Energy Research*: 26, p. 403-423.
7. Wei, H. *et al.* (2019) Experimental study on the performance of a novel RC-PCM-wall. *Energy and Buildings*: 199, p. 297-310.
8. Li, Z. and Zhang, Z (2014). Dynamic heat transfer characteristics of wall implanted with heat pipes in summer. *Energy And Buildings*: 170, p. 40-46.
9. Noie, S. H. (2005). Heat transfer characteristics of a two-phase closed thermosyphon. *Applied Thermal Engineering*, 25: p. 495-506.
10. Alizadehdakhel, A. *et al.* (2010). CFD modeling of flow and heat transfer in a thermosyphon. International Communications In Heat And Mass Transfer, 37: p. 312-318.
11. Ahmed, I. S. and Jubori, A. M. A. (2020). Assessment of heat transfer and flow characteristics of a two-phase closed thermosiphon. Heat Transfer, 50: p. 1351-1370.
12. Zhou, L. and Li, C (2021). Study on thermal and energy-saving performances of pipe-embedded wall utilizing low-grade energy. *Applied Thermal Engineering*, 176: p. 115477-115498.
13. Triana, M. *et al.* (2015). Characterisation of representative building typologies for social housing projects in Brazil and its energy performance. *Energy Policy*, 87: p. 524-541.
14. ISO 7730 (2005). Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Genebra: International Organization for Standardization.
15. Brazilian Association of Technical Standards. NBR 16401: Air conditioning installations - Central and unitary. Rio de Janeiro, 2008.
16. Tan, R. and Zhang, Z. (2016). Heat pipe structure on heat transfer and energy saving performance of the wall implanted with heat pipes during the heating season. *Applied Thermal Engineering*, 102: p .633-640.
17. Mantelli, M. B. H. (2021). Thermosyphons and Heat Pipes: theory and applications. p. 413.
18. Incropera, F. P., *et al.* (2012). Fundamentos de transferência de calor e de massa. p. 643.
19. Bellani, P. *et al.* (2019). Theoretical and experimental analyses of the thermal resistance of a loop thermosyphon for passive solar heating of buildings. *Interfacial Phenomena And Heat Transfer*, 7: p. 57-68.
20. ASHRAE, AMERICAN SOCIETY OF HEATINGREFRIGERATING AND AIR CONDITIONING ENGINEERS (2020). ASHRAE Standard. 55: Thermal Environmental Conditions for Human Occupancy.
21. Wang, Q. *et al.* (2018). Parametric analysis of using PCM walls for heating loads reduction. *Energy And Buildings*, 172: p. 328-336.
22. Yu, C. *et al.* (2021). Parametric analysis of the phase change material wall combining with micro-channel heat pipe and sky radiative cooling technology. *Renewable Energy*, 178: p. 1057-1069.

PLEA STGO 2022
WILL CITIES SURVIVE? SUSTAINABLE ARCHITECTURAL DESIGN

Development of accessibility evaluation checklists for public sports facilities

On the basis of assessment criteria for Barrier-Free (BF) certification in the Republic of Korea

SI-YEON BAEK[1], YOONG-HO BAE[1], JIN-CHEOL KIM[2], SUNG-WAN KIM[1], AND KYUNG-HOI LEE[1]

[1] Korea Research Institute of Eco-Environmental Architecture, Republic of Korea
[2] DanDan Architecture, Republic of Korea

ABSTRACT: This study includes accessibility requirements to support facility users with various impairments. The checklists in this study have been developed by focusing on indoor sports facilities such as swimming, badminton, table tennis, basketball, and volleyball, which are representative and popular sports in Korea. The accessibility evaluation checklist in the research has been designed for "Excellent Para-sports Facilities" and "Disability-friendly Sports Facilities" to establish suitable accessibility evaluation checklists for each facility.
KEYWORDS: Accessibility, Para-Sports Facilities, Disability-friendly Sports Facilities, Barrier-Free, Universal Design

1. INTRODUCTION
1.1 The significance of this study

Sports activities are social and cultural activities that not only improve participants' physical strength but also provide a sense of accomplishment and confidence that reminds people that they are members of a society through cooperation. In particular, for people with disabilities, physical activity can help prevent the decline of functionality caused by their impairment and can enhance their other physical capabilities. This could include social means that help maintain positive human relationships and improve social adaptative abilities. Thus, an important role of society is to provide barrier-free sports facilities that promote universal equity.

Enabling everyone to engage in sports equally requires improving social awareness and providing facilities without obstacles. Despite the growing interest in daily sports activities regardless of disability, it is often still difficult for the disabled to use sports facilities independently and voluntarily and to socialize with people in their communities.

The purpose of this study is to realize a society without any obstacles by preparing an evaluation checklist for a specific facility type, sports facilities, instead of a consistent approach to the issue.

1.2 Background on the Accessibility of Sports Facilities

Korean society has evolved over a long period of time to create "Barrier-free Buildings" and accessibility rights have been legally guaranteed by laws, regulations, certifications, and so forth.

1. The Act on Guarantee of Promotion of Convenience of Persons with Disabilities, the aged, Pregnant Women (Act on the Promotion of Convenience)

This Act was enacted in 1997 and has been in effect since 1998 to contribute to the promotion of social activities and welfare of the disabled, the elderly, pregnant women, etc. by ensuring that they can safely and conveniently use facilities and access information in their daily lives.

2. Barrier-free (BF) Certificate

As the Act on the Guarantee of Promotion of Convenience of Persons with Disabilities, the Aged, Pregnant Women (Act on Promotion of Convenience) was amended in 2015, public buildings such as government buildings and cultural facilities newly built by the state and local governments and facilities designated by the President among public facilities must compulsorily obtain certification.

3. Detailed Accessibility Standards for the disabled

This "Detailed Standards" designed by the Ministry of Health & Welfare (MOHW) has been the standard design document for Act on Promotion of Convenience. This "Detailed Standards" has been adopted by "Barrier-free (BF) Certificate."

4. Build Bandabi Sports Centers on a national scale

The government has set a plan to build 150 new "Bandabi Sports Centers," which are integrated sports facilities that can accommodate both disabled and non-disabled people, by 2025 as a part of the project "Legacy of the 2018 Pyeongchang Winter Paralympic Games"; this consists of 80 gymnasiums, 40 swimming pools, and 30 buildings for specific sports events.

2. COMPARATIVE ANALYSIS

Existing domestic and foreign design guidelines and standards have been compared and analyzed to develop comprehensive indexes.

2.1 National Guidelines and Regulations

The PyeongChang Organizing Committee for the 2018 Olympic and Paralympic Winter Games (POCOG) and the manual for the adequate design of facilities for persons with disabilities at public sports facilities (Manual for Public Sports Facilities) were investigated for national guidelines. POCOG illustrates stronger standards in general while the Manual for Public Sports Facilities sets out requirements on diving aids at swimming pools, supports for sitting volleyball, and goalposts for goalball.

The Act on Guarantee of Promotion of Convenience of Persons with Disabilities, the Aged, Pregnant Women, etc. (Act on Promotion of Convenience) and Barrier-free Certification Standards (BF Standards) were examined for national regulations. It was found that the BF Standards apply stricter criteria than the Act on Promotion of Convenience overall. The criteria of "Barrier-free (BF) Certification" were taken among other potential domestic standards because its criteria embrace others.

2.2 Overseas Standards and Cases

The Tokyo 2020 Accessibility Guidelines and the Americans with Disabilities Act (ADA) were analyzed as overseas standards. The ADA presents standards for existing construction, which current national standards lack.

For overseas cases, the Design Guidelines for accessibility for the Elderly and the Disabled (Japan) and Barrierefrei-Bauen fur die zekunft criteria appl (Germany) were explored. These cases demonstrate more focused detail, including securing visibility in the stands and using appropriate materials for furniture.

After analyzing overseas standards, some issues were applied to supplement the Korean national standards. For some standards that go contrary to those in Korea, national standards were adopted as a priority.

3. DEVELOPMENT OF CHECKLISTS
3.1 Application of the results from field studies

The project "Certificate Sports Facilities for the disabled friendly sports facilities and Excellent Para-Sports Facilities" was established since 2019 in Korea to select and certify sports facilities for promoting accessible sports facilities. For the project conducted by the Ministry of Culture, Sports and Tourism(MOCPT) with the Korea Paralympic Committee to discover and disseminate the best practices for sports facilities. MOSCT selected 18 facilities recommended by 17 local administrative governments. It was found that facilities were not properly installed and accessibility were insufficient as follows:

· Connections Facilities – 61.1% (11 locations) of all survey subjects showed inappropriate slope of the access roads.

· Interior Facilities – 27.8% (five locations) were found to be inappropriate in terms of steps to the entrance door and 22.2% (four locations) were found to be inappropriate in terms of height differences between corridors and passages.

· Sanitary Facilities – 11.1% (two locations) of the survey subjects had not installed point-type blocks, had not attached Braille signs, and did not secure effective floor areas or side activity spaces, resulting in 33.3% (six locations) and 22.2% (four locations) of the sink. The shower rooms and changing rooms of 27.8% (five locations) horizontal and vertical handles were either absent or inappropriately installed, and 16.7% (three locations) and 27.8% (five locations) had no installed shower foldable chairs, respectively, making it difficult for wheelchair users.

· Informative Facilities – inappropriate installation of point-type and linear blocks, information facilities, Braille information boards and tactile information boards were evident at 22.2% (four locations) each. In warning and evacuation facilities, 16.7% (three locations) had none installed, including emergency warnings for the hearing impaired, showing vulnerability to guidance for the hearing impaired.

· Other Facilities – Unsecured lower space of the reception desk and information desk accounted for 50% (nine places), 61.1% (11 places) could not provide a sign language interpreter service in terms of convenience/personal service, and 22.2% (four places) had non-disposition of mobile assistants and receptionists. Evidently, the provision of human services is insufficient.

· Additional Facility – swimming pool category, 30.8% (four locations among the 13 swimming pools) had not installed, 46.2% (six locations) had no diving lifts installed, and 23.1% (three locations) were inappropriate for the effective width installation of diving ramps. In the indoor gymnasium category, 61.1%

(11 locations) had no seated volleyball supports and 83.3% (15 locations) had no goalposts where these are mandatory facilities under the Act on the Prohibition of Disability Discrimination.

Analyzing the above evaluation results, it seems necessary to supplement wheelchair activity spaces in access roads and toilets, induction and guidance facilities for the visually and hearing impaired, provision of human services, and additional facilities for indoor gymnasiums.

The results were provided and used to develop evaluation checklists. Through the field survey, Accessible roads and paths, sufficient space for wheelchairs in disabled toilets, and the provision of convenience and human services were supplemented in the evaluation checklists.

3.2 Subdivision of the checklist

It is generally considered that it would be better for people with disabilities to use facilities dedicated to the disabled. Therefore, it is common to think that disabled people will use facilities specifically designed to accommodate disabled people more than common facilities. However, according to a survey on participation in sports for the disabled by the Korea Statistical Information Service (KOSIS), on average, the disabled use “common public sports facilities” 3.5 times a week, “public sports facilities for the disabled” 2.9 times a week, and “private sports facilities” 3.37 times per week. As can be seen from these statistics, disabled people use “common public sports facilities” more than “public sports facilities for the disabled.”

Places for Sports Activities	No. of Use (Average)
Home	4.32 times / week
Outdoor	3.86 times / week
Common Public Sports Facility	3.50 times / week
Private Sports Facility	3.37 times / week
Other Facility	3.35 times / week
Public Sports Facility for Disabled	2.90 times / week
Schools / Work place Sports Facility	2.78 times / week

Figure 1. Average number of using places for sports activities[1]

The statistics show that people with disabilities use “Common public sports facilities” more than sports facilities for the disabled. A statistical indicator shows that it is a false perception that people with disabilities will use more facilities for disabled people.

In this study, the accessibility evaluation checklists target either facilities for common and facilities for the disabled to broaden options for the disabled to realize a universal life for people with disabilities; *“Disability-friendly Sports Facilities”* and *“Excellent Para-sports Facilities.”*

3.3 Classifications and Categories

For the structure of the checklist, relevant categories have been analyzed from (1) Act on Guarantee of Promotion of Convenience of Persons with Disabilities, the Aged, Pregnant Women (hereafter referred to as “Act on Promotion of Convenience”), (2) Act on the Prohibition of Discrimination against Persons with Disabilities, Remedy against Infringement of Their Rights, etc. (hereafter referred to as “Act on Prohibition of Disability Discrimination”), (3) Barrier-free Certificate (hereafter referred to as “BF Certificate”).

The breakdown structures consist of classifications, categories, and subsections. The classifications are composed of (1) Connections Facilities — Access to buildings, (2) Interior Facilities — overall use of internal facilities, (3) Sanitary Facilities — use of accessible sanitary facilities, (4) Informative Facilities — informative facilities that enable independent use for everyone, (5) Other Facilities — collateral facilities for using the entire facilities, and (6) Additional Facilities — equipment for specific sports. Each classification has two to four categories and each category has several subsections.

· “Connections Facilities” are facilities that connect from the outside to the main entrance and consist of effective width and slope of access roads, classification of steps and sidewalks, roughness of floor surfaces, and installation of braille blocks (linear and point blocks) on sidewalks between building main entrances and roads, and transportation facilities.

· “Interior Facilities” evaluates the effective width and activity space of the entrance (door), the type of door, handle, and Braille signs, and the effective width, floor, and safety of corridors and passages.

· “Sanitary Facilities” is divided into five categories: general information on toilets available to the disabled, toilets, washbasins, and shower/dressing rooms. It evaluates whether various users—including the disabled, elderly, and pregnant women—can use them safely and conveniently.

· “Informative Facilities” are divided into Braille blocks, guidance and guidance facilities, and warning and evacuation facilities. Braille blocks are evaluated by dividing them into specifications, colors, and installation methods, and induction and guidance facilities refer to Braille information boards, tactile information boards, voice information devices, and other induction signal devices.

· “Other Facilities” evaluates the securing of space in front of the reception desk/workstation, the height and lower space of the reception desk/workstation, the convenience of using the accessible seats, and the installation of rest facilities for pregnant women.

· “Additional Facilities” evaluates the installation of access aids such as ramps and handles in swimming pools for wheelchair users, changing and shower aids, auxiliary wheelchairs, sitting volleyball supports, and goalball goalposts.

As can be seen from Figure 1 in which additional contents in the same classification are colored red, “BF Certificate” embraces other laws, “Act on Promotion of Convenience” and “Act on Prohibition of Disability Discrimination” exclude “Additional Facilities” within “Act on Prohibition of Disability Discrimination.”

Generally, Barrier-free (BF) Certificate takes a more conservative approach as follows;

1. Present stricter standards
   It suggests a stronger standard for subsections. For example, the slope of the approach was taken as 1/24, which is gentler than 1/18.
2. Propose additional measures
   It provides additional standards for the installation of evacuation exits and measures that consider wheelchair users for the accessibility of stages and information desks.
3. Presenting more specific criteria
   It presents detailed standards such as the shape of the bathroom sink and mirror and the shape and material of the dotted block.

To set high standards and complete a comprehensive evaluation checklist, apply the criteria from the “Barrier-free (BF) Certificate” and add the “Additional Facilities” classifications from “Act on Prohibition of Disability Discrimination.”

	Laws		Certification
	Act on Promotion of Convenience	Act on the Prohibition of Discrimination	Barrier Free(BF) Certificate
Connections Facilities	Accessible roads and path	Accessible roads and path	Accessible roads and path
	Disabled Parking Lot	Disabled Parking Lot	Disabled Parking Lot
	Main Entrance Floor-Level	Main Entrance Floor-Level	Main Entrance Floor-Level
Interior Facilities	Doorway		Doorway
	Hallway	Hallway	Hallway
	Staircase or Elevator	Staircase, Ramp-way, Elevator	Staircase, Ramp-way, Elevator
Sanitary Facilities	Accessible Toilet	Accessible Toilet	Accessible Toilet
	Room for Shower and Changing	Room for Shower and Changing	Room for Shower and Changing
Informative Facilities	Guiding Blocks	Guiding Blocks	Guiding Blocks
	Guiding Facilities	Guiding Facilities	Guiding Facilities
	Alarm and Evacuation	Alarm and Evacuation	Alarm and Evacuation
			Doorways for evacuations
Other Facilities	Seating	Seating	Seating
	Information Desk		Information Desk
	Ticket Booth, Vending Machine, Hydration station	Ticket Booth	Ticket Booth, Vending Machine, Hydration station
	Rest room for maternity		Rest room for maternity
Additional Facilities		Diving aids at swimming pools	
		Supports for sitting volleyball	
		Goalposts for goalball	

Figure 2. Relevant Categories from Laws and Certification

3.4 Advice from professional advisors

Three experts from Barrier-free (BF) Certificate were appointed as consultation members and 10 advisors from the Korea Paralympic Committee for the Disabled also participated in the consultation. The general consensus on the checklist from the advisors is as follows:

· The proportion of designated parking areas for the disabled should be at least 15–20% of the total number of parking spaces.

· Additional canopy installation items are required in parking areas for the disabled.

[1] Survey conducted in 2019 by Korea Statistical Information Service

· Install pedestrian safety passages on both sides of the parking area.

· Include a waiting space for getting on and off in the intermediary facility.

· Competition wheelchairs have a wider effective width than ordinary wheelchairs, so it is necessary to expand the effective width standard.

· On a ramp, each waiting spaces should be installed at a height lower than the domestic legal standard of 0.75 m.

· Ramps need to be expanded to 1.5–2.0 m in effective width.

· Toilets for the disabled need to be connected the shower room.

· The purpose of use of swimming pool entrance ramps, diving lifts, and transfer walls varies depending on the type of user disability, so all should be installed so that users can choose by themselves.

· Informative facilities require the ability to use IT technology.

· It is necessary to add evaluation items related to exercise equipment for specific sports such as sitting volleyball pillars and goalball goalposts.

4. ACCESSIBILITY EVALUATION CHECKLISTS

The accessibility evaluation checklists are designed for two types of facilities: *"Disability-friendly Sports Facilities"* and *"Excellent Para-sports Facilities."* These have hierarchical structures consisting of classifications, categories, and lists. Each list was evaluated in four stages: proper installation (three points), normal installation (two points), inappropriate installation (one point), and non-installation (zero points).

Table 1: Composition of evaluation index for "Disability-friendly Sports Facilities"

Classifications	Categories	No. of Subsections
Connections Facilities	Accessible roads and paths	8
	Disabled Parking Lot	5
	Entrance	4
Interior Facilities	Doorway	5
	Hallway	4
	Facilities for moving another level	1
	Staircase	4
	Ramp-way	4
	Elevator	5
Sanitary Facilities	Accessible Toilet	9
	Urinal	1
	Washbasin	3
	Room for Shower and Changing	3
Informative Facilities	Guide information	4
	Alarm and Evacuation	1
Other Facilities	Stage and platform	4
	Seating	1
	Reception and Information	2
	Ticket Booths, Vending Machines, Hydration stations	3
	Exits for evacuation	4
	Restrooms for maternity	3
	Swimming pool diving aids	7
Additional Facilities	Supplies	1
	Sports Equipment	1
	Assistance	3
Additional Points		

Table 2: Composition of evaluation index for "Excellent Para-sports Facilities" (additional features are colored)

Classifications	Categories	No. of Subsections
Connections Facilities	Access roads	8
	Disabled Parking Lot	5
	Waiting area for transportation	1
	Entrance	4
Interior Facilities	Doorway	5
	Hallway	4
	Facilities for moving another level	1
	Staircase	4
	Ramp-way	4
	Elevator	5
Sanitary Facilities	Accessible Toilet	9
	Urinal	1
	Washbasin	4
	Room for Shower and Changing	3
Informative Facilities	Guide information	4
	Alarm and Evacuation	1
Other Facilities	Stage and platform	4
	Seating	1
	Reception and Information	2
	Ticket Booth, Vending Machine, Hydration station	3
	Exit for evacuation	4
	Restroom for maternity	3
	Diving Aids at Swimming pool	7
Additional Facilities	Supplies	1
	Sports Equipment	1
	Assistance	3
Additional Points		

Comparing the evaluation standards of *"Disability-friendly Sports Facilities"* with those of *"Excellent Para-sports Facilities"* shows that they are generally iterative but require stricter evaluation criteria; therefore, the following further details have been added to the index: waiting areas for transportation has been added to the classification Intermediate Spaces and extra equipment has been added to the category Washbasin.

Table 3: Evaluation index for "Excellent Para-sports Facilities" and strengthened categories (in color) and strengthened contents compared to those of "Disability-friendly Sports Facilities"

Classifications	Categories	Contents strengthened
Connections Facilities	Access roads	·Rate of installation ·Effective width ·degree of inclination ·level difference ·separation of roadway
	Disabled Parking Lot	·Rate of installation ·Installation pedestrian-way ·Effective width of pedestrian-way · Installation canopy
	Waiting area for transportation	
	Entrance	·Effective width
Interior Facilities	Doorway	·Effective width
	Hallway	·Effective width and intersection
	Facilities for moving another level	·No. of elevators for the disabled
	Staircase	·Effective width ·Material ·Handrails
	Ramp-way	·Height and size of landing
	Elevator	·Size of elevator
Sanitary Facilities	Accessible Toilet	·Rate of installation ·Space along the toilet
	Urinal	
	Washbasin	·Shower added
	Room for Shower and Changing	·Size of space
Informative Facilities	Guide information	
	Alarm and Evacuation	
Other Facilities	Stage/platform and seating	·Rate of installation
	Seating for reading	
	Reception and Information	
	Ticket Booth, Vending Machine, Hydration station	
	Exit for evacuation	
	Restroom for maternity	
	Diving Aids at Swimming pool	·Installations of types
Additional Facilities	Supplies	
	Sports Equipment	
	Assistance	

Looking at the strengthened evaluation contents in *"Excellent Para-sports Facilities"* compared to *"Disability-friendly Sports Facilities*,*"* the most frequently applied are the expansion of the effective width, space, height, and so forth. Furthermore, facilities such as canopy installation in parking spaces and shower installation in washbasins were added.

5. CONCLUSION

Increasing the participation rate of the disabled in daily sports requires improving the affinity of existing public daily sports facilities and new public sports facilities for the disabled and creating a foundation for the disabled to enjoy better lives.

The purpose of this study is to include accessibility requirements to support facility users who have a range of impairments (not only visual, hearing, or physical impairments but also intellectual disabilities). The checklists in this study have been developed to focus on indoor facilities for sports such as swimming, badminton, table tennis, basketball, and volleyball, which are representative and popular sports in Korea.

The accessibility evaluation checklist in the research was designed for *"Excellent Para-sports Facilities"* and *"Disability-friendly Sports Facilities"*. The former requires higher accessibility and standards for accommodation; it is intended to establish accessibility evaluation checklists suitable for each facility by applying national standards for *"Disability-friendly Sports Facilities"* and stronger standards for *"Excellent Para-sports Facilities"*. Specifically, in the case of *"Disability-friendly Sports Facilities,"* the criteria for installing convenience facilities under the Act on Prohibition of Disability Discrimination were applied to the evaluation checklist and in the case of *"Excellent Para-sports Facilities,"* the highest Barrier-free (BF) Certificate criteria were applied, which are stricter than those of the "Act on Promotion of Convenience."

The evaluation index of this study was developed based on the criteria of Barrier-free (BF) Certificate, which requires relatively strict domestic standards. By comparing and reviewing domestic and foreign laws, overseas standards were applied to standards if the standard in Korea does not exist; if foreign standards were higher than domestic ones, the standards were raised according to overseas standards. In addition, deficiencies were supplemented by reflecting the analysis of the current status of *"Excellent Para-sports Facilities"* conducted in 2019 and evaluation indicators were completed by reflecting the opinions of professional advisors.

Further study should examine parking areas and auditorium installation rates for the disabled, indoor gymnasium installation standards for each event, and outdoor playground installation standards.

ACKNOWLEDGMENTS

The research reported herein was performed under research commissioned by the Korea Paralympic Committee in 2020.

Jin-Cheol Kim, one of the examiners of Barrier-free (BF) Certification, assisted with the analysis and provided the results of the field survey.

REFERENCES

1. Americans with Disabilities Act Accessibility Guidelines, (2020). edited.
2. Americans with Disabilities Act Accessibility Standards, (2020). edited.
3. Japanese Ministry of Land. Design Guidelines for accessibilities for the Elderly and the Disabled, (2015). Japan.
4. Korean Ministry of Culture, Sports & Tourism and Korea Paralympic Committee, Manual for adequate designing facilities for people with impairments at public sports facility, (2015). Republic of Korea.
5. The PyeongChang Organizing Committee for the 2018 Olympic & Paralympic Winter Games, (2015). Republic of Korea.
6. Tokyo Organizing Committee of the Olympic and Paralympic Games, (2017). Tokyo 2020 Accessibility Guidelines.
7. Sport-und Freizeitanlagen, (2013). Ulriche Rau, Barrierefrei – Bauen fur die zekunft, Beuth Verlag.

PLEA 2022 SANTIAGO

Will Cities Survive?

The effects of an airtightness prescriptive regulation code in a developing country

The Chilean new housing airtightness requirements and its effects on the timber construction quality

FELIPE VICTORERO[1,2,3] DANIELA MÉNDEZ[2]

[1] School of Architecture, Pontifical Catholic University of Chile, Chile
[2] UC Timber Innovation Center, Pontifical Catholic University of Chile, Chile
[3] Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), Pontifical Catholic University of Chile, Chile

ABSTRACT: This paper shows the performance of houses' airtightness in six districts of Chile, within three are affected by technical specification requirements, but not on-site tests, and three does not have any type of obligation in the matter. The results show that the implementation of the normative regulation has allowed a better airtightness performance in timber frame social houses, but it has not been able to achieve the desired standard. Therefore, the importance of carrying out field tests is revealed, to analyse the real performance and obtain the expected benefits in energy efficiency and interior comfort of the dwelling. The study also shows that the Chilean airtightness regulation goals could be compromised, sins the buildings and houses do not need to be tested on-site after they are built; therefore, designer, contractors, and public policy maker do not know what to improve or if the technical specification used in projects are enough.
KEYWORDS: hermeticity, regulation, field testing, air infiltrations, airtightness.

1. INTRODUCTION

Since the energy crisis of the seventies, and strengthened by the subsequent global warming crisis, many countries have carried several public policies and the enforcement of specific building codes, focused on increase energy efficiency in the building sector. This, while maintaining adequate comfort and health indoor conditions, with the main goal of reduce space conditioning energy requirements and associated GHG emissions of the building sector. Moreover, most of the energy efficiency building codes start in developed countries, stablishing minimum thermal insulation and airtightness requirements, which later evolve in more complex systems and certification. It is also important to notice that later, many of the standards and mandatory regulations involved in these codes, were adopted with some modifications by developing countries in different parts of the world.

As a building's airtightness, along with the thermal insulation, is a key factor for reducing space heating requirement; many codes define very low and strict air infiltrations rates to reduce energy requirements. Also, these requirements are commonly accompanied by minimum ventilation rates, to maintain minimum indoor air quality conditions and prevent the "sick building syndrome". Nevertheless, despite the efforts of developed countries enforcing energy efficiency building codes regulations, space heating remains the main source of energy use in building operation worldwide and specially in developing countries.

In this matter, the United Nations Environment program states that although space heating participation in the building and construction sector is declining since 2010, it still has the biggest impact on the sector with roughly a 35% of the final energy use [1]. Also, in relation to the pandemics events of COVID-19, United Nations declares that during the 2020 there was a shift of the final energy use from the commercial and retail sector, towards the residential sector. This could be of most interest regarding dwelling buildings, since lockdowns and the soar of telecommuting technologies, could traduce in a tendency on the short or even long term. Further, although new commercial and retail buildings tend to have higher standards in energy use, the residential sector presents greater gaps in this matter, especially the old infrastructure. What is more, developing countries could be the most affected by this tendency, since a shift in this matter could mean an increasing energy use related with less clean energy sources or an increase in energy poverty and living conditions. Therefore, regulations that aim to improve new and existing buildings energy efficiency performance in the housing sector, could be of most relevant during the next decade.

From above, it is also important to notice that most of the countries that have stablished minimum airtightness standards, have done it through voluntary requirements and with no specific validation's prerequisites; while only few of them, such as France, UK, or Ireland, consider mandatory conditions with specific on-site test or certification methods [2]. Furthermore, since not all requirements or regulations are mandatory or inspected through compulsory quality controls, it opens the question if adequate airtightness levels are being achieved in voluntary or not tested scenarios; as well as if thermal insulations applications, which depends on airtightness to perform correctly, is being as effective as it is expect.

2. THE CHILEAN SCENARIO

From 2014 till this moment, Chilean governments have implemented increasing building's minimum constructive standard requirements for housing in high polluted cities of the colder south regions. These requirements are framed under the Atmospheric Decontamination Plans (PDA, by its Spanish's acronym), which mainly pursuit to reduce firewood stove pollution problems associated to cultural conditions, but mostly to poorly insulated and air leaked houses. This pollution has meant that some Chilean cities have important health risk conditions associated to airborne particulate matter; therefore, cities such as Coyhaique in the Patagonian region, have been classified with the poorest air-quality in all Latina America. This was also specially complicated during the pandemic lockdowns of 2020, since while most cities in the world achieved to reduce their airborne pollution; southern Chilean cities such as Coyhaique, maintained it or even increase it due to more residential space heating demands.

Regarding the PDAs specific requirements, these stablish different needs according to local conditions and pollution risks. Which in the case of the housing sector, demand minimum standard for the new houses, and offer economic incentives to retrofit existing infrastructure. In this matter, most of Chilean southern cities usually require minimum building's envelope thermal insulation, condensation risk precautions, minimum indoor air quality ventilation rates, certified windows and doors maximum air infiltration rates, and minimum overall buildings airtightness conditions. Although all these requirements can be easily incorporate in the early stages of design, through construction materials specification sheets or laboratory tested mockups; the whole houses' airtightness is particularly complicated, since it requires that the final building must be finished and then tested to get its actual envelope's tightness. In this respect, and depending on climatic conditions, air tightness requirements in these specific cities can range from 5 to 7 air changes per hour (ACH) with a pressure difference of 50 pascal (n50).

Nevertheless, the PDA regulations that stablishes the airtightness standards, on contrast to thermal insulation or windows tightness, does not require to verify by any sort of test or certifications, the final airtightness of the house envelope. On the contrary, it only requires new housing projects to declare in their specifications and design details, the use of airtight seals on the building's envelope, but without any kind of previous validation or on-site revision. Moreover, there are no studies that could prove that these mandatory requirements with no on-site test or certification process are achieving airtightness requirements in practice. Even more, social houses receive additional funds, by the Chilean Ministry of Housing and Urban Planning (MINVU), to accomplish these stricter energy efficiency requirements; although there is no evidence that this investment is effective in achieve more energy efficient houses or even produce more airtight buildings.

Currently, MINVU have plans to expand PDA's requirements to the rest of the new buildings that would be constructed in the country, through its incorporation in the national building code. What makes testing its effectiveness on built houses of most interest and specially in social houses that receive specific public financial aid for this purpose.

Figure 1:
Typical firewood stove' chimney [3]

Note: The use of firewood stoves in the southern regions of Chile is due to cultural traditions and that firewood is the cheapest and most accessible fuel for space heating.

3. STUDY CASES, METHODOLOGY AND RESULTS

According to the Chilean National Statistics Institute (INE), most of the residential projects in Chile correspond to small 1-2 story houses; although their share in the surface annual granted construction permits, has been continually fallen from 75% in 2002 to a 43% in 2019 [4]. Nevertheless, and despite the popularity of apartment buildings in the last years, this type of houses still being the most common in the residential sector, and it represents the vast majority of the social housing projects in the country.

In addition, nearly 45% of all the country's small houses surface permits consider timber frame structures, while this percentage could reach 70% in southern regions such as Bio-Bio. This is of particular interest, since due to their multiple elements and more sophisticate construction systems, timber frame structures tend to have poorest airtightness rates when compared to other materials such as cast concrete or brick masonry constructions. This also means that more economic timber houses, which usually relay in cheaper construction solutions, present an inclination to have even poorest airtightness performance.

Due to the conditions previously stated, this article tries to give a first glimpse on how timber frame social housing projects, in areas with and without PDA airtightness requirements, perform. This, specially having in consideration the restrictions associated lo low-cost constructions and the complexities of air infiltration seals specifications in timber frame envelopes. And most important, to try to identify if compulsory specifications regard airtightness, but without field tests of the final constructions, achieved the expected airtightness standards or at least help to improve the houses overall performance.

3.1. Study cases

Six housing projects were selected for this study considering PDA and non-PDA locations, with the help of MINVU, to represent current average construction timber frame social houses of the country, and in particular the southern regions where this type of construction system proliferate. As it is usual in Chilean social houses, due to budget restrictions, the finishes are not totally completed, considering that the future occupants would have to render interior, do paint jobs, and install light fixtures. Nevertheless, to test the houses on-site and previous they were hand over to the families, what would have eventually affected the results, the cases had to be in a construction stage that would allow to perform the study; this was a critical factor, since only a few social housing projects in the PDA regions had constructions in these stages.

The chosen housing projects names, which in some cases consider a same contractor company, are: (Case 1) "*Sin Casa Rural*" with 40 houses, in Puerto Octay, Los Lagos Region; (Case 2) "*Megaproyecto Labranza*" with 126 Houses, in Temuco, Araucania Region; (Case 3) "*El Renacer de Pillanlelbun*" with 159 Houses, in Lautaro, Araucania Region; (Case 4) "Porvenir II" with 110 houses in Osorno, Los Lagos Region; (Cases 5) "*Nueva esperanza de Folilco*" with 57 Houses, in Los Lagos, Los Rios Region and (Cases 6) "*Guacamayo II*" with 131 Houses, in Valdivia, Los Lagos Region. All these projects had houses ready to be handed to the families, and in condition to be tested during the study; though in some cases the construction stage of the whole complex did not allow to test the necessary number of houses to have an accurate enough sample of the overall.

Figure 2:
Social houses interior finishing. Guacamayo II" in Valdivia, Los Ríos Region.

Note: When social houses in Chile are given to the families, they don't consider finishes such as interior plasters, interior paint jobs or light sockets.

Figure 3:
Blower Door test of a house in Labranza complex, Temuco, La Araucanía Region.

Note: The houses in this picture were about to be handover to the families a few days after the tests.

3.1. Methodology

A fieldwork, testing the six study cases new houses' airtightness that were chosen to be representative of Chilean timber frame social dwelling, was carried using on-site equipment and the project's design specifications. In parallel to these field tests, an analysis of the data collected was carried, contrasting the airtightness results of each house with PDA's local specific airtightness requirements. Moreover, to determine if prescriptive non-tested airtightness regulations have any effects on new houses, the airtightness results were also compared to previous research data, carried before PDA regulations were implemented.

Therefore, A team from the UC Timber Innovation Center (CIM UC) conducted several Blower Door tests on different houses of each case study. This according to the national standard NCh3295 (ASTM E779-10 equivalent), to determine a building's airtightness through the fan pressurization method; and the NCh44 (ISO 2859-1 equivalent) to determine the number of tests that would be representative of a whole housing project. For the NCh44 Chilean sample standard, a general inspection level II scenario was used to determine the number of houses to be tested at each housing complex.

An analysis of the technical specifications and drawings was carried out to check air seals details and products, where the records were given by the contractors and MINVU. After each test, the result of the airtightness was compared to each location's PDA minimum ACH(n50) requirements. It is important to notice that, due to two contractor's delay in some of the study cases, it was not possible to test all the houses needed according to the sampling standard (NCh44). The housing complex that met the minimum requirements were cases 1 to 4, while in cases 5 and 6 it was not possible to carry out the number of tests necessary to comply with the standard. The main issues for this, were delays in finishing stages and the lack of air sealants of the remaining houses, not meeting the minimum requirements to carry out the tests in a representative way. However, although not ideal, the results of the last cases had a low standard deviation, therefore they are included in the present analysis.

On the other hand, a previous study carried by the Bio-Bio University, regarding existing Chilean housing airtightness levels before the PDAs were implemented; was used to contrast how new PDA's standard timber frame social houses perform, and if any improvement was achieved by the non-tested requirements. For all purpose, the Bio-Bio's study declared that houses airtightness national average, for all construction systems, is of 12.9 ACH(n50) and the specific timber frame national average is of 24.6 ACH(n50) [5].

3.2. Results

Figure 4 shows the results obtained by blower door field tests, for (Case 1) "Sin Casa Rural", (Case 3) "*El Renacer de Pillanlelbún*" and (Case 5) "*Nueva Esperanza de Folilco*" with non-PDA airtightness regulations; plus (Case 4) "*Porvenir II*" and (Case 6) "*Guacamayo II*" with PDA 5 ACH (n50) minimum airtightness requirements, and (Case 2) "*Megaproyecto Labranza*" with PDA 7 ACH (n50) requirement. The national average and specific timber frame houses airtightness are also plotted.

Table 1:
Sample number and contractor for each case study

Cases	Sample	Houses	Contractor	PDA
Case 1	8	40	Ingesur	No
Case 2	20	126	Luis Saez	Yes
Case 3	20	159	Dadelco	No
Case 4	20	110	Peña y Peña	Yes
Case 5	6	57	W&M	No
Case 6	3	131	Peña y Peña	Yes

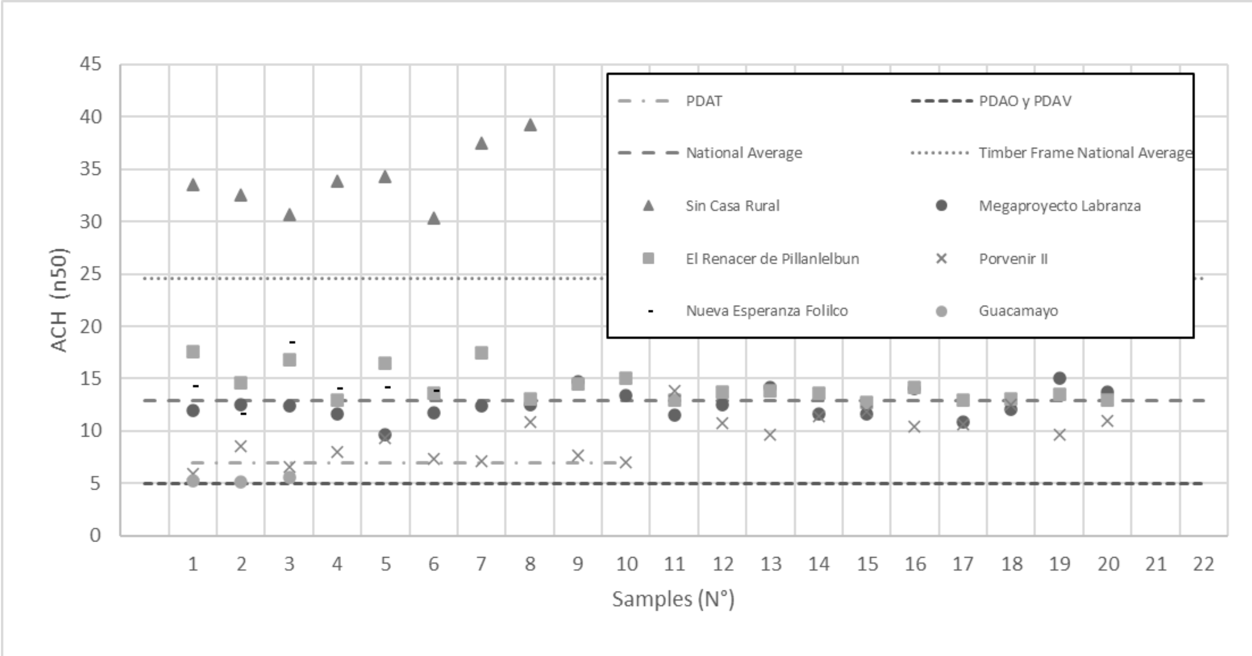
The results analysis shows that, although PDA houses apparently improve airtightness performance against non-PDA house and national averages, minimum PDA requirements of 5 ACH(n50) are not meet by any of the tested houses. Although, some houses reach results beneath the 7 ACH(n50) requirements for the Temuco city, these houses were in locations with stricter requirement, and the Temuco houses (Case 2) got barely under 10 ACH(n50). This means that reaching standards below 7 ACH(n50) with current construction technics and products is achievable, although require special efforts from the contractors.

Additionally, it is observed that the PDA houses reach an average of 9.01 ACH(n50), in contrast to non-PDA houses with an average of 20.90 ACH(n50). This meaning that on average, PDA houses have less than the half of the air infiltrations than the non-PDA houses. Moreover, as Figure 5 shows, PDA houses have a smaller dispersion of results with maximum and minimum of 15.02 ACH(n50) and 5.15 ACH(n50) respectively; while non-PDA houses present a greater data dispersion, with maximum and minimum values of 39.30 ACH(n50) and 11.60 ACH(n50).

The previous dispersion results also means that for the moment it is not possible to state that all PDA houses have a better performance than non-PDA houses. This since it is possible to identify non-PDA tests with higher airtightness levels than PDA cases; for instance (Case 2) "*Mega Proyecto Labranza*" present air infiltration rates similar or even lower than (Case 4) "*Porvenir II*" with PDA requirements.

Although timber frame structures were expected to present higher infiltrations rates, due to the complexity of the different elements encounters and the sophistication of the sealants applications; during the field tests and previous inspection, it was possible to identify that most of the gaps were sealed using cheap materials such as caulking guns with common silicone or equivalents. Also, low quality installation fixtures (e.g., electric boxes), cheap weather membranes and limited flashing tape were used, mostly because of financial restrictions associated to low social housing budgets. Therefore, the durability over time of the materials, and after seismic events, could prove insufficient to maintain the initial airtightness in the years to come.

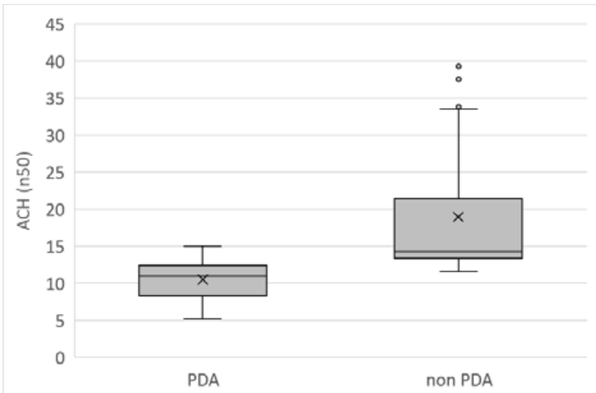
Figure 4:
Airtightness ACH (n50) for tested houses in all study cases.



Note: Each case study's sample was determined according to the number of houses in the complex. PDAT is the maximum airtightness for new houses in Temuco city (Case 2), while PDAO and PDAV is the maximum for new houses in Osorno and Valdivia Cities.

Finally, factors that could explain previous results, include: (1) errors and omissions in design (2) lack of workers with skillsets; (3) absence of suitable inspections; (4) poor quality materials; (5) deficiency in process standardization; (6) material stock problems, (7) among others.

Figure 4:
Airtightness ACH(n50) results' dispersion.



Note: non-PDA correspond to cases 1, 3 and 5, while PDA correspond to cases 2, 4 and 6.

4. CONCLUSION

The study shows that enforcing regulations with prescriptive airtightness minimum requirements, without test validations, does not assure that houses would reach desire standards. Nevertheless, it also shows that it promotes better designs and building constructions process, that could lead to improvements in better airtightness performance when compared to projects that have no requirements of any kind. Yet, the lack of airtightness field tests, could give the false impression of achieving the expected results, not allowing designers and contractors to improve their work. Even more, this generates a lack of knowledge for policy makers, what could impact regulatory goals on the long term.

More important, future inhabitants would not experience the supposed energy efficiency and comfort benefits advertised by these types of houses. Meaning that in the case of locations with firewood stove pollution, this could still be an increasing problem for public health and the urban air quality; meantime, all the public financial aids given to improve housing envelops, to reduce space heating requirements, could be inefficient or even lost.

Additionally, it is important to notice that due to the low quality of the airtightness barriers, and the use of temporary sealants such as silicones, new houses airtightness could be diminished relatively quickly. Therefore, a second study with new Blower Door tests is planned on the same house complexes, to analyze their performance once they have been in used for 3 years. This in line with other studies, such as the carried out by the NHBC Foundation, which shows that in general 30% of the hermeticity is lost after some time [6].

At last, it is also relevant to have in mind that future sustainable construction policies, that promote materials with low embodied carbon such as timber, could help that timber frame construction proliferate in higher building structures (e.g., six story dwelling buildings or higher). This need to be study in more detail, since airtightness sealants and construction systems could vary drastically in comparison to small residential houses. This is also interesting if we consider that dwellings could also increase their space heating requirements due to future pandemic lockdowns or new telecommuting tendencies.

ACKNOWLEDGEMENTS

The authors acknowledge the funding provided by the Chilean Ministry of Housing and Urban Planning (MINVU), as well as the support of the ANID BASAL FB210015 CENAMAD and the UC Timber Innovation Center of the Pontifical Catholic University of Chile.

REFERENCES

1. UN Environment programme (2021), *2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. Nairobi.
2. Leprince, V., Carrié, F., & Kapsalaki, M. (2017). *Impact of Energy Policies on Building and Ductwork Airtightness*. Proceedings of the 10th International BUILDAIR-Symposium. Hannover: BUILDAIR.
3. MMA (2016). *Guía de Calidad del Aire y Educación Ambiental*. Santiago.
4. *Estadísticas*. Diseña Madera. Retrieved March 27, 2022, from https://www.disenamadera.cl/estadisticas
5. CitecUBB & DECON UC (2014). *Manual de Hermeticidad al aire de Edificaciones*. Concepción.
6. NHBC Foundation (2011). *Ageing and airtightness, how dwelling air permeability changes over time*.

¿Innovation or effectiveness?

Using a competition as a teaching tool

RAFAEL HERRERA-LIMONES[1] MARIA LOPEZDEASIAIN[2] MILAGROSA BORRALLO- JIMÉNEZ[1] JORGE ROA-FERNÁNDEZ[1] MIGUEL HERNÁNDEZ-VALENCIA[1]

[1] Instituto Universitario de Arquitectura y Ciencias de la Construcción, Universidad de Sevilla, Spain. HUM-965 & TEP 206
[2] Departamento de arte, ciudad y territorio, Universidad de Las Palmas de Gran Canaria, Spain.

ABSTRACT: This research addresses the opportunity of competitions as an educational strategy for the inclusion of sustainability aspects in the teaching of architecture. It analyzes various experiences developed in the School of Architecture of the University of Seville and their results in terms of acquiring skills in sustainability (environmental, social and economic). It analyzes both, specific competences related to the courses developed, as well as generic competences, all relevant for awareness and complete training. A comparison is made between the different types of competitions, assessing their advantages and disadvantages, weaknesses, strengths, threats and opportunities. It is concluded that competitions are a relevant educational strategy, with great educational potential in terms of results and student participation. However, they are difficult to manage logistically to reinforce the subjects educationally and can constitute an end in themselves for the students when they acquire excessive relevance, compared to the educational environment that teachers intend to use.
KEYWORDS: Competition, Education, Architecture, Sustainability, Design

1. INTRODUCTION

Architectural competitions are usually used to foment the implication of students in architectural design courses. The possibility of been awarded is a strong commitment to students apart from just passing their courses. The potentiality of these competitions is however not maximized in educative terms. Students usually participate in groups and they need to collaborate to develop the design on time. This fact gives us the possibility as teachers to perform different strategies in order to improve their cooperative and collaborative skills.

There is another interesting possibility teachers can address by student's competitions and it is the similarity to professional labour situations. Teaching is usually divided and developed in pieces, all different subjects and corresponding courses are taught separately. They are supposed to be always related but these relations sometimes are difficult to be perceived by students and they frequently are not capable to integrate them into a real and complete design process.

In addition, this type of educational approach allows to incorporate aspects related to environmental, social and economic sustainability in a transversal way. These are specific targets of the selected competitions themselves wich are used as an educational medium. This paper explains a research carried out in the School of Architecture of Seville about the potentialities this kind of competitions can offer.

2. COMPETITIONS AND COMPETENCES

The research approaches and studies the different possible competitions from the point of view of the competences students acquire during the participation process. It is analyzed in terms of specific competences linked to sustainability aspects and in terms of transversal general competences of educationally great relevance and sometimes, treated as secondary by knowledge areas. The state of the art has been developed related to competitions that approach firmly the sustainability development concept in architecture and/or urban design. The selection of the experimental competition cases of study responds to the different amplitude of the process of design and construction that proposes the competition in order to analyse advantages in several stages of the process relating them to different educational competences [1] to acquire.

Three types of competition have been selected for the experiment: the Solar Decathlon competition, the EDUCATE competition and the small format competitions such as SIKA, COSENTINO Desing Challenger, PLADUR Construction solutions competition, and ANfhARQ competition. Conclusions are presented here, and different proposals for several years have been analysed [2–5].

3. EDUCATIONAL ASPECTS AND CONTENTS TARGETED

The issues in which the innovative educational methodology has centred are: urban regeneration process, bioclimatic adaptation, life cycle assessment, spatiality, construction definition, affordability, accessibility and resilience. The transversal competences analyzed are: teamwork capacity, autonomy (both: student's or group of students'), critical capacity for decision-making, ability to integrate knowledge from different areas, introspection of the labor market and knowledge of material culture. The educational strategies and methodologies used in the experiments are active methodologies such as project-based learning, collaborative learning, and/or service learning. It is considered that these methodologies can foster more collaborative dynamics and therefore a closer approach based on social sustainability that should be transmitted and promoted linked to architecture, in order to improve urban governance through participatory strategies.

4. METHODOLOGY

The objective of this research has been to determine the opportunity that architectural competitions represent as an educational tool in relation to the introduction of sustainability issues. To this end, several case studies selected and developed at the School of Architecture of the University of Seville have been analyzed. A SWOT study has been conducted for each case study in relation to the objectives approached:

- The contents apprehended by the students. Defining methodological bioclimatic design processes that students can embrace
- The transversal competences acquired. Implementing collaborative and cooperative processes between students. Encouraging greater capacity to take responsibility for decisions
- The strategies, methodologies and educational tools developed by teachers.The design results obtained in student learning.

5. SD CASE STUDY

Since the competition is a student's experience, the whole Solar Decathlon University of Seville Team has approached the process from a previous students design proposal. However, the also previous selected issues and contents were targeted as core priority for objectives definition.

The SD Europe 2019 call established in its bases that the competing teams had to design and build prototypes that incorporated sustainable construction criteria for the intervention on existing residential buildings. The Solar Decathlon University of Seville Team presents the Aura 3.1 prototype, which develops a strategy for the urban regeneration of obsolete residential neighborhoods [6].

SD Europe 2019 offers the opportunity for a team of students, supported by professors and researchers, to have an innovative teaching experience that reproduces the complex and complete process of the professional practice of architecture. This experience explicitly incorporates concepts of environmental sustainability and social and economic responsibility. Students acquire competencies through the full development of a project for approximately two years, culminating in the construction with their own hands of the Aura 3.1 prototype in Szentendre (Hungary). The prototype was assembled in just two weeks, and during the following two weeks the exhibition and competition period took place.

The proposal that has been developed as an experiment for the SD 2019 Europe by the Solar Decathlon University of Seville Team approaches the urban perspective as a regeneration process. This means that no isolated construction prototype makes sense, there is always a previous urban situation needed to define the social needs to be solved. Participative processes are equally necessary in order to deeply understand the place in a social, economic and environmental perspective. Several exercises developed with the students try to underline and practice some possible participative processes although timetables do not permit to develop a study case during the competition.

Bioclimatic analysis of a place is one of the key issues taught to students during the competition process. Passive and active system are studied and explored as potential solutions. Several bioclimatic tools are explained in a specific methodological analysis due to improve students' capacities to take decisions. A bioclimatic analisys methodology has been defined and developed in order to do so.

Several reflections and exercises have been developed during the design process in order to include some life cycle assessment tools as an approach due to the main sustainability goal the students have to confront. It should not be difficult to reflect and understand that point for students but since the architectural design is a very complex process, taking into account every single requirement and responding to it, is sometimes unaffordable for them. Thus one of the conclusions of the experiment lies in the necessity for further reflection and study of possible solutions in terms of life cycle assessment after the end of the competition.

Different tools and instruments are used during the whole competition process at different levels to test the architectural spatiality of the prototype: material and virtual models, 2d and 3d designs, etc. but the most important teaching tool of all these instruments is the construction of the prototype itself. Nothing can be compared to the real experience of a prototype scaled one to one. Students can experiment their spatial solutions and compare them to another universities' proposals.

The Solar Decathlon competition has demonstrated to be a very useful tool for teaching construction since all construction decisions need to be taken for the accomplishment of the competition.

Studying the prototype affordability in economic terms is also a good experience for students. Usually they do not take into account economic restrictions into the design process since it usually is only an academic exercise but it is very important to realize for them how economic situation can sometimes compromise design and spatial proposals.

Architects as professionals must comply with the regulations in terms of accessibility in buildings and urban space but these issues are not definitely included in the teaching design process due the complexity of it. Sometimes this requirement comes after the spatial design and the main decisions of the project have to be changed. In addition, construction decisions are often a difficult input to guarantee the prototype accessibility for everybody, thus this competition provides a perfect situation in which every requirement has to be solved in order to present and conclude the architectural project.

Structural, constructive and social urban resilience are defined as goals for the student's proposal. This way the environmental, economic and social context is always present during the whole design and construction experiment.

6. EDUCATE CASE STUDY

During the experimental phase of the European Educate project [7] workshops were held in which many School of Architecture of Seville's teachers participated and during which the teaching projects of different subjects were worked on to incorporate specific environmental competences and to ensure that students acquired the necessary skills to work from an approach based on sustainable development. Similarly, and from the same European research project, an experience linked to a European architecture competition for students was carried out.

The Educate Prize [8] proposed an intervention and architectural proposal of more sustainable habitat, designed in the location previously chosen and defined by the students as a challenge. These had to be tutored by those teachers who had included environmental competences in their teaching project, and would use the Educate portal as a potential teaching tool. [9]. This portal included information and specific content on the subject, from conceptual explanations, calculation bases, design examples and even professionally developed and constructed practical examples. It also included tools for communication information and debate between students and teachers from all participating architecture schools and researchers [10] (more than 30) specialists in the field and participants in the research project.

This experience was conclusive in several aspects: it showed that the interest in incorporating environmental and sustainability issues in the teaching of architecture by educators was a reality and a peremptory need [11]; It also demonstrated that the rigorous doctrinal corpus on the subject was fully defined, completed and accessible to educators and learners; And finally, it showed that there was a great need to develop new or reinterpreted teaching strategies and methodologies appropriate to the new approaches and transversal concepts that should be incorporated into teaching.

7. SMALL FORMAT COMPETITIONS CASE STUDY

It is quite common for construction companies that manufacture products to carry out several ideas competitions for the constructive application of their products for university students. The game of the SIKA record, COSENTINO Desing Challenger, Pladur Constructive Solutions Contest, and ANfhARQ Contest, are some of the competitions and companies that have more than ten editions and that are proposed in the School of Architecture of Seville in the Department of Architectural Constructions I. The purpose of these calls is clear. Companies make themselves known among their future customers and carry out a work of approaching their brands while promoting the use of their products in practical cases. The incorporation of these competitions to the practices of different subjects of the degree of Architecture or even of the different master's degrees is an interesting possibility to generate learning that goes beyond the mere resolution of a practical exercise.

The association of this type of exercises to the teaching program is always carried out with a purpose that exceeds the objectives that the subjects generate. It involves a small additional effort for students and teachers in order to adapt their work to the rules of the competition, but they are rewarded with the experience received and the possibility of the prizes offered, usually in cash, to the winning students. Companies have learned to make the deadlines of these competitions increasingly more flexible in order to fit the dynamics of the teaching times and thus facilitate that they can be carried out within the contents of the teaching itself and not as a parallel exercise. This greatly facilitates the dedication to the proposals, the final quality of them and also greatly increases participation in the calls.

The teaching task of programming, therefore, must be to put in parallel the objectives of the contests with the learning objectives of his own subject. This is a relatively easy task since, in general, they are quite flexible ideas competitions in terms of the content of the presentation. They are usually contests of ideas with a level of development that allows them to be incorporated as teaching exercises and in very few cases require an extraordinary dedication that does not go beyond adapting the contents to the delivery formats.

These competitions establish in general terms, an evaluation criteria in which they include sustainability and habitability issues that go beyond the mere application of their own products and that exceed in many cases the teaching objectives themselves. Thanks to this, students face the realization of an architecture project from all perspectives, in a holistic way, which addresses issues that go beyond the subject of the course itself. They are also encouraged to incorporate knowledge acquired in other subjects and courses in a synthetic and transversal way. The fact that the assessment and ideas presented is made by an external qualified technical jury serves as a professional experience and incentive wich always exceeds the usual evaluation of a single teacher.

This experience complements the teaching practices and generates different procedural and attitudinal learning proceses for students. The need and the challenge of adapting to a specification made by an external agent, the participation in competition with the ideas of other students and the necessary acceptance, of the vast majority, of the failure experienced by not being chosen as winners, suppose learning contents and skills linked to the profession of architecture that can hardly be incorporated into a merely teaching exercise.

Finally, there is, in addition to the financial reward, merely symbolic, an added curricular merit for the winning proposals. Beyond learning in the development and realization of proposals, this incorporation of final rewards for the student, which exceed the mere qualification by the teacher, are adequate motivations that generate, in general, good quality results.

Table 1: Overall results of swot analysis performed for case studies

SWOT ANALYSIS	Sustainability content	Transversal competences	In relation to teachers	In relation to students
Weaknesses	They can be displaced by the specific objectives of the tender specifications.	The incorporation of the contest to the dynamics of a subject with a specific subject.	The need to adapt the deadlines, contents and format to those of the subject.	The specificity of the products and themes eliminates the possibility of more generic learning
Threats	If they are not specifically assessed in the contest rules, they may not be treated rigorously.	The final proposal may be too influenced by the teaching of a specific subject.	The specificity of the objectives of the contest.	The focus on the final result can generate lack of attention in theoretical contents not applicable to the contest.
Strengths	They can be added values, as it is a contest of ideas in which contemporary realities and problems are valued as such.	In general, they are usually exercises where knowledge acquired in the rest of the subjects and courses is applied in a transversal way.	The existence of the evaluation by an external jury that complements the evaluation itself.	Additional motivations, experience similar to professional practice and carrying out a transversal exercise with clear objectives.
Opportunities	Being architectural proposals of innovative ideas, the incorporation of sustainability indicators are being increasingly valued by technical juries.	It is a real and motivating opportunity to carry out exercises of synthesis and synergy of procedural contents that go beyond the teaching program of a single subject.	For the teacher it is an opportunity to make flexible and update the proposals and complexity of the teaching tasks.	Contact with practice outside the teaching field and the business fabric.

Source: the authors

8. DISCUSSION

After the SWOT study [12] for each case study, we obtain the following results: (Table 1). The results presented here are the hierarchical objective summary of the SWOT analysis of each type of contest and its comparison. These allow us to extract the possibilities of the set of competitions in the educational field of the incorporation of aspects of sustainability in the teaching of architecture and urbanism :

From this analysis, we observe that the suitability of competitions as an educational strategy for the inclusion of aspects of sustainability and regenerative development in the teaching of architecture is evident, since relevant specific and generic competences are addressed in their development. These competences have a grate impact on the awareness and complete training of students, through their involvement in the whole process.

The validity of the process compared to the pure finalist character of the competitive proposals, the richness of the innumerable limit situations raised along the way, and even the bidirectional learning between teachers and students, makes this type of teaching experiences unbeatable teaching instruments. It is likewise stimulating for students to get in contact with the most current conceptions developed in other universities and with the possibility of exchanging concerns, ideas, concepts and materializations. Moreover, it is considered extremely suitable for the future professional projection of the students.

On the other hand, it is evident -in these cases of work by projects in higher education through the concurrence to innovative competitions-, that learning depends to a much greater extent on the consideration and value of the process, compared to the final result, which consolidates the idea of making the process an end in itself. These initiatives should serve as a starting point to gradually promote a change in the approach to university teaching methodology, which must not only adapt to the reality of the profession, but must align, like other administrations, to the requirements launched by international organizations, such as the 2030 Agenda [13] and the 17 Sustainable Development Goals [14,15].

Finally, it is noted that the current advances and the most innovative proposals in the field of research in educational sciences focus on transdisciplinary fields, on "integrated curriculum" teaching methodologies, and on the incorporation of the concept of sustainability in a transversal way: in short, in the learning processes through problem solving. However, the question of interdisciplinarity needs new tools and lines of research to achieve a successful implementation in higher education.

9. CONCLUSION

This paper demonstrates how competitions can be an useful teaching tool for a more sustainable approach to architecture in terms of contents, capacities and design methodologies.

However, it also detects the threats posed by addressing this type of educational strategies without prior exhaustive planning and strategic methodological preparation by teachers. It is necessary to deepen the study of the opportunities that these contests represent and the limitations they have as educational tools.

It is concluded that they should be used prudently and balanced within the academic curriculum to maximize their educational potential without turning them into an end in itself.

In relation to the different educational stages and origin of the students for each type of contest, it is necessary to indicate that there is a notable difference in this aspect and this is of great importance for the learning outcomes. The dynamics of groups and interconnection between areas of knowledge that is generated according to the type of experience, and collaborative learning versus individual one, offer completely different levels of achievement.

- SD case study: Interdisciplinary groups of different degrees and Schools, Universities, Professional Companies. High degree of interdisciplinarity and collaborative learning.
- EDUCATE case study: Groups of Schools of Architecture. Intermediate degree in Interdisciplinarity and collaborative learning.
- SMALL FORMAT COMPETITIONS case study: Experiences in a class and mostly individual deliveries. Low degree in Interdisciplinarity and collaborative learning.

In the SD contest, the most complex work teams are generated, formed by university students from different undergraduate and postgraduate courses, areas of knowledge, departments and even Universities. For example, in SD19 these teams were generated incorporating students and professors of different grades from various Faculties and Schools. The development of the SD 2019 competition was carried out by the University of Seville, with the joint participation of different faculties: the Higher Technical School of Architecture, the Higher Polytechnic School, the Higher Technical Schools of Building Engineering and Informatics, the Faculty of Medicine, Monterrey Institute of Technology and Higher Education and finally, the Development Cooperation Office of the University of Seville.

Thus, students, professors, professionals and companies collaborate in the project, linking teaching, research and entrepreneurship. This multidisciplinary and holistic group stimulates learning synergies while requiring a much more complex planning of the subgroups of work and sessions since the objective is the presentation of a single project or common result that has a great character of collaborative balance and consensus. For all these reasons, it is a more complete learning opportunity.

ACKNOWLEDGEMENTS

The authors wish to acknowledge all members of the “Equipo Solar Decathlon - Universidad de Sevilla” team for the Aura Project.

REFERENCES

1. Herrera-Limones, R.; León-Rodríguez, Á.L.; López-Escamilla, Á. Solar Decathlon Latin America and Caribbean: Comfort and the balance between passive and active design. *Sustain.* 2019, *11*, 3498, doi:10.3390/su11133498.
2. Herrera-Limones, R.; Rey-Pérez, J.; Hernández-Valencia, M.; Roa-Fernández, J. Student competitions as a learning method with a sustainable focus in higher education: The University of Seville ‘Aura Projects’ in the ‘Solar Decathlon 2019’. *Sustainability* 2020, *12*, doi:10.3390/su12041634.
3. Herrera-Limones, R.; Gómez, I.; Borrallo, M.; De la Iglesia, F.; Domínguez, A.; Gil, M.A.; Roa, J.; López, E.; Granados, M. Solar Decathlon Latino América y Caribe. Cali 2015 (Colombia) Proyecto Aura. In Proceedings of the II International and IV National Congress on Sustainable Construction and Eco-Efficient Solutions / Congreso Internacional de Construcción Sostenible y Soluciones Ecoeficientes; Mercader-Moyano, P., Ed.; Sevilla, España, 2017; pp. 769–794.
4. Herrera-Limones, R.; Pineda, P.; Roa, J.; Cordero, S.; López-Escamilla, A. Project AURA: Sustainable social housing. In *Sustainable development and Renovation in Architecture, Urbanism and Engineering*; Mercader Moyano, P., Ed.; Springer International Publishing, 2017; pp. 277–288 ISBN 978-3-319-51442-0.
5. Herrera-Limones, R.; Gómez García, I.; Borrallo Jiménez, M.; Iglesia Salgado, F. de la; Domínguez Delgado, A.; Gil Marti, M.A.; Granados Cabrera, M.; López, E.; Roa-Fernández, J.; Serrano Fajardo, J. Solar decathlon latino América y Caribe. Cali 2015 (Colombia), Proyecto AURA. 2015.
6. Herrera-Limones, R.; Hernández-Valencia, M.; Roa-Fernández, J.; Vargas-Palomo, A.C.; Guadix-Martín, J.; Torres-García, M. *La Universidad de Sevilla en ‘Solar Decathlon Europe 2019’. Innovación docente a través de un proceso de transferencia de conocimiento.*; 2021;
7. Altomonte, S. Environmental Education for sustainable architecture. *Rev. Eur. Stud.* 2009, *2*, 2–5.
8. EDUCATE Project Partners *EDUCATE Prize International Student Award*; EDUCATE Press/University of Nottingham, 2012; ISBN 9780957345034.
9. Cangelli, E.; Altomonte, S.; Yannas, S.; Herde, A. De; Fink, D.; Lopez De Asian, M.; Becker, G.; Partners, E.P. *EDUCATE Portal Development and Testing*; EDUCATE Press 2012, 2012;
10. Altomonte, S.; Cadima, P.; Yannas, S.; De Herde, A.; Riemer, H.; Cangelli, E.; De Asiain, M.L.M.L.; Horvath, S. Educate ! sustainable environmental design in architectural education and practice. In Proceedings of the Proceedings - 28th International PLEA Conference on Sustainable Architecture + Urban Design: Opportunities, Limits and Needs - Towards an Environmentally Responsible Architecture, PLEA 2012; 2012.
11. EDUCATE Project Partners *State of the Art of Environmental Suatainability in Professional Practice*; Altomonte, S., Ed.; First publ.; EDUCATE Press/University of Nottingham, 2012; ISBN 9780957345072.
12. Benzaghta, M.A.; Elwalda, A.; Mousa, M.; Erkan, I.; Rahman, M. SWOT analysis applications: An integrative literature review. *J. Glob. Bus. Insights* 2021, *6*, 55–73, doi:10.5038/2640-6489.6.1.1148.
13. United Nations *Transforming our World: The 2030 Agenda for Sustainable Development*; United Nations: Quito, Ecuador, 2015;
14. Organización de las Naciones Unidas Informe de los Objetivos de Desarrollo Sostenible 2020. *Onu* 2020, 64.
15. Secretaría de Habitat III *Nueva Agenda Urbana*; Naciones Unidas: Quito, 2017;

PLEA STGO 2022

November 22 - 25, 2022

SUSTAINABLE BUILDINGS AND TECHNOLOGY

DAY 03
09:00 — 10:30

CHAIR
BARBARA WIDERA

PAPERS
1615 / 1599 / 1559 / 1158 / 1344

34TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA SANTIAGO 2022
Will Cities Survive?

Photocatalytic wall shingles from recycled high-density polyethylene

An environmental solution to remove atmospheric gaseous pollutants in urban areas

CARBONNEL, ALEXANDRE [1]; PEREZ, HUGO [1]; GAVILANES, DAYANA [1]; LOYOLA, MAURICIO [1,2]; MORENO, CRISTOBA [1]; ESCOBAR, DANIEL [1]; JIMÉNEZ, MARIA PAZ [1]; MURILLO, HERMAN [1]; CHACÓN, CARLA [1]; FORMANDOY, YANARA [1]; MASFERRER, ROXANA [1]

[1] Environmental Architectural Materials Laboratory (LEMAA), School of Architecture, University of Santiago, Chile
[2] Architectural and Urbanism Faculty of the University of Chile.

ABSTRACT: The research develop a photocatalytic wall shingle prototype, the design problem of the prototyping process lies on thermochemical and mechanical properties, the chemical stabilization of the TiO2 nanoparticles additive and the constructive variables of the shingle. The results noticed a satisfactory behavior to mechanical tensile stresses. Expectedly, the polymer reflected some degradation, and it still represents a challenge to be further investigated so that the polymer can remain useful without compromising the photocatalytic activity of the nanocomposite. However and remarkably, NOX removal aims were achieve through plasma-based impregnation with 4.01% and 8.36% removal efficiencies obtained for two degradation tests, which represents removal class 1 and 3, respectively, according to the UNE EN 127197_1:2013 method. The novel photocatalytic films presented in this study give new insights into designing building materials on the utilization of plastic waste for urban air pollution control using photocatalytic materials from a sustainable perspective.
KEYWORDS: Shingle wall, removal pollutants, design materials, recycled plastic, photocatalytic

1. INTRODUCTION

This research aimed to develop a photocatalytic wall shingle prototype using recycled High-Density Polyethylene (HDPE) through mechanical recycling [1]. Recycled HDPE was mixed with titanium dioxide (TiO_2) nanoparticles by mechanical extrusion to produce nanocomposites showing photocatalytic activity. The final product was a film able to decompose air pollutants (e.g., NOX) under ultraviolet radiation.

Figure 1:
Recycled photocatalytic HDPE prototype for facades

This novel prototype was developed from an interdisciplinary approach involving architecture, industrial design, and chemical engineering. The objective was to integrate new strategies for manufacturing architectural components towards sustainable production.

On previous work, it was found that the thermal behavior of the films remained almost constant after the incorporation of the nanoparticles into the polymer matrix [2]. Similar results have been reported when ZnO or TiO2 nanoparticles were incorporated into polyethylene - PE [3].

Consequently, these similar thermal properties of the composite matrix would suggest analogous processing conditions as that of virgin PE. [2,3]

2. ENVIRONMENTAL ISSUES

The application of these prototypes can be addressed from multiple environmental concerns, particularly urban air pollution and plastic waste. On the one hand, the OECD has given critical advice about urban air pollution to a global extent, stating that air pollution may be the leading cause of diseases and deaths by 2050 if we do not tackle its control urgently [4]. On the other hand, 242 metric tons of plastic waste were generated worldwide in 2016, representing 12% of municipal solid waste [5]. Unfortunately, only 25% of these residues were recycled according to the European Union [6]. Since further investigation for the valorization of plastic waste is required, the proposed prototype emerges as an outstanding alternative to create valuable products from recycled plastic.

2.1 Design problems

The design complexity of the wall shingle lies in the mechanical recycling process and three important related criteria design; the thermochemical and mechanical properties, the chemical stabilization of the additive and the constructive variables of the shingle.

In a first step, the polymers' thermochemical and mechanical characterization is critical to achieve a stable and homogeneous coating as a semi-finished product.

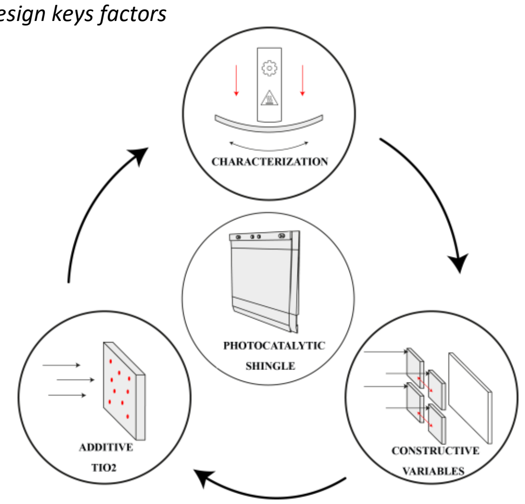
A second critical design factor, concern the chemical stabilization of additives, the way the TiO2 nanoparticles are supported on the plastic surface of the shingle is also relevant as a uniform distribution of the nanoparticles is mandatory to maximize photocatalytic activity.

Currently, several processes about incorporating additives to a polymeric matrix are available. Direct melt blending is among these processes, which is widely employed due to its techno-economic feasibility as well as the possibility to apply it at both laboratory and industrial scale.

Nevertheless, the way the nanoparticles are fixed over the matrix surface is the main issue regarding the melt blending process. This is crucial since it may affect the photocatalytic activity of the nanocomposite.

Plasma-based impregnation could be a suitable alternative to fix the additives over the polymer surface that was previously manufactured via melt blending and pressing.

Figure 2:
Design keys factors

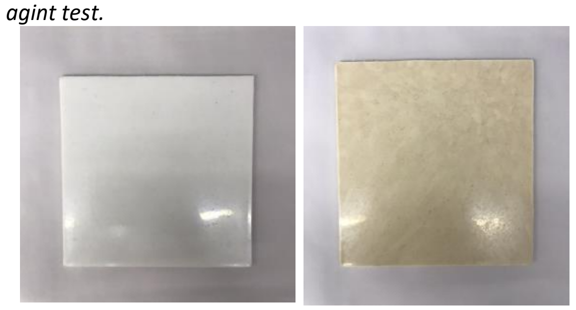


3. SUBMISSION INSTRUCTION

In regard to the first design factor, recycled HDPE films (without additive and with the TiO2-based additive) were characterized via infrared spectroscopy (FTIR) and mechanical tests. In addition, an accelerating aging test was conducted to evaluate the performance of the material before and after exposure to the UV radiation.

For the aging test, the samples were exposed to 720 hours of UV radiation according to the standard ASTM G154 for promoting an adequate exposure of the sample to outdoor conditions.

Figure 3:
Film without and with TiO2 additive, before and after agint test.



About the mechanical tests, the method ASTM D 638 was applied, which implies the type I samples must undergo tensile stress tests using a Instron machine (Emic 23-100 model) by applying a speed of 50 mm/min.

This test allows determining the maximum rupture stress (σm) of the material, the percentage of deformation (εB) and Young's Modulus (E).

Regarding the second design factor, two manufacturing processes and their capability to produce a photocatalytic effect were employed to assess the chemical stabilization of the additive. The first one was the melt blending process of the recycled HDPE with TiO2 via extrusion and pressing. The other one was the plasma methodology as previously mentioned.

To check the chemical stability of the additive and its photocatalytic potential, the films were characterized by Scanning Electron Microscopy (SEM). Additionally, photocatalytic activity was evaluated in terms of the NOX removal based on the ISO 22197-1 method [7].

Finally, the third design criteria was conducted through an iterative design and prototyping process combining thermofusion pressing and 3D printing to observe the geometric and physical performance of the shingles as a constructive part.

Figure 4:
Recycled HDPE films obtained by injection

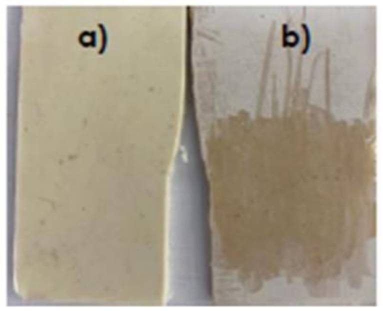
Results were analyzed considering an experimental design including the following factor levels: a) films without photocatalytic nanoparticles (FTIR, tensile and aging test, and Finite Element Analysis), b) films with photocatalytic nanoparticles (SEM, FTIR, tensile and aging test, and NOX removal method), and c) films with photocatalytic nanoparticles impregnate trough plasma method (NOX removal method)

4. RESULTS AND DISCUSSION

Regarding the thermochemical and mechanical characterization of the films, the samples of recycled HDPE with TiO2 were exposed to 720 h of UV radiation, showing a whitish coloration on their surface compared to the samples without exposure. Figure 5 shows the difference in coloration between the recycled HDPE sample with TiO2 before and after the aging test.

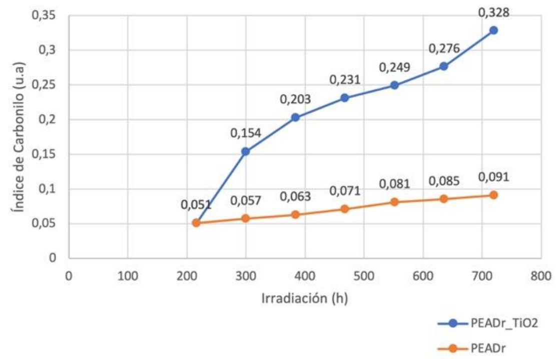
Solar radiation (especially the UV portion) is crucial in terms of plastic degradation.

Figure 5:
Recycled HDPE with TiO_2 before and after aging test.



The carbonyl index is appropriate to evaluate the polymer degradation, which is a measure of the share of C=O and C-H bonds that can be identified from the FTIR spectra. Figure 6 shows a comparison of the carbonyl index of the recycled HDPE and recycled HDPE/TiO2 samples after the accelerated aging test. It can be noticed that after 4 cycles of exposure to the UV radiation, the carbonyl index of the recycled HDPE did not increased significantly. In contrast, the carbonyl index was increased significantly after a 300-hour exposure for the HDPE/TiO2 sample, demonstrating the polymer degradation. It could be attributed to the TiO2 addition since its photocatalytic activity is improved under UVA exposure, decomposing the polymeric chains and affecting its mechanical properties.

Figure 6:
Carbonyl index for the recycled HDPE and recycled HDPE/TiO_2



Finally, the recycled HDPE showed increments of 3.84% and 15.83% in the maximum stress and strain at rupture, respectively, for the mechanical properties. On the other hand, the modulus of elasticity decreased 7.30% after the UV exposure in the aging test. When comparing with the results of the recycled HDPE/TiO2 sample, it was found a-7.4% decrease in both the maximum stress and strain at rupture, whereas the modulus of elasticity increased by 5.87% after the UV exposure in the aging test.

Table 1:
Mechanical properties through tensile test

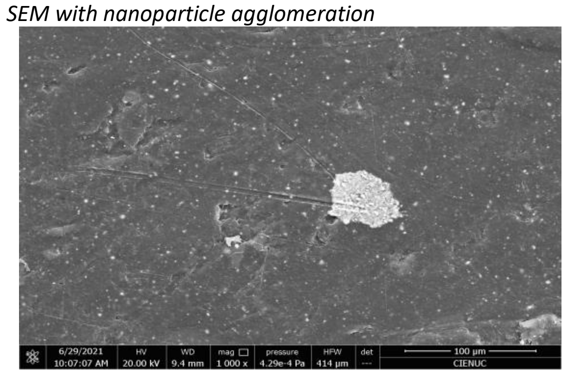
Sample	σm(MPa)		ε (%)		E(MPa)	
Recycled HDPE	19.2	+3,8%	8.7	+15,8%	967	+7,3%
UV Recycled HDPE	20.0		10.1		896	
Recycled HDPE/TiO_2	18.1	-7,4%	3.6	-7,4%	967	+5,8%
UV Recycled HDPE/TiO_2	16.7		3.3		1023	

A plastic material is considered to be aged and unsuitable for use, when it retains < 50% of the evaluated mechanical properties after exposure to solar radiation or to the accelerated aging. Therefore, based on the results from the mechanical tests, the mechanical behavior of the samples lies in acceptable ranges with < 10% variations of the maximum rupture stress (σm), the percentage of deformation (εB), and Young's Modulus (E) in both samples.

In summary, it was noticed a satisfactory behavior to mechanical tensile stresses after thermochemical and mechanical characterization. Expectedly, the polymer reflected some degradation, and it still represents a challenge to be further investigated so that the polymer can remain useful without compromising the photocatalytic activity of the nanocomposite.

Regarding the chemical stability of the additive to achieve a photocatalytic activity, from the SEM images, it was observed nanoparticles were deposited on the film surface; however, the distribution of the nanoparticles could be further improved since also some nanoparticle agglomeration was identified.

Figure 7:
SEM with nanoparticle agglomeration



This observation is consistent with the low NOX removal yields (< 4%) were obtained from preliminary degradation tests, probably due to the nanoparticle agglomeration mentioned previously.

Remarkably, NOX removal results were within reasonable levels for the samples impregnated with plasma. 4.01 and 8.36% removal efficiencies were obtained for two degradation tests, which represents removal class 1 and 3, respectively, according to the UNE EN 127197_1:2013 method. These results are detailed in Table 2.

Table 2:
Samples tested for NO_X removal ISO 22197-1 method

ISO 22197-1	HDPE_TiO_2 Extrusion Sample 1	HDPE_TiO2 Plasma Sample 1	HDPE_TiO2 Plasma Sample 2
NO (%) removal	1.38	10.48	22.18
NOx (%) removal	0.54	4.01	8.36

Even though these NOX removal results are promising, we strongly suggest the experimental runs should be repeated to achieve statistical significance.

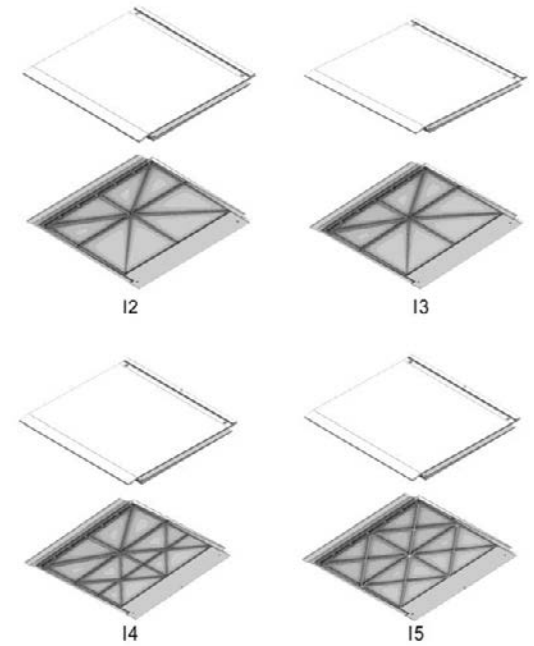
The most remarkable finding from this study lies in the fact that the melt blending process might not be providing the desired results in terms of photocatalytic activity. It could be attributed to the nanoparticle agglomeration showing no uniform distribution of the nanoparticles on the polymer surface.

In contrast, the plasma methodology for nanoparticle impregnation seems to be a promising alternative for a better distribution of the nanoparticles in the matrix surface, thus improving the photocatalytic activity.

About the coating constructive variables, the results of the iterative process of manufacturing samples in 3D printing allowed identifying the required modifications for the manufacturing and final assembly of the coating.

An iteration series was developed by groups, where iterations 2 to 5 were very relevant. The coating herein was transformed into a 2mm-thick film showing interior ribs, which is in concordance with an injection manufacturing process. A 2mm 45° mechanical lock was designed on the bottom and top edge for vertical hooking, and a 1mm 90° lock on the right edge for horizontal hooking. This allows the fastening to the substrate, which facilitates a proper screw adjustment as well as to identify a potential risk of water infiltration.

Figure 8:
Iteration shingle process 12 to 15.



The rest of the iterations allowed adjusting variables related to size, shape, tightness and fixation and assembly.

Critical issues were found out in regard to the potential thermal expansion and contraction of the polymer that may affect the coupling between shingles. Based on this background, finite-element-iterations 9 and 11 and subsequent adjustments on iterations 12 to 15 permitted defining the latch at 45° and 3 mm of overlap. It ensures the latch even during conditions of maximum thermal expansion.

5. CONCLUSION

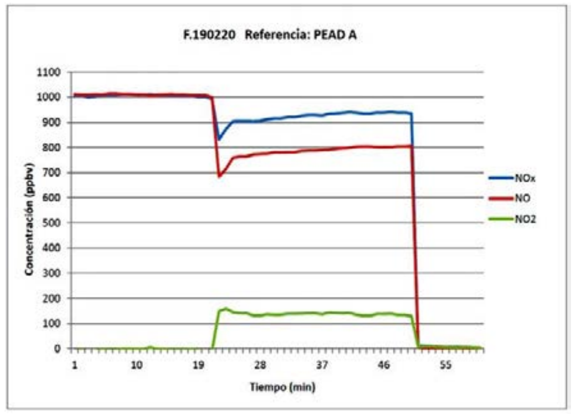
The studied design factors exhibited a satisfactory scenario for the development of an industrial prototype comprising of a photocatalytic wall coating, using recycled High-Density Polyethylene (HDPE) through mechanical recycling.

Although the degradation degree observed in the polymer aging test is a critical variable, further studies should be conducted to assess the behavior of the coating by incorporating stabilizing additives such as carbon black.

On the other hand, the mechanical properties remained within reasonable ranges, without reflecting significant decreases.

Remarkably, based on the results from the NOX removal tests based on the ISO 22197-1 method, a photocatalytic wall shingle can be obtained via plasma impregnation of TiO2 over a polymeric matrix.

Figura 9:
Curve of NOx removal. Sample with 8,36% .



The novel photocatalytic films presented in this study give new insights into designing building materials from a sustainable perspective, and contribute to the efficient utilization of plastic waste for urban air pollution control using photocatalytic materials.

This material design approach provides useful insights in terms of circular economy and environmental impact, which can be scaled up to the construction and architectural sectors.

ACKNOWLEDGEMENTS

FONDEF IDeA ID20I10291. Subdirección de Investigación Aplicada, Agencia Nacional de Investigación y Desarrollo, ANID

EPTISA Laboratorio. Valladolid, España. NOX removal based on the ISO 22197-1 method

CIPA. Centro de investigación de polímeros avanzados. Concepción, Chile. Mechanical an aging test.

REFERENCES

1. ISO 15270:2008. Plastics — Guidelines for the recovery and recycling of plastics waste. Second edition 2008-06-15.
2. Carbonnel, A., Pérez, H., Lucares, M. I., Escobar, D., Jiménez, M. P., & Gavilanes, D. (2021). Upcycling plastic waste for the development of construction materials. TECHNE-Journal of Technology for Architecture and Environment, 170-176.
3. Rojas, K., Canales, D., Amigo, N., Montoille, L., Cament, A., Rivas, L. M., ... & Zapata, P. A. (2019). Effective antimicrobial materials based on low-density polyethylene (LDPE) with zinc oxide (ZnO) nanoparticles. Composites Part B: Engineering, 172, 173-178.
4. George, C., Beeldens, A., Barmpas, F., Doussin, J. F., Manganelli, G., Herrmann, H., ... & Mellouki, A. (2016). Impact of photocatalytic remediation of pollutants on urban air quality. *Frontiers of Environmental Science & Engineering*, *10*(5), 1-11.
5. Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). What a waste 2.0: a global snapshot of solid waste management to 2050. World Bank Publications.
6. Europea, C. (2015). Cerrar el círculo: un plan de acción de la UE para la economía circular. *Union Europea, Bruselas-Bélgica*.
7. ISO 22197-1:201. Test method for air-purification performance of semiconducting photocatalytic materials - Part 1: Removal of nitric oxide

Calculating Algorithm to Estimate the Hygrothermal Performance of Vegetation for Green Screen Façades

CAMILA DA ROCHA[1] CLAUDIO VÁSQUEZ[1-2] PEDRO PABLO DE LA BARRA[1]

[1] Pontificia Universidad Católica de Chile, Escuela de Arquitectura
[2] Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD) Pontificia Universidad Católica de Chile

ABSTRACT: Using plants as sun protection is of increasing interest because of the many benefits of vegetal material, in contrast to conventional sunscreens. However, its application and studies are currently limited by the complexity of considering organic variables as part of its performance in relation to a climate context. These limitations are evident in digital simulation softwares, which does not allow quantifying the thermal benefits that distinguish this protection from conventional ones in energy balance simulations. This work presents a method for evaluating the cooling potential of green screen façades that allows the model to differentiate and measure the effect of green screen façades as a shading device and as an evaporative cooling strategy. For this, a hygrothermal model is developed integrating calculation models provided by various authors within the Grasshopper platform using the EnergyPlus simulation engines. The results portray it is possible to simulate the virtual thermal behavior of the vegetal material, incorporating the evapotranspiration of the plant and its properties in the calculation of the air conditioning demands of buildings.
KEYWORDS: Green screen façade, Evapotranspiration, Simulation, Thermal comfort, Plants.

1. INTRODUCTION

As a consequence of global warming, in Chile, the projections for the following years suggest a temperature increase of 2°C to 4°C throughout the country, and a reduction of around 40% of rainfall in the Central Zone, where the densest urban areas are located [1]. Among the strategies to mitigate the effect of climate change, the increase in urban green areas for the creation of microclimates to mitigate the phenomenon of urban heat islands is widely accepted, given that the vegetal material provides shade and increases the air humidity through evapotranspiration, as well as contributes to the reduction of environmental pollution and the conservation of biodiversity [2].

At the building scale, because of the high impact these structures have on the local microclimate, solutions such as green screens and roofs use the benefits of the properties of the vegetal material to mitigate the urban heat. Integrating live plants in the façade design allows to regulate the surface temperature of the envelope, blocking the incident solar radiation, reducing the effect of the wind, and cooling the air through evapotranspiration [2]. As a result, this strategy allows to avoid heat loss in winter, overheating in summer and potentially improving the building's energy performance [3].

Unlike conventional sunscreens applied to buildings to protect them from sun exposure and reduce overheating due to excessive solar gain, green screen façades are a more efficient passive strategy given the additional benefits the vegetal material can provide, both at a large and small scale, because the surface temperature of the leaves is lower than that of the materials traditionally used [4]. It has been shown that, for the same incident solar radiation, the surface temperature of the walls decreases double the amount with a vegetal screen compared to a conventional solar protection, since the surface temperature of the vegetation stays under 35 ºC when an unprotected wall can reach up to 55 ºC [5]. This is because traditional materials have a higher density and heat capacity under solar exposure, causing them to have a higher surface temperature transmitting this caloric energy. Plants instead have an additional function of perspiration that allows to maintain a lower temperature against direct sun exposure due to the fact that around 60% of the energy absorbed by the plant is transformed into latent heat as a physiological process of evapotranspiration [6].

Despite the potential benefits of using vegetation as a cooling strategy in buildings, its use is limited by the difficulty of incorporating its contributions into the calculation of the building's energy balance. This issue is currently being worked on through three fundamental methods: experimental studies, measurements of buildings in operation, and digital modelling.

Experimental studies and measurements of existing buildings are more abundant, however, for both types of study methods the results are only valid for the climates and orientations of each case

[7]. In Berlin, studies were carried out to analyse the behaviour of the vegetal façade in buildings with different orientations, determining shade and evapotranspiration as the main factors of their performance [6]. In Shanghai, a study compared the building performance before and after the installation of green screens for south and north façade, achieving an average decrease in the daily temperature of 0.4°C and 0.2°C and maximums of 5.5°C and 3.3°C, for each orientation respectively [8]. In Hong Kong, after the application of green screens as a solar protection for buildings, a 16% energy saving was achieved in summer [9] and, in another study, the green screen caused reductions of 6.1°C in the cavity between the envelope and the screen, and reductions of 3.6°C inside the building, compared to the exterior temperatures [10].

In Chile, studies regarding the phenomenon of urban heat islands associated with environmental pollution showed that vegetation can be used as a strategy to thermally regulate the city [11]. Recent studies of the hygrothermal potential of green screen façades through measurements of buildings in operation in Santiago de Chile, have registered differences of 8°C in temperature and 30.4% in relative humidity between the green screen and the building envelope. Where it was determined that the fundamental factors for its performance are the orientation and density of the foliage, further validating its effectiveness in dry Mediterranean climates such as Santiago [12].

Studies based on digital modelling face the difficulty of representing the geometry and density of vegetation, in addition to considering its cooling potential for calculating buildings energy demands. The common method is the calibration of models experimentally to predict the optical properties of vegetation and reframe the energy balance from the plant's metabolism, based on the reference climate [13,14]. With this method, it has been verified that green walls have a greater impact in hot climates since they allow to reduce cooling loads if they have an efficient irrigation system [7]. A model based on the morphology of the vegetation has also been proposed and experimentally verified, determining that, in order of importance, the relevant climatic variables for its performance are solar radiation, wind speed, relative humidity, and outdoor air temperature [15].

The problem that the design of green screens faces today is how to calculate the latent heat and evapotranspiration produced by a plant in order to quantify its potential or capacity to produce passive cooling by regulating the temperature and relative humidity in the environment.

Thus, the application and projection of green screen façades are still limited by the complexity of considering organic variables as part of its performance in relation to a climate context [3,4]. These limitations are evident in digital simulation softwares, which does not allow to quantify the thermal benefits that distinguish this protection from conventional ones in energy balance simulations, given that current simulation softwares that includes this material in thermal calculation models only integrate the optical properties of the vegetation, reducing its effect to that of a traditional solar protection, leaving aside its hygrothermal contribution [16]. Developing a method to calculate the energy potential of vegetation would allow them to be incorporated as a passive cooling strategy, both in early design stages and in improving the thermal performance of buildings in operation.

Authors such as Suklje, Susorova and Larsen, have generated significant contributions to the thermal modelling of green protections, considering the effect of evapotranspiration on heat transmission through the buildings envelope, both for green walls and green screen façades [4,13,15]. These mathematical models are based on the method proposed by the Food and Agriculture Organization (FAO) [14-17] to calculate plants evapotranspiration through the Penmann-Monteith equation. However, there are no antecedents of calculating the contribution of humidity to the air generated by latent heat, which may have a high potential when associated with the evaporative cooling method, as the energy consumed by the change of state of water from liquid to gas removed from the air reduces the air temperature [4] as this energy is obtained from the sun and from the sensible heat transmitted by the air.

Therefore, the aim of this paper is to propose a method for quantifying the contribution of humidity through evapotranspiration and thermal balance of plant screens in relation to a glazed façade by integrating calculation models, provided by various authors, which allows the following variables to be determined: the evapotranspiration of the vegetation; the latent heat released in said process; the contribution of humidity to the environment; and the evacuated heat that will finally inform the cooling potential.

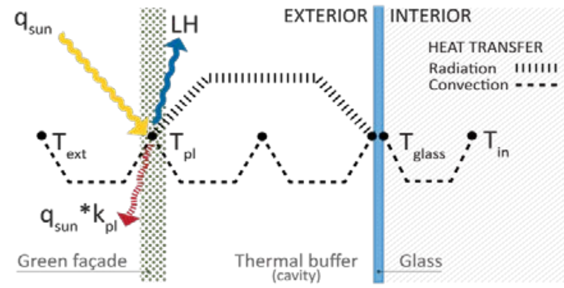
2. MATHEMATICAL MODEL

The leaves are the organ where 90% of its water loss is concentrated and where photosynthesis occurs by synthesizing carbon dioxide and water to produce oxygen [4].

Leaf transpiration occurs through two processes: evaporation and diffusion of water vapor, together with evaporation from the soil or plant substrate, producing evapotranspiration. The rate of evapotranspiration depends largely on meteorological factors such as light intensity, wind speed, temperature, and air humidity, all of which are directly related to the responses of plant cells, as well as the plant factors such as leaf area index, leaf size, stomatal conductance, and aerodynamic resistance [17].

In this way, the model for estimating the cooling potential of double vegetable skins refers to the calculations that account for the thermal effect of the plant to be incorporated as a new element in the thermal balance of the building when estimating the energy required for acclimatization of the interior space (Fig. 1). The energy balance of this process has three components: one part is released as sensible heat, which is what can be perceived as heat; another part as latent heat, which is the energy absorbed in the change of phase of the water; and a minimum part is used for photosynthesis.

Figure 1:
Heat exchange network diagram of a green screen façade



Note: q_{sun}: Incident solar radiation; k_{pl}: plant absorption coefficient; T_{air}: Outside air temperature; T_{pl}: vegetation surface temperature; T_{glass}: Internal surface temperature of the glass; T_{in}: Indoor air temperature.

2.1 Evapotranspiration

For the specific case of indirect plant systems or green screen façades, the heat transfer processes involved in the energy balance of foliage are the absorption of the incident solar radiation, the transmission of sensible heat by convection between the leaf and the surrounding air, the transmission of infrared energy between the sheet and the components of the building façade by radiation, the latent heat expelled by the plant by transpiration, the storage of energy in the tissues, conduction through the leaf (generally insignificant), and the energy used for the metabolic processes necessary for the photosynthetic or catabolic reaction [4].

These factors are expressed in the Penman equation (Penman 1948) for the calculation of evapotranspiration (*Equation 1*):

$$ET = (\Delta(q_{sun}K_{pl} - q_{rad} - G) + \rho_{air}\, C_{air}(e_0 - e_{air})/ r_a)/ (\lambda(\Delta + \gamma\, (1 + r_{s/}\, r_a)) \quad (1)$$

In this equation *ET* is the evaporated water in g/sm^2. In the case of vertical plant systems, the area of the plants is greater than that of the substrate, for which transpiration is dominant, due to this, the heat absorbed by the soil (*G*) (W/m^2) is negligible (*G=0*) when compared to the other contributions. The total energy absorbed is represented by $q_{sun}K_{pl}$ which corresponds to the incident radiation q_{sun} (W/m^2), and K_{pl} the absorption coefficient of the plant. γ is the psychrometric constant in (kPa/ºC), ρ_{air} is the air density (Kg/m^3) and C_{air} is the specific heat of the air (J/kg K), e_0 is the saturation vapor pressure at mean air temperature (kPa), e_{air} the real vapor pressure (kPa), r_a and r_s are the aerodynamic resistance (s/m) and the stomatal resistance (s/m) respectively, Δ is the slope of the saturation vapor pressure curve (kPa/ºC) at air temperature (ºC) and λ is the specific heat of evaporation of water (λ = 2490 kJ/kg considered at a temperature of 20°C. Finally, q_{rad} corresponds to the net infrared flux between the ground floor and the glazed surface of the façade (W/m^2), expressed by the Equation (2):

$$q_{rad} = \sigma\, \varepsilon_{pl}\, F_{ground}\, (T_{pl}^4 - T_{soil}^4) + \sigma\, \varepsilon_{pl}\, F_{sky}\, (T_{pl}^4 - T_{sky}^4) + \sigma\, (\varepsilon_{pl}\varepsilon_g /(\varepsilon_{pl} + \varepsilon_g - \varepsilon_{pl}\varepsilon_g))*(T_{pl}^4 - T_g^4) \quad (2)$$

Where σ is the Stephan-Boltzmann constant (σ = 5.67x10-8 W/m^{2}K^4), ε_{pl} and ε_g are the emissivities of the vegetation and glass respectively, T_{pl}, T_{soil} and T_{sky}, T_g are the foliage, ground, sky, and glass temperatures (K) and F_{ground} and F_{sky} are the corresponding view factors.

2.2 Latent heat

From evapotranspiration it is possible to determine the latent heat (*LH*) (W/m^2). In practical terms, this value corresponds in this case to the absorption of energy caused by the change of state of water from liquid to gaseous. The Equation (3) allows its calculation as presented below:

$$LH = ET*\lambda \quad (3)$$

Where ET corresponds to the evapotranspiration (g/sm^2) and λ (λ = 2490 kJ/kg) is the specific heat of vaporization of water.

2.3 Humidity contribution

The contribution of humidity to the environment (H_{pl}) is expressed in kilograms of water per kilogram of dry air (kg water/kg dry air). It refers to the transfer of water vapor to the surrounding air mass by the effect of evapotranspiration from the green façade. Consequently, this transfer of water vapour, causes an increase in the concentration of water in the environment and, therefore, its absolute humidity. However, as the plant evapotranspiration data describes the water content per surface unit, it is not possible to determine its contribution using relative humidity differentials. For this reason, the air density (ρ_{air}) is used, which contains the environmental variables that inform the basic conditions of the contribution of the vegetal façade, such as atmospheric pressure, ambient temperature, and relative humidity, necessary to obtain the kilograms of water contributed by the vegetation. As expressed by the Equation (4):

$$H_{pl} = LH*A_{gf}/(1000\rho_{air}f_{air}*\lambda) \quad (4)$$

Two variables are incorporated into the described equation. The green façade area (A_{gf}) (m^2) that reports the dimension of the green façade that is being evaluated and the air flow (f_{air}) expressed in cubic meters per second (m^3/s) that accounts for the mass movement that integrates the rate of air renewal after the evaporative discharge has been produced. This last variable is important because it establishes the need to move the mass of air that surrounds the vegetal façade to avoid its saturation and thus keep the cooling principle contained in the evapotranspiration principle active.

The mass of air in contact with the vegetal façade presents a reduction in energy that corresponds to that used for the evapotranspiration process and, therefore, a reduction in its temperature. In this way, said cooled air can be used as an evaporative cooling strategy which can be integrated into the building from an air injection and extraction system.

2.4 Heat evacuated

The heat evacuated (q_{air}) (W/m^2), being the energy absorbed from the environment surrounding the plant to reach the vaporization process of the released water, is obtained from the humidity contribution (H_{pl}) (kg water/kg dry air) and the specific heat of the water (λ), detailed in the following Equation (5):

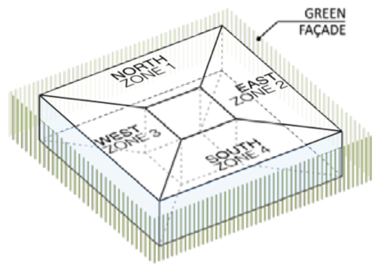
$$q_{air} = H_{pl}*\lambda \quad (5)$$

Finally, the heat evacuated provides the information on the cooling potential of the green façade indirectly associated with the building envelope, since it describes the energy consumed in a given volume of air by the plant's evapotranspiration process. If said volume of air is incorporated into the building by some type of ventilation strategy (natural or forced), the energy consumed in the evapotranspiration process can be subtracted from the internal loads accumulated in the building after its thermal balance, as the potential thermal conditioning of the vegetal façade in the interior space.

3. MODEL PARAMETERS

For the implementation of the mathematical model described, the equations were incorporated as programmed routines in the Grasshopper programming platform (Version 1.0.0007-2019) in the Rhinoceros 3D software plugin (version 6 SR13-2019), simulated through Energy Plus with the DIVA-Toolbar 4.1.0.11 interface.

Figure 2:
Case model elaborated for the estimation of the thermal contribution of the vegetal screen



Two cases will be analized: base case model, which considers the plant screen solely as a shading system; and a green screen model, which considers both solar protection and cooling potential [1]. For the two scenarios, a building with a square floor plan of 20 meters on each side is used, with a glazed façade and plant screens as solar protection, oriented perpendicular to the north. The floor plan was divided into four thermal zones differentiated by their orientation (Fig. 2).

To simulate the vegetal material the "big leaf" method is used [4], translating the plant layer as a single leaf that covers the entire façade as a constant solar screen. For this a custom Radiance material is created with properties resembling climbing plants optical characteristics are assigned to a monolithic glass (Table 1), as a simplified solution established in previous studies to analyze primarily its shading effect [4].

Table 1:
Material properties assigned to simulate a green façade

Properties	Values
Solar transmittance	0.3
Sun reflectance	0.2
Visible transmittance	0.06
Visible reflectance	0.09
Thermal emissivity	0.95
Conductivity [W/m² C]	0.59

In both models, the internal gains are active for twenty-four hours to show the effect that solar radiation and evapotranspiration has on cooling loads. The air conditioning modeled is controlled with a set-point of 26°C and humidity with an activation threshold of 30%. For the second case a natural ventilation is considered to incorporate the effect of evapotranspiration into the thermal balance.

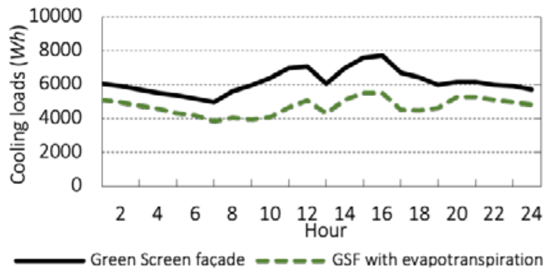
To illustrate the impact of the climate factors on the green façade the model is simulated for three representative days of summer: sunny (January 1), cloudy (February 5) and partial (February 17).

4. RESULTS

4.1 Overall performance

The average hourly energy demands of the three representative summer days are analyzed (Fig. 3). It is observed that the evapotranspiration of the vegetal screen generates a reduction of the loads throughout the day, however, in the sun light hours the cooling effect of the vegetal screen is accentuated.

Figure 3:
Cooling consumption

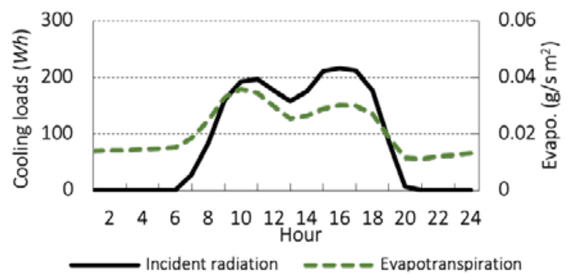


Note: Graph of cooling loads on a representative summer day. This does not distinguish orientation or type of day.

4.2 Relation between incident radiation and evapotranspiration

The graph (Fig. 4) compares the incident solar radiation and the evapotranspiration of the plant during the day, showing their correlation. The higher the solar radiation, the better the evaporative performance of the vegetable screen. During the hours when there is no solar radiation, the plant's evapotranspiration remains in operation due to other variables such as outside temperature and relative humidity, which are also considered in the mathematical model.

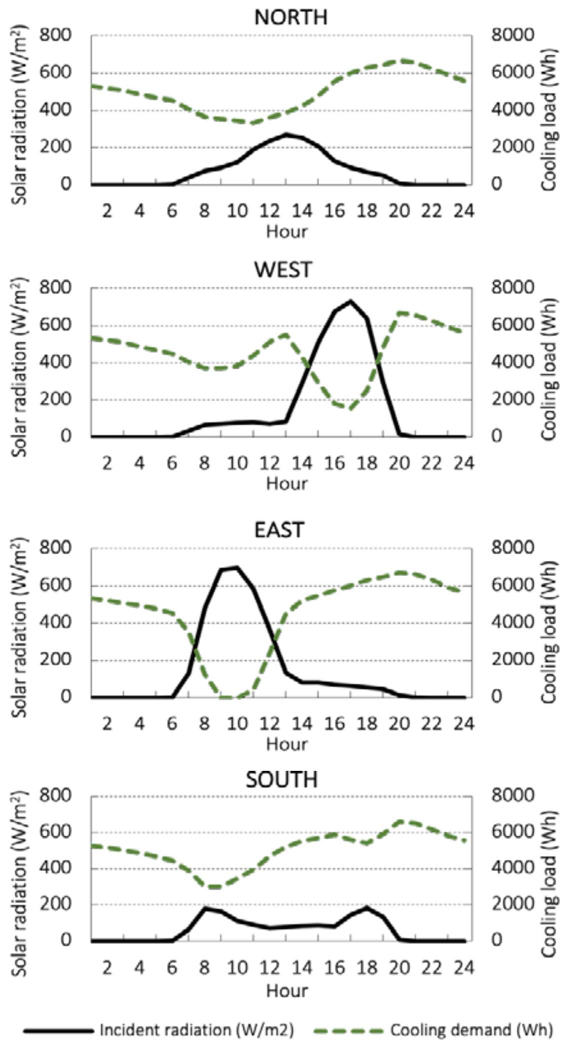
Figure 4:
Relationship between incident radiation and the evapotranspiration of the vegetal screen



4.3 Dependence between evapotranspiration and orientation

Figure 5 shows four graphs comparing the incident solar radiation and the cooling loads by orientation considering the evapotranspiration. It is observed that the peak of incident radiation occurs according to the solar path and is correlated with the reduction of the energy demand. This shows that, in the presence of solar radiation, the plant not only acts as sun protection since it also functions as a passive cooling system.

Figure 5:
Relationship between incident radiation and cooling loads of the case that incorporates the thermal effect of the plant screen by orientation



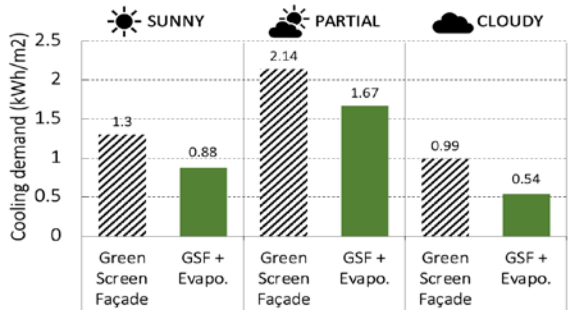
4.4 Performance according to the climate context

The Figure 6 shows the daily average energy demands for the two scenarios and each of the three types of days simulated. The case that considers the contribution of evapotranspiration has constantly lower cooling loads, achieving a reduction of 33% of the demand for a sunny day, 22% for the partial day, and 45% for the cloudy day,

[1] The evapotranspiration results were penalized by 50% to represent that a plant does not receive constant solar radiation since the leaves shade each other.

expressing its cooling potential. Thus, showing that the thermal contribution of the plants has a positive impact.

Figure 6:
Refrigeration demands for each representative day of the summer season and its cooling potential.



5. CONCLUSION

A method has been shown to incorporate the evapotranspiration of the vegetal screens in the calculation of the cooling loads of the buildings. This model integrates algorithms provided by different authors and allows to compare the difference between considering the plant screen solely as sun protection or both as a shading system and as a contribution to the air conditioning of the building.

The proposed model was applied to evaluate the behaviour of a virtual green façade placed in the climate of Santiago de Chile, the results show vegetal screens can be used as a passive cooling system on sunny, partial, and cloudy days where the cooling potential of the plants is related to the incident radiation in the façade's plane. Therefore, their incorporation in the energy loads calculations would support their application.

However, the primary aim of this study is to present a mathematical model to estimate the potential cooling of a vegetal screen, which is an abstraction of reality and therefore results can vary according to the model parameters and climate conditions considered. Thus, further research is necessary in order to validate, evaluate the model sensitivity and be able to determine which are the virtues and which are the issues that should be discussed or incorporated into the method developed. For this, an experimental approach would be beneficial to provide real data to calibrate the model and be able to calculate the thermal benefits of plants with greater efficacy.

ACKNOWLEDGEMENTS

This work was supported by Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD) Pontificia Universidad Católica de Chile, and forms part of the Master thesis developed by Camila Da Rocha in the Master program in Sustainable Architecture and Energy (PUC).

REFERENCES

1. Cifuentes, L., & Mesa, F. (2008). Cambio Climático: consecuencias y desafíos para Chile. Santiago: Universidad Católica.
2. Hunter, A., Williams, N., Rayner, J., Aye, L., Hes, D., & Livesley, S. (2014). Quantifying the thermal performance of green façades: A critical review. Ecological Engineering, 63: p. 102–113.
3. Pérez, G., Rincón, L., Vila, A., González, J., & Cabeza, L. (2011). Behaviour of green facades in Mediterranean Continental climate. Energy Conversion and Management, 52(4): p. 1861–1867.
4. Larsen, S., Filippín, C., & Lesino, G. (2015). Modeling double skin green façades with traditional thermal simulation software. Solar Energy, 121: p. 56–67.
5. Belén, C., Ruiz, L., Larsen, S. F., & Hoyos, D. (2019). Análisis de la eficiencia energética de una doble fachada verde para el clima de la ciudad de Salta. INENCO, 23: p. 01.259-01.266.
6. Hoelscher, M. T., Nehls, T., Jänicke, B., & Wessolek, G. (2016). Quantifying cooling effects of facade greening: Shading, transpiration and insulation. Energy and Buildings, 114: p. 283–290.
7. Djedjig, R., Bozonnet, E., & Belarbi, R. (2015). Analysis of thermal effects of vegetated envelopes: Integration of a validated model in a building energy simulation program. Energy and Buildings, 86: p. 93–103.
8. Yang, F., Yuan, F., Qian, F., Zhuang, Z., & Yao, J. (2018). Summertime thermal and energy performance of a double-skin green facade: A case study in Shanghai. Building and Environment, 96: p. 293-300.
9. Pan, L., & Chu, L. (2016). Energy saving potential and life cycle environmental impacts of a vertical greenery system in Hong Kong: A case study. Building and Environment, 96: p. 293–300.
10. Pan, L., Wei, S., & Chu, L. (2018). Orientation effect on thermal and energy performance of vertical greenery systems. Energy and Buildings, 175: p. 102–112.
11. Romero, H., Irarrázaval, F., Opazo, D., Salgado, M. & Smith, P. (2010). "Climas Urbanos y Contaminación atmosférica en Santiago de Chile." EURE (36): p. 35-62.
12. Vásquez, C., De La Barra, P. , D'Alençon, R., Fagalde, M., & Salza, F. (2020). Hygrothermal potential of applying double-skin green façades for a warm-summer Mediterranean climate. Journal of Facade Design and Engineering 2020: p. 19-38.
13. Suklje, T., Medved, S., & Arkar, C. (2016). On detailed thermal response modeling of vertical greenery systems as cooling measure for buildings and cities in summer conditions. Energy (115): p. 1055–1068.
14. Allan, S. & Kim, H. (2016). A Study of Workflow for Simulations of Vertical Greenery Systems. Architecture Research (6): p. 142–153.
15. Susorova, I., Angulo, M., Bahrami, P., & Brent Stephens. (2013). A model of vegetated exterior facades for evaluation of wall thermal performance. Building and Environment, 67: p. 1–13.
16. Ip, K., Lam, M., & Miller, A. (2010). Shading performance of a vertical deciduous climbing plant canopy. Building and Environment, 45: p. 81–88.
17. Allen, R., Pereira, L., Raes, D., & Smith, M. (1998). FAO Irrigation and drainage paper No.56. Food and Agriculture Organization of the United Nations, 56: p. 26-40.

Thermal Insulation with Discarded Sheep Wool

Social, Environmental and Economic Impact of Large-Scale Use in Social Housing

ALEJANDRA NUÑEZ BERTÉ[1], JOHN MARTIN EVANS[1], LUIS FERNANDEZ LUCO[2]

[1]Maestría Sustentabilidad en Arquitectura y Urbanismo, FADU, Universidad de Buenos Aires
[2] Facultad de Ingeniería, Universidad de Buenos Aires

ABSTRACT: *This paper presents an evaluation of the use of wool as thermal insulation material considering the specific conditions and resources available in Argentina and in the Province of Buenos Aires. The sheep production in this province is principally aimed at meat production, with coarse wool as a low value waste by-product that is not used commercially. The paper presents the favourable qualities of the product, the quantities available, the potential use as a thermal insulation for buildings and the potential requirements to satisfy the new thermal standards for social housing. The requirements for a typical social housing unit are calculated to relate potential supply and demand. The spatial distribution of production units in the province is also evaluated to resolve the problems of recollection, processing and transport of this low-density product. The number of beneficiaries of this new supply chain is also calculated, considering rural employment and improvement of social housing. Finally, an example of this new application of coarse sheep wool is shown to demonstrate the feasibility of this production.*
KEYWORDS: Wool, thermal insulation, social housing, thermal conductivity.

1. INTRODUCTION

Buildings are a leading contributor to greenhouse gas emissions, generating nearly 40 % of annual global CO2 emissions. Of this total, building operations are responsible for 28 % annually, while building materials and construction, typically referred to as embodied carbon, are responsible for an additional 11 % annually (1).

From an integrated assessment of sustainability and energy efficiency in buildings, thermal insulation from discarded sheep wool offers an effective circular economy option for massive application in social housing. Coarse thick sheep wool is a natural and renewable resource for the industrial production of thermal and acoustic insulation blankets. Innovative design processes can transform solid rural waste into raw material to produce construction products, reusable and compostable at the end of their life cycle.

This material is currently a difficult issue for small producers as sanitary shearing is mandatory, but wool from breeds that are used for meat production has no value for the textile industry, so it must be burned, buried, or delivered as part of the shearing payment.

Data from the Sheep Council of the Province of Buenos Aires (2) indicates a significant volume of discarded wool, so the feasibility for industrialized production is analysed, evaluating the creation of a new chain of added value that starts with small producers in family farms, to the organization of wool collection points, and a centralized production system.

As a result of its favourable properties, this product can be used in the construction industry to improve building envelopes, walls and roofs, due to its excellent thermal insulation, moisture control, and sound absorption characteristics. This case study of wool insulation in social housing for Buenos Aires Province provides comparative data of environmental impact.

2. METHODOLOGY

2.1 Geographical location of waste raw wool

There are different kinds of wool, and they grow in different thicknesses. It depends on breed, gender, age, feeding, rainfall, etc. (3). Not all sheep wool is suitable for the textile industry, considering the fibre diameter. Fine sheep breeds like Merino are found in Patagonia, while Dual purpose or Meat breeds, like Romney with its Medium or Coarse wool are found in the province of

Buenos Aires. This results in waste wool, a by-product of the meat, and the present study considers the potential production of insulation blankets and their contribution to reduce environmental impacts.

The price for wool is determined by its diameter measured in microns and washing yield expressed in % of clean fleece weight. This percentage can vary between 72 % to 50 % (4). Table 1 shows the diameter classification published by the Argentine Wool Federation (5).

Wool	From	To
Fine	finer	24.5
Medium	24.6	32.5
Coarse	32..6	stronger

Table 1. Fineness equivalent in microns

According to the Sheep Council of Buenos Aires Province, the production of coarse sheep wool in 2019 is around 3500 / 4000 tons, based on a population of 1.040.000 sheep and 3,5 to 4 kilos per animal (2).

Sheep wool production is expressed in ¨greasy tons¨ or kilos. The washing yield percentage for sheep breeds from Buenos Aires is around 50 or 55% of clean fleece weight.

The livestock population is widely dispersed in the territory, with many small farmers with less than 500 sheep, and more than 24000 production units in the Province of Buenos Aires (2). In this context, the map of the province (Figure 1) was prepared with the size and stage of collecting points and location of Sheep Councils, with the information from the Sheep Council of the Province of Buenos Aires (2). The circle in the map highlighted the 300 km area around CABA to be considered in freight analysis.

2.1 Sheep wool insulation characteristics

Sheep wool insulation properties are well known from ancient times: it was used as felt for Mongolian yurkas, and in fabrics, carpets, and furniture to conditioning building interiors in different ages and cultures. It's renewable, sustainable, and a natural insulation with durable and long-lasting performance. It can be reused, and it is totally recyclable. A healthy material, with no negative health impact during handling. It is easy to install, does not produce irritation in skin or eyes, and does not require specific tools or equipment.

Figure 1: Map of Buenos Aires showing sheep-rearing locations with Information from Sheep Council of the Province (2).

Wool thermal conductivity is between 0.038-0.054, Table 2 shows an evaluation (7) comparing it with fiberglass and expanded polystyrene.

Insulation Material	λ Value	R Value (100 mm)	Thickness for U-Value	Density	Embodied Energy	Sound Absorption Coefficient	Water Absorption
	[W/m K]	[m²K/W]		[kg/m³]	[GJ/m³]	[500–2000 Hz]	[% wt/wt]
Sheep wool	0.034–0.067	2.5–2.6	180–200	18–23	0.11	0.77 (60 mm)	up to 35%
Glass wool	0.032–0.04	2–3	170	10–30	0.83	0.65 (100 mm)	0.2%
Polystyrene foam	0.033–0.035	2.5–2.8	150	30–50	3.03	0.35 (50 mm)	0.03–0.10%

Table 2. Comparison of wool performances and common insulation material [6]

Wool fibres also exhibit hygroscopic behaviour, which allows them to absorb up to 33-34% (kg/kg) of their dry weight (7). This characteristic lets the insulation work as a thermal regulation system, to absorb and de-absorb excess humidity.

Excess of air relative humidity is the main cause of mould which has detrimental effects on building structure and human health. Wool's capacity to absorb the excess moisture without significant changes of its thermal performance differs from the case of mineral fibre insulation that deteriorates (8). Wool also possesses natural antibacterial properties (9). In the event of fire, wool has self-extinguishing properties; it has a high proportion of nitrogen in its composition and therefore does not support propagation of the flame and has a fire reaction class "E" (10).

Another favourable property is the potential to be recycled and reused; it can be composted at the end of the life cycle, contributing to zero waste, mitigating concerns about the impacts of building materials. It also contributes to toxin sequestration, because its high protein content captures VOC´s like formaldehyde, toluene, limonene, and dodecane. These gasses emitted from furniture and several construction materials are present in most of the buildings. Therefore, sheep wool insulation contributes to the improvement of indoor air quality (11).

Sheep wool is a carbon smart material. According to the conversion factors published by the International Wool Textile Organization (12) and Carbon Smart Material Palette (13), 1 kg of clean wool equates to 1.8 kilograms of CO2-e removed from the atmosphere and stored, considering carbon taken from the pasture, following sequestering from the atmosphere 1 or 2 years earlier, resulting in negative emissions. In contrast, 1 Kg of fiberglass has positive emissions and a footprint of 1,35 Kg CO2 and 28 MJ embedded energy (14).

As Figure 2 shows, sheep wool has the lowest embodied energy value of the insulation materials shown, considering material extraction, manufacture, transport, use, and end of life cycle.

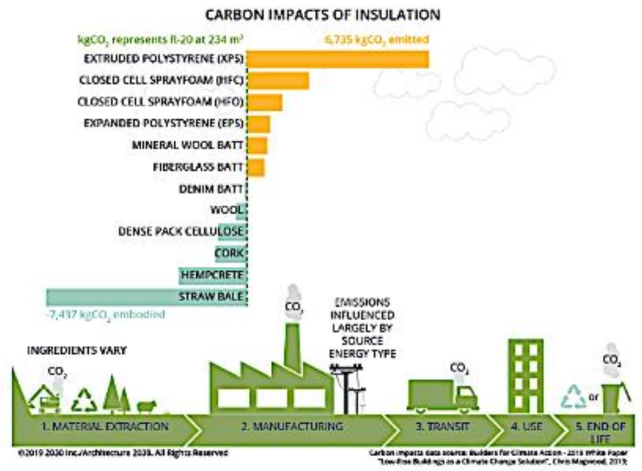


Figure 2: Carbon Impacts of insulation (13)

2.3 Comparison with conventional insulation

Fiberglass and Expanded Polystyrene are the conventional and most widely used insulation options available in Argentina. Environmental impact is evaluated in comparison between sheep wool and conventional insulation products and their CO2 emissions and embedded energy along their life cycle, with the Strategic Matrix D4S (15, 16) from UNDP, the United Nations Environment Programme.

For the selection of low-impact material, fiberglass uses sand as raw material which is abundant but not renewable material, and EPS is made from a derivative of petroleum. In contrast, raw material for sheep wool insulation blankets is a waste material, a bioproduct from the meat industry.

In the evaluation of the logistics and distribution impacts, most insulation materials contain air, so there is little difference according to density and transport costs. It is interesting to note that insulation materials compared in this matrix do not present much difference during use with similar thermal properties, they are installed inside cavities during the lifetime of the building and they offer similar thermal conductivity values.

At the end of the life cycle, sheep wool as a compostable material has a great advantage compared with fiberglass and EPS that will be deposited in landfills and will take more than 500 hundred years to decompose.

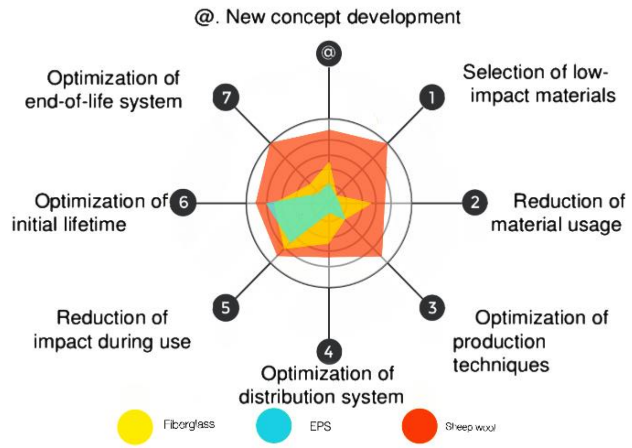
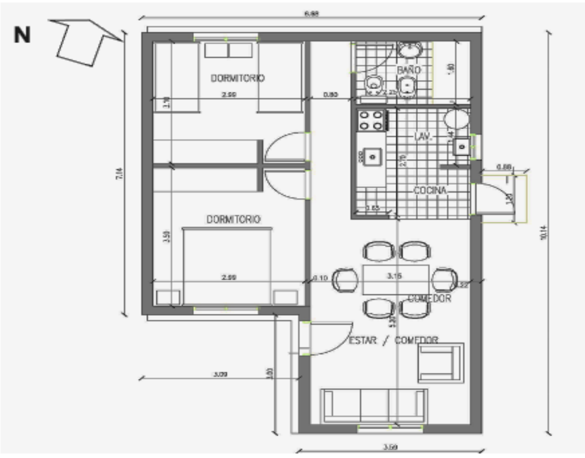


Figure 3: Strategic Design Matrix D4S [15] for wool in comparison with conventional insulation; glass wool and expanded polystyrene, prepared by the author.

3. External Walls and roof assemblies for social housing prototype, with sheep wool insulation blankets

For the present study, a social housing prototype for Buenos Aires, from the Provincial Housing Institute, is analysed to calculate insulation for walls and roofs according to IRAM Standards for Thermal Conditioning.

The two-bedroom free-standing single-story house of 58 m^2 is used to calculate the area of insulation blankets, considering 50 m^2 for roof and 95 m^2 for exterior walls, and interior walls that require acoustical insulation.



The social house prototype, located in Almirante Brown, Province of Buenos Aires, Argentina, 34.8° S, 58.3° W is located in the Bio-environmental Zone IIIb according the IRAM Standard 11603 (17). IRAM Standard 11605 (18) defines three levels of thermal transmittance, or K value, in three levels from high to minimum comfort: A, B y C. Social housing prototypes formerly used level C to comply with the requirements until 2000, when the Provincial legislation in Law 13059 established new obligatory Thermal Conditions for Buildings in Buenos Aires Province. This level is now required in all social housing. So, from this date, they have to comply with Level B, like all other building types.

Exterior Design Temperature	A		B		C	
	Walls	Roofs	Walls	Roofs	Walls	Roofs
- 4 °C	0.32	0.28	0.87	0.72	1.52	1.00

Table 3: K maximum Values for winter condition (W/m2K)[18]

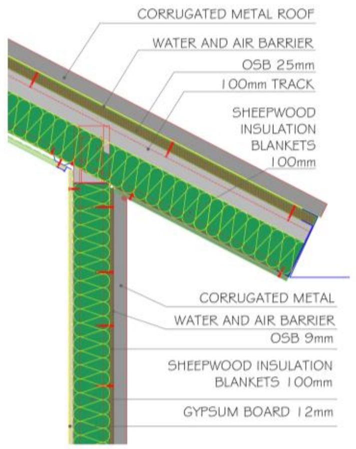


Figure 5: External wall and roof assembly with sheep wool insulation.

As traditional masonry does not reach these values, the Steel Framing system is considered for roof and wall assemblies in order to calculate the demand for sheep wool insulation at 18/23 kg/m3 density, and layers of 100 mm thickness. The results are shown in Table 4.

K Wall assemblie thermal transmitance (W/m2K)	0,391
K Maximum thermal transmitance admissible (IRAM 11605) (W/m2K)	0,74
	complied
K Roof assemblie thermal transmitance (W/m2K)	0,402
K Maximum thermal transmitance admissible (IRAM 11605) (W/m2K)	0,602
	complied

Table 4: Calculated K values for wall and roof

4. RESULTS OBTAINED

The total number of housing units to be insulated can be estimated according to the raw material available. In order to reach 11-14 kg/m3 density for 100 mm, it takes 1,10 - 1,40 Kg/m2 of clean sheep wool to produce the insulation blankets. For one house, to manufacture 150 m2 of insulation, it will require 210 kilos of clean sheep wool. Considering 4.000 greasy tons yearly production, and applying 55% clean wool fleece, current availability provides enough raw material to install 10476 houses, per year.

From the social-economic perspective, a fair price for coarse wool would be U$S 1.- per kilo, according to with Sheep Council of Buenos Aires, improving the actual theoretical price of U$S 0,55.- at MOBA Bulletin 31, December 2021, (1) for coarse sheep wool. Considering a fair price for coarse wool, this would represent a yearly income of more than U$S 4.000.000.- for the small farmers in Buenos Aires Province.

On average, according to Buenos Aires Sheep's Council, 4 people work at each production Unit, which means almost 100.000 workers who would benefit from the development of the resource, in addition to new labor opportunities for certificated shearers and other works related to sheep farming.

Improving air quality in houses has a direct impact on their inhabitants. Sheep wool capacity to capture VOC's will collaborate to reduce health problems associated with them, improving their quality of life and social inclusion.

The environmental impact, processing 4.000 tons of sheep wool, would contribute with 7.000 tons of CO2 sequestered [10] and the possibility to avoid 1060 tons of CO2 replacing conventional insulation [11].

The use of wool waste as raw material would also reduce the impact on soil and air of 4000 tons of solid waste to be burned, buried, or deposited in landfills.

Sheep Council of the Province of Buenos Aires is supporting research to develop products based on coarse wool, like the AbrigA project, with thermal and acoustical insulation solutions manufactured 100% pure sheep wool.

Figure 6: sheep wool insulation blankets installed in La Escocesa. a house in the Province of Buenos Aires.

Figure 6 shows Architect Angie Dub´s project, La Escocesa Guest House, located in 25 de Mayo, Province of Buenos Aires, which is the first building where AbrigA blankets were installed in roofs and exterior walls, and interior partition (20).

Energy efficiency in buildings is strongly related to construction envelope insulation. To achieve a sustainable building process, it is vital to find new material solutions. The provision of sheep wool insulating blankets, a sustainable and renewable bio-insulation, creates a new chain of added value for the small producers in family farms and the construction industry, promoting local and regional sustainable development.

Clean sheep wool as carbon capture, contributes to transforming buildings into carbon-storing units promoting action on climate change leading to an effective CO_2 drawdown. The contribution of this study is the integration of economic, social, and environmental benefits in the framework of regional and local sustainable development.

REFERENCES

1. IEA & UNDP2018 Global Status Report: Towards a zero-emission, efficient and resilient buildings, and construction sector. (2018) International Energy Agency and United Nations Development Program with Global Alliance for Building and Construction.
2. Faverio, I., Galán, N. Informe de lana. (2019). Ley Ovina Argentina 25.422. Coordinación UEP. Buenos Aires.
3. Equipo Técnico PROLANA (2018) Manual de acondicionamiento de lana, PROLANA
4. AS/NZS 4492.2:2000. Wool-Fleece testing and measurement - Determination of washing yield and clean fleece weight, Standards New Zealand
5. Flasite. Federación Argentina Lanera (2021). Argentina wool statistics. FLASITE
6. Rajabinejad, H.; Buci¸scanu, I.I.; Maier, S.S. Practical ways of extracting keratin from keratinous wastes and by-products: A review. Environ. Eng. Manag. J. (2016), 15, 1131–1147.
7. Tuzcu, T. (2007). Hygro-thermal properties of sheep wool insulation. Civil Engineer Faculty, Delft University of Technology
8. Parlato, M.; Porto, S. (2020) Organized Framework of Main Possible Applications of Sheep Wool Fibers in Building Components. Department of Agriculture, Food and Environment, University of Catania, Building and Land Engineering
9. B Caven, B, Redl, B. and Bechtold, T. (2018) An investigation into the possible antibacterial properties of wool fibers. Textile Research Journal 0(00) 1-7
10. Dénes, O.; Florea, I.; Manea, D.L. (2019) Utilization of Sheep Wool as a Building Material. Procedia Manuf. 2019, 32, 236–241.
11. Mansour, E., Curling, S., Stéphan, A. and Ormondroyd, G., (2016). Absorption of volatile organic compounds by different wool types.
12. Carbon Cycle of Wool | International Wool Textile Organisation. (2022). Retrieved 25 March 2022, from https://iwto.org/sustainability/carbon-cycle/
13. SHEEP'S WOOL – Carbon Smart Materials Palette. (2022). Retrieved 25 March 2022, from https://materialspalette.org/wool/
14. Prof. Geoff Hammond & Craig Jones, Inventory of Carbon & Energy (ICE), Version 2.0. Sustainable Energy Research Team (SERT), (2011) Department of Mechanical Engineering, University of Bath, SHEEP'S WOOL – Carbon Smart Materials Palette
15. United Nation Environment Program (2009) Design for sustainability. A step-by-step approach. United Nation Environment Program, Delft University of Technology
16. Canale, G. Manual de diseño para la sustentabilidad (2020) Diseño Editorial. Buenos Aires.
17. IRAM 11603. Acondicionamiento térmico de edificios. Clasificación Bioambiental de la República Argentina (2011) IRAM Instituto Argentino de Normalización
18. IRAM 11605, Acondicionamiento térmico de edificios, condiciones de habitabilidad en edificios. Valores máximos de transmitancia térmica en cerramientos opacos (1996) IRAM Instituto Argentino de Normalización.
19. Mesa Ovina de Buenos Aires (2021). Boletín diciembre 2021. Ley Ovina Buenos Aires

PLEA SANTIAGO 2022
Will Cities Survive?

Analysis and Assessment of the Global Warming Potential of Solid Wood and Timber Frame Construction based on a Life Cycle Assessment including Forestry Production and Transport Options

NICO FRANK STRANGER[1] ERIK FINDEISEN[1] SVEN STEINBACH[1]

[1] Fachhochschule Erfurt - University Of Applied Sciences, Germany

ABSTRACT: This study analyses and evaluates the global warming potential of solid wood and timber frame construction based on an overall cycle analysis including forestry production and transport variants. The presentation of the three production and logistics variants designed for this study is based on the life cycle assessment database "Ökobau.dat according to EN 15804+A1", as well as the forestry background data from the "Factsheets" of the University of Natural Resources and Applied Life Sciences Vienna. The objective was to determine process steps in the value chain with high global warming potential and their effects on the life cycle assessment of timber buildings with the help of the efficiency, inefficiency and standard variants developed by combining individual work steps. The scope here extends to a "cradle to gate with options" approach according to DIN EN ISO 15804:03/2020. For this purpose, three LCA data sets each were created for the wood materials solid structural timber, glulam, cross laminated timber and oriented strand board under different conditions of primary production and logistics. Following on from this step, a life cycle assessment of a sample house in timber frame and solid wood construction was carried out for each production and transport variant. The results of this investigation four LCA variants for each residential building were under examination. From these it could be deduced that the global warming potential of the forestry production processes is many times lower than that of the logistical expenses. Accordingly, the effects of forestry production on the product balance of wood-based materials and the overall balance of timber construction are also lower than those of transport. In addition, it was found that the life cycle assessment of a solid wood building is on average thirty times better than that of a timber frame building.

1. INTRODUCTION

The use of wood in residential construction has recently experienced a massive renaissance (cf. Fingerlos, 2021b; Gruber, 2021; proHolz Austria, 2021; proHolz Bayern, 2021). The reason for this is the increased demand for quickly available and affordable housing. This is particularly feasible through the use of timber construction. The timber construction quota has therefore risen continuously in both residential and non-residential construction in recent years, and is now over 20 % at the national level (cf. Holzbau-Deutschland, 2021, pp. 3-4). The reasons for this are the short construction times and the low weight of timber construction. (cf. Cheret & Schwaner, 2013; Cheret & Seidel, 2014, p. 44; Ebner, 2021a; Lennerts, 2021). In addition, timber construction methods open up the possibility of sustainably construction. Life cycle assessment is one way of verifying this.

With the advent of LCA standardization, research and development in this area has been driven forward. The Johann Heinrich von Thünen Institute for Wood Research is one of the strongest research institutions with comprehensive publications in the field of life cycle assessment of wood. A milestone of the Thünen Institute is, for example, the study "Ökobilanz-Basisdaten für Bauprodukte aus Holz" (Life Cycle Assessment Basic Data for Building Products Made of Wood) from 2012 (cf. Rüter & Diederichs, 2012). On the basis of this study, it was possible to create "Ökobau.dat" as a public database for life cycle assessment values of materials in the building sector. On the basis of this database, it is now basically possible for every citizen to balance a building, for example, with the associated quantities of the building materials used and to calculate a preliminary global warming potential estimate (cf. Bundesministerium des Innern, für Bau und Heimat, 2021a).

[1] Klepeis et al. (2001).

According to a study by the University of Natural Resources and Applied Life Sciences Vienna (BOKU), however, there are rather few research results in the field of forestry that deal with an LCA analysis of product systems. According to the study, there were only 13 publications in 2007. By 2017, the number had risen to 73 (cf. Kühmaier et al., 2019a, Section Summary). In 2019, BOKU published a very important research paper based on these cornerstones entitled "Ökobilanzierung der Holzbereitstellung bis zum Werk unter Einbeziehung neuer Technologien". The results of this study show the forestry production processes, based on the current state of the art (status 2018) and taking into account all upstream chains of forestry.

2. RESEARCH QUESTION

The research question of this paper is to what extent the inclusion of different forestry production variants has an influence on the life cycle assessment of timber buildings in timber frame and solid wood construction. At the same time, the question of whether and to what extent trans-port distances jeopardise possible climate compatibility is to be addressed. Furthermore, it should be clarified whether one of the two house construction variants is more favourable than the other in a direct comparison of the life cycle analysis under identical conditions. The results should then serve as a research basis for further studies and investigations in order to promote the use of wood in the long term in terms of climate protection and at the same time to optimise it. Finally, this work is to be used by environmentally conscious, interested, but undecided building owners as a support for decision-making in the question of the right service partner for them with the respective construction method.

3. METHOD

To calculate the LCA, three hypotheticals, but in practice applicable forestry production models were compiled. The decisive factor for the definition of an efficiency and an inefficiency variant was the consideration of the global warming potential. Thus, the efficiency variant is defined as one with the lowest possible GWP, irrespective of other factors such as economic efficiency or occupational health and safety. The opposite inefficiency variant embodies a production chain with the highest possible global warming potential, irrespective of other parameters. The efficiency variant is characterised by a low degree of mechanisation in timber harvesting and a required minimum number of production steps. The associated distance for the transport of raw wood to the mill is 40 km. The character of the inefficiency variant lies on the one hand in the high degree of mechanisation of the timber harvest. On the other hand, a large number of work steps are included in this production method. The transport distance for the inefficiency variant is 320 km. The standard variant was chosen as a production scheme for the production of softwood mass assortments that is frequently used at the present time. It is characterised on the one hand by the high degree of mechanisation of the timber harvest and on the other hand by a large number of work steps during the production process. The distance of the raw material logistics is defined here as 160 km. Subsequently, the global warming potential of forestry, the global warming potential of wood-based materials and the global warming potential of buildings were calculated for the efficiency, inefficiency and standard variants.

4. RESULTS

The results of the comparison of the forestry production variants show that the global warming potential of raw wood production is subject to smaller fluctuations than that of logistics (cf. Figure 1). In each production model, wood removal exceeds the global warming potential of forestry expenditure many times over. The influence of forestry production on the total global warming potential is therefore of secondary importance in contrast to that of wood removal. Accordingly, the greatest emission saving potentials also result from a few short delivery routes in the area of transport. The efficiency and inefficiency variants serve as an example. Here, the forestry expenditures coincide except for about seven kg CO_2 eq / m³, although there are elementary differences in the form of the terrain, the number of production steps and the working methods used with the associated work equipment. In contrast, there is a difference in the global warming potential of wood removal. Here, the emission value increases eightfold in parallel to the eightfold increase in the transport distance when comparing the efficiency and inefficiency variants.

FIGURA

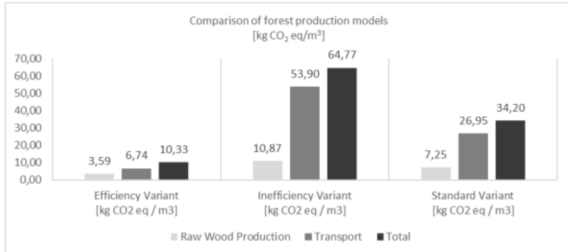
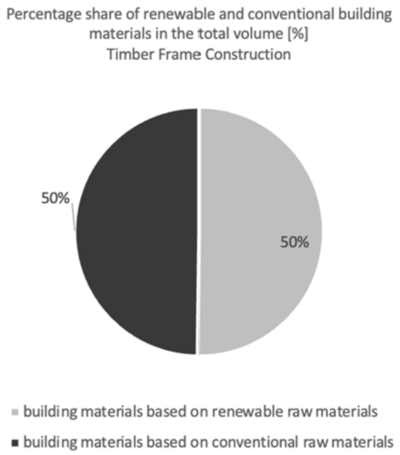


Figure 1: Comparison of the GWP for each production variant based on raw wood production (light grey), transport (dark grey) and the sum of both components (black)

4. RESULTS

With regard to the LCA comparison of timber frame construction and solid wood construction, construction method-specific properties that have an influence on the LCA were considered. Figure 2 shows the construction method-related percentage share of renewable and conventional building materials in the total volume of all building materials without taking the fastening material into account.



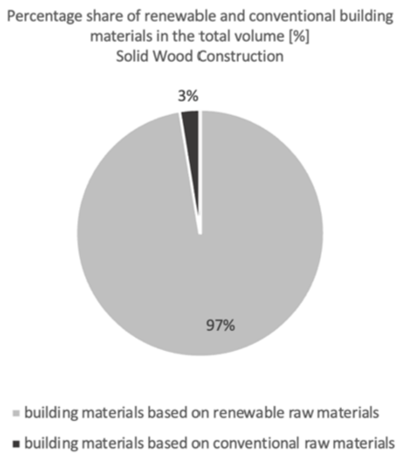


Figure 2: Percentage share of renewable and conventional building materials in the total volume for TFC and SWC

The term "renewable building materials" includes SST, GLT, OSB, CLT, SWF and roof battens. The volume of all building materials is 95.1 m³ when considering the timber frame construction method and 159.2 m³ when considering the solid wood construction method. The material volume of the solid wood construction exceeds that of the timber frame construction by a factor of 1.67. In the timber frame construction, it can be seen that the shares of renewable and conventional building materials are 50 % each. This is primarily due to the low use of wood-based materials in the construction method and the simultaneously high use of mineral insulation. The use of plasterboard also contributes significantly to the result. In comparison, the proportion of renewable building materials in solid wood construction is 97 % and the proportion of conventional building materials is 3 %. Here, the result is due to the construction-related use of solid wood materials and the use of softwood fibreboards in combination with a small number of conventional building materials.

Table 1 shows the wood-based materials used in the corresponding construction method with the corresponding volumes. In total, around 48 m³ of timber materials are used in the construction of the house in timber frame construction. Solid structural timber (SST), glued laminated timber (GLT), OSB boards, softwood fibre boards and roof battens are used. In comparison, fewer wood materials are used in the construction of the solid wood house, but their volume (approx. 155 m³) exceeds that of the timber frame construction variant by more than three times. This special feature of the individual construction methods becomes even clearer when looking at and comparing the volumes in relation to the solid wood materials (SST, GLT, CLT, roof battens). With a total volume of around 116 m³, the solid timber construction method exceeds the timber frame construction method by almost five times with around 24 m³.

Table 1:
Wood-based materials used in both construction methods according to their masses [m³]

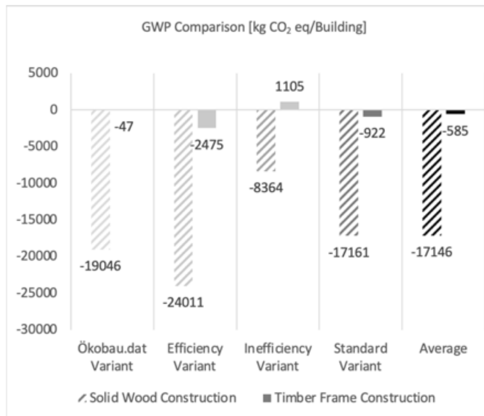
Nr.	wood-based materials WFC [m³]		wood-based materials SWC [m³]	
1	SST	13,34 m³	CLT	115,66 m³
2	GLT	9,97 m³	soft wood fibre board	39,02 m³
3	OSB	8,22 m³	roof battens	0,38 m³
4	soft wood fibre board	15,81 m³		
5	roof battens	0,38 m³		
Total		**47,72 m³**		**155,06 m³**

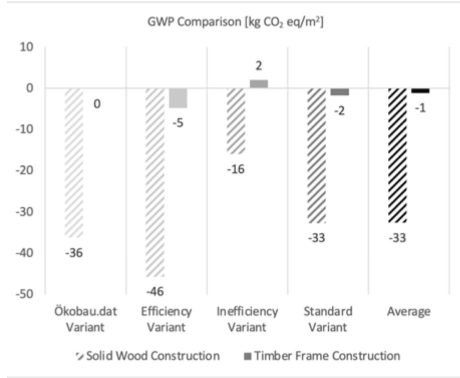
Figure 3 illustrates the GWP of construction-related logistics from the factory to the construction site of the building. The weight of the solid timber construction adds up to around 64.4 t without roof tiles. The weight of the timber frame building is around 26.1 t without the roof tiles. The solid wood building is thus almost 2.5 times heavier than the lighter timber frame building. The ratio of the logistical global warming potential is almost analogous to the ratio of the weight of solid wood and timber frame construction. The logistical global warming potential of solid wood construction is therefore on average 2.3 times higher than that of timber frame construction.

Figure 3: GWP of construction-related logistics (Modul A4) for each variant

Figure 4 shows the comparison of the life cycle assessments of the two construction methods considered. The shaded columns represent the life cycle assessment of the solid wood construction method, the non-shaded columns that of the timber frame construction method. The left part of the graph serves to visualise the results in relation to the overall project. The right part is dedicated to the presentation of the square-metre-related results. It can be seen that, despite the higher transport costs, the solid wood variant has a better balance result due to the greater use of wood materials in conjunction with a lower consumption of climate-intensive building materials. Regardless of the production variant, the solid wood building always has a positive life cycle assessment. When considering timber frame construction, three of the four product variants have a positive life cycle assessment.

Figure 4: GWP Comparison of SWC and TFC in total and per square meter.





equivalents per square metre. In relation to the building as a whole, this represents an overall balance of around 17.2 t CO2 equivalents. In contrast, the ecological balance of timber frame construction is 1.11 kg CO2 equivalents per square metre on average. At the building level, this corresponds to an absolute balance of around 585 kg CO2 equivalents. The ratio of timber frame and solid wood construction based on the average life cycle assessments shows that the overall balance of solid wood construction exceeds that of timber frame construction on average by almost thirty times in a positive sense. When considering the Ökobau.dat variant, timber frame construction saves around 50 kg CO2 equivalents compared to the solid wood building with around 19 t CO2 equivalents. In relation to one square metre of the same building, this results in 0.09 kg CO2 equivalents for timber frame construction and 36.23 kg CO2 equivalents for solid wood construction. The life cycle assessment of solid wood construction thus exceeds that of timber frame construction by a little more than four hundred times.

When considering the standard variant in terms of square metres, a balance result of 1.75 kg CO2 equivalents is recorded for the timber frame construction and 32.95 kg CO2 equivalents for the solid timber construction. In absolute terms, this corresponds to a total balance of around 920 kg CO2 equivalents for timber frame construction. In comparison, the total balance of solid wood construction is around 17.3 t kg CO2 equivalents. Here, too, the life cycle assessment of the solid wood construction is almost nineteen times higher than that of the timber frame construction. For the other variants, the life cycle assessment of the solid wood construction exceeds that of the timber frame construction once by almost ten times (efficiency variant) and once by almost nine times (inefficiency variant). The associated global warming potentials in absolute and relative form can be examined in Figure 4.

5. SUMMARY

In summary, both construction methods make a positive contribution to climate-friendly building, as conventional building materials are substituted by the use of timber construction materials. At first glance, the results of timber frame construction seem rather sobering compared to those of solid timber construction, but it is clear that here, too, a not insignificant amount of carbon is removed from the atmosphere in the long term and stored in the building. Both construction methods are therefore an effective means of reducing the global warming potential of the building sector and enabling climate-friendly construction.

The potentials of increased wood use and its positive influences on the climate compatibility of the building sector have already been analysed and presented in a large number of studies (cf. Albrecht et al., 2008; Braune et al., 2021; Bundesministerium des Innern, für Bau und Heimat, 2019; Cheret et al., 2021; Dolezal, 2012; Gärtner et al., 2012, 2013; Griesebner & Egle, 2013; Hafner et al., 2017; Nagler et al., 2018; Rüter, 2017; Scheer et al., 2007; Wolpensinger, 2009). Despite this, there are still barriers to the use of wood in the building sector. One of the biggest obstacles to the further expansion of wood use in the building sector is the currently valid fire protection regulations. These often impose considerable restrictions on the use of multi-storey timber construction, especially in urban areas, or in some cases prohibit its use completely. A large number of studies and experiments have already shown in the past and are currently showing that building with wood also offers maximum safety in terms of fire protection (cf. Cheret et al., 2021; Engel et al., 2020, 2021; Zehfuß et al., 2019). Therefore, training and further education of building planners, architects and all planning personnel is required so that safety-related prejudices against timber construction can be eliminated.

Finally, the efficiency of wood processing must be increased. Despite the fact that wood is a renewable raw material in not insignificant quantities, it must nevertheless be used carefully and must not be used wastefully under any circumstances. Regardless of other influences such as transport or manufacturing costs, it can be said that the positive ecological balance of a building increases with the degree of wood use and the amount of wood used. The LCA would improve further if, however, a lower material input was required to produce the wood-based materials.

However, all optimisations of the production chain and legal framework conditions will only be effective if the use of wood products is no longer seen as an exception but as the standard. The basic prerequisite for this is that the social benefits of timber construction are internalised among building owners, planning staff and consumers.

Vacuum-glazed windows

A review on recent projects' methods, results, and conclusions

ULRICH PONT[1], PETER SCHOBER[2], MAGDALENA WÖLZL[1], MATTHIAS SCHUSS[1], JAKOB HABERL[2]

[1] TU Wien, Department of Building Physics and Building Ecology, Karlsplatz 13, 1040 Vienna, Austria
[2] Austrian Forest Products Research Society (HFA-ÖGH), Franz-Grill-Straße 7, 1030 Vienna, Austria

ABSTRACT: Windows are relevant for the design and performance of buildings for several reasons, such as daylight and natural ventilation provision. However, window constructions are considered as weak spots in the thermal envelope compared to opaque elements. This is due to increased heat transfer in comparison with full-fledge insulated opaque elements. Moreover, thermal bridges, mold growth, water penetration and draught are phenomena that occur often in window constructions. To tackle these, windows have been undergoing different improvements (e.g. multi-layer glass panes, rubber seals, foil add-ons on glass pane, etc.) majorly addressing their hygrothermal and acoustical performance. Vacuum glass products (VGs) are highly insulating glass products that are offered on the market with reasonable degrees of vacuum-upkeep today. While the development of such glass products has been widely published, little R&D efforts have been observed targeting the integration of such VGs into contemporary and existing window constructions. The present contribution reports on recent projects focusing on the integration of highly insulating VGs into historic and new window constructions. In existing windows, significant improvement of the thermal performance can be reached. New windows, tailored to the requirements of VGs provide extraordinary performances, if properly designed and integrated in the building envelopes.
KEYWORDS: Vacuum glazing windows, Existing windows, Development of new windows, Numeric Thermal Bridge Simulation, Hygrothermal performance.

1. INTRODUCTION

The production of durable, high-insulating vacuum glass products has been challenging for about a century, following Anton Zoller's first patent in Germany in 1913 [1]. "Durable" thereby means that the vacuum inside the vacuum glass product should persist at least for periods that allow to utilize these products for building construction purposes. Given the loss of inert fill gases of comparable double and triple insulation glass, this time period should be at least 25 to 30 years. Since about a decade such durable vacuum glass products are available on the market. At a very small thickness (8 to 10 mm) they offer very low U_g-values ranging between 0.4 to 07 $W.m^{-2}.K^{-1}$. While a lot of effort has been conducted pertaining to the technical aspects of the vacuum glass products itself, little research efforts have been conducted regarding the integration of the glass in contemporary and past window constructions. The authors of this contribution started to work upon this topic in 2014 and since then have been constantly working in this field and were able to successfully finalize four research projects. These projects were two (early-stage) exploratory projects and two collaborative research and development projects encompassing industrial partner. Moreover, one exploratory and one collaborative project focused on the integration of vacuum glass projects into new / contemporary windows (projects MOTIVE and projects FIVA), while the other exploratory and collaborative projects targeted the integration of vacuum glass products in existing windows of cultural meaningfulness as a mean of thermal improvement of the culturally sensitive part of the existing building stock (projects VIG-SYS-RENO and VAMOS). Furthermore, the two exploratory projects and the collaborative project focussing on new windows can be described as engineering-focused, while the collaborative project focussing on existing windows (VAMOS) can be described as implementation and monitoring-based. In other words, in this project existing casement windows of historically meaningful buildings were equipped with vacuum glass and their performance was monitored. Figure 1 illustrates the "landscape" generated by these four different projects that were conducted between 2014 and 2021. It needs to be mentioned that the generation of vacuum-glass equipped windows follows two different priorities depending on the application scenario:

If the goal is the development of **new windows** employing vacuum glass, a "best performance paradigm" can be fully deployed. This means that, instead of equipping existing window constructions with a new glass product, the window construction can be fundamentally redesigned to the needs of the vacuum glass and targeting best performance in view of thermal performance (and of course other performance domains). Moreover, this fundamental rethinking of transparent building components allows considering alternative operation/opening schemes as well as motorization and integration in building automation approaches.

In contrast, if one targets the integration of vacuum glass in **existing windows**, the thermal performance still plays a large role, given that many older window constructions (e.g. casement windows) are considered as dissatisfactory regarding certain performance parameters (such as air tightness, U-value, etc.). However, the desire to generate best-performing windows needs to be balanced with aspects of visual appearance and fundamentals of monument/cultural heritage preservation and cityscape maintenance. As such, the challenge here is to improve the performance of the windows as much as possible with as little as possible change of the existing windows and avoidance of external effects, such as mould growth. The importance of this approach has to be emphasized today, as not alone the operational energy required for building conditioning is to be minimized, but also the life cycle performance (in view of circular economy aspects) can be improved with upkeep of existing windows that simply get a glass change.

To be able to understand the challenges connected with the employment of vacuum glass in window constructions, it is important to understand the principles and constituents of vacuum glass products. Regularly, vacuum glass products encompass two parallel glass panes with a small interstitial space in between (regularly less than a millimetre). Along the perimeter of the glass panes the interstitial gap is closed with a vacuum/gas tight edge seal. To maintain the form after evacuation (which regularly is done via an evacuation opening that is later sealed with a getter, that is a reactive substance able to bind any left air particles) a grid of so-called distance pillars can be found in vacuum glazing products (grid interval 20 to 40 mm). The evacuation happens mainly via mechanic pumps and leads to a high vacuum state (pressure in the evacuated space about 10^{-6} Pa). Figure 2 illustrates terminology and constituents of vacuum glass products. A major challenge connected to the employment of vacuum glass in window constructions is to cover the thermal bridge effect along the perimeter. The perimeter, as well as the distance pillars (however to a far less extent) transport heat via conduction, while conduction and convection is widely eliminated in the vacuum gap. There, the remaining and prevailing heat transfer process is radiation. This explains why the U_g-value of even very slim vacuum glass products is rather low in contrast to other glass products. Figure 3 shows typical vacuum glass products.

Figure 2: Schematics of constituents and terminology of vacuum glass products (and vacuum glass employment in window constructions).

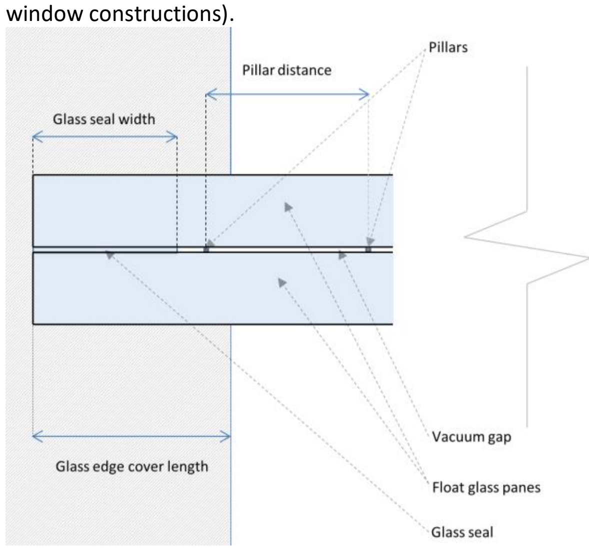


Figure 1: Landscape of vacuum-glass-equipped windows conducted by the authors between 2014 and 2021.

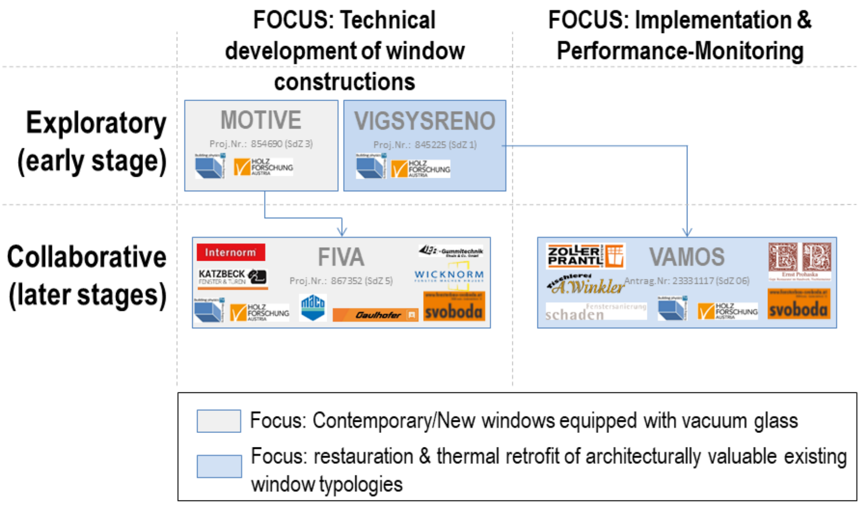
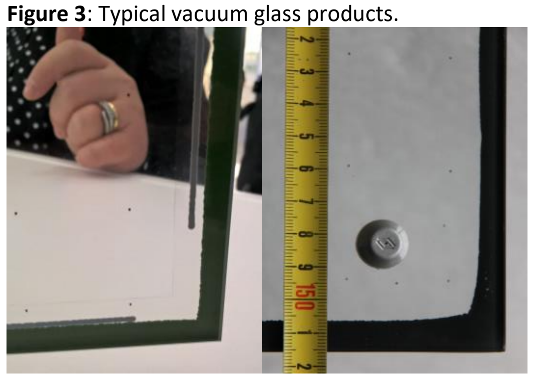


Figure 3: Typical vacuum glass products.



2. METHODOLOGY

To achieve (new as well as historic) highly insulating vacuum glass windows, a multi-method approach had to be deployed, including skills and instruments from the domains of building construction, monument preservation, building physics and construction management / economics. The development efforts were in all projects conducted in iterative optimization slopes, which led to numerous drafts, CAD drawings, as well as thermal performance assessment of virtual an physical models. The input by engineers from major window building companies was a valuable asset, which in parallel to the work at the involved research institutions led to the continuous further development of different prototypes. Thereby, the perspective of realisation and feasibility were considered already in early stages of the efforts. Thermal performance of the windows was in part evaluated by numeric thermal simulation (old windows and new windows) as well as lab testing (also both old and new windows), and in part by monitoring original and updated windows on-site (historic casement windows). Indicators that have been considered pertaining to the thermal performance include the U_{Win}-value, the f_{Rsi}-value, and the lowest indoor surface temperature $\theta_{si,min}$ of the windows. Simulation was rigorously deployed as mean of iterative performance improvement within the design and construction processes.

3. RESULTS & DISCUSSION

As the description of the overall process and results cannot be conveniently described with the limited space of a research paper, the final reports of the projects shall be mentioned as resource for interested readers [2-5] (even if these are written in German language, graphical material on the one side and English summaries may allow to gain an overview).

3.1 New windows designed for vacuum glazing employment.

In the exploratory project, MOTIVE a large set of window constructions has been envisioned. All of these window designs were subjected to an extensive SWOT (strength-weakness-opportunities-threats) analysis to evaluate their potential for vacuum glass integration. Thereby, the focus was not set solely onto vacuum glass integration, but also to redesign windows fundamentally in view of operability/opening schemes, construction / mounting effort, usability, motorisation, and integration into building automation systems. In the project FIVA the most promising four window designs were discussed and furtherly developed with major stakeholders of the window-building industry as well as with industrial partners from the component industry (i.e. seals and fittings). Via extensive deployment of numeric thermal bridge simulation instruments promising approaches toward excellent thermal performance (i.e. low U_{Win}-values, avoidance of thermal bridges, high indoor surface temperatures) were iteratively improved. For all of these windows, motorization was foreseen, and the integration of sun shading devices was discussed and examined. The final four windows were constructed as fully functioning mock-ups and presented to the interested public audience and stakeholders of the building industry [6]. Figure 3 provides an overview about these four windows. All four of the windows have been subjected to an extensive evaluation during the development process. Moreover, questionnaires with interested domain experts but also with persons without domain knowledge have been conducted, which identified prototype A and D as the most promising prototypes for a broad-market rollout. Evaluation criteria in the questionnaire included architecture and aesthetics, contemporary nature of the design, level of innovation, aspects of technical realization, mounting, comfort in operation, and general acceptance of customers. Thereby, the degree of innovation of type D (offset-sliding window, principle shown in detail in Figure 4) was emphasized by the questionnaires, while some constraints were seen pertaining to mounting and technical aspects of the construction. Regarding type A, the level of innovation was not considered to be extraordinary, however in all other categories these windows received the best evaluation. It has to be underlined that all of the realized prototypes provided excellent U_{Win}-values given that the construction was very slim and of limited weight due to the thin thickness and good thermal performance of the vacuum glass. If the utilized glass product would be supplemented with another glass pane U-values of contemporary, insulated opaque constructions are in gripping distance. However, such amendment would negatively influence both the appearance of the window and its low weight.

Figure 3: Four functional window prototypes employing a vacuum glass pane of 8 mm (U_g-value: 0.4 $W.m^{-2}.K^{-1}$) resulting in very low U_{Win}-values.

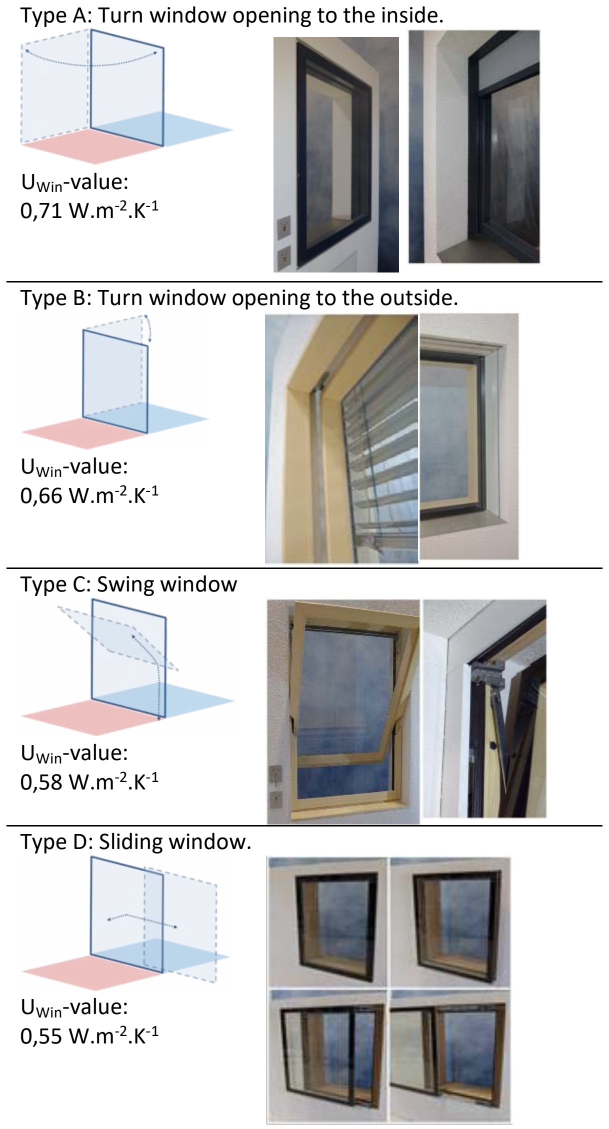
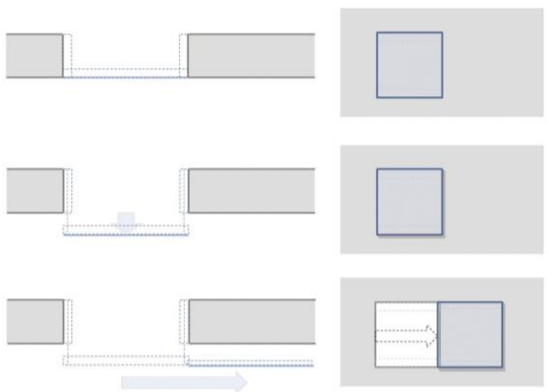


Figure 4: Operation principle of prototype D in horizontal section and as view.



3.2. Historic windows improved with vacuum glass products.

Regarding the existing windows optimization, the principle suitability of vacuum glass for casement window improvement both in simulation and via lab-testing has been proven in the exploratory project VIG-SYS-RENO. However, due to the limited extent of this project, only a limited number of casement window construction could be assessed in the efforts of this venture. Moreover, a monitoring-based proof of the approach in real construction and building settings had been missing. Toward this end, the recently conducted and finalized project VAMOS was designed to cover these shortcomings. A wide array of different casement window constructions has been selected, and all together demonstration sites (i.e. casement windows) at six different locations in Austria could be equipped with vacuum glass. The improved windows have been different in location (i.e. prevailing microclimate), framing construction, and surrounding wall material. Moreover, the windows have been equipped with different vacuum glass solutions. Figure 5 illustrates two of the monitored windows equipped with vacuum glass. The U_{Win}-values could be improved down to values around 1.0 $W.m^{-2}.K^{-1}$ (which means 60% heat transmission reduction compared to the original state).

Figure 5: Two of the vacuum-glass equipped casement windows used for on-site testing and monitoring.

The U_{Win}-value allows determining energy losses via windows for calculations or simulations targeting the overall energy performance of buildings. However, it does not provide any insight pertaining to risks of condensation or mould growth at the unavoidable thermal bridges. Given that in traditional constructions one major principle of new windows with vacuum glazing products regularly cannot be applied – namely the fulfilment of the 40 mm glass edge cover length, other indicators are required to assess the mentioned risks, which determine acceptance of vacuum-glass based improvement of casement windows. Suitable assessment can be done via constant visual monitoring (is there condensation visible at large temperature spans between indoor and outdoor conditions?) and the measurement of key temperatures at critical points. One criteria for assessing the temperature of a (indoor) surface point at a specific position of the window construction in contrast to the temperature span is the f-value, e.g. documented in EN ISO 10211 [7]. Figure 6 illustrates f-values for original and vacuum-improved casement windows.

It can be clearly seen that the integration of vacuum glass in the outer and inner wing of the casement window can lift the f-value at the majority of spots (which had been at corners of frame/glass joints of outer and inner wing). While the application of the vacuum glass on the inner wing improves the f-values majorly on the inner side of the inner wing, the application of vacuum glass on the outer wing also improves critical points in the interstitial space. It has to be emphasized that based on the shown graph only general effect analysis can be conducted. A general recommendation on the application position of the vacuum glass cannot be derived from the examined case study windows and buildings. This has to do with the large diversity in window constructions and prevailing circumstances. Amongst the decision criteria, aside from the window position in the window niche and the casement material, the air tightness of both wings has to be critically reviewed to find the correct position. Needless to say, the construction planning requires domain knowledge by planners and craftspeople.

The six case study demonstration sites did generally underline that the heat loss via the casement windows can be significantly lowered by vacuum glass application. Moreover, in 5 out of 6 demo sites no issues with condensation could be found even in harsh Winter conditions. At one of the case study buildings issues with condensation and icing could be observed, however, the reason for these unwanted effects was due to erroneous seal application during the construction process. The architectural appearance of all of the case study windows could be maintained, aside from the distance pillars that – at certain daylight and artificial lighting situation – could be seen from inside and/or outside. The assessment of this "grid"-effect is rather marginal, however might be an issue for listed objects in heritage protection and has to be carefully considered in each case.

4. CONCLUSION

This contribution highlighted the approach and findings of R&D efforts toward vacuum-equipped windows. Two different approaches were followed:

On the one hand the emerge of vacuum glass products was used as motivation to overthink the current practice of window construction fundamentally. Instead of integrating vacuum glass panes into existing window frame constructions, the moveable part of the window (wing) was constructed around the employed vacuum glass and thereby considered the technology specifications of such glazing products (such as sufficient edge seal cover). In contrast, the window frame was designed and constructed around the necessities of the specifications of the deployed fitting and motorization systems. Following this design principles, very attractive new windows could be realised as close-to-market functional prototypes that offer very low U_{Win}-values at low weight and large format possibilities.

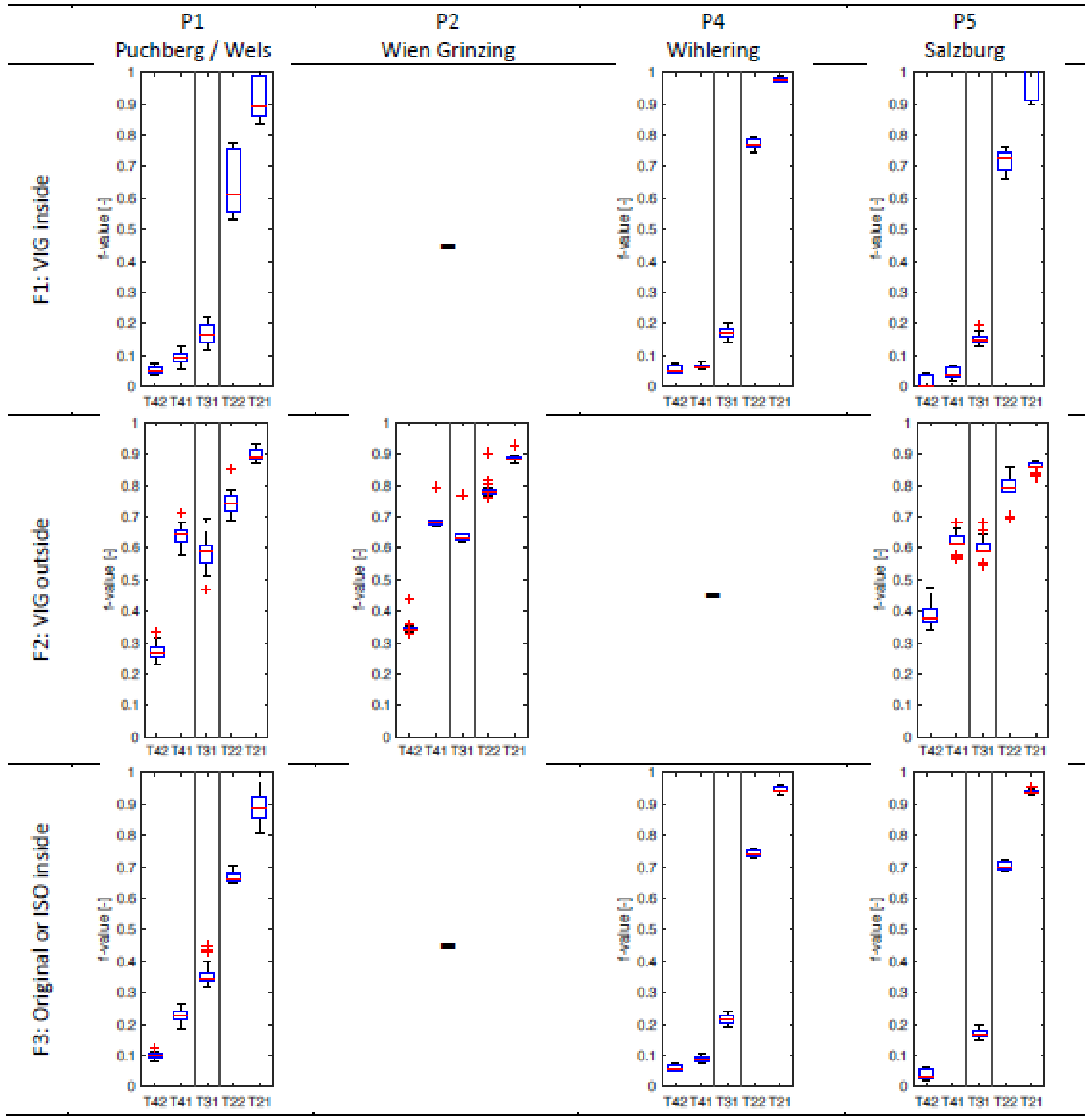
On the other hand thermal improvement of historically meaningful window constructions could be successfully proven. The integration of vacuum glass in existing windows requires in-depth construction and building physics knowledge and evaluation to find ways of sustainable and damage-free integration. U_{Win}-values of casement windows could be lowered by 60% in comparison to original setups based on two float glass window planes (U_{Win}-value – original: 2.5 $W.m^{-2}.K^{-1}$ [8], U_{Win}-value improved: circa 1.0 – 1.1. $W.m^{-2}.K^{-1}$)

If successfully, such windows could significantly reduce window-related energy losses and thus provide a valuable contribution to the global climate protection initiatives.

5. ACKNOWLEDGEMENT

The research and development projects described in this contribution have been generously funded by the Austrian Research Promotion Agency (FFG). The project numbers and durations were as follows: Project VIG-SYS-RENO 845225 (2014-2015), Project MOTIVE 854690 (2016-2017), Project FIVA 867352 (2018-2020) Project VAMOS 878272 (2019 – 2021). The projects have in part been conducted in collaboration with major and small-scale companies in the window construction domain in Austria. Beside the authors, representatives of these companies as well as further staff of the authors' affiliations have been involved in the four projects.

Figure 6: f- value comparison for selected spots of high condensation/mold-growth risk in casement windows at four out of six demo-sites.



REFERENCES

1. Zoller,A. (1913) Hohle Glasscheibe. Patent-Nummer: No 387655., see: https://patents.google.com/patent/DE387655C/ru

2. Endreport of the VIG-SYS-RENO Project (2018); see: www.nachhaltigwirtschaften.at

3. Endreport of the MOTIVE-Project (2018); see: www.nachhaltigwirtschaften.at

4. Endreport of the FIVA Project (2020); see: www.nachhaltigwirtschaften.at

5. Endreport of the VAMOS Project (2022); see: www.nachhaltigwirtschaften.at

6. Pont U., Schober, P.,Wölzl, M., Schuss, M., Haberl, J.: "Das Morgenfenster - Entwicklung smarter und energieeffizienter Fensterprototypen"; Keynote Lecture: Fenster-Türen-Treff 2020, Salzburg (invited); 2020-03-05 - 2020-03-06; in: "Happy Birthday - Fenster-Türen-Treff 2020 - Tagungsband 5.-6. März 2020 Salzburg", Holzforschung Austria (ed.); (2020), ISBN: 978-3-9504488-8-7, p 30 - 38.

7. ISO 10211:2017_ Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations.

8. OIB-Richtlinie 6, Leitfaden Energietechnisches Verhalten von Gebäuden, April, 2019; accessed via www.oib.or.at (last Access: March 2022)

PLEA STGO 2022

November 22 - 25, 2022

CHALLENGES FOR DEVELOPING COUNTRIES

DAY 03
09:00 — 10:30

CHAIR
ALESSANDRA PRATA

PAPERS
1374 / 1129 / 1445 / 1531 / 1552

35TH PARALLEL SESSION / ONSITE

WILL CITIES SURVIVE?

PLEA 2022 SANTIAGO

Will Cities Survive?

Endogenous constructions under abnormal conditions

Taking two new rammed earth constructions in rural areas of Southwest China as examples

LIU XIAOXUE [1] WAN LI[2] CHI XINAN[2]

[1] The Chinese University of Hong Kong

ABSTRACT: In the context of industrialization and globalization, the unification of construction types in rural areas makes the area vulnerable to disasters and other abnormal social conditions.Referring to relevant theories and combining with practice, a new rammed earth construction mode under the framework of endogenous development has been selected. It can well combine the characteristics of rural areas, improve the resilience of the region and deal with many unexpected situations under abnormal conditions.

In this paper, two practical cases of new rammed earth construction in rural areas of southwest China after earthquake disaster and during COVID-19 pandemic were introduced, and the role of endogenous development strategies in improving regional resilience was analyzed and discussed, as well as its positive significance to regional stability and sustainable development. It is expected to provide reference experiences and options for the integration of architecture with other social disciplines for endogenous sustainable rural development, using actual construction projects as examples.

KEYWORDS:Endogenous development，Rural resilience，Rammed earth，Social suspension

1. INTRODUCTION

After the Industrial Revolution, industrial production was favored by the market due to its advantages of high efficiency and uniform quality, which gradually replaced traditional production and expanded from cities to rural areas.

In the construction of houses, modern construction techniques using reinforced concrete and brick are also rapidly gaining ground.

In rural China, The vast majority of folk construction techniques that have not been improved and upgraded cannot meet safety requirements according to the government's standards for poverty eradication and reconstruction. [1] These codes encourage the attempt of various technologies and materials, but there are no specific technical rules and guidance yet.[2] Therefore, almost new buildings are constructed using industrial materials such as brick concrete structure in rural areas, the proportion of minority building structures and materials decreased year by year(Fig. 1). [3,4]

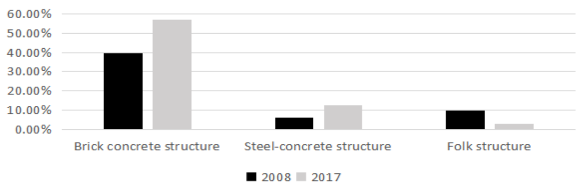


Figure 1: Proportion of rural housing structure in China.

While large-scale industrialization has raised the material standards of people's lives, it has also squeezed out the space for the survival and development of traditional manufacturing industries, and even caused the disruption of the transmission of some production skills. The gradual of production patterns has led to an increased dependence of society on the overall system and a reduction in its resilience to withstand severe disasters. After realizing the risks brought by globalization, a systematic study was formed on "Risk Society" and "Reflexive Modernity". [5] At the same period, a Development response strategy of "Endogenous Development" was proposed. [6] Compared with cities, rural areas have natural resource advantages and is more suitable for endogenous development. [7]

In this paper, two practical cases of novel rammed earth construction in rural areas of southwest China after earthquake disaster and during COVID-19 pandemic were introduced.

2. LITERATURE REVIEW

2.1 Endogenous Development in Rural Areas

The concept of endogenous development was first put forward by UNESCO in 1988. [6] It is a new development paradigm suitable for rural areas which is promoted and participated by the interior of the development region, make full use of the strength and resources of the development region. [7] The comparison of old and new differences is shown in the table1.

Table 1: The comparison of old and new differences

Modernization paradigm	New rural paradigm
Inward investment	Endogenous development
Top-down planning	Bottom-up innovation
Sectoral modernization	Territorially based integrated development
Financial capital	Social capital
Exploitation and control of nature	Sustainable development
Transport infrastructure	Information infrastructure
Production	Consumption
Industrialization	Small-scale niche industries
Social modernization	Valorization of tradition
Convergence	Local embeddedness

The development strategy can make the regional development more dynamic and sustainable, and the production activities within the region have stronger resilience due to autonomy. [8]

2.2 Resilience of Society

Society resilience is about cultivating the capacity to sustain development in the face of expected and surprising change and diverse pathways of development and potential thresholds between them. Resilience can be assessed in two ways: 1. Proportion and ability to return to the original state after a disturbance ; 2. Ability to be resilient to change and control it to maintain stability [9]

Recently, "resilient city" has been proposed and received a lot of attention. It also has certain reference value in rural areas. It has the following properties:[9]

- **Robustness:** The ability of a city to resist disasters. Reduce the economic, social, human, material and other losses of cities caused by disasters;
- **Rapidity:** The ability to recover quickly after a disaster. The city can recover to a certain level of function in a short period of time after the disaster;
- **Redundancy:** The key functional facilities in the city should have certain spare modules. When a disaster occurs suddenly and the function of some facilities is damaged, the spare modules can be replenished in time, so that the entire system can still play a certain level of functions without being completely paralyzed;
- **Resourcefulness:** having basic disaster relief resource reserves and the ability to reasonably allocate resources. It can optimize decision-making and maximize resource benefits under limited resources;
- **Adaptability:** Cities can learn from past disasters and accidents, thereby improving their ability to adapt to disasters.

2.3 Present Situation of Rural China

By 2020, China will have achieved the total elimination of poverty among the rural poor under the current standards, eliminating absolute poverty and overall regional poverty [10]. Rural revitalization is the focus of China's work in the next stage after comprehensive poverty alleviation.

"Poverty alleviation" is only a solution to the most basic problem of survival guarantee [10], while the regional development characteristics caused by the special geographical environment in rural areas of southwest China still exist: [11]

- The physical and geographical conditions are poor, the settlements are scattered and the population density is low, and the transportation conditions are generally poor .
- The operation level of the rural social and economic system is low, young and middle-aged labor force mostly go out to earn money to make a living, resulting in serious hollowing out of villages.
- Relatively poor subjects are characterised by a low level of education, a weak capacity for self-actualisation, and a lack of self-identity and self-confidence.

Because of this, many of today's policies do not adequately consider the remote rural areas of the southwest and are not widely adaptable. A single model of modernised rural development is no longer appropriate for the poorer rural areas of the South West.

2.4 Rural new rammed earth construction

The new rammed earth construction technology is improved on the basis of the traditional rammed earth technology by using modern mechanical technology. By enhancing the density of the wall, it can meet the safety requirements. It combines the original characteristics of being able to take materials from the local area and being recyclable, energy saving and environmental protection in line with the requirements of sustainable development; at the same time the earth wall has good thermal stability and good thermal insulation performance. With the '3Ls' (local materials, local technology, and local labour) as its guiding strategy, the '1U1V' project has undertaken a number of new rammed earth construction demonstration projects in relatively poor rural areas of southwest China. [12]

3. CASE STUDY A: POST-EARTHQUAKE RECONSTRUCTION OF GUANGMING VILLAGE

3.1 Earthquake damage

In 2014, a 6.5 magnitude earthquake struck Ludian County, Yunnan Province, at a depth of 12 kilometres. The people's government of Ludian County reported that almost all rural houses in the whole region have been seriously damaged. Among them, 80% of the houses collapsed due to the earthquake were traditional rammed earth houses of adobe construction [13], which not only caused damage to property but also took the lives and health of some of the inhabitants. This has led to a loss of confidence in, and even fear and resistance to, traditional rammed earth buildings, and almost always a preference for modern building types when rebuilding. However, due to economic and technical constraints, the brick and mortar structure, with reinforced concrete cast-in-place frames as the load-bearing structure and red bricks or hollow bricks as the main wall filling material, has become the only choice for most people.

The post-quake reconstruction project is located in Guangming Village, Longtoushan Township, close to the epicentre of the earthquake. As a result of the earthquake, local social and productive operations were hit hard, and the dramatic increase in demand for the reconstruction of farm buildings caused a serious supply shortage of industrial construction materials and labour in the area. Under such a background, the cost of conventional house-building strategies rose sharply, far beyond the means of villagers, and demand outstripped supply. The ability of villages and villagers to heal after major disasters is thus weakened and recovery time is lengthened.[14]

3.2 Demonstration Project of Guangming Village

The team entered the village of Guangming 2 months after the earthquake and selected two homes to serve as demonstrations of the new rammed earth construction model. Detailed project information can be found in the table.2 [14]

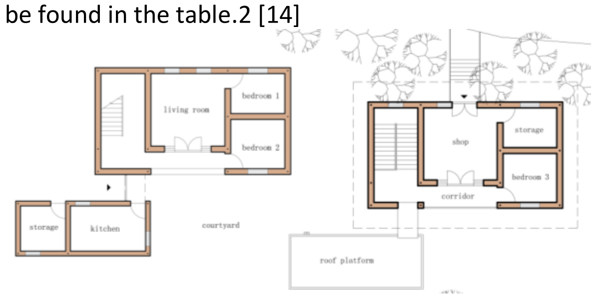


Figure 2: First floor plan and second floor plan of demonstration 1

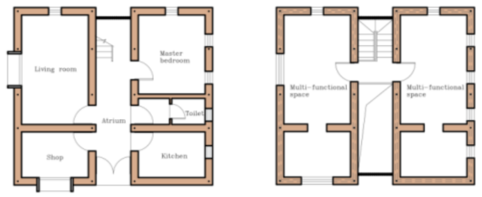


Figure3: First floor plan and second floor plan of demonstration 2

Table 2:Construction details

	Rammed earth demonstration 1	Rammed earth demonstration 2	Other building
Year	2015	2016	2015-2016
Structure type	Rammed earth wall bearing + steel and concrete floor slab ring beam structure		brick-concrete construction
Roof	Sloping roof with thermal insulation construction layer		Cement flat roof
construction organization	Self-built by villagers		Construction team contract system

Table 3: Comparative analysis of constructions

	Rammed earth demonstration	Other building
Costs	Labour: 60% Building materials: 40%	Labour: 50% Building materials: 50%
Labour	Skilled labour (Formwork): 33.33% Unskilled labour (Mixing, transporting materials, ramming walls): 66.67%	Skilled Worker (Formwork, Walling): 66.67% Unskilled labour (mixing and transporting materials): 33.33%
Resource required	Adequate (Earth): 15.6% Average (Unskilled labour): 39.6% Shortage (Skilled labour, commercial building materials): 44.8%	Adequate: 0% Average (unskilled labour): 16.5% Shortage (skilled labour, commercial building materials): 83.5%
Capital Flow	Local: 65.2% External: 34.8%	Local: 16.5% External: 83.5%

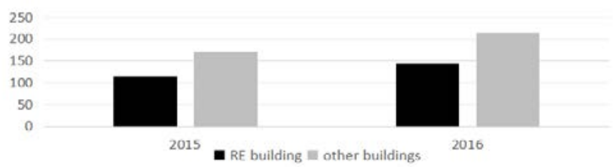


Figure 4: cost comparison between demonstration and other constructions （$）

The demonstration case shows better stability through comparative analysis with conventional construction.

1/ construction costs for both types of buildings increased in 2016 compared to the previous year,and the growth of the new paradigm is smaller.

2/ As the main building material used in rammed earth construction (soil) can be sourced locally ,the cost of rammed earth construction is 29-42.9$ per square metre less than conventional construction of the same period.

3/ The rammed earth construction technique is simple, requiring less skilled labour than conventional construction, and is less exclusive and more inclusive.

4/ Of the resources required to build a house, rammed earth construction requires only 44.8% of the scarce, irreplaceable resources, compared to 83.5% for conventional construction. Therefore, the price increase for conventional construction (42.6$) is greater than that for rammed earth construction (29$) and is more volatile due to market influences.

5/ A greater proportion of the money from the rammed earth building process stays in the region and continues to participate in the region's economic cycle.

4. CASE STUDY B: CONSTRUCTION OF MALONG VILLAGE DURING THE COVID-19 EPIDEMIC

4.1 COVID-19 And Rural China

The COVID-19 that broke out in late 2019 swept the world. Mainland China has largely contained this major local public health event 2 months after the outbreak and has shifted to a post-pandemic period with the dynamic zero COVID-19 strategy.[15]In the post pandemic period (as of the completion of the article), any production activities need to make way for the COVID-19 control, so the whole society has increased a lot of uncertainty than before.

The village has always been the most basic unit of governance. Its social structure is based on blood, kinship and local ties, creating a society of "acquaintances" with a simple demographic composition[16] which facilitates the detection and control of epidemics. In times of recurring epidemics, by cutting off access roads, a "large quarantine, small circulation" defence circle can be formed and social production activities within the region can be guaranteed to function normally. At present, many sociological studies and analyses have pointed out that a greater proportion of self-sufficiency in rural areas has largely reduced the impact of the epidemic and control measures, but most of them remain in the regional supply self circulation of daily consumables.[18]

Theoretically, the changes around construction brought about by the COVID-19 pandemic in rural areas can be tackled with the new paradigm:

Table 4: Changes around construction brought about by the COVID-19 pandemic and the new paradigm

The impact of the epidemic and containment measures	Conventional construction	Rammed earth construction
Reduced movement of people and lower circulation of materials	External materials and technicians	Local materials, local labour as the mainstay
The situation is fluid and unpredictable	There are construction beats and time costs	Flexible construction schedule to accommodate other production
External work stoppage and reduction in	Buy materials and services	Self-sufficiency, internal circulation

4.2 Demonstration Project of Malong

4.2.1 Project and Farmer Information

The Malong Rammed Earth Demonstration Project is located in an ancient village protected by national policies in Miyi County, Panzhihua City, Sichuan Province. Its regional characteristics are universal in the rural areas of Southwest China:

- **The transportation is inconvenient.** The construction site is located in a mountainous area with narrow roads. The straight-line distance from the county seat is 23.5km, the distance is 66km, and the drive is 1h45min.
- **Abundant in natural resources and lack of industrial products.** Due to the limitation of transportation distance, the local industrial products are less in quantity and higher in price. In particular, most industrial building materials need to be purchased in the county seat. Taking steel as an example, the final use cost is 110%~120% of the purchase price of the county seat.
- **Single means of livelihood and labor outflow.** The local traditional industry is mainly fruit and vegetable cultivation. The government is developing and encouraging tourism to gradually attract foreign-exchange laborers to return to their hometowns for employment.

The construction of the project is an economical house for three families (the three heads of households are siblings). The household information is shown in the table below:

Table 5: The household information

Families (Age)	Situation
Father (58) + Son (32)	The fathers of the two families basically lost their labor force and were widowed divorced due to illness and divorced; The sons used to go out to work, but are currently unemployed and unmarried.
Father (55) + Son (32)	
Husband (45) Wife (35) + Daughter (12) + Son (5)	The whole family works and goes to school, hoping to return home to earn a living.

The current demographic structure of this extended family is relatively common and representative in rural China:

- **The family demographic structure is unstable.** In rural areas, there has long been a lot of manual labor and the phenomenon of "preference to women" is serious. Women have little living space and low social status in rural areas. Rural women will move to cities on their own when conditions permit. Therefore, the older generation cannot retain women, and the younger generation cannot attract women. The younger generation has to choose between going out to earn a living and taking care of the family.
- **Long-term shortage of labor force, period surplus.** Due to the shutdown of industries and the uncertainty of the future of the epidemic, some of the labors who would otherwise have gone to work were left behind in the local countryside, creating a surplus of labour. This is the case with the 2 young men of the family who are now out of work.

4.2.2 Residential Design

The design of the house follows the order of importance of safety, economy, comfort and aesthetics. The residence is a 2-story building with two entrances, shared by three households. (The kitchen is unified and built separately)

In terms of appearance, the sloping roof design of this household complies with thetraditional village protection code and meets the waterproofing of raw soil buildings. In order to prevent the old-fashioned earth walls from being weathered and eroded, and to unify the architectural style, all buildings in Malong need to spray a layer of real stone paint (about 21.4 $/㎡) on the outer walls. The new paradigm's own strength, durability, and aesthetics have all met the requirements, so no further treatment is required.

Picture 1:Malong project

Figure 5: First floor plan of Malong project

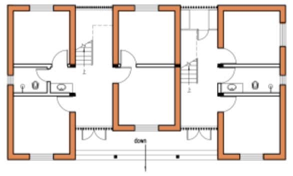
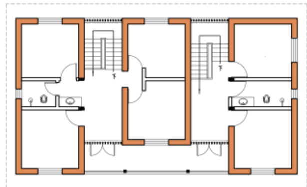


Figure 6: Second floor plan of Malong project



4.2.3 Construction

The project adopts the construction model of "university-guided technology + farmer-organized construction + employment of local odd workers". It is mainly sent by our university research team to send two master craftsmen who are proficient in this technology to train and guide on-site. According to the progress and requirements of the foundation construction of the household head, we can flexibly hire the required labor force locally to participate in the construction.

- The project will start in November 2021 and be completed in February the following year. The area and the entire construction process were not directly impacted by the pandemic, but were also affected to varying degrees in many aspects:
- The labor force is tense at stages, and the personnel are not fixed. The pandemic has caused the import of fruits and vegetables to be blocked. The fruit and vegetable industry in Miyi County has experienced a surge in prices (in the case of tomatoes, the price is 4 to 7 times that of the same period last year), which indirectly leads to a large flow of labor to fruit and vegetable planting and harvesting positions. Labor prices on construction sites are rising and personnel are unstable.
- Inflation led to rising prices of labor and building materials. The local construction labor wages in the past three years obtained after the interview and survey show that the labor wages have increased year by year, and the wages of foreign workers are higher than those of the same type of work in the same period.

In this situation, the application of "high science and low technology" with the participation of universities and the advantages of using local materials and local labor are becoming more and more prominent.

4.2.3 Comparative Analysis

The actual data generated during the construction of the project are recorded truthfully:

Table 6: Quantity and cost of construction

Details		Quantity	Price
Building materials	Processing materials	6.14t	10145 $
	Natural materials	355.7t	5821 $
Labor	Skilled worker	138	6357 $
	Unskilled worker	345	7885 $
Tool and equipment damage ($)		628 $	
Total cost ($)		30838 $	

Combining the interviews with the construction workers and the material market at that time, we calculated the cost of the same design scheme, the same structure type (wall load-bearing), and different types of walls (section of wall, beam, floor) for analysis and research:

Table 7: Comparison of three type of walls

Wall type	Hollow brick wall 200mm	Red brick wall 240mm	Rammed earth wall 350mm
Cost $ (Material:Labor)	11994 (1:1.69)	13525 (1:1.14)	11131 (1:2.68)
Material (natural:processed)	91.75 t (1:0.3)	197.39t (1:2.1)	345.63t (1:0.18)
Labor people (Skilled:Unskilled)	220 (1:1.8)	235 (1:1.9)	254 (1:4.5)
Seismic safety	Poor	Medium	Good
Thermal resistance	0.25 K/W	0.3 K/W	0.5 K/W

(If exterior wall spraying is considered, the cost of brick houses will be increased by 5000 $)

From the above table7, it can be get：

1/ This new paradigm obtains a safer and more comfortable living building at a lower cost than conventional ones.

2/ larger percentage of money is being paid to people rather than being used to purchase foreign materials, which enhances the economic vitality of the region.

3/ The use of a larger proportion of native natural materials, which saves costs and reduces the energy consumption of the construction process.

4/ A larger proportion of labor wages are paid to non-technical employees, allowing more local ordinary people to participate.

5. CONCLUSION

The five indicators of resilience are used to analyze the construction mode:

- **Robustness:** Scientific structure improves the structural strength of buildings and pre reduces the damage to people's lives and property caused by natural disasters.
- **Rapidity:** Local personnel and materials can respond quickly by themselves after trauma.
- **Redundancy:** Low technical requirements and easy operation reduce the threshold of construction, so that many idle manpower and material resources can be converted into buildings.
- **Resourcefulness:** The local materials, technologies and labor are abundant and replaceable resources in abnormal times.
- **Adaptability:** The relatively abundant labor, materials and technologies make the construction highly adaptable and flexible, and reduce the opportunity cost.

The Guangming Village project demonstrates the advantages of return rate after major trauma; the Malong Village project demonstrates the advantages of elasticity and stability in the abnormal period of society. The two paradigms under the background of different social conditions are concrete examples of construction that meet the requirements of the Endogenous development model (Figure 7). Both projects address and respond to the characteristics and difficulties caused by the special period of rural areas in southwest China, and improve the resilience of the area in terms of construction.

Indeed, the slight participation of research institution played an indispensable and important role in the early stage of these projects, but after a short period of learning and adaptation, the village can operate this model independently.

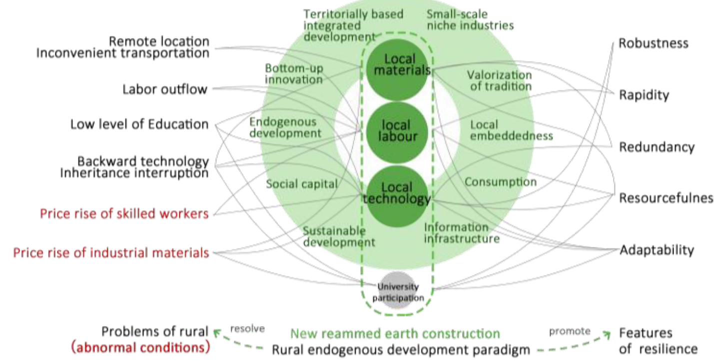


Figure 7: Action mechanism between endogenous development & resilience & rural problems

ACKNOWLEDGEMENTS

Thank Chan Cheung Mun Chung Charitable Fund Ltd for the financial support .

REFERENCES

1. Ministry of Construction of the PRC. Code for seismic design of buildings[M]. GB 50011-2001. Beijing:China Architecture& Building Press , 2008.
2. Basic safety technical guidelines for reconstruction of dilapidated buildings in rural areas, [Online], Available: http://www.qsq.gov.cn/information/qsq43/msg10795218272 .html.[25 March 2018].
3. Main data bulletin of the second national agricultural census (No. 4), [Online], Available: http: // www. stats.gov.cn/tjsj/tjgb/nypcgb/qgnypcgb/200802/t20080226 _30464. html.[26 February 2008].
4. Main data bulletin of the third National Agricultural Census (No. 4), [Online], Available: http: //www. stats. gov.cn/tjsj/tjgb/nypcgb/qgnypcgb/201712/t20171215_156 3634. html.
5. Beck U. World risk society: in search of the lost security[M]. ISBN: 9780745622217. Polity Press, 1999.10.01.
6. UNESCO . Endogenous development strategy [M]. Beijing : Social Sciences Literature Press, 1988 : 1.
7. Philip Thornton. Born from within: Practice and perspectives of endogenous rural development[J]. Agricultural Systems,1997,53(1):
8. Chi Xinnan, Wan Li, Ng Edward.Study On Architectural Strategy Based On Sustainable Development In Rural Areas Of Southwest China[J].Architectural Journal,2014(S2):55-59.
9. Folke C. Resilience[J]. Ecology and Society, Dec 2016, Vol. 21(No. 4).
10. China's poverty alleviation campaign creates "human miracles" and "two worries and three guarantees" are fully realized . [Online], Available: http:// www. chinatoday. com.cn/zw2018/rdzt/2021lh/pl/202103/t20210302_80023 7772.html
11. Liang Ping. A study on anti-poverty in western rural areas in the new stage[D]. Chongqing : Southwest University of China, 2009 : 64-66.
12. Wan Li, Chi Xinnan, Ng Edward, University–based rural sustainable development assistance strategies [C] The University of Sheffield· Architecture and Resilience On the Human Scale, 2015
13. Zhang Yongsheng. Earthquake resistance survey of post disaster buildings [N]Beijing News, 2014.8.11
14. Wan Li, Ng Edward, Chi Xinnan, Post-earthquake reconstruction demonstration project of Guangming village [J].AT,2017(08):24-29.
15. Correct epidemic prevention and control strategy, [Online], Available: https: // baijiahao. baidu. com/s?id =1659777281949255431&wfr=spider&for=pc
16. Xiaotong F. From the Soil: the Foundations of Chinese Society[M]. ISBN : 3002-253. HongKong:Joint Publishing , 1985.6.

PLEA SANTIAGO 2022
Will Cities Survive?

Ethics of a brick

Investigating the common wood fired brick in Uganda

MARK OLWENY[1,2], ALEX NDIBWAMI[3], ACHILLES AHIMBISIBWE[1], THOMAS NIWAMARA[1], PATRICK MUGEMA[1], BRENDA KIRABO[1], DEREK AYEBARE[1]

[1] Uganda Martyrs University, Uganda
[2] University of Lincoln, U.K.
[3] University of Rwanda, Rwanda

ABSTRACT: Architecture has among its goals, to ensure the health, safety and wellbeing of society. Inevitably in this quest, we will be faced with ethical decisions as part of the process of making architecture. In some cases, these values are enshrined in the architectural codes of conduct, although these are largely geared to the production of architecture with an emphasis on the client as the customer, the purchaser of the architects' services. Often little attention is paid to the back casting and the processes that lead up to these decisions. As we debate global issues of sustainability, the very essence of the design and construction of buildings comes into question – the brick, the essence of most construction in Uganda, thus becomes a symbol of this discourse. The Brick encapsulates several ethical positions, not only ecological and economic aspects of sustainability, but just as important, the social issues completing the triple bottom line. In its physical form and as a metaphor, the brick can be viewed as encapsulating various ethical positions. This paper looks at the common wood fired brick and how understanding its manufacturing process may cause us to view it in a different light.
KEYWORDS: Ethical Considerations, Uganda; Embodied Energy; Social Cultural Settings; Wood Fired Brick

1. INTRODUCTION

Discourse on the sustainability of buildings has grown exponentially over the past half century, incorporated discussions and research on materials, construction, in-use energy consumption, end of life reuse, recycling, and disposal. Significant in these explorations has been the foregrounding of technical processes as a means to resolve some of the challenges arising in the construction of buildings. While there is no denying the value of these explorations, and the need to improve the processes that form the basis of building construction and their impact on the sustainability of architecture, what is often lacking is the link to activities that underly architectural designs. This is pertinent when we consider that buildings in many parts of the world could be described as 'hand-made-buildings', for which human labour forms a significant component of the construction process.

We often forget that buildings incorporate a significant component of human labour, from the role of the designer, through to the team that assembles the various components or modules on site. There is increasing talk about the reduction of this component in the construction of buildings, in order to make construction efficient, and 'cost effective'. This is the rationale for the development of 3D printed dwellings, taunted as a way to meet the housing deficit across the world by spreading up the process through the reduction of labour. It is acknowledged that across sub-Saharan Africa the housing deficit is estimated at over 50 million units in 2014 [1], and there is pressure to meet this demand. This figure is daunting, more so considering the potential impact on global carbon emissions and the ability to achieve global emission targets, given that across much of sub-Saharan Africa, the predominant material for housing construction is the fired clay brick, a ubiquitous module that gained favour over the past century, with a manufacturing process based on the burning of timber derived largely from old growth forests.

It has been possible to map the steps in the manufacture of these bricks and to ascertain the associated embodied energy of this material [2], what did emerge from these investigations was the stark reality of the challenges associated with the manufacture of these bricks. This goes far deeper than environmental degradation, emissions targets and the associated environmental heroism that stems from calls to ban the production of fired clay bricks, to be immediately replaced by an alternative.

Often lacking in such discussions is the human factor, relegated to the background, despite being an ever-present part of the entire manufacturing process. Nowhere is this more apparent than in the increasing promotion of technical solutions to the housing crisis in sub-Saharan Africa, as though this is the key challenge that is faced by the population. However, when considering sustainability beyond technical solutions, we may have to consider our ethical responsibilities and associated values, in this case ethical positions that are inclusive of the makers of these handmade bricks.

Ethical positions and values are believed to be inherent within the architecture profession, embedded within professional codes of conduct. However, we can reflect on a position by Jeremy Till who noted that, "[P]rofessional codes of conducts are an example of phony ethics: these are not ethical guidelines, they are principles for relating to the client"[3]. Similar sentiments are expressed by Chris Brown in an interview with Froud and Harriss [4], and more recently by Roberts [5]. This is significant considering the need for transition towards sustainable architecture solutions to address the climate emergency. Negating our ethical responsibilities beyond the client may not be the best approach and does suggest that our ethical responsibility should extend well beyond the narrow scope of the client to encompass society and the environment.

Any investigation of architecture and its material components is incomplete without explicit engagement with the social, economic and cultural activities that surround their production. Indeed, as suggested by Last [6], "[a] focus on pure, matter-less' social relations, … leaves humans with an inflated self-perception and an exclusive interest in means (wealth, power) rather than long-term ends (greater good)." To counter this prospect, Last suggests we engage with the idea of 'Creative Attention' or the idea of paying attention to what is not immediately apparent or obvious, and by extension implies "… 'unlearning' social norms and becoming attuned to the level of matter or 'necessity'"[6].

Addressing this contextual question, we consider sustainability inclusive of social-cultural issues, explored through an ubiquitous construction module across much of sub-Saharan Africa, the humble fire clay brick. For this study, we will be concerned with Eastern Africa, where the described processes are found. The investigation looks at the vibrant but undocumented artisan processes of informal brick manufacturing which constitutes a significant majority of brick manufacturing [7].

2. HISTORY OF BRICK IN UGANDA

Christian missionaries first introduced brick to Uganda at the turn of the 19th century. Use of brick distinguished their construction efforts from vernacular buildings which made use of perishable materials, often succumbing to fires, termites, and the elements. The use of fired-clay brick provided a degree of permanence, with the completion of St. Peter's Anglican Cathedral, Namirembe, Kampala (1919), and St. Mary's Catholic Cathedral, Rubaga, Kampala (1925) standing testament to their early endeavours. It was the scale and magnificence of these radically different buildings that forever cementing the humble brick as the material of choice for construction in Uganda.

The value of these projects in developing a brick building tradition is undeniable and seen in the formal (and informal) brick kilns that have emerged over the years, supporting a developing craft based around the brick module. Bricks have been used extensively for the construction of numerous buildings ever since, although concrete and concrete block became an alternative, particularly after the commissioning of the Tororo Cement Factory in eastern Uganda after the Second World War to supply cement for the construction of the Owen Falls Dam on the River Nile at Jinja.

From the mid-1990s a major construction boom has seen a rapid increase in the brick manufacturing industry, taking advantage of improvements in the local economy. A combination of a lack of capacity in the formal brick manufacturers, as well as various socio-economic challenges following years of civil war served to bolster the informal brick manufacturing to meet the growing demand for bricks that could not be met by the few formal kilns spread around the country.

The domination of brick is seen in the most recent census data, which indicated that more than 67% of the total housing stock (61% in rural areas, and 81% in urban areas) are constructed using some form of brick [8]. The fired clay brick is the most common version, made in scove kilns that are an ever-present and dominant feature across the urban and rural landscape (See Figure 1).

Figure 1: Scove Kilns, Central Uganda (Authors)

The ubiquity of suitable soils for brick making, ranging from heavy clays readily available in wetlands, to laterite soils with a high clay content, found virtually everywhere has contributed to the proliferation of scove kiln, fired using timber felled from old-growth hardwood forests. The desirability of brick as a building material is linked to its prestige status in comparison to perishable materials like

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

thatch, reeds, and wood. The fact that it is easy to come by, and easy to use relative to concrete block or other contemporary building materials, adds to its appeal. Significantly, it can be made relatively cheaply anywhere, by anyone with time and muscle. It is for this reason that the relative value of the brick becomes an important area for investigation.

The lack of legal enforcement of regulations, a consequence of years of economic and political turmoil, has contributed to the growth of this unregulated industry. While this would seem an easy and quick fix, the reality is much more complex. A large proportion of brick makers are informal sector artisans. For this reason, their labour and work conditions often go undocumented. While it is possible to capture some aspects of their endeavours in typical environmental performance analysis models, some intricate details may not necessarily feature. The often-hidden realities of the artisans' lives is somewhat hidden within the broader discussion of global issues and technological solutions.

3. UNLOADING THE BRICKS

Looking to review the nature of the informal sector brick industry, this study was undertaken in conjunction with brick makers in and around Nkozi, Mpigi District in the central region of Uganda. Through a detailed monitoring and evaluation process, the study sought to learn about the activities of the brick makers, part of a broader study investigating the brick making process and the activities of the brick artisans. This was to provide a holistic view of the manufacturing and firing processes and the lives of the brick makers as a means of interrogating some of the ethical issues associated with the making and choice to specify, or even condemn these bricks.

Working with the artisans, it was possible to uncover the often-hidden realities associated with this industry. These realities were made particularly apparent during the lockdowns imposed in response to the COVID-19 pandemic in 2020. This brought home the complexities of life for many people across sub-Saharan Africa and Uganda in this case. We took this opportunity to reflect on this reality, building on a previous study undertaken as part of the project Energy and Low-Income Tropical Housing (ELITH) project that among many activities, explored embodied and operational energy in buildings in East Africa.

Documenting the brick making process was an important step in understanding the value of brick, beyond its monetary and constructional value. While the initial focus of the study was to do with the technical aspects of bricks, the stories that emerged from our interactions with some of the brick makers revealed an aspect of construction that is largely hidden from mainstream discourse. Concern often does not interrogate how the bricks are made, by whom and why? A review of the literature revealed a study by Aniyikaiye et al. [9] that investigated the process of traditional brick making in South Africa, and one of the few studies to investigate the socio-economic and environmental impacts of brick making in sub-Saharan Africa. The study did give an indication of some of the unseen elements, such as the age and gender of workers, work hours, education status and health. While not all of these were collected for the current study, there was discussion around some of these topics as part of the on-site interactions with the brick makers.

Information was collected from seven kilns across three sites, with scove kiln sizes ranging from 7,000 to 20,000 bricks. Brick manufacturing in this location was largely undertaken in wetlands, close to the source of the raw material as all the work is undertaken using human labour (apart from the transporting of firewood to the kilns).

Figure 2: Wetlands Exploitation, Central Uganda (Authors)

As part of the investigation, each stage of the brick making process was meticulously documented, recording the source of the raw materials, time taken to mould the bricks, source of wood fuel for the firing process, through to an investigation of the mechanical properties of the final product (this will not be covered in this paper). A key factor was the need to engage the artisans in the local dialect, a means of building trust and ensuring they were comfortable in discussing their activities. Gaining trust was critical in ensuring the validity of collected data, given a general mistrust of authorities.

3.1 Brick Making

The process starts by identifying a good location with available raw materials; preferably clay-based soils (in this case found in wetlands) or in some cases heavy laterite soils locally known as *Murrum*. Use of the latter brings brick manufacturers into competition with farmers, as deep laterite soils are invaluable for subsistence farming. Three types of clays (alumino-silicates) were found within the study area: Grey clays; Yellow clays, and; Red clays. The brick making was always close to the source of materials, a means to eliminate the need to transport raw materials, understandable as virtually all work is undertaken by hand. Plots are leased for a nominal fee of UGX100,000 to 200,000 for each kiln, depending on the site (€26 to €52).

Material is excavated or dug out using hoes, mixed by hand or with hoes before being transferred into a wooden mould. Where *Murrum* is used, water is added to make it malleable. Each brick maker works with a single mould and is able to make approximately 250 - 300 bricks per day, working on average 10 hours per day. The moulded bricks, which are fairly wet, are tipped out onto grass-covered ground, and left to dry for one or two weeks, depending on the season. Bricks are then stacked and left to cure for another two to four weeks. Curing times were largely dependent on weather conditions (largely related to rain).

3.2 Firing Process

Two to three people undertook assembly of the scove kilns. Experienced stackers complete this task within a day, including plastering of the outer surface with a clay slurry in preparation for firing. The average kiln size was about 2.4 x 3.0 metres at the base, with a height of about three metres, containing approximately 13,500 bricks. It was observed that bricks were stacked tightly in each kiln, making conductive heat transfer the only real means of heating the bricks. The firing process generally started early evening, with two to three people working to keep the fire blazing through the night and into the next day. Keeping the kilns burning through night, involved stationing two men at the kilns with food and drink and a lot of wood fuel. The initial wildfire slowly tempers to glowing high temperature fire that was continually fed with new firewood to keep the heat consistent. The timing varies depending on weather conditions and the nature of the clays used. Brick makers reporting that bricks derived from grey clays required more time and fuel wood, and red clays the least. Kilns are only disassembled when a buyer was found. In most cases, kilns were only fired as and when bricks were needed (fired to order), and not as a speculative endeavour.

The source of the wood fuel is one of the more contentious elements of the brick making process (beyond the destruction of the wetlands). While formal brick manufactures often make use of agricultural waste (coffee and rice husks) to fire their kilns, informal artisans rely on wood fuel, - largely off-cuts from trees felled for timber. Trees used were predominantly hardwood, such as *Milicia excelsa* (Mvule), as brick makers believe they 'burn longer'. The use of Mvule put brick makers in direct competition with charcoal producers, who also make use of timber off cuts. While *Eucalyptus grandis* is in use in Kenya and Tanzania, it was not the case in the area of study, with a visual inspection of most kilns indicating no evidence of use of Eucalyptus grandis (See Figure 3). Use of old growth hardwood has increased over the years, despite the growing availability of Eucalyptus plantations. One of the reasons for this is that Eucalyptus plantations are on private land, while old growth forests, while in public forest reserves are deemed to be accessible to all. This does point to the lack of enforcement of laws protecting forest reserves, a consequence of Uganda's lax forest conservation policies [10].

Figure 3: Wood to Fire Kilns, with curing bricks in the background (Authors)

Wood fuel is the only material sourced away from site, at times transported from well over 100km away, brought to site on small and medium size trucks. This is a major monetary expense for the brick makers, and the reason why kilns are often not fired until a buyer is guaranteed. It is often intermediaries who take charge of this stage of the process, brokering the sales, and sourcing the wood fuel. It is this, along with the emissions from the kilns that have drawn the most attention. Therefore, it is easy to dismiss this as an undesirable practice. However, this fails to address more pertinent problems of how to clean up the industry, and how the entire chain can be considered.

4. SOCIAL CONSTRUCTION OF BRICKS

Brick makers in the area studied came from a host of backgrounds. Some were farmers looking to supplement their income during the dry season, youth seeking some form of income, others were students looking to earn money for their high school or university studies, or youth who needed an income. Students were generally not paid, as they were helping out their families, with income going towards their tuition. They generally only worked during the school vacations. Away from the high-profile wetlands close to the main urban areas, there were very few full-time brick makers.

Figure 4: Making bricks (Authors)

Activities were carried out over a full day, beginning just after sunrise, and continuing till just before dusk. For an average size kiln of 14,000 bricks, a total of 645 hours of labour goes into the production process. Reflecting on the socio-economic conditions in which these bricks are produced. It is here that the reality becomes significant, but not captured in formal environmental performance criteria such as embodied energy and life cycle assessments. What is not captured are the conditions endured by the brick makers, the long days in the field, the back breaking work, the nights spent stoking the fire, the reality that this is an important part of household income, and the only thing keeping them from a life of crime. How is wellbeing of the brick makers taken into account in the cost of the bricks? Further, where do they factor in with regard to material specifiers and the decisions made by architects?

Reported manufacturing loss of 20 to 30% of fired bricks; the high temperature near the source of the fire contributing to a substantial proportion of bricks fusing together, while bricks near the outer surfaces and the top of the kiln are never fired completely, remaining brittle and of questionable strength [11]. Taking a 20% loss, a brick kiln of 13,400 bricks will yield about 10,700 useable bricks. This is a substantial loss given the labour input to the process.

While each brick is sold at between UGX150 and UGX250 (€0.04 to €0.06) depending on location, soil type, equating to UGX 300,000 to UGX 450,000 (€75 to €113) for a small kiln of two to three thousand bricks, to UGX 5 million (€1,260) for a large kiln of 20,000 bricks. The total embodied energy for the bricks was 13.25MJ/brick (per useable brick), or 4.26MJ/kg, similar to Hashemi and Cruickshank [12] who estimated it as 4.76MJ/kg, and Mishra and Usmani [13] who suggests that the embodied energy of Burnt Clay bricks to be about 5.0MJ/brick with average size 100mm x 50mm x 50mm, typically used in India. Neither monetary cost nor embodied energy acknowledge the underlying conditions of the brick makers. This raises a key question as to whether decisions of how to address the industry could be changed given the reality faced by the brick makers. This is significant with respect to the Sustainable Development Goals (SDGs), particularly SDG 12 – Responsible Production and Consumption.

For many architects and specifiers, the reality of the brick making process, the environmental and social impacts are absent in decisions made, more so for architects where their responsibility often stops after the design stage. Further, in terms of ethical responsibility, Codes of Conduct are largely silent on concerns that include societal issues. In the context of Uganda, and much of East Africa, the decision as to which material is used largely lies with the contractor, who generally makes the decision based on the lowest cost. “You can’t be ethical by doing beautiful buildings! You have to assume an ethical stance, a responsibility for the other. If we start thinking that every line on a piece of paper is an act of social responsibility, then every line assumes significance”[2]. This is often neglected in the decisions made by professionals, whose responsibility is believed to be only to the client. When we consider sustainability, our responsibilities extend well beyond specific clients, and to the wider community and the environment. Certainly, considering the impact of procurement decisions on the lives of the wider community, our ideas are far different, and as has been seen in some projects, this shifts from nonchalance, or avoidance, to working to improve efficiency and in so doing improve livelihoods and reduce the potential environmental costs.

5. CONCLUSION

Contrary to common belief, ethical positions are not inherent in society, but are learned as part of the formal and/or informal education process, with, students are exposed to a multitude of ethical positions, from basic value judgements related to beauty and aesthetics - good and bad; to investigations of historical attempts to portray truth and purity; to the more pragmatic and contemporary issues dealing with context, sustainability and social equality. In the context of architecture, the sourcing of materials (and construction processes) need to be scrutinised for their contribution to the overall sustainable goals of a project, and contribution to achieving the SDGs.

The findings of this study are part of a process to unpack sustainability issues in the context of sub-Saharan Africa, which are extremely complex. It is evident that neither energy analysis nor the social economic factors are considered as part of the decisions made in the selection and use of materials. Seeking to quantify the environmental impact of various materials may provide the impetus for the change, and a catalyst for responsible materials management as the most viable means of reducing environmental impact of existing practices.

There is a need to widen the study to include different regions to build a more accurate picture of the activities associated with the production of wood fired bricks. By placing a value on activities related to the manufacture of these products, it may be possible to influence decisions. According to Cortese [14], common assumptions are rarely questioned, directly impacting on the ability to act ethically in the face of conflicts. Certainly, we cannot continue to maintain the status quo as it has not served two ends that are desirable, but rather to perpetuate a myth that architects are separate from reality. Understanding the links both upstream and downstream are vital in contributing to our appreciation of the decisions we have to make to effect change for a sustainable future.

ACKNOWLEDGEMENTS

This study was undertaken with support from the project: Energy and Low Income Tropical Housing (ELITH), funded by EPSRC/DFID/DECC as part of the energy and international development programme (Grant number: EP/L002604/1).

REFERENCES

1. Bah, E.-h. M., I. Faye and Z. F. Geh (2018). The Housing Sector in Africa: Setting the Scene. Housing Market Dynamics in Africa. London, Palgrave Macmillan UK**:** 1-21.
2. Niwamara, T., M. R. O. Olweny and A. Ndibwami (2016). Embodied energy of low income rural housing in Uganda. Proceedings of the 32nd International Passive and Low Energy (PLEA 2016) Conference: Cities, Buildings, People: Towards Regenerative Environments. P. La Roche and M. Schiler. Los Angeles, CA., USA, Passive and Low Energy Architecture (PLEA). **1:** 361-368.
3. Till, J. (2013). Architecture Depends. Cambridge, Ma., The MIT Press.
4. Froud, D. and H. Harriss (2015). A Dangerous Weakness. Radical Pedagogies: Architectural Education and the British Tradition. D. Froud and H. Harriss. London, RIBA Publishing**:** 97-101.
5. Roberts, D. (2021). "Why Now: The Ethical Act of Architectural Declaration.” Architecture and Culture **9**(4): p. 587-605.
6. Last, A. (2017). "We Are the World? Anthropocene Cultural Production between Geopoetics and Geopolitics." Theory, Culture and Society **34**(2-3): 147-168.
7. Eweje, G. (2009). "Labour Relations and Ethical Dilemmas of Extractive MNEs in Nigeria, South Africa and Zambia: 1950–2000." Journal of Business Ethics **86**(2): 207.
8. Uganda Bureau of Statistics (2017). Uganda National Household Survey 2016/17. Kampala, Uganda Bureau of Statistics.
9. Aniyikaiye, T. E., J. N. Edokpayi, J. O. Odiyo and S. J. Piketh (2021). "Traditional Brick Making, Environmental and Socio-Economic Impacts: A Case Study of Vhembe District, South Africa." Sustainability **13**(19): 10659.
10. Naughton-Treves, L., D. M. Kammen and C. Chapman (2007). "Burning biodiversity: Woody biomass use by commercial and subsistence groups in western Uganda’s forests." Biological Conservation **134**(2): 232-241.
11. Okello, P. A. (2010). Studying key attributes of the common clay brick from selected locations in Uganda. (Master of Architecture). Uganda Martyrs University, Nkozi.
12. Hashemi, A., and H. Cruickshank (2015). “Embodied energy of fired bricks: The case of Uganda and Tanzania.” Paper presented at the Sustainable Energy for a Resilient Future: Proceedings of the 14th International Conference on Sustainable Energy Technologies, Nottingham, UK.
13. Mishra, S. and J. A. Usmani (2013). "Comparison of embodied energy in different masonry wall materials." International Journal of Advanced Engineering Technology **4**(4): 90-92.
14. Cortese, A. D. (2003). "The critical role of higher education in creating a sustainable future." Planning for Higher Education (March-May): 15-22.

PLEA 2022 SANTIAGO
Will Cities Survive?

Can solar thermal heating mitigate fuel based space heating in the high mountains of Lebanon?

TONY L. GEAGEA [1] PHILIPPE H. SALEH[2]

[1] DAR[e], for sustainable research, Lebanon

ABSTRACT: Reliance on fossil fuels is a global concern especially in Lebanon, where it lacks natural resources. Previous studies show that renewable energy could replace the fuel in all sectors, particularly, where the residential sector consumes 40% of the energy on heating and cooling. However, no research could be found on the high mountains of Lebanon's potential to benefit from solar radiation for winter indoor heating. This research occurred in the cold area of Lebanon and studies the thermal performance of 8 houses investigating their potential of replacing diesel fuel for indoor heating with solar thermal energy during fall 2019 and winter 2020. The climate is about long and rigorous winters and cool summers. This is done by software simulation and calculations of the houses studying each house's consumption with different external envelopes. Results show that detached houses could achieve a sufficient energy status while implementing solar collectors on their roofs under the given climate conditions, while multi-story buildings need to implement solar collectors on roofs and on the external envelopes to meet the required amount of energy. However, solar panels are capable of achieving a 90 % of the needed energy with a payback period between 7 to 8 years.
KEYWORDS: Energy, Renewable Energy, Cold Climate, Winter Indoor Heating

1. INTRODUCTION

Winter indoor heating is extensively used to provide indoor comfort in the high mountains of Lebanon, where the residential energy statistics show that heating and cooling consumes 47% of the produced energy [1]. Moreover, the energy analysis of the Lebanese residential sector shows that the highest consumptions levels in the high mountains of Lebanon are reached in winter due to excessive heating demand [1]. In addition, Lebanon lacks any oil and gas resources; therefore, all fuel is imported. Due to the high demand for electricity, Lebanon suffers from a daily power shortage [2]. In order to compensate for the lack of required energy, people tend to depend on diesel generators provided by the private sector [3]. Bcharre, Lebanon 34.2507° N, 36.0117° E is located in the northern part of the country with an inhibited altitude of 1400m. This area falls within the high mountains zone and classified as cold temperature climate according to Koppen-Geiger world climate classification [4]. The monthly temperatures and relative humidity fall outside the comfort zone for all the months [5]. Two main sources of heating are available in the high mountains of Lebanon based on diesel: one through diesel stoves; and the other through diesel boilers space radiators [6]. Within Lebanon, market studies show that during the past 10 years, the installation of solar panels for domestic hot water are growing exponentially [7]. This due to the public market which had an important role in financing solar panels for hot water to reduce the individual investment cost [7]. The idea of using solar panels for space heating has not been dealt with so far at the country level.

This research will limit the focus on heating indoor spaces through renewable energy (solar panels) in residential buildings in the high mountains of Lebanon concerning consumption and demand. This research monitors the internal temperature of 8 houses for a period from the 1st of October 2019 till the end of April 2020 (divided into individual houses and apartments in multi-story buildings). The average winter temperature is 9 °C, a minimum of -5 °C, and a maximum of 17 °C as recorded during 2019-2020. The average daily solar radiation recorded for December 2019 is 2330 Wh/m^2. These temperature and solar radiation data were gathered from a Davis weather station located on a nearby building's roof. Similarly, data of overall seasonal fuel consumption for space heating are also recorded. The aim of the paper is to combine all these data from the internal temperatures, weather data, and fuel consumption, to study the feasibility of implementing solar panels to mitigate the fuel for heating. Thus, reducing reliability on scarce non-renewable energy price volatility and reducing the country's carbon footprint.

2. PREVIOUS STUDIES

Researches have been studying the potential of solar collection for energy production for the short and long-term in reducing energy consumption for space heating. According to [8], solar energy can cover all the heating needed for individual and multi-story buildings in cold climates. The study was done over 52 houses in Montreal Canada using solar thermal collectors and thermal energy storage. The research showed that 97 % of the total needed heat was supplied [9]. The purpose of this project was to reduce Greenhouse gas emissions using solar thermal energy collection. It provided 798 flat plates of solar panels of 2.8 m² each south-oriented [9]. [10] outlined solar heating systems in Helsinki, Finland. modelling 100 houses, the simulation showed that a non-renewable energy reduction of 81 % can be achieved by heating water for indoor heating through solar panels. [11] proposed a methodology for estimating the amount of solar system needed to shaping any building form. [12] investigated New Zealand's solar energy potential as calculating the roof area needed. Recent developments in solar technologies, such as solar panels systems and thermal collectors enable building envelopes to have the role of energy generators for heating and enhance energy efficiency [13]. Single-floor houses have better thermal generation compared to multi-story buildings, due to the minimal roof area single floor house has, and in vertical façade surfaces [14]. Since the 2000s, awareness about energy conservation in the Lebanese context started to be raised. During this period, the government launched the Lebanese Centre for Energy Conservation (LCEC). At the same time, the Association Libanaise pour Maitrise de L'Energie et de L'Environment (ALMEE) was founded as a non-governmental organization. These institutes, with Lebanon Green Building Council (LGBC), published several energy studies that encourage less dependency on fuel energy. They also specified general and specific guidelines for the local context. Within the work on climate and comfort, passive strategies for Lebanon, the UNDP (2005) published the thermal standards for buildings in Lebanon. In 2010, an updated edition was issued with grouped a larger number of contributors: The order of Engineers and Architects, ALMEE, LGBC, and others [15].

3. METHODOLOGY

This research is carried out on 5 residential low-rise buildings having two different archetypes: detached houses and attached houses. Two buildings were only inhabited, while the others were not occupied.

3.1 Multi-Story Buildings

Three apartments are monitored in the first building which is composed of five floors (Building A; Fig. 1). Slabs and columns are made out of reinforced concrete. The external envelope is built from cavity concrete masonry units (25 cm), plastered, painted, and stone cladded from the outer side. The second studied building is composed of five stories including the pitched roof (Building B; Fig. 1). Its slabs and columns are made of reinforced concrete. The building's envelope is constructed of a single CMU (15 cm), plastered, and painted. Two apartments are monitored in this building. The third building is composed of three stories (Building C; Fig. 1). Its envelope is constructed of cavity concrete masonry units (25 cm), plastered from both sides, white painted from inside Only the first-floor apartment is monitored in this building.

3.2 Detached Houses

The first house has its external envelope made of timber wood insulated construction (22 cm diameter) (House A; Fig. 1). The second house has its walls made of limestone (30 cm thick), plastered, and painted from the inner side (House B; Fig. 1).

Figure 1: Studied Buildings and Houses. Source: Authors.

3.3 Energy System

Thermal and energy requirements for heating of all buildings typologies have been identified and estimated through Insight 360 (Autodesk) and manual calculation for energy consumption and energy internal gain. Solar thermal systems are sized to cover the thermal energy needed of each house or apartment. The solar thermal collector (flat plate solar panels) are assumed to be installed on additional structures within the roof area, on the needed façade, or in areas adjacent to the individual house. Energy storage tanks and distribution systems won't be taken into account in this study, assuming that tanks capacity and mechanical system are suitable for such study.

3.4 Energy Calculation Tool

Measuring energy consumption is obtained by using dry bulb temperature recordings at the hour in °C, outdoor air temperature and solar radiation at hourly intervals in °C, as well as simulation software. Insight 360 (Autodesk) and Green Building Studio (GBS) are energy simulation software that allows designing, analysing, predicting, and evaluating energy consumed in models in a specific location, orientation, climatic conditions [16-17]. In order to simulate the models and analyse them, several steps must be followed. The first step determines the characteristics and thermal properties of the studied materials. The second step identifies the scenarios of existing and non-existing wall type assemblies through various conditions of usage. The third one consists of taking a benchmark and comparing it to all scenarios through simulation-based software. This step requires a comparison of the baseline with the different scenarios using Insight 360 software. Each residential unit (detached houses and apartments) is modelled as a single heated entity.

4. RESULTS AND DISCUSSION

4.1 Comfort and Performance Indicators

Before diving into the performance indicator, energy loss, and energy calculation, a short remark on temperature comfort is required. The internal temperature benchmark of the high mountains of Lebanon is set by the local and international reference: [5], where the temperature should not fall under 18 °C. Within this context, u-values in this climatic zone, according to [5,7] should be equal to 0.55 W/m²k. As for heating, [7] specified the energy consumption for heating as194 kWh/m²/year.

$$Q = \Delta t \times A \times U \qquad (1)$$

"Equation (1)": takes into account the energy consumed due to outdoor temperature compared to indoor temperature with respect to the area of the external envelope heat exchange [18-19].

Δt – Indoor and Outdoor Temperature Difference;
A - External Envelope Area (m²);
U – Heat Transfer Coefficient (W/m²K).

The temperature value for internal comfort was taken as 17 °C due to the benchmark set by ASHRAE 90.1 for the simulation software in this context [18].

4.2 Energy Consumption

Starting with the window to wall ratio (WWR) comparison between the studied apartments and houses which differs as single and double glazed. Figure 2 shows that individual house #1 has the biggest window size compared to all studied apartments. As shown in Figure 2, the biggest percentage of the window to wall ratio is also found in individual house #1, whereas, the lowest percentage is found in apartment # 2.

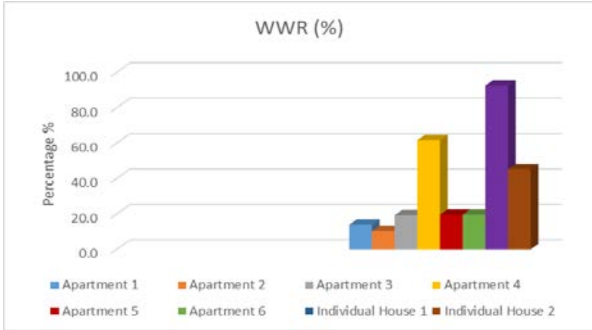


Figure 2: The comparison between the different 8 houses window to wall ratio. Source: Authors.

The performance of the different scenarios is analysed based on the energy consumption of the apartment floor per studied period and per kWh/m² per studied period (Figure 3).

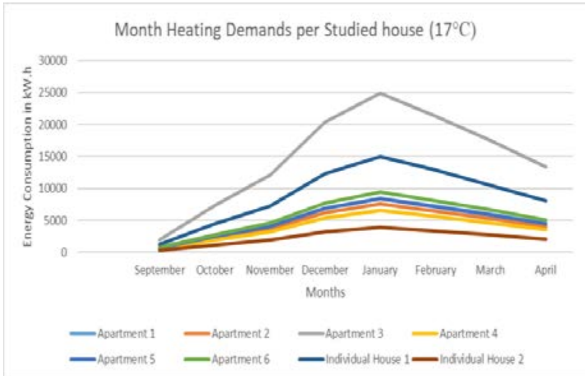


Figure 3: The comparison between the monthly energy needed in kWh for the 8 houses. Source: Author.

After calculating the energy consumption of each apartment, internal gains and solar gains should be added to the calculation. The daily internal gains consist of lighting, occupancy, and equipment per day. The total internal gains are calculated over the study period then added to the total energy calculation (Fig. 4).

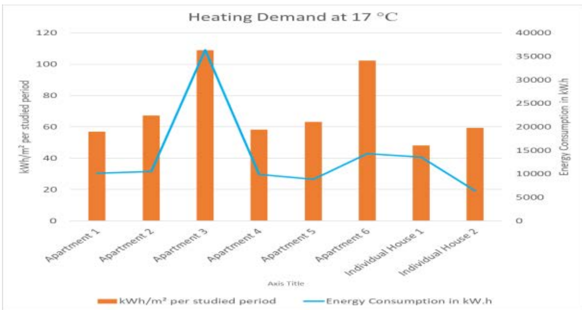


Figure 4: The comparison between the monthly energy needed in kWh 17 °C for the 8 houses. Source: Author.

As for the solar radiation gain, starting by calculating the solar radiation entering from the sun into each apartment through the windows openings according to each month's sun angle. The energy consumption consists of energy used for indoor space heating only. As it is shown in figures 3 and 4, apartment #3 has the highest energy consumption of all studied scenarios. This is because it has the biggest floor area.

Initially, during the study period, individual house #1 had the lowest energy consumption with a difference of 67 kWh/m² per studied period, followed by apartment #4 by 58 kWh/m² per studied period. While this targets fuel consumption (diesel fuel). Observation showed that apartment #3 recorded the highest energy consumption by 109 kWh/m² per studied period. Individual house #1 consumes less energy consumption on space heating 48 kWh/m² per studied period at a 17 °C indoor temperature (Fig. 5).

Figures show that also the energy spent on indoor space heating differs from one house to another. This is due to the floor area of each house. Hence, Apartment #3 still constitutes the highest share of energy consumption per study period, followed by apartment #6.

According to [19], each Litter of diesel fuel is equal to 10 kWh. Therefore, (Fig. 5) shows the diesel fuel consumption of each house during the study period. Individual house #2 recorded the lowest fuel consumption between all studied houses with 1870 L of diesel, followed by apartment #4 by 3131 L, then apartment #2 by 3615 L, apartment #5 by 4007 L, apartment #1 by 4037 L, apartment #6 by 4509 L, individual house #1 by 7169 L, and finally apartment #3 by 11905 L.

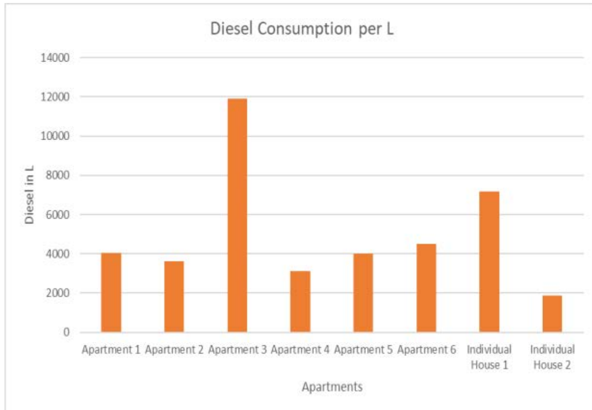


Figure 5: The comparison between the monthly energy needed in kWh 17 °C for the 8 houses. Source: Author.

4.3 Solar Thermal Collectors

Concerning the solar thermal collectors, the main data are reported in Table 1. It includes the operating months and the studied period, needed solar panels units, and heat generation potential.

Panels Efficiency				50	%		
Panels Angle				57			
Based On Solar Radiation							
		a	b= a x 24	c= b x 30/31		50	
Months	Solar Angles for Beirut	Mean Irradiance of Global Radiation Horizontal	Mean Irradiance of Global Radiation Horizontal			Efficiency %	Total monthly Generated per m²
				57			
		W/m²	W/m²	Coefficient	W/m²	W/m²	
January	15	94	2,249	3.675	8,264	4,132	128,095
February	22	115	2,755	2.620	7,219	3,610	101,070
March	28	187	4,488	2.122	9,523	4,762	147,611
April	35	210	5,051	1.742	8,801	4,400	132,012
Oct	28	172	4,119	2.122	8,740	4,370	135,475
Nov	20	221	5,301	2.849	15,102	7,551	226,528
Dec	15	97	2,331	3.675	8,565	4,283	132,765

Number of Panels needed to cover the daily needs							
apartment 1	apartment 2	apartment 3	apartment 4	apartment 5	apartment 6	individual house 1	individual house 2
72	64	211	56	71	80	127	33

Table 1: The comparison between the 8 houses showing the difference in solar panels need. Source: Author.

Thermal requirements for indoor heating of all studied apartments and houses have been identified and estimated according to insight 360, Green Building Studio (GBS), and manual calculation based on references mentioned previously. Solar thermal systems are implemented on each external building envelope to cover the needs of each house. The solar thermal collectors are assumed to be installed on additional structures. A south orientation and tilt angle of 57° are engaged in the calculation.

Table 1 shows the potential of solar heating for indoor space heating according to the weather data taken from the weather station located in Bcharre. It divides the monthly mean irradiance with the solar panels' angle and efficiency to generate to calculate the needed solar panels for every month during the study period at 17 °C. After dividing the needed amount of energy per month by the total monthly generated from the solar panels at 50% efficiency, the highest number of solar panels is needed for February, followed by January, then December. October requires the least number of solar panels.

Comparing energy generation potential to the total energy consumption shows that the individual houses can achieve the total energy status for indoor heating (Fig. 6). While apartment buildings depend on the roof area that should be divided on the numbers of apartments per building. This indicates that solar panels should be implemented on the external walls to be able to have sufficient hot water for indoor space heating.

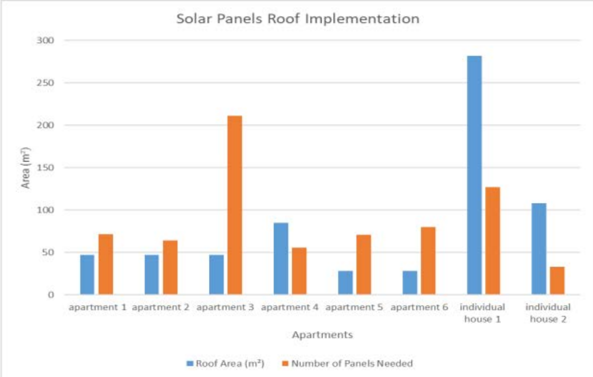


Figure 6: Showing the needed solar panels for the 8 houses. Source: Author.

The first building has 7 apartments. Therefore, the area of the roof should be divided equally for solar panels implementation which is 334 m² divided by 7 equals 47 m². For this reason, apartment #1 still missing 34 % of the needed solar panels to reach the maximum solar panels required, which is 25 panels to be implemented on the external southern walls. Apartment #2 is still missing 27 % of the needed solar panels, which is 17 solar panels. Apartment #3 which has the biggest area in this building, still needs 78 %, which is 164 solar panels.

The roof of the second building can provide more than the needed amount of solar panels for apartment #4. The area of the third building's roof should be divided equally for solar panels implementation which is 140 m² divided by 5 equals 28 m². For this reason, apartment #5 still missing 61 % of the needed solar panels to reach the maximum solar panels required, which is 43 panels to be implemented on the external southern walls. Apartment #6 is still missing 65 % of the needed solar panels, which is 52 solar panels.

	Diesel Cost per $	Solar Panels Cost per $	Payback Periods (years)
Apartment 1	2,422	18,000	7.4
Apartment 2	2,169	16,000	7.4
Apartment 3	6,643	528,000	7.9
Apartment 4	1,879	14,000	7.5
Apartment 5	2,404	17,800	7.4
Apartment 6	2,705	20,000	7.4
Apartment 7	4,301	31,800	7.4
Apartment 8	1,122	8,300	7.4

Table 2: The comparison between the 8 houses showing the Payback Period of the solar panels needed. Source: Author.

With the case presented, each apartment has its missing solar panels to achieve full indoor heating from solar radiation. The figures show that implementing solar panels on external walls could achieve the needed amount of solar panels calculated except apartment #3.

The simulation of the houses allowed an accurate insight into the potential of achieving full indoor heating. Even with the same thermal parameters calculation, each house performed differently due to many factors as:

a- Thermal transfer from walls and roof.
b- Direct gains from sunlight through windows.
c- Direct gains from indoor sources.
d- Area of each house.
e- Roof area that is dividing for each apartment.

The external envelope varies considerably between the different studied houses which are affecting the needed energy for indoor heating. This ends up by calculating the heating load per square meter. Whereas, whenever the house area increase, the heat load increase. Accordingly, the need for solar panels will increase. Concerning the individual houses, #2 had the lowest energy consumption per m² and per total energy. Individual house #1 had the third lowest energy consumption per m² while it had the second-largest total energy consumption in the study period. This is due to the house area which the second biggest house between all studied houses. The more the envelope is efficient, the less it needs solar panels for indoor heating. The energy simulation of different house types indicates that detached houses could achieve a sufficient energy status from using the roof only, under the given climate conditions. Not all apartment houses are capable of generating all their required energy from the roof. Therefore, solar panels on the external envelope are capable of achieving a minimum of 93 % of the needed energy.

4.4 Payback Analysis

To achieve the cost-effectiveness of this system, the simulation results the consumption per L of diesel fuel of each house. It is estimated that 1 L of diesel fuel cost is 0.85 $ in Lebanon [19

]. Adding the solar panels' system cost to the initial cost, wherein Lebanon no accurate data can be found for solar collector's prices. For this reason, the prices were chosen according to experience in the field, knowledge, and choice of technicality. The cost of 1 solar panel in Lebanon is 250$. Table 2 shows each house's fuel reduction and the solar panels cost for each house with the payback period. It can be noticeable that the payback period is between 7 to 8 years depending on each house (Table 2).

5. Conclusion

The current paper presents an innovative and holistic approach to the analysis of the impact of installing solar panels for different house types in the high mountains of Lebanon with different thermal performance towards the cold climate.

The implementation of solar thermal collection has a significant impact on energy consumption, especially in a country that lacks resources. In the case of the studied houses, it can reduce the total energy consumption of the individual houses by implementing solar panels on the roof. Whereas, the apartments in a multi-story building will need to implement solar panels on the external façade of the building to be able to reduce and replace a minimum of 93 % of the non-renewable energy consumed for space heating. The methodology of this paper consisted of analysing 8 apartments with different thermal performance for fall 2019 and winter 2020. This allowed reaching the objective of replacing the non-renewable resources with renewable energy through solar radiation for indoor space heating.

Results show that this can be done. Yet, what makes this complicated to implement is the typology of houses within the rural area. this study shows that the payback period of such implementation would need between 7 to 8 years.

6. REFERENCES

1. MOEW, G., UNDP (2015). Energy consumption in the commercial and institutional sector.
2. Fardoun, F., Ibrahim, O., Younes, R., & Louahlia-Gualous, H. (2012). Electricity of Lebanon: Problems and Recommendations. Energy Procedia, 19, 310-320. doi: 10.1016/j.egypro.2012.05.211
3. Rabah, M. (2018). Lebanon's electricity crisis fueled by decades of mismanagement. The Arab Weekly. Retrieved from https://thearabweekly.com/lebanons-electricity-crisis-fuelled-decades-mismanagement.
4. Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006). World Map of Koppen-Geiger Climate Classification updated. Meteorologishe Zeitschrift. 15 (3), 259-263.
5. UNDP. (2005). Climate and Comfort: Passive design strategies for Lebanon. Prime Design, 1, 13-42. Rtreived on October 28, 2018 from: http://primedesignpea.com/pdf/2005,ClimateandComfort.pdf.
6. LCEC. (2016). THE SECOND NATIONAL ENERGY EFFICIENCY ACTION PLAN FOR THE REPUBLIC OF LEBANON. Beirut.
7. LCEC (2014). National Energy Efficiecny and Renewable Energy Action (NEEREA). RCREEE; Banque du Liban; LCEC.
8. Hugo, Alexandre, Zmeureanu, Radu, Rivard, Hugues, 2008. Modelling of a seasonal thermal storage system in a residential building. In: 3rd Canadian Solar Buildings Conference Fredericton, N.B.
9. Sibbitt, B., McClenahan, D., Djebbar, R., Thornton, J., Wong, B., Carriere, J., Kokko, J., 2012. The performance of a high solar fraction seasonal storage district heating system – five years of operation. Energy Proc. 30, 856–865.
10. Rehman, Hassam, Hirvonen, Janne, Sirén, Kai, 2017. A long-term performance analysis of three different configurations for community-sized solar heating systems in high latitudes. Renew. Energy 113, 479–493.
11. Compagnon, R. (2004). Solar and daylight availability in the urban fabric. Energy and Buildings, 36(4), 321-328. doi: 10.1016/j.enbuild.2004.01.009
12. S. Ghosh, R. Vale, the potential for solar energy use in a New Zealand residential neighborhood: a case study considering the effects on CO2 emissions and the possible benefits of changing roof form, Australasian Journal of Environmental Management 13 (2006) 216–225.
13. Hestnes, A.G., 1999. Building integration of solar energy systems. Sol. Energy 67 (4), 181–187.
14. Hachem, C., Athienitis, A., & Fazio, P. (2014). Energy performance enhancement in multistory residential buildings. Applied Energy, 116, 9-19. doi: 10.1016/j.apenergy
15. Saleh, P. (2019). Towards nearly zero energy buildings in Lebanon. London: University of Westminster.
16. Fasi, M. A., & Budaiwi, I. M. (2015). Energy performance of windows in office buildings considering daylight integration and visual comfort in hot climates. Energy and Buildings, 108, 307-316. doi: 10.1016/j.enbuild.2015.09.024
17. Green Building Studio Validation | Search | Autodesk Knowledge Network. (2020). Retrieved 7 August 2020, from https://knowledge.autodesk.com/searchresult/caas/CloudHelp/cloudHelp/ENU/BPA-Help/files/GUID-EF68E7D5-C0A54805-BFE5-7C74C57B712E-htm.html
18. Ashrae.org. 2022. Standard 90.1. [online] Available at: <https://www.ashrae.org/technical-resources/bookstore/standard-90-1> [Accessed 7 March 2021].
19. Lebanon diesel prices, 28-Jan-2022 | GlobalPetrolPrices.com. (2021). Retrieved 28 January 2022.

Experimental construction site and student autonomy

Perspectives of another teaching for equitable cities

CONRADO CARVALHO[1] MARCOS SILVOSO[1]

[1] Universidade Federal do Rio de Janeiro

ABSTRACT: This paper presents a contribution to the field of construction technology in the teaching of architecture, as a strategy to prepare architects for the demands of cities in the 21st century. It aims to develop reflections on experiences of constructive practices to encourage a review of architecture teaching, considering the expansion of constructive experimentation in schools and an integrated and interdisciplinary approach. The paper is part of an ongoing doctoral research and is guided by the democratization of access to the work of architects and the constitution of sustainable and equitable cities. In this sense, it considers the panorama of Brazilian cities, the new sociodemographic profile of students, the development of constructive practices in different universities, and the experience of the Experimental Construction Site of the Faculty of Architecture and Urbanism of the Federal University of Rio de Janeiro. The methodology is based on (i) bibliographic review related to experiences of constructive practices in architecture teaching in Brazil and internationally; and (ii) carrying out an analysis of the reported experiences, identifying elements and aspects with potential to be a reference to the elaboration of proposals to strengthen constructive experimentation supported by Brazilian social architecture.

KEYWORDS: Architecture teaching, Learning by doing, Construction technology, Social architecture.

1. CONSTRUCTION FOR STUDENT AUTONOMY

In architecture teaching in general, there is a hegemonic view centred on the design and on the theoretical approach, which overlaps the construction disciplines and shapes the architect's profile. However, many initiatives around the world qualify as exceptions, some of which will be the focus of this work.

In Brazil, the topic of construction technology has been historically neglected and underestimated in architecture teaching. In addition to the growing reduction in the workload of construction technologies disciplines, the teaching of construction usually occurs in an abstract way, not integrated with the teaching of design and detached from the real applications of the professional practice and the needs of society.

Learning tends, then, to be constituted by memorization and abstract reproduction of reasoning, which weakens the student's curiosity [14]. For educator Paulo Freire, this didactics hinders the student's freedom and ability to venture into critical thinking. Freire sees that in this process there is a banking concept of education, in which the student's role is restricted to receiving deposits of information from the teacher and archiving them, in a unidirectional process that does not make room for dialogue and critical thinking [6].

When the student receives information from the educator without there being space and time for questioning, the content is received and stored, but it is not processed, since the student does not participate as a subject in this process. Therefore, the information does not become knowledge [6; 9].

Freire defends a Problematizing Pedagogy, which is liberating, questioning, and dialogic, which encourages reflection on the state of things and instils 'epistemological curiosity' in the student, determined by the critical exercise of the ability to learn, which is opposed to the naive curiosity of common sense. Freire conceptualizes the Pedagogy of Autonomy, supported by experiences that stimulate the student's decision and responsibility, always permeated by dialogue: "Autonomy is constituted in the experience of countless decisions that are being taken" [6].

To feed perspectives for an architecture education that encourages students' autonomy from constructive practices and the interlocution between design and construction, a presentation of arguments and experiences that reinforce this reflection will be made in the continuity of the text. Initially, an overview will be made of the urban context of Brazilian cities in the 20th century, the concern of some architects in the face of this situation, and their relationship with the creation of Experimental Construction Sites in architecture schools.

In addition to the Experimental Construction Sites in Brazil, this study will present an overview of initiatives in other countries that approach the constructive practice similarly to Paulo Freire's ideas, as for example Chilean experiences at the Pontifical Catholic University of Valparaíso (PUCV) and the University of Talca.

Next, we will discuss the sociodemographic reality of Brazilian universities, which now have a robust (and unprecedented) representation of poor students living in favelas, as to relate this new scenario to the theme of this study. What is the potential of this "new university" to support the production of healthier, more equitable, and sustainable housing, neighbourhoods, and cities?

The study focuses on the teaching of architecture in Brazil but considers that there are many points of similarity with the reality of other Latin American countries.

2. ARCHITECTS FACING THE HOUSING CRISIS

One can affirm that the experimental sites of Brazilian architecture schools are rooted in the debate on the process of production of cities, in the historical panorama of the housing deficit, and the change of view about the social role of architects. In this sense, we highlight the creation of an understanding of the need for architects to approach the favelas and a greater understanding of the reality of the residents and their construction culture.

The Brazilian urbanization process in the 20th century produced the effect of shaping a generalized scenario of high inequality in cities, in a phenomenon of 'favelization', with a concentration of poverty and environmental problems in peripheral urban areas, at an extremely difficult level to be repaired.

At the end of the period of the military dictatorship in Brazil (1964-85), the civil society began to mobilize for social justice, the right to the city and quality housing. At that moment, there was an organization of social movements struggling for housing and urban reform, initiatives that were and are very active and essential for the debate and the conformation of public policies until today.

At the same time, there was a discussion about the role of the Architect and Urban Planner in society, where criticisms and revisions were made about the real impacts of architecture on the life of the population. These reflections, which were initially produced in universities, began to be developed in poor communities, in association with Housing Movements, ecclesiastical organizations, and progressive political parties [1; 9].

In this context, it is essential to highlight the work of the New Architecture (Arquitetura Nova) group (1962-70), composed of architects Sérgio Ferro, Flávio Império and Rodrigo Lefèvre. They sought to formulate a new program for Brazilian modern architecture, guided by the issue of the housing deficit, social housing, and the development and application of techniques and materials accessible to the population. In the words of Sérgio Ferro, in a critique of Brazilian architectural production at the time, published in Revista Projeto, nº 86 of 1986, New Architecture was "(...) thinking about another client, the one that did not exist – the poor people". The New Architecture group was paradigmatic and inspired the debate of the following years about the housing crisis and the Brazilian high social inequality, and the importance of the architects approach to the favelas [1].

Motivated by the progressive ideals of the moment and directly inspired by the New Architecture group and the action of ecclesiastical bases in poor urban communities, groups of architects emerged in the 1970s and 1980s that sought to act directly in the favelas, together with the struggle of the housing movements. There was the emergence of the defence of Technical Assistance in urban peripheries and the creation of housing cooperatives, in which participatory processes were developed, often based on the realization of collective efforts to carry out construction works.

Regarding that moment of action and debates on technical assistance and housing cooperatives, it is essential to highlight the influence of Uruguayan housing cooperatives represented by the Federation of Housing Cooperatives of Mutual Support (Federación de Cooperativas de Viviendas por Ayuda Mutua – FUCVAM).

At that point of inflection in the understanding of the role of architects, with the emergence of a 'new' way of thinking and producing architecture and cities, and the search for the valorisation of social architecture, initiatives hitherto unheard of in universities began to occur. Through professors and students committed to the cause of social housing, some architecture schools began to develop works in favelas and praised the importance of mastering constructive technologies so that architects would be better prepared to respond to society's demands.

In this sense, the experience of the Architecture and Urbanism course at the School of Fine Arts of São Paulo (Escola de Belas Artes de São Paulo) stands out as a reference point for a didactic initiative that made a good articulation between design, technology, and construction teaching, through the prism of social architecture. The course was created in 1980 with a curricular organization that allowed permeability between disciplines, with application in practical activities. In the course was created (1982) the first housing laboratory in Brazil, Laboratório de Habitação (LabHab), which, according to João Marcos Lopes, one of the professors, “allowed for the practical extension of the design action situated in an unquestionably concrete social reality – the periphery of the city of São Paulo and its housing movements” [8].

The LabHab's trajectory is paradigmatic in the teaching of architecture in Brazil for presenting a more organic approach to professional practice. Theoretical contents were reflected directly in the favelas, in association with the residents, in environments conducive to a practical exercise. LabHab generated reverberations in other universities, which also created similar initiatives. The ideas that emerged at LabHab evolved with the accumulation of experiences and debates throughout the country, and culminated in what is currently known as the Experimental Construction Sites [8].

In 1993, influenced by the New Architecture group and LabHab, some professors of the Faculty of Architecture and Urbanism of the University of São Paulo (FAUUSP) started the development of practical activities on the construction site to carry out exercises related to a Construction Technology discipline. In 1998, FAUUSP gained its own space for construction site activities and, progressively, the actions carried out there gained prominence and highlight, unfolding in the consolidation of the Experimental Construction Site.

3. THE ‘EXPERIMENTAL CONSTRUCTION SITE’ STRATEGY

The FAUUSP initiative culminated in the creation of the Experimental Construction Site, a didactic-pedagogical equipment that over the years was disseminated and appropriated in other schools, and which is structured as a strategy to contribute to the autonomy of architecture students.

In the Experimental Construction Site, practical activity does not overlap with intellectual activity, because the understanding is that there is no such separation. It is, therefore, the place of full activity. It should not be mistaken for a laboratory, where materials, phenomena, and processes are studied separately, via analytical methods. Neither is the Experimental Construction Site a School Construction Site, in which it is sought to faithfully reproduce the space of a “real” construction site. This is an understandable confusion, since the Experimental Construction Site also seeks to develop construction techniques and materialize projects through the use of construction materials. The Experimental Construction Site is, in essence, a space for exploring the transformative potential, which seeks to go beyond the understanding and reproduction of conventional construction processes, with a view to the student's freedom to create with greater complexity and criticality an understanding of the profession [12].

The Experimental Construction Site is, therefore, an innovative didactic strategy in the teaching of architecture in Brazil, which offers much more than a space for the practice of projects execution. It enables the confrontation of reality and the materialization of ideas from the problematization and exploration of creative freedom, exposing and analysing errors and successes of the elaborated processes. It is a place of emancipation that constitutes a didactic opportunity, with high potential for expanding both the knowledge of construction technology and the exercise of design, through an approach that privileges critical teaching and provides conditions for the deepening of questionings.

It is a dialogic space that brings students closer to their daily reality and promotes ‘learning by doing’, encouraging students to take responsibility for their decisions and operations, contributing to the development of their autonomy, and overcoming the abstraction of the contents taught, encouraging architectural design through the act of building [14].

Despite the positive evaluation of the experiences of the Experimental Construction Sites by students and professors, until now only a minority of architecture schools in Brazil have this equipment. We can say, however, that there are increasing efforts to create Experimental Construction Sites.

3.1 The FAU/UFRJ Experimental Construction Site

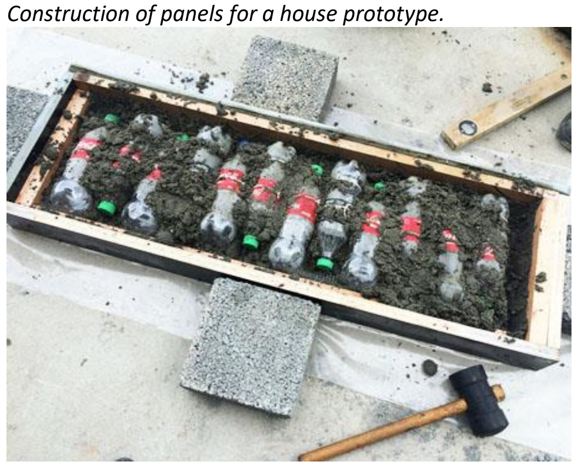
Although the Faculty of Architecture and Urbanism of the Federal University of Rio de Janeiro – FAU/UFRJ is a reference school, the implementation of the Experimental Construction Site only took place in 2014. FAU/UFRJ's strategy seeks to converge its activities of practical constructive experimentation as an action of confluence between teaching, research and extension [14].

In this way, activities are developed through: mandatory disciplines, such as of Construction Processes, where experiments with conventional, vernacular (Fig. 1), and reused materials are explored, and works are developed based on the concepts of Circular Economy [2]; elective disciplines, such as Earth Construction Technology; support activities for Degree Final Projects (Fig. 2); Scientific Initiation research; Extension activities; and Construction Workshops, often associated to events, such as the one that took place in 2018 with Rede Terra Brasil, an institution that seeks to promote earth constructive technologies [14].

Figure 1:
Experimentation with earth bricks.

Note: Exercise self-production of earth bricks and construction of prototypes with students in the first year of graduation, 2022.

Figure 2:
Construction of panels for a house prototype.



Note: Degree Final Project entitled “From Garbage to Home: Housing Unit with materials from waste”, by student Mariana Dimbarre, 2015.

With 5 years of operation completed in 2019[1], despite the positive evaluation from active professors and researchers and approximately 1,200 undergraduate students who have experienced the equipment until then, the FAU/UFRJ Experimental Site still has enormous integrative and systemic potential to be explored.

Thus, this study defends the strengthening of the Experimental Construction Site strategy of FAU/UFRJ to promote the emancipation of students, deepening the close design-construction relationship and the link between architecture and its social and economic dimension, to support a professional training that aims at a social architecture close to the daily reality of FAU/UFRJ students and Brazilian society.

[1] In early 2020 activities were interrupted due to the Covid-19 pandemic. The return is scheduled for April 2022.

4. A ‘FLIGHT’ THROUGH FOREIGN EXPERIENCES OF CONSTRUCTIVE PRACTICES

Aiming to provide contents to the reflections in this study, we will present brief notes on foreign references with different characteristics that approach the constructive practice as a way to architecture teaching, showing convergences with the problematics exposed in this paper.

We will present two paradigmatic experiences of Chilean universities that deal with constructive practices. The School of Architecture and Design of the Pontifical Catholic University of Valparaíso (Escuela de Arquitectura y Diseño de la Pontificia Universidad Católica de Valparaíso – PUCV) stands out for its teaching-learning relationship based on poetry, design and construction, and for the incorporation of these activities as part of everyday life, with a strong appeal of belonging to the South American continent [4; 5]. From the Amereida proposal, which aims to unite the daily activities of life, work and study in the encounter between poetry and crafts, unfold the Ciudad Abierta and Travessias initiatives, which promote reflections in action and the integration between construction and design, through the execution of perennial and ephemeral installations in 1:1 scale. In Ciudad Abierta, the projects are implemented in an area linked to the PUCV, which is located in Ritoque, 16 kilometres away from Valparaíso. In Travessias, students and teachers design and build in distant places in Latin America, on study and work trips that explore the perception and reading of the territory and communities to define the program, materials and construction processes [4; 5].

The other Chilean experience is that of the School of Architecture of the University of Talca (Escuela de Arquitectura de la Universidad de Talca), located in the Valle Central region, which has a pedagogical project with strong links to the place where the school is located. It is a course intensively based on practice, on the exploration of available materials, on the analysis of the territory, and the training of students for professional performance. Students develop design and execution activities for architectural structures observing the availability of and access to resources in the region. The course explores the creative capacity and the development of operational skills of future architects, giving them autonomy for professional performance. The pedagogical project is based more on the material than on the space, and the profile intended for graduating students is that of a professional with a broad view of architecture, based on the exploration of three domains: Operate, related to the proactivity necessary for good professional performance; Officiate, relating to the conception, design, and supervision of works; and Innovate, which considers competencies related to the transformation of knowledge into wealth, in the broadest sense of the term [10; 11].

We also highlight the experience of Rural Studio, linked to the School of Architecture, Planning and Landscape of the University of Auburn, in the United States. The Rural Studio promotes students' immersion in poor communities in Alabama, with the integration of design teaching and construction teaching, in a process that culminates in the execution of buildings for the community, and which considers the local constructive culture and labour [13].

Another relevant experience analysed is that of the Aura Strategy, proposed by the transdisciplinary team of the University of Seville (Universidad de Sevilla), Spain, created to participate in the 'Solar Decathlon 2019', a competition promoted by the United States government, which supports the development of high-performance buildings and the use of renewable energy. The Aura Strategy is based on the creation of a transformative network between professors from different disciplines and departments at the Universidad de Sevilla, with the establishment of a teaching methodology based on problem solving, on the transversal concept of sustainability and on holistic study approaches [7].

For the 'Solar Decathlon 2019', housing prototypes were developed from a project that considered all the design and construction stages of real architecture. The variety of professors and departments that participated in the process highlights the Aura Strategy as a reference for the development of proposals for reviewing Higher Education [7].

There are many other experiences around the world approaching construction and design in an integrated, systemic and interdisciplinary way. In any case, the highlighted experiences are complementary, considering their specificities, and bring very relevant aspects that will be deepened, elaborated, and perhaps incorporated during the doctoral research, with a view to adapting to the context of the Experimental Construction Site of FAU/UFRJ.

For the same purpose, it is essential to include in this reflection the panorama that will be exposed in the following topic.

5. SOCIODEMOGRAPHY OF BRAZILIAN STUDENTS

Only 15% of the Brazilian population that has built or renovated their home used the services of an architect [3]. The reality of the country shows that, in general, architects work for the upper classes of society. Considering this fact, the Council of Architecture and Urbanism of Brazil – CAU/BR points out that it is crucial to rethink the training of architects, aiming to qualify professionals to meet the primordial demands of society, from knowledge that is focused on the daily life in Brazilian cities [3].

Faced with the scenario of concentration of inequities and environmental problems in Brazilian cities, it is essential to broaden the debate on teaching, intending to value architects in society and democratize the access to architectural services, including poor families among those attended.

At the beginning of the 21st century, the Brazilian government initiated a policy of democratization and expansion of Higher Education, based on a package of measures that resulted in the inclusion of a new sociodemographic profile of students in public and private universities, enabling a historic transformation through the presence of students from poor families, who usually live in peripheral urban areas, with less infrastructure. Before that, university environments were generally occupied by students from privileged social classes, residents of the most valued areas of the cities.

As a result, there is an emergence in the country of students – and recently graduated architects – who are poor and residents of urban areas that until then were not lived and experienced by the architecture professional. It should be noted that these areas lack the services of architects, and concentrate housing, urban and environmental problems. Another point of view about this new scenario is that before this transformation took place, the situations of people living in favelas experiencing and contributing academically in university environments - spaces for the construction of scientific and technological knowledge - were exceptions.

Despite this advance, we can say that architecture schools in Brazil have not opened up to the scientific and technological potential of inclusion of these 'new' students in Brazilian society. Although this debate has been growing in the academia, the teaching of architecture in Brazil remains largely guided by conceptual and technological references from countries in the global north, whose urban, social and cultural conformations are essentially different from the global south. A hegemony of application of architectural programs persists in the design disciplines of Brazilian schools, far from the social and urban reality of these future professionals and far from the daily needs of society.

This study understands that the presence of students living in favelas and urban peripheries - places with specific urban culture, dynamics and development - is both a justification for the promotion of new reflections and propositions in architecture schools and an opportunity for these people to constitute themselves into agents of transformation of their local realities.

Thus, it is necessary to review the teaching of architecture based on the strengthening of a systemic view of the profession, with an appreciation of the integration between knowledge of construction technology and other disciplines related to architecture. Likewise, it is essential to guide teaching following the daily demands of society and the country's environmental and urban problems, constituting curricula that are based on the training of architects who understand and act in the unequal and complex contexts of Brazilian cities, especially those most vulnerable [15].

The Experimental Construction Site is a place of convergence of academic and non-academic understandings and knowledge. It is a space of freedom for the development of innovative constructive practices that, directed towards finding solutions to urgent urban problems, play a fundamental role in the education and training of architects committed to the future of cities.

> "(...) it is necessary to prepare young people who arrive at university for a responsible action in the social reality, and not just train them to meet the way the market organizes the consumption of their profession" [12].

6. FINAL CONSIDERATIONS

There are several possibilities for strengthening the integration between design teaching and construction teaching in architecture schools. The experiences presented here are relevant, bring together aspects that converge with this study, and seek to promote critical, problematizing and liberating teaching, very consistent with Freire's principles. These are initiatives committed to reducing inequalities, which consider the knowledge and culture of poor communities, such as the works of New Architecture and LabHab or Rural Studio. Experiences that explore 'learning by doing' through the exercise of constructive practice based on the search of problem solving and encouraging students' autonomy, as in the Chilean experiences and the transdisciplinary team of the University of Seville, in which the interdepartmental interlocution carried out is also highlighted in an innovative institutional arrangement.

Despite the experiences of the Experimental Construction Sites in Brazil being well evaluated in general, much effort is still needed to explore their interdisciplinary potential and expand the integration of knowledge, aiming at the training of more committed and prepared architects to contribute to the production of cities that are more equitable, healthy and sustainable, following the Sustainable Development Goals (SDGs), especially SDG 11, which seeks to transform cities and communities into more inclusive, safe, resilient and sustainable spaces.

This study understands that despite the difficulties faced in seeking to overcome the hegemonic teaching model, as well as in facing the adversities related to the current political, economic and social crisis that the country is experiencing, the search for the reduction of inequalities and the valorisation of the profession persists and becomes even more urgent.

ACKNOWLEDGEMENTS

This study was carried out with support from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Funding Code 001.

REFERENCES

1. Arantes, P., (2002). Arquitetura Nova - Sergio Ferro, Flavio Império e Rodrigo Lefèvre: de Artigas aos Mutirões.
2. Caldas, L., Figueiredo, L. and M. Silvoso, (2020). Economia circular no ensino de arquitetura: a experiência do canteiro experimental. [Online], Available: https://www.archdaily.com.br/br/942501/economia-circular-no-ensino-de-arquitetura-a-experiencia-do-canteiro-experimental [21 October 2021].
3. Conselho de Arquitetura e Urbanismo do Brasil – CAU/BR. Percepções da sociedade sobre arquitetura e urbanismo, [Online], Available: https://www.caubr.gov.br/pesquisa2015 [20 August 2021].
4. Corporacíon Cultural Amereida. [Online], Available: http://amereida.cl/Ciudad_Abierta [12 February 2022].
5. Escuela de Arquitectura y Diseño de la Pontificia Universidad Católica de Valparaíso (PUCV). [Online], Available: https://www.ead.pucv.cl/ [12 February 2022].
6. Freire, P., (1996). Pedagogia da autonomia: saberes necessários à prática educativa.
7. Herrera-Limones, R., Rey-Pérez, J., Hernández-Valencia, M., and J. Roa-Fernández, (2020). Student Competitions as a Learning Method with a Sustainable Focus in Higher Education: The University of Seville "Aura Projects" in the "Solar Decathlon 2019". *Sustainability*. 12(4), 1634.
8. Lopes, J., (2014). Quando menos não é mais: tectônica e o ensino tecnológico da Arquitetura e do Urbanismo. In *ENANPARQ*. São Paulo, BRA, October 20-24.
9. Lotufo, T., (2014). Um novo ensino para outra prática - Rural Studio e Canteiro Experimental: contribuições para o ensino de arquitetura no Brasil.
10. Ortiz, J., (2011). La Escuela de Arquitectura de la Universidade de Talca: um modelo de educación. In *Dearq* (9): p. 62-73.
11. Román, J., (2013) Talca: Inédito.
12. Ronconi, R., (2005). Canteiro experimental: uma proposta pedagógica para a formação do arquiteto e urbanista. *PosFAUUSP* (17): p. 142-59.
13. Rural Studio. [Online], Available: http://ruralstudio.org [16 February 2022].
14. Silvoso, M., Cordeiro, P. and R. Albuquerque, (2017). O ato de construir como uma ação integradora de conteúdos no canteiro experimental da FAU/UFRJ. In *ENEEEA*. Ouro Preto, BRA, June 07-09.
15. Wilderom, M. and P. Arantes, (2020). Arquiteturas da distância: o que a pandemia pode revelar sobre o ensino de Arquitetura e Urbanismo. [Online], Available: https://www.archdaily.com.br/br/944738/arquiteturas-da-distancia-o-que-a-pandemia-pode-revelar-sobre-o-ensino-de-arquitetura-e-urbanismo [16 September 2021].

PLEA SANTIAGO 2022
Will Cities Survive?

Streetscapes for Sao Paulo: walkability and ergonomics

An urban assessment methodology for urban design policies

ANDRE EIJI SATO[1] PAULA LELIS RABELO ALBALA[1] ROBERTA CONSENTINO KRONKA MÜLFARTH[1]

[1]Faculty of Architecture and Urbanism of the University of São Paulo (FAUUSP), São Paulo, Brazil

ABSTRACT: In the Brazilian COVID-19 context, the city of São Paulo was the most affected city and thus, many of its vulnerabilities were heighted by the pandemic, exposing the social and territorial weaknesses. However, walking emerged even more relevant since pedestrian-friendly streets have a great importance in offering a more inclusive, safer and comfortable environments and thus, can also play a central role for a sustainable pandemic recovery's policy. This paper aims to present an ergonomic urban assessment methodology in two central zones of São Paulo (with high macroscale walkability but different in terms of microscale displacements on foot). The method was applied in 19 streetscapes and after comparative analysis, it was found that the groups "Crossing", "Sidewalk", "Public Infrastructure", "Blocks", "Buildings" might have a significant impact on the pedestrians. It concludes that the form of how those elements combine with each other has a deeper relationship to the streetscapes' power to attract or repel the pedestrians. Another conclusion is that the application of Ergonomics in cities can be fostered, not only as a theory, but more importantly as a method for assessing the quality of the built environment of cities, especially those on developing countries such as São Paulo.

KEYWORDS: Ergonomics, Walkability, Streetscapes, Fieldwork, Analytical work.

1. INTRODUCTION

The COVID-19 pandemic is a global crisis that has exposed and accentuated pre-existing inequalities, impacting all aspects of our lives. Unlike many cities around the world, Brazilian cities still lack strategies to ensure public health safety for their users and, therefore, vulnerabilities were heightened by the pandemic, exposing the social and territorial weaknesses of these cities. In the Brazilian context, São Paulo is the most affected city in number of infected people and deaths [1]. The Sustainable Development Goals Report 2021 [2] exposes the devastating impacts of the pandemic on the SDGs.

Regarding urban mobility, the pandemic has made walking even more relevant than never, due to its safety. Sidewalks are open spaces and pedestrians can usually keep a safe distance from others. Furthermore, pedestrian-friendly streets promote more inclusive and safer environments, especially for women, children, older people, and people with disabilities. Also, it contributes to mitigate climate change. Consequently, the promotion of more walkable cities has not only been essential during the pandemic but can also play a central role for a sustainable pandemic recovery.

This paper aims to contribute to this debate and thus, it presents an urban assessment methodology that correlates criteria of Walkability with Ergonomics. The case study evaluated two nearby areas in the central region of São Paulo: Barra Funda and Francisco Matarazzo Origin-Destination (OD) Zones. The selected areas present similar level of macroscale walkability, but they are very different regarding microscale displacements on foot. The technical work was based on the field application of this ergonomic method having the streetscapes as spatial scale.

2. CONCEPTUAL FRAMEWORK: WALKABILITY, ERGONOMICS AND STREETSCAPES

The concept of walkability emerged for the first time in 1993, being defined as the "quality of place" [3]. Since then, many authors have adopted this expression, creating more detailed definitions to the concept. For Southworth, for example, there is walkability when the streets encourage people to choose walking over driving. Also, the author argues that there are six criteria to be met for a successful pedestrian network: connectivity, linkage with other modes, land use patterns, safety, quality of path and path context [4].

For this paper, walkability is defined as the quality of the perceived walkable environment by pedestrians that enables and encourages their own walking through their walking experiences based on physical, environmental, sociocultural and behavioural factors [5].

Ergonomics, on the other hand, can be defined as the study of actions and mutual influences between the human being and the environment through reciprocal interfaces, having as study's object the person in the environment [6]. Many authors argues that the Ergonomics concept has been reduced to dimensional and anthropometrics aspects, losing its potential [6,7]. In Brazil, Ergonomics is strongly linked to universal design and accessibility. However, due to its interdisciplinary factor, Ergonomics can also play a significant role on accessing well-being quality on other scientific field areas.

Over this way, this research brings the Ergonomics to the Urbanism debate. In other words, Ergonomics is applied to the pedestrians and sidewalks' reality, as a method of walkability assessment. Thus, Ergonomics contributes to gather information about the pedestrian behaviour and its relation to the physical quality of the built environment, supporting urban strategies and policymaking towards a more human and sustainable city.

Since the actual pandemic context exposed the social and territorial vulnerabilities of the Brazilian cities, such as São Paulo, this paper also aims to draw attention to Ergonomics as a potential evaluation tool of those vulnerabilities of the urban environment.

Taking advantage of this opportunity, the research reinforced the insertion of the concept of 'streetscape' in the Brazilian scientific field. In the country, this concept is not commonly used by national researches, but through the work developed by [5], it has proven to have a great contribution as a territorial scale for this Ergonomic assessment. Here, 'streetscape' is defined as a visualization or an image of a street formed by a combination of its physical and non-physical urban qualities apprehended by the pedestrian though a spatial perception process [5].

To sum up then, by inserting Ergonomics as an assessment method of walkability, it was not only possible to correlate this discipline field to the Urbanism one, but also to introduce the concept and the practical application of the streetscape in the Brazilian context.

After consolidating this conceptual framework, an empirical investigation based on field surveys took place to validate the ideas proposed on it.

3. CASE-STUDY SELECTION

3.1. Case-study selection: macroscale analysis through the National Travel Survey's Zones

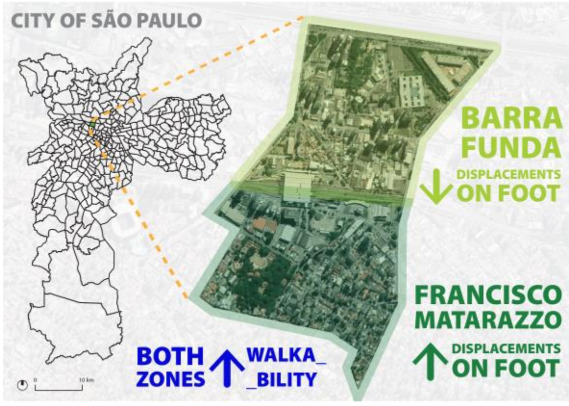
The Ergonomics assessment has been applied in two areas of São Paulo, based on the National Travel Surveys' zones: Barra Funda (BF) and Francisco Matarazzo (FM). São Paulo's 2017 National Travel Survey [8] (*"Pesquisa Origem e Destino 2017"*) is an important and main source of travel's information in the city. It shows the findings on how the citizens of São Paulo move daily throughout the city – their transport's choices and the location of where they are leaving and where they are going. It divides the city of São Paulo into 342 small zones, called 'Origin-Destination Zones'. As the name suggests, Origin-Destination (OD) data contain details of trips between two geographic zones.

The case-study presented on this paper was selected through a macroscale walkability analysis using the Geographic Information System (GIS). This macroscale analysis consisted in the evaluation of all OD zones in terms of urban density, land use, distance to transit and displacements on foot. The number of trips on foot in this survey are only those made exclusively on foot (when the travelled distances are greater than 500 meters) or when the reasons for the trips are work or school, regardless of the distance. For this reason, these numbers were corrected, through an augmentation factor, considering that people who travel by collective transport also travel, part of the trip, on foot.

From these analyses, maps of walkability vs. walking distances were generated for all zones.

Therefore, the case-study of this paper is composed by two adjacent areas in central São Paulo: the Barra Funda Zone and the Francisco Matarazzo Zone. In the case of Barra Funda, the zone was classified as a place of high walkability and few displacements on foot. Francisco Matarazzo, in turn, is highly walkable and has many displacements on foot (Fig.1).

Figure 1:
National Travel Survey Districts analysed. Source: Authors' own elaboration.



So, this case-study selection was based on two areas that have high walkability, but differ in terms of displacements on foot. Having this in mind, the research dedicated to investigate if there was a difference in the built environment and if so, how was the quality of the pedestrians' microscale level?

3.2. Case-study selection: microscale analysis through the Streetscapes

From the macroscale analysis of the entire city of São Paulo, which culminated in the selection of both zones, it was necessary to make a microscale approach of the case-study. Since the ergonomic method imply an empirical fieldwork assessment of the pedestrians' environment, a microscale analysis was performed through a streetscape scan of the two areas. It is important to emphasize that this microscale step was strictly done online and virtual due to the COVID-19 lockdown restrictions at that time. Thus, the scan was made taking virtual tours using the Google Street View tool and taking technical data from the GeoSampa online open data portal (created by São Paulo's Townhall) that was visually treated by GIS.

Having this in mind, the process started by identifying all of the 52 streets that are located on those two OD zones. After this, a virtual tour was taken in each one identifying several and different streetscapes along the street.

For this research, the graphic representation of a streetscape was defined by a street section drawing. From all of the 52 streets observed, only 4 of them were chosen to be evaluated by the method – especially because of the time limit. Those 4 streets were selected according to two major criteria: one was taking 2 streets of each OD Zone; from those 2 streets, the other criterion was taking one street classified as Arterial Road and the other as Collector Road. Thus, the ergonomic method was applied in the entire extension of each street. For the Barra Funda Zone, the selected streets were: Avenida Marquês de São Vicente (Arterial Street) and Rua do Bosque (Collector Street). For the Francisco Matarazzo Zone, they were: Avenida Franciso Matarazzo (Arterial) and Rua Turiassú (Collector).

From each of these streets a series of streetscapes were determined for each one. For the Avenida Marquês de São Vicente were chosen 3 streetscapes; For Rua do Bosque, 6 streetscapes; For Avenida Francisco Matarazzo, 3 streetscapes and for Rua Turiassú, 7 streetscapes.

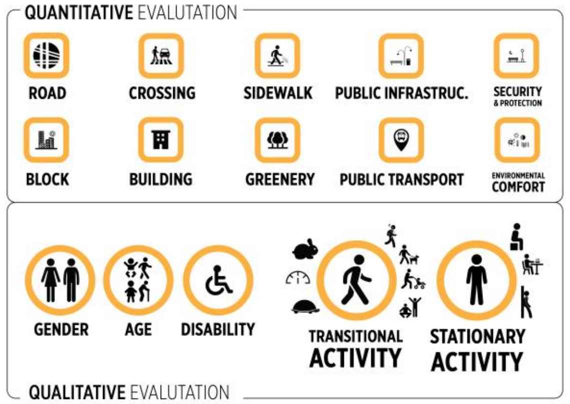
To determine this set of streetscapes, another virtual tour was taken through Google Street View on each of those 4 streets. Then, the streetscapes were determined as long as the urban context and setting kept the same. That is to say that when the use of buildings changed (from a residential to a commercial use change), a streetscape was determined. Or even when the occupancy of each building changed (from a set of active façade small buildings to a sidewalk full of high and extensive walls), another streetscape was determined.

Then, a total of 19 streetscapes were chosen to be evaluated by the ergonomic methodology.

4. METHOD: THE ERGONOMIC ASSESSMENT OF THE URBAN ENVIRONMENT

The methodology "Ergonomic Assessment of The Urban Environment" was created on 2017 by Professor Roberta Consentino Kronka Mülfarth [6] and is a systematic fieldwork analysis which focuses on assessing urban qualities of the built environment based on four ergonomic factors that influences the well-being of pedestrians. These four factors are measured through *in situ* observations and are classified in two categories: the quantitative category (physical and environmental factors) and the qualitative category (sociocultural and behavioural factors). The method is applied on the microscale level of several streetscapes and uses the ergonomic assessment sheets (Fig.2).

Figure 2:
The quantitative and qualitative variables of the Ergonomics Assessment Sheets. Source: Authors' own elaboration.



The quantitative ergonomic assessment sheet focuses on the collection of the ergonomic physical and environmental factors distributed on the 10 following groups (and its representative variables): Road (automobile flux, maximum speed and width); Crossing (pedestrians' lane width, pedestrian traffic light, crossing type); Sidewalk (width, slope, pavement material, presence/absence of steps and obstacles); Public Infrastructure (public lighting, benches, public waste bin, bus stop and visual communication signs); Security and Protection (pedestrians' flux and policing services); Block (width, slope, building's height, active ground floor, presence/absence of walls or fences); Building (residential use, commercial use, industrial use, physical permeable façade, visual permeable façade); Greenery (presence/absence of trees; trees blocking or not the sidewalk); Public Transport (bike lane, bus lane, train lane and connection/distance from each other); Environmental Comfort (sun/shadow, wind, temperature, noise, etc.).

The qualitative ergonomic assessment sheet focuses on the pedestrians and thus, on the sociocultural and behavioural ergonomic factors through the following variables: gender; age; disabilities; type of activity on the urban space: whether transitional or stationary activities – if transitional activities: perceived walking speed + type of activity (just walking, talking, exercising, listening to music, walking the dog, walking with a baby stroller) – if stationary activities: sitting, leaning or eating.

5. CASE-STUDY EVALUATION: APPLYING THE ERGONOMIC ASSESSMENT OF THE URBAN ENVIRONMENT

The fieldwork was carried out on February 2021, when some of the COVID-19 restrictions were more flexibles in São Paulo. Although there was a relevant pedestrian movement on the streets, it was lower when compared to a pre-pandemic situation.

The method was applied in each of the 19 streetscapes (9 for Barra Funda and 10 for Francisco Matarazzo) as a spatial scale and on the time scale of weekdays at three different hours: 9am, 12pm, 6pm. The reason to collect the data only in this period is because from the previous *in situ* test analysis of both zones, it was detected that the pedestrian's flow in the region was largely composed by workers and thus, the fieldwork research took place only at commercial time and days. So, the first hour (9 am) represents the entry time of these workers in their places, the second (12pm), the time of lunch and the third (6 pm), the departure time.

According to the Ergonomic Evaluation, the data is collected by an *in situ* systematic observation guided by both quantitative and qualitative ergonomic sheets.

It is important to say that the data collection techniques of each step were different. For the quantitative step, the researcher has to punctuate which physical and environmental variables are present or not, marking a simple "x" on the correspondent square. On the other hand, the qualitative step requires a more extend observation. On a time-limit of 5 minutes, the researcher stops at a point and quantify the number of pedestrians that has passed her/his view through separating them on the 4 groups (gender, age, disabilities and activities). Since it can be hard to document all the pedestrian's data depending on the flux, the qualitative sheet offers a more agile way of counting. The count here is performed from a single line that forms a square when the number reaches 5.

Another point to highlight is that the collection of the empirical data was done in a non-simultaneous way of all the streetscapes. Since there was only a researcher to evaluate all the quantitative and qualitative variables, it took about three weeks of fieldwork. However, the qualitative measurements occurred in sequence. For example, to collect the qualitative data of the Rua do Bosque (6 streetscapes) on the first hour, the researcher started at 9am at the first streetscape (B#1), and after 5 minutes, he then proceeded to the next streetscape (B#2) and so on. After 30 minutes he had all the qualitative data collected for the Rua do Bosque.

6. RESULTS

6.1. Tabulation and data processing

From the fieldwork, a total of 3000 data were collected (both quantitative and qualitative). Before analysing them comparatively, all data were tabulated in Microsoft Office Excel software. Since there were a lot of data and they differed depending on the number of pedestrians found in that specific streetscape, the Ergonomic method suggests to standardize them in the same format. Thus, all the data were transformed into percentage.

For the quantitative data, the percentage was made from the relationship between the total of physical and environmental variables with the quantity of this total was positive and negative (this quality criteria are already marked in the quantitative sheet). It is important to say that the positive quality of the quantitative data is called "urban kindness" and the negative quality, "urban arrogancies". Those terms were used since the early researches of [5] and it focuses on a classification of the elements of the urban environment that stimulates or discourages walkability, respectively.

For the qualitative data, the percentage was made from the total of pedestrians seen on the streets during the 5 minutes limit and how much of this total was distributed according to each variable (gender, age, disabilities and activities).

From this step, the method also suggests a classification of those percentages (especially for the qualitative step) on three possible situations: red (the worst situation, values ≤ 40%), yellow (regular situation, 41% ≤ values ≤ 59%) and green (best situation, values ≥ 60%). This strategy uses the same colours as a traffic light and the reason for doing this is to facilitate the apprehension of the data's quality in a visual way.

6.2. Comparative analysis

The results presented here came from a series of systematized comparative analysis in two different scales: macroscale and microscale. The macroscale results are the ones that compares both Origin-Destination Zones in a general way. The microscale compares the quality of the streetscapes.

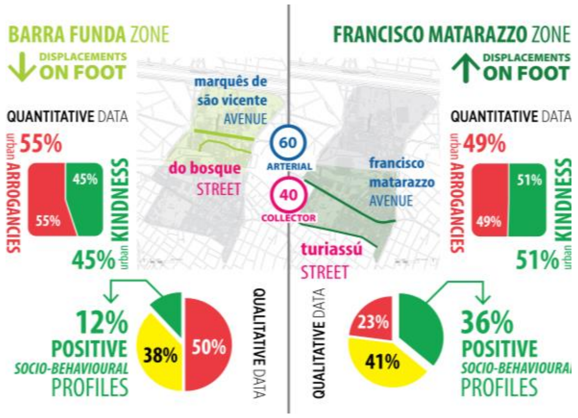
Just to point out, the objective here is to show the results accordingly to those scales and taking into account the questions raised from the beginning, before the fieldwork took place: in which urban scenarios do a more positive pedestrian socio-behavioural profiles appear? Which elements of urban space are common among these scenarios? How are the urban scenarios in a situation where there is not a such large presence of pedestrians?

6.2.1. Macroscale results: Barra Funda (BF) Zone X Francisco Matarazzo (FM) Zone

One of the main reasons the ergonomic method was applied in this study was to find out if there was a difference in the urban built environment – considering the presence or absence of pedestrians – of two OD zones that were both classified as "high walkability" but differed in terms of the classification of "displacements on foot" (Barra Funda was classified as low displacements on foot and Francisco Matarazzo as high).

When the quantitative data was analysed more closely (Fig.3), BF showed 55% of urban arrogancies and 45% of urban kindness, while FM showed 49% and 51%, respectively. Although the FM quantitative scenario was almost the same, in qualitatively terms, it presented a majority of data being in the best situation (green colour) with 36% – the best qualitative situation is when there is a greater variety of pedestrians: women, children, elderly, people with disabilities walking slowly and developing stationary activities. While BF presented 50% as the worst qualitative situation (red) – presenting a majority of male, adult, with no disability pedestrians, walking faster and developing no permanent activities.

Figure 3:
Comparative analysis between BF and FM OD zones. Source: Authors' own elaboration.



Considering the macroscale results, not only the Barra Funda Zone has shown a lower overall urban quality when compared to the Francisco Matarazzo one, but also it presented a major qualitative data classified as being in the worst situation (red).

6.2.2. Microscale results: streetscapes and street classification

To investigate even further which elements are key to the appearance of certain socio-behavioural pedestrians' profiles, the comparative analysis then focused on the microscale. In order to achieve that, the research divided the analysis according to the street classification – between arterial and collector roads. By doing that, some discoveries were found.

The arterial roads in Brazil are streets that allow a maximum speed of 60 km/h. They are larger roads that usually hold more than two lanes. Besides the car lane, it can also present exclusive bus lanes and sometimes, bike lanes. So, the spatial scale is bigger than the other types of classification.

The 6 arterial streetscapes (3 from BF and 3 from FM Zone) presented some agreement between the quantitative and qualitative data. In other words, the arterial streetscapes that showed more urban arrogancies (red), also showed a lower socio-behavioural profile (red) (men, adult with no disabilities, walking fast and developing just transitional activity).

Another finding was that there were some physical and environmental groups that seemed to have a significant influence on the appearance of a more positive socio-behavioural profile (green). Thereby, the groups "Crossing", "Sidewalk" and "Public Infrastructure" seemed to be more decisive on the appearance of women, children, elderly walking slowly and developing stationary activities such as sitting.

This discovery was possible through the microscale comparative analysis of the quantitative and qualitative data. When all of the three groups presented a majority of urban kindness (green) at the same time, the pedestrians showed a positive (green) social-behavioural profile. However, when only two of them showed more urban kindness (green) and the other one, more urban arrogancies (red), the social-behavioural profile tended to be from a medium (yellow) to low (red) level. This was not happening with the other 7 quantitative groups. This may occur due to the larger scale of the arterial roads. Since it was made for a rapid transit movement, the physical and environmental criteria of urban infrastructure (crossing, sidewalk and lighting) seemed to be crucial for the presence or absence of pedestrians.

On the other hand, the collector roads are streets that allow a maximum speed of 40 km/h in Brazil. These types of roads are characteristic to a local neighbourhood, smaller and slower. It usually connects an arterial road to a local one. For this research, 13 collector streetscapes were evaluated.

If the results for the arterial roads indicated that "Crossing", "Sidewalk" and "Public Infrastructure" as the ones that could possibly have a major influence on stimulating a positive walkability, for the collector roads the groups "Blocks" and "Buildings" seemed to be the ones. Using the same argument as before, when both of them presented a majority of urban kindness (green), the social-behavioural profile was green. There were situations when the three groups (from the arterial roads) were classified as urban arrogancies (red) for the collector roads, "Blocks" and "Buildings" groups as urban kindness (green) and still, the social-behavioural profile was positive (green). Maybe it can be inferred that because of its smaller scale the building's use and occupancy of the collector's street matters significantly for the pedestrians. They are more responsible in attract or repel the pedestrians in a smaller scale since those two groups deal with the urban elements that correlates to attractivity and accessibility criteria, such as mix-used buildings, active façade and ground floor permeability.

7. CONCLUSION

Having said all the above, from this finding, it was possible to affirm that how the built environment is presented visually through its streetscapes to the pedestrians has a deeper relationship to its power to attract or repel them. There are various urban elements that can have this power but what is decisive is how those elements combine with each other in the urban built environment.

The studies have also shown that the street classification also matters since the spatial scale changes too. The arterial roads seemed to present pedestrians developing more transit activities and the collector roads seemed to present pedestrians developing more permanent activities.

Thus, this research has shown that areas of high walkability and low displacements on foot tend to present not only streetscapes of lower environmental quality but also a more negative social-behaviour pedestrian's profile (low diversity on gender, age, and urban activities), while areas of high walkability and high displacements on foot presented more women, children and seniors walking slowly and even developing on site activities such as sitting and chatting.

It is possible to conclude that the application of Ergonomics in cities can be fostered, not only as a theory, but more importantly as a method for assessing the quality of the built environment of cities, especially those on developing countries such as São Paulo. In Brazil, the concept of 'streetscape' is not used and known, but through this research it has turned out to be a valuable tool. The main reason is that it has worked here as a visual synthesis between the material elements of the urban built environment and the subjective elements of pedestrians. Both 'Ergonomics' and 'Streetscape' proved to be useful as a mean of assessment of the urban built environment focusing on the human needs, comfort and well-being. That said, the pandemic recovery requires the participation from all sectors of society. The university-society knowledge transfer is essential in this process. Thus, the lessons learnt during this research can be used to provide guidance for policymaking in São Paulo, especially in a post-pandemic scenario, contributing to increase urban resilience towards a public crisis.

ACKNOWLEDGEMENTS

Thanks to the São Paulo Research Funding Agency - FAPESP (no. 2017/24998-1) and FAUUSP.

REFERENCES

1. SEADE (2021). SP Contra o Coronavírus, [OnLine], Available: https://www.seade.gov.br/coronavirus/ [20 September 2021].
2. United Nations (2021). The Sustainable Development Goals Report 2021, [OnLine], Available: https://unstats.un.org/sdgs/report/2021/#sdg-goals [20 September 2021].
3. Bradshaw, C., (1993). Creating – and using – a Rating System for Neighbourhood Walkability: Towards an Agenda for "Local Heroes". Canada.
4. Southworth, M., (2005). Designing the Walkable City. *Journal of Urban Planning and Development*, 131(4): p.246-57.
5. Sato, A. E., (2021). Streetscapes para São Paulo: Caminhabilidade & Ergonomia [Master's dissertation, University of São Paulo]. Digital Library of Theses and Dissertations of the University of São Paulo. https://www.teses.usp.br/teses/disponiveis/16/16132/tde-20092021-115608/en.php
6. Kronka Mülfarth, R. C., (2017). Proposta metodológica para avaliação ergonômica do ambiente urbano: a inserção da ergonomia no ambiente construído [Habilitation Thesis]. Digital Library of Theses and Dissertations of the University of São Paulo. https://teses.usp.br/teses/disponiveis/livredocencia/16/tde-07012019-141802/en.php
7. Wisner, A., (2004). Questões epistemológicas em ergonomia e em análise do trabalho. A ergonomia em busca de seus princípios – debates epistemológicos (1st ed.). Editora Blücher.
8. Pesquisa Origem e Destino 2017 do Metropolitano de São Paulo, [Online], Available: http://www.metro.sp.gov.br/pesquisa-od/ [10 January 2022].

PLEA STGO 2022
WILL CITIES SURVIVE? CHALLENGES FOR DEVELOPING COUNTRIES

WILL CITIES SURVIVE?

PLEA STGO 2022

November 22 - 25, 2022

WILL CITIES SURVIVE?

The future of sustainable buildings and urbanism in the age of emergency.