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 1 ONLINE SESSIONS

PLEA
STGO
2022

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PLEA STGO 2022: WILL CITIES SURVIVE?

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ORGANISED BY

Passive and Low Energy Architecture (PLEA)
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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

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.

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.

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.

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PLEA SANTIAGO 2022
Will Cities Survive?

How density affects energy demand in urban grids

The case study of the *Eixample* district of Barcelona

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ABSTRACT: High density and compact urban morphology are usually considered prerequisites for sustainable development. This paper explores the effect of density on the air-conditioning demand of urban grids in the Mediterranean climate, based on the case study of the Eixample of Barcelona. Representative periods in the district's history are selected to create four urban energy models. We calculate their annual heating and cooling demands through dynamic thermal simulations in Honeybee. Results show that the denser the block, the lower the total air conditioning demand for cooling and heating. Since the energy demand of the dwellings on the top floors significantly exceeds those of intermediate floors, increased densities achieved with taller buildings allow for reducing the air-conditioning needs at the block scale.

KEYWORDS: Air-conditioning energy demands, Urban grid density, Urban regulations, Eixample, Barcelona

1. INTRODUCTION

Cities play a central role in climate change since they are responsible for more than 70% of global CO_2 emissions. A significant share of these emissions is due to the buildings' energy consumption for heating and cooling, which is heavily dependent on urban form [1-3].

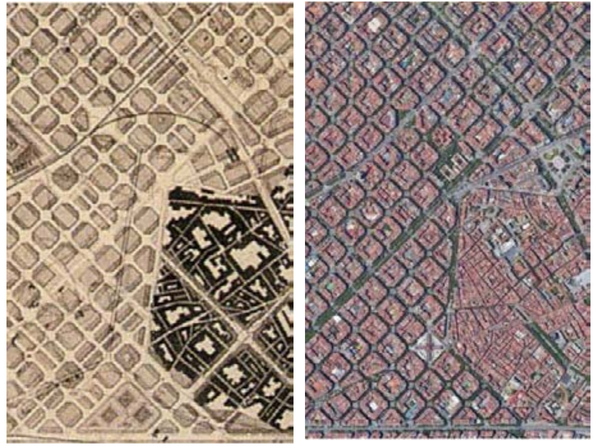
The evolution and shaping of cities are extraordinarily complex, resulting in multiple urban forms. However, most cities in the world use regular grids as the basic growing structure for allowing rational development and guaranteeing minimum quality levels to citizens. Thanks to its flexibility and capacity to adapt to diverse uses, the grid layout has been described as the closest thing cities have to a universal language, able to produce infinite variations in different cultures and times.

Among urban grid layouts, those with high density and a compact urban form are often considered sustainable developments because of their capacity to promote diverse and vibrant urban spaces, foster energy efficiency, and limit environmental impacts [1]. In this framework, it is crucial to understand how this specific archetype of urban form interacts with the energy balance of the compact city.

Selecting the most efficient urban form to limit air conditioning demands in a particular location requires accounting for the local climate. In extremely hot regions, highly compact and dense cities perform better than those following sprawl-like patterns [2]. In temperate zones, where cooling and heating are both necessary (e.g., Mediterranean climate), it is desirable to find a compromise because excessively high densities can limit winter solar gains, increasing hence heating needs [3, 8-10].

Our study aims to explore the impact of built density on energy demand for cooling and heating of urban grid layouts in the Mediterranean climate. To do so, we select the Eixample district of Barcelona (Spain) as the case study. In this fabric, there have been different urban proposals and regulations over the same grid for more than 150 years [4], making it a compelling example where study the energy effects of density changes.

Figure 1:
Plan Cerda (left) and actual aerial views of the Eixample of Barcelona (right). Source: The authors, based on public domain jpg & Google Earth Pro Imagery.



2. METHODS

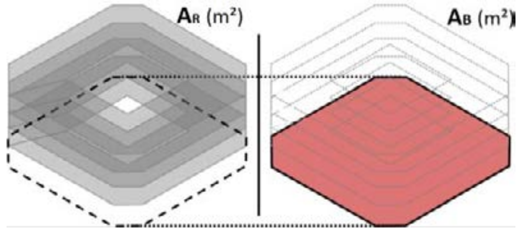
First, we carried out a bibliographic review of the urban regulations of the Eixample from its origins to the present. Based on this, we selected four representative periods in Eixample history and created four geometric urban models using Rhino/Grasshopper (Fig. 1). Then, we computed their annual heating and cooling demands through dynamic thermal simulations in EnergyPlus/ OpenStudio using Honeybee 1.1.0 [5]. Finally, we discussed the link between energy demand for air conditioning and built density, here expressed in terms of "Residential Floor Space Index" (Eq. 1):

$$FSI_R = A_R / A_B \quad (1)$$

where FSI_R - Residential Floor Space Index (m^2/m^2);
A_R - Residential built-up area (m^2);
A_B – Block area (m^2).

FSI may refer to different spatial scales (lot, block, fabric, district, or city) and generally reflects the building intensity independently of the programmatic composition [6]. In this study, the focus is on the residential energy demands at the block scale. Therefore, we exclude the ground-floor area, usually used for commerce and other facilities, from the computation of FSI (Fig.2).

Figure 2:
Graphical definition of FSIR.



3. CASE STUDY

3.1 Urban layouts

The *Eixample* plan emerged as a solution to the demographic growth and poor sanitary conditions experienced by the city in the first half of the 19th century, one of the prominent periods of urban expansion [4]. The plan is based on a regular grid of streets 20 m wide, whose basic unit is a square block (113x113 m) with chamfered corners, oriented 45° North [7, 8]. In this paradigmatic grid, urban form and building shape evolved over decades: from the original *Plan Cerdà* based on open blocks permeated by open spaces to the following closed blocks, more compact and with fluctuating values of building density (Fig. 3).

For this study, we defined and analysed four urban layouts, which are representative of different urban planning ordinances [4]. Fig. 3 describes the configuration of the basic block for each layout, specifying their height, the number of floors, FSIR, and Ground Space Index (GSI [6]).

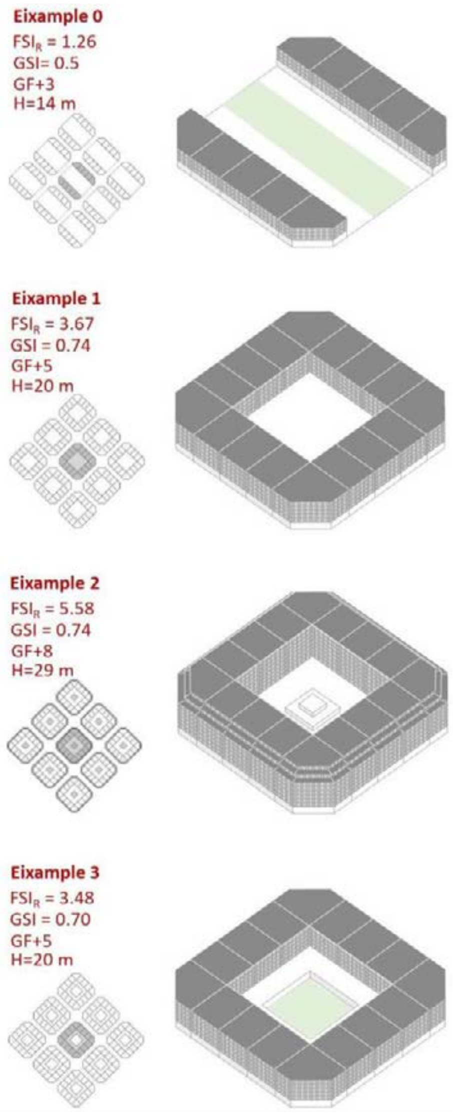
Eixample 0 represents one of the blocks of the original plan of 1859. The main limitations of the ordinance were a plot GSI of 0.5 and a maximum height of 16 m (Ground Floor + 3).

Eixample 1 is the classic Eixample block of 1891 urban regulation (GF+5). Then, the maximum GSI was 0.74, which allowed 27.9-m-depth buildings. Also, one-story buildings were allowed in the block courtyard.

Eixample 2 reproduces the time of highest built density allowed by 1958 urban regulations. GSI and building depth remained the same, but an FSI increase was allowed (up to GF+8, counting attics).

Eixample 3 corresponds to the current urban planning regulations (1976-2002). The floor area and the building depth are reduced, taking up features of the classic block (GF+5).

Figure 3:
Urban models according to the four urban regulations.



3.2 Simulation settings and building features

To investigate the link between urban density and air-conditioning demand in the Eixample, we analysed the four urban models in Fig. 3 through energy simulations.

Each urban model comprises nine blocks distributed in a 3x3 array. The one in the middle is the target of the thermal analysis, while the rest act just as the built environment that casts shadows and creates reflections. The target block comprises a set of buildings made up of several 3-meter-height residential floors over a 5-meter-height commercial ground floor. All the interior partitions and intermediate floors allow for thermal exchanges, except those separating residential and commercial units, considered adiabatic. All buildings have a 30% window-to-wall ratio [7] and thermal properties corresponding to the typical construction system in Spain before the arrival of thermal regulations in 1979 (non-insulated, medium-weight, low air-tightness). Tables 1 and 2 summarise the main building features and settings used for the energy modelling in this work.

Table 1:
Building features of the urban energy models.

Parameter	Value
U-façade wall (W/m²K)	1.5
U-roof (W/m²K)	1.8
U-window (W/m²K)	5.7
U-interior floor	2.0
U-interior walls	2.1
Window-to-wall ratio (%)	30
Infiltration rate (m³/s per m² façade)	0.0006
Façade & roof reflectance [-]	0.30
Ground reflectance [-]	0.30

Table 2:
Simulation settings.

Parameter	Setting
Heating set-point & schedule (1 Oct – 31 Apr)	20°C from 8:00 to 23:59 17°C from 00:00 to 07:59
Cooling set-point & schedule (1 May – 31 Sept)	25°C from 16:00 to 23:59 27°C from 00:00 to 07:59
Free cooling (1 May – 31 Sept)	Whenever Tint > Text If: Tint>21 & Text>16
Ventilation rate	0.63 ach
People density & schedule	0.036 people/m² **Mon to Fri** 100% from 23:00 to 07:59 25% from 08:00 to 15:59 50% from 16:00 to 22:59 **Sat, Sun & Holidays** 100% all day long
Internal gains & schedule • Lighting • Appliances	4.4 W/m² 10% from 0:00 to 07:59 30% from 8:00 to 18:59 50% from 19:00 to 19:59 100% from 20:00 to 22:59 50% from 20:00 to 22:59

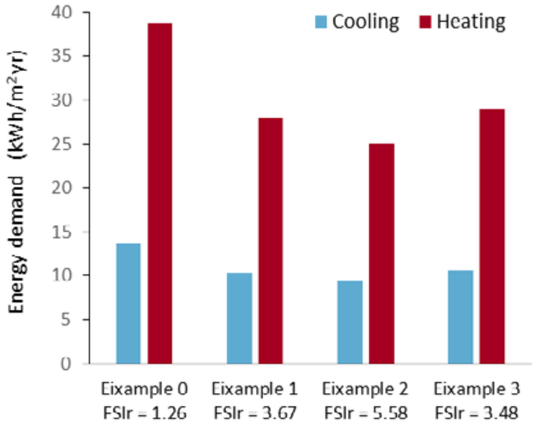
Using Honeybee 1.1.0 [5], we compute air conditioning energy demand to achieve the heating and cooling set-point temperatures at each residential unit, as scheduled in Table 2. These settings, along with internal gains (people, lighting, appliances), follow standards from the Spanish thermal regulation (CTE [11]). Our simulations do not account for shading devices but include a free-cooling strategy to avoid excessive indoor overheating during the cooling season.

4. RESULTS

Though the majority of the regions with Mediterranean climates have relatively mild winters and warm summers, temperatures may vary significantly among regions and, thus, air-conditioning demands. In the case of Barcelona, both heating and cooling are necessary, but the first is far more significant (Fig. 4). For the *Eixample* layouts studied here, normalized heating demands range between 25 and 39 kWh/m², while the cooling ones vary between 9 and 14 kWh/m², which means that heating requirements are 2.6 to 2.8 times higher than the cooling ones.

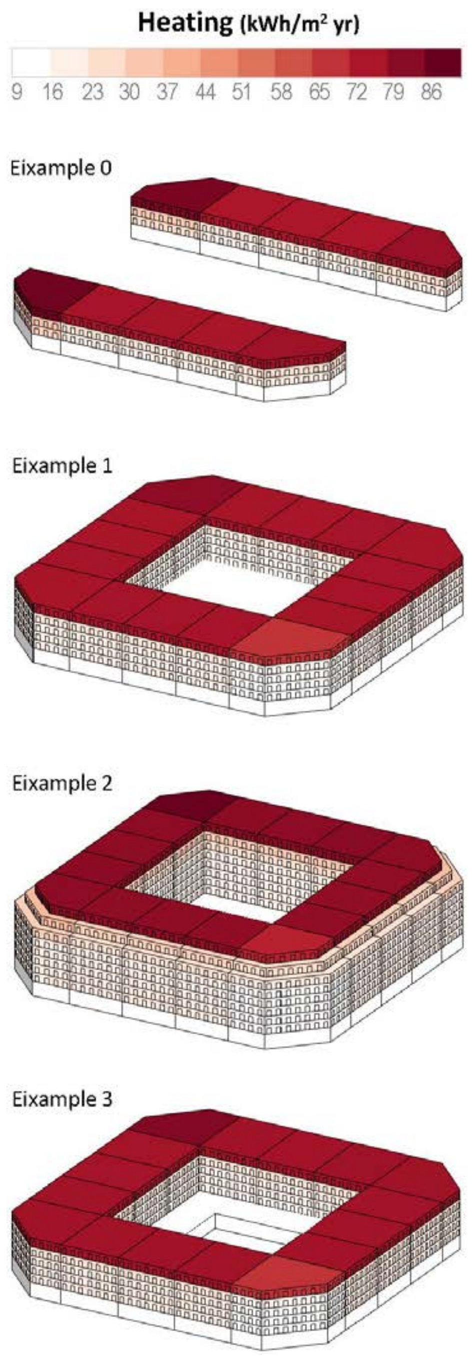
Our simulations show that the density changes in the *Eixample* have a direct impact on air-conditioning demands. The denser the urban tissue, the lower the energy needs for cooling and heating. The normalized heating demand of the block faithful to Cerda's original idea (*Eixample* 0) is 35% higher than those of the densest block ever allowed by regulations (*Eixample* 2). Regarding cooling, this decrease is slightly smaller, 31%.

Figure 4:
Annual heating and cooling energy demands per floor area for the four layouts of the Eixample block analysed.



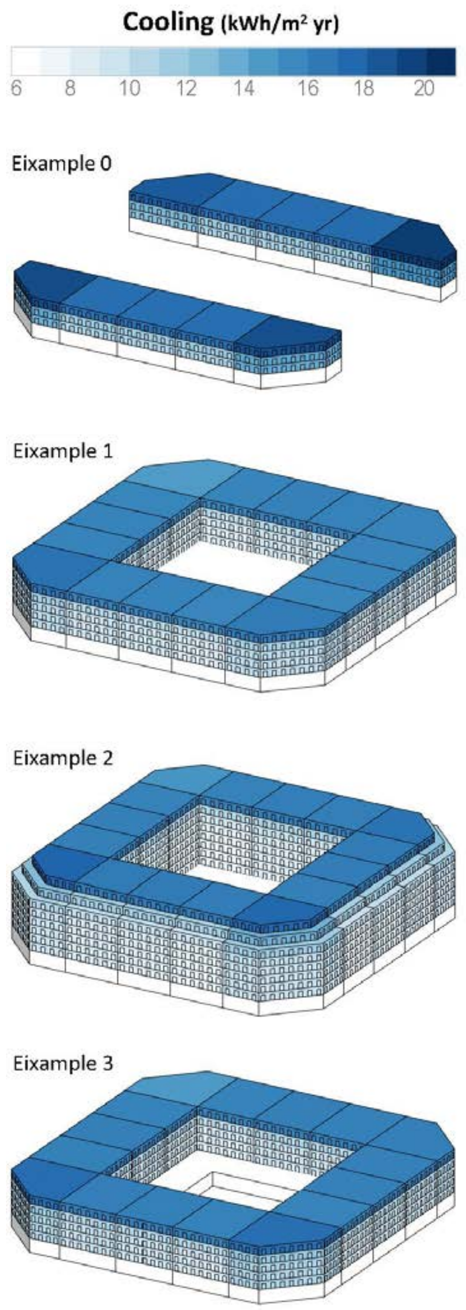
To investigate the reasons behind this behaviour, we conducted a spatialized analysis of the simulation results. To this end, we coloured the dwellings of each model according to their heating, cooling, and total demands (Fig. 5, 6, and 7).

Figure 5:
Annual heating demands per floor area for different Eixample models: E0, E1 , E2 and E3.



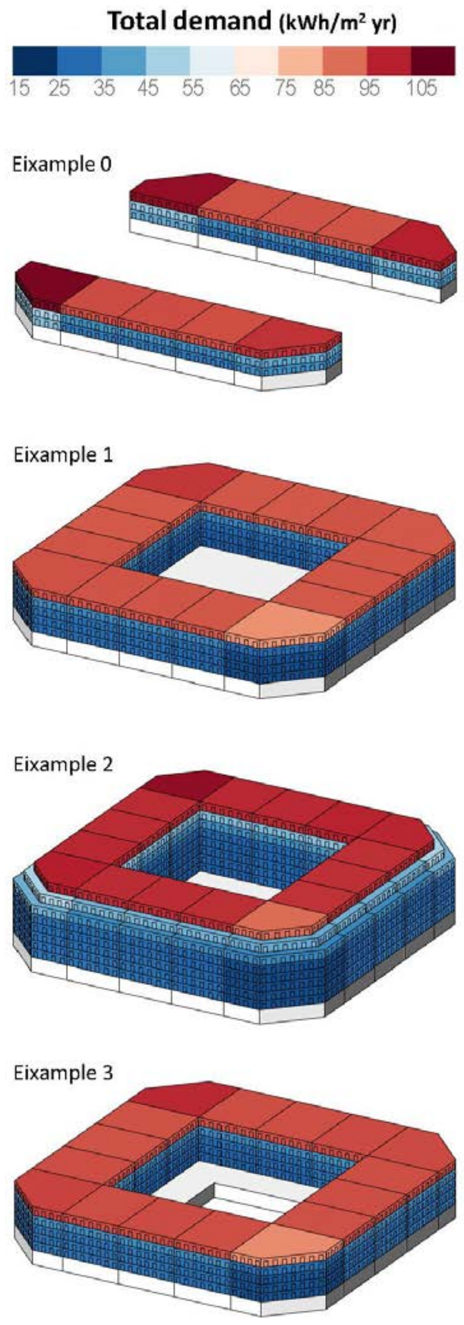
Heating demands range between 10 and 86 kWh/m² per year among the studied urban models. In all the cases, the highest heating demands locate on the last floor of the block, with values between 65 and 86 kWh/m² per year. In contrast, dwellings located at mid-level have lower heating needs, which vary between 10 and 42 kWh/m² depending on their orientation and floor. These results evidence the significant variation in heating demand that can exist among the dwellings of a single block, which may arrive up to 800%.

Figure 6:
Annual cooling demands per floor area for different Eixample models: E0, E1 , E2 and E3.



As for cooling demands, values range between 7 and 19 kWh/m² per year among the studied models. Like for heating, top-floor dwellings have the highest cooling needs in all urban layouts, with values between 14 and 19 kWh/m² per year, while in the rest of the building, they vary between 7 and 15 kWh/m² per year. Cooling needs are more evenly distributed between levels than heating ones because solar gains over façade are more homogenous in summer than winter due to a higher sun elevation.

Figure 7:
Total air-conditioning demands per floor area for different Eixample models: E0, E1 , E2 and E3.



The addition of heating and cooling demands brings total air conditioning demands ranging between 20 and 103 kWh/m^2 per year (Fig. 7). Again, top floors present the highest demands, with values over 81 kWh/m^2, while mid-level dwellings have much smaller demands, below 52 kWh/m^2. Two factors explain this behaviour: the higher exposed-to-air surface of top-floor dwellings and the significance of heat losses/gains through the roof. Differences in demand among block sides are less noticeable than among floor levels because most buildings in this study have symmetrically oriented façades (except in the chamfers).

5. DISCUSSION

To discuss the impact of urban density on energy demand, we analysed the normalized total air-conditioning demand of the blocks by Residential Floor Space Index for the four *Eixample* layouts (Fig. 8).

Figure 8:
Air conditioning demand (kWh/m^2 per year) by Residential Floor Space Index (FSIr) for the Eixample layouts analysed.

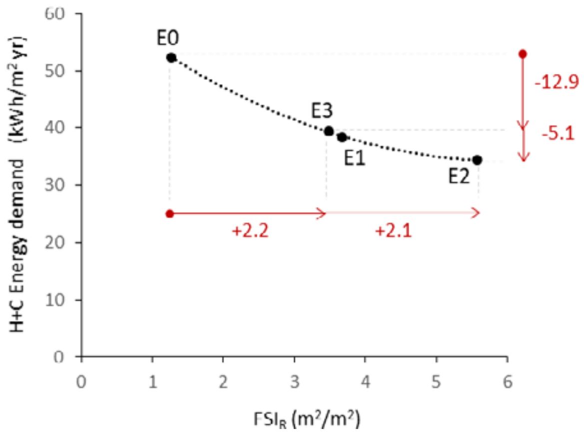


Fig. 8 shows that the denser the tissue (↑FSI_R), the lower the total air-conditioning demand per floor area. The main reason for this behaviour is that the density increase in the *Eixample* is mainly due to a rise in the building height. In taller buildings, the roof represents a lower proportion of building skin. Similarly, the top-floor dwellings represent a lower share of the total block surface. Consequently, the high air-conditioning demand of these dwellings is divided by a larger built area, giving lower energy demands per area at the block scale. These results highlight the crucial role of roofs in the energy performance of tissues, pointing to them as a target for urban refurbishment policies.

The relationship between density and block air-conditioning demand in *Eixample* is non-linear. As marked in red, similar changes in density affect the block air-conditioning demand differently depending on the initial and final density levels. The difference in density between the models E0 (least dense layout) and E3 (mid-density layout) is 2.1 FSI_R points, roughly equal to the change between E3 (mid-density layout) and E2 (densest layout). In contrast, the reduction in air conditioning demands when changing from low to medium density (E0 to E3) is 2.5 higher than changing from medium to high density (E3 to E2). The trend in Fig.8 suggests that increasing density beyond a certain level does not bring significant reductions in the energy demand at the block scale and might be counterproductive.

Another aspect worth discussing is that density increase may have different effects at dwelling and block scales. In this study, the increase in urban density leads to decreases in cooling and heating demands at the block scale. However, not all the dwellings in the block follow this trend individually. Results show that those on the lower floors present higher heating demands as urban density increases due to poorer solar access in winter, especially from the street.

Except those in the chamfer, we modelled dwellings as spaces with two opposed façades (SE&NW, SW&NE), one overlooking the street, the other, the inner courtyard. Two-façade dwellings were one of the main ideas of the original *Eixample* plan and are still quite frequent in the district. Due to speculative urban pressures, single-faced dwellings are also recurrent. From the simulation point of view, choosing two-façade dwellings over single-façade ones is expected to have minor repercussions on the results at block and building levels, which ultimately was the focus of our study. However, this approach limits the possibility of studying certain local behaviours as it provides an average demand between orientations.

Future works could explore the sensitivity of the results to the level of insulation in buildings and other density-related aspects, such as the intensity of the urban heat island effect.

6. CONCLUSION

This paper explores how changes in the built density of urban grids affect their demand for air conditioning in a Mediterranean climate, taking the *Eixample* district of Barcelona as a case study.

Our simulations show that increasing density reduces the air-conditioning demand per floor area at the block scale, both for heating and cooling. The reason is that the densification in the *Eixample* is mainly due to an increase in the building height, that is, to growth in FSI_R while maintaining GSI. Since the top floor has significantly higher demands than intermediate floors, the taller the building, the more intermediate floors that offset the energy demand of the top floor, thus resulting in lower air-conditioning needs per area. This decrease in block-scale energy demands might be associated with an increase in the heating needs of dwellings in the lower levels. Spatialized analyses like the ones in this work can help find strategies to minimize the urban demand without excessively affecting the performance of lower-floor dwellings.

Urban density affects cities' liveability and performance in multiple ways. Among them, the air-conditioning need is an aspect rarely considered by policy-makers when developing urban regulations. Our study helps to overcome this limitation. Finally, the findings in this work can also help prioritize retrofitting interventions targeting the energy efficiency of the built environment.

ACKNOWLEDGEMENTS

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Will Cities Survive?

Urban verticalization

Predicting the effect of a Master Plan on microclimate in Bagé, Brazil

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ABSTRACT: Many factors constantly modify the urban morphology, such as the urban density and buildings' height. Those changes generally occur without a proper analysis of their future effects on the microclimate and resulting thermal comfort in open spaces. We simulated three urban scenarios in the CFD model ENVI-met for Bagé, a Subtropical city in the Southern Brazilian State: a) the current scenario; b) a prediction of the density growth by 2060; and c) the maximum height allowed by the Master Plan. As for the boundary conditions, we averaged the summer and winter extreme days from a TMY file. For scenarios a) and b), we considered changes in the global temperatures from 2021 to 2060. The results showed that higher and denser squares improved thermal comfort in the summer. Although the cooling effect was less pronounced in the winter, it cannot be ignored in subtropical climates because it can result in colder mean radiant temperatures and, consequently, discomfort by cold. In the scenarios that we considered the increase in air temperature input by climate changes, the T_{mrt} results increased compared with the current scenario, except on the Sidewalk in the highest scenario due to the biggest shading from the buildings.

KEYWORDS: Urban Densification, Thermal Comfort, Open Spaces

1. INTRODUCTION

The effect of urban density on microclimate has been studied by researchers over the last decade. Qualified and healthy open spaces can ameliorate the impacts of urbanization. Master Plans have a crucial role in the urban density increases due to the constructive limits allowed. The modifications of the urban fabric have consequences on microclimate, which can happen at different scales [1]. Changes in the urban morphology impact climate variables such as wind speed and direction, air temperature, air relative humidity, and medium radiant temperature.

Studies of winter and summer seasons in locations with extreme temperatures have shown that, for both seasons, vertical buildings influence outdoor thermal comfort. The Physiological Equivalent Temperature Index (PET) showed that tall buildings reduced the daily thermal amplitude for both summer and winter [2].

In warmer climates, high-rise buildings promote better thermal comfort at a pedestrian level due to the shading, which decreases the mean radiant temperature (T_{mrt}) [3,4]. In addition, progressive building setbacks imposed by Master Plans contribute to achieving better outdoor thermal conditions in tropical cities, mainly with semi-arid climates [5].

A Study in Bandung, a dense city with a hot-humid climate, simulated six squares with Podium, Tower, and Courtyard typologies with a floor area ratio of 2.2 in the existing scenario and 5.6 in the five proposed scenarios, diversifying the building coverage ratio between less than 0.40 and 0.74 [6]. The results demonstrated a direct correlation between the building coverage ratio with the air temperature and relative humidity and a direct correlation between the floor area ratio and relative humidity. Indirect correlations were found between the building coverage ratio, wind direction and speed, and between floor area ratio and air temperature.

In extreme cases, the verticalization of buildings intensifies the adverse effects of climate change, increasing the air temperature, particularly at night, accentuating the urban heat islands [7].

The verticalization of Brazilian urban centres leads to discomfort in open spaces such as the edge of Copacabana, Rio de Janeiro [8]. The urban morphology was simulated for January 1930, 1950, and 2010. The results demonstrated an increase in air temperature from 1930 to 2010.

The high-rise buildings change the wind speed, resulting in canalization or wind shade[1] [9]. Another consequence of the rise in buildings' height is the creation of urban canyons such as the ones in Fortaleza, Brazil [10].

Besides the verticalization, the geometry of street grids can interfere with thermal comfort in open environments at pedestrian level [11]. Similarly, studies that analyse building typologies, such as perimeter block, slab, and tower buildings, observed different microclimate results due to the geometry and characteristics of the sites. In São Paulo, Brazil, tower buildings (with fourteen storeys) showed better thermal performance (on April 27th, at 3 p.m.) than perimeter blocks (with eight-storey and ten-storeys) [12]. Conversely, a study in The Netherlands showed that perimeter blocks resulted in better thermal comfort in the centre of the square in June if compared to singular and slab blocks (both scenarios with 9 meters in height) [13].

This study integrates broader research about the effect of densification on outdoor thermal comfort in the South of Brazil. We analysed the effects of urban densification on microclimate variables, for an urban centre. The studied city was Bagé, a Southern Brazilian city with Cfa climate (warm temperate, humid with a hot summer) [14]. In this clipping, we analysed the central block within the studied area. We compared three scenarios for this square: the current, medium, and maximum verticalized as allowed by the Master Plan, predicting the microclimate at the pedestrian level through computer simulations.

2. METHODS

This study analyses three urban scenarios with different built densities and verticalization for summer and winter. We ran 24-hours simulations in the software ENVI-met 5.0.2. The parameters were the mean radiant temperature (Tmrt), wind speed, and relative humidity.

2.1 Case study

The studied city is Bagé, in the Southern Brazilian part (31°19' South, 54°6' West; altitude of 232m). In that region, medium-sized cities have mainly low-rise buildings. The subtropical climate with high thermal amplitude represents a challenge to city planners from the point of view of thermal comfort. The weather often requires different architectural and urban strategies to respond to the opposite hot temperatures in the summer and cold temperatures in the winter.

To select the studied location, we have adopted the following criteria: an area where higher densification and verticalization occurred in recent years; high permissiveness for verticalization, according to the master plan; few historical buildings (which would not allow an increment in height); few urban voids and low-rise in most existing buildings. In this paper, we simulated the central part inside nine downtown squares.

2.2 Parametric scenarios and modelling

We have established three configurations for the buildings within the square. Whereas the first scenario represents the current square densities of the studied area, the second scenario predicts the density growth by 2060. The increase in the density rate was 10% from 2011 to 2021. We have applied this rate progressively by decade to the current densities of each square, as shown in Table 1. In this study, we analysed the square number 5. We conducted a random selection to establish which buildings would be modified due to the density arising, as projected by 2060.

Table 1:
Square density rates - current vs. by 2060

	Square density rate			Square density rate prognosis by 2060
Square	2011	2021	increase	
1	0.57	0.65	0.08	0.94
2	1.15	1.15	0.00	1.67
3	0.91	0.94	0.03	1.36
4	0.48	0.48	0.00	0.70
5	0.64	0.88	0.24	1.27
6	0.39	0.41	0.02	0.59
7	0.68	0.89	0.21	1.28
8	0.94	1.02	0.08	1.48
9	0.52	0.54	0.02	0.78
total	6.28	6.96	0.68	10.07

The third scenario reflects the maximum verticalization of the city's Master Plan (24 meters in height, or eight storeys). We kept buildings with three or more storeys in their original versions (for the three scenarios). We applied the same rule to the historical buildings. Table 2 shows the height of buildings, square density, and building coverage rates of the scenarios. The square morphologies are demonstrated in Figure 1, which shows the receptors points used to collect microclimate variables.

Table 2:
Height of buildings, square density, and building coverage rates of the scenarios

	Majority height of buildings	Square density rate	Building coverage rate
S.1	1 to 2 storeys	0.88	43%
S.2	3 storeys	1.28	47%
S.3	8 storeys	3.13	46%

Figure 1:
The square morphology in the current scenario (S.1), density growth by 2060 (S.2), and maximum verticalization (S.3) scenarios.

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[1] Wind is blocked by some barriers, like buildings.

We raised the square densities and building heights successively among the three scenarios. While the first scenario (the current one) has a low total density, the second has an intermediary density (buildings until three storeys), and the third scenario has the highest density of them (buildings until eight storeys height - until 24m). For scenarios 2 and 3, the new buildings respect the minimum side retreat to parcels of land whose widths are bigger than seven meters (2.5 meters). To be consistent with the current scenario (S.1), we kept free spaces in the centre of the square.

The weather data was averaged from the representative extreme summer week (22 to 28 December) and the representative extreme winter week (6 to 12 July) of the Test Reference Year (TRY) file [15]. Table 3 presents the boundary conditions in ENVI-met. Table 4 shows the surfaces' materials within the squares.

Table 3: *Initial input data in the ENVI-met simulations*

Current Meteorological data

Configuration Data	Summer	Winter
Initial simulation hour (24 hours)	5 a.m.	5 a.m.
Max T_{air} of the atmosphere (ºC)	31.1	13.1
Mini T_{air} of the atmosphere (ºC)	20.5	1.4
Diurnal T_{air} amplitude (ºC)	10.6	11.6
Max relative humidity (%)	82.7	96.3
Min relative humidity (%)	53.4	65.1
Wind speed at 10m above ground level (m/s)	3.2	2.8
Wind direction (º)	45	45

Table 4:
Characteristics of the surfaces' materials within the squares

Element	Material	Colour	(α)	(ε)
Roofs	Ceramic tiles	Terracotta	0.5	0.9
External Walls	Brick: burned	Terracotta	0.6	0.9
External floors				
Pavement	Concrete	Gray	0.7	0.9
Pavement	Granit	Gray	0.6	0.9
Pavement	Asphalt Road	Dark	0.8	0.9

(α) Absorptance. (ε)Emissivity

Lastly, we simulate S.2 and S.3, increasing 3.1°C in the air temperature inputs at all times for the summer. This increase represents changes in global surface temperature from 2021 to 2060 [16].

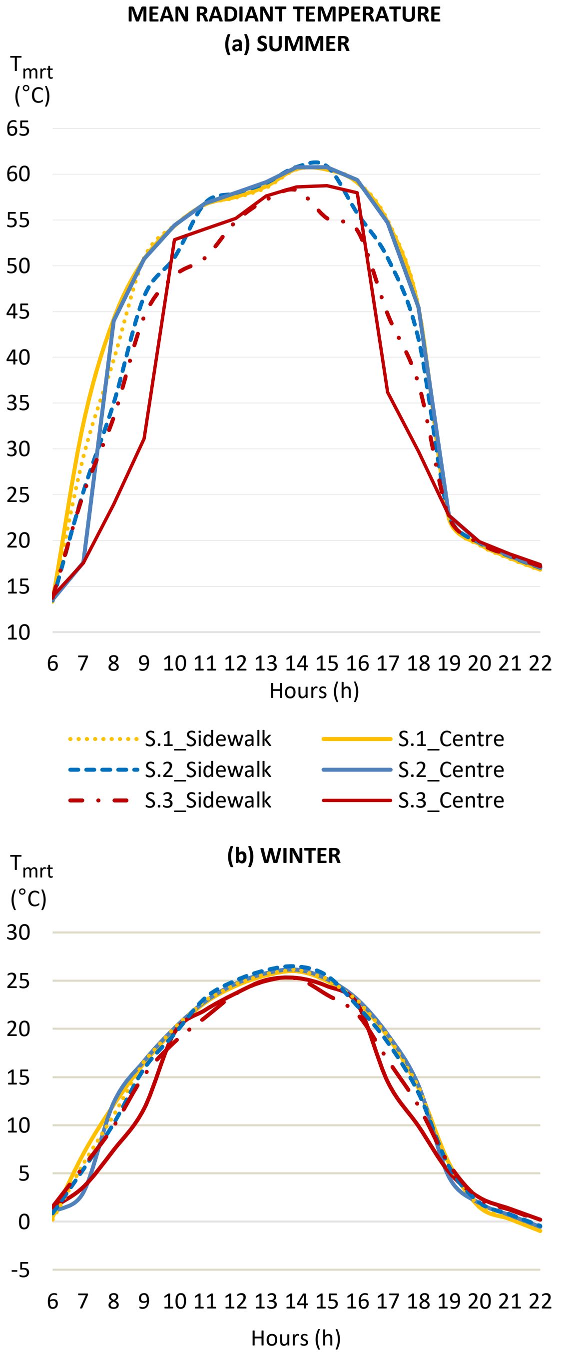
The scenarios originally had a one-metre grid and five receptor points. However, as the simulation was too slow (more than a week-long), we changed the grid value. Thus, we used a three-metres grid with receptor points. The results named "sidewalk" are the medium of the four receptors located in the sidewalks.

3. RESULTS

The changes in T_{mrt} and wind speed results confirmed the improved thermal comfort in the summer, as shown in studies in hot climates. Conversely, the winter results showed moderately adverse effects caused by more extensive shadows, as expected in high latitudes.

Figure 2 shows Tmrt from 6 a.m. to 10 p.m. (warmest daily time), at 1.5m height in the summer and winter. In the summer, the highest Tmrt was at 3 p.m. in all scenarios. An exception was Scenario 3, on the sidewalk, where the highest Tmrt was at 2 p.m. In the winter, the highest Tmrt was at 2 p.m. in all scenarios and analysed points. We observed a drop comparing extreme scenarios (S.3 to S.1) up to 0.97°C in the winter and 5.35°C in the Summer. S.2 compared with S.1 showed a decrease in the highest Tmrt of up to 0.32°C in the summer and 0.28°C in the winter.

Figure 2:
Results of T_{mrt} in the summer (a) and the winter (b) for scenarios 1, 2, and 3.



For Scenario 3, in summer, the urban density raising dropped the Tmrt up to 10.25 °C on the sidewalk and up to 20.17°C in the centre's square. In the winter, results showed a Tmrt increase of 1.18°C on the sidewalk and 1.28°C in the centre at night. The most significant decrease occurred at 5 p.m. on the sidewalk and 8 a.m. in the centre for the two analysed seasons. Besides, the summer simulations showed a discreet increase in Tmrt up to 0.71°C, and winter results showed an extreme decrease of 4.73°C, at 9 a.m., in the centre of the square.

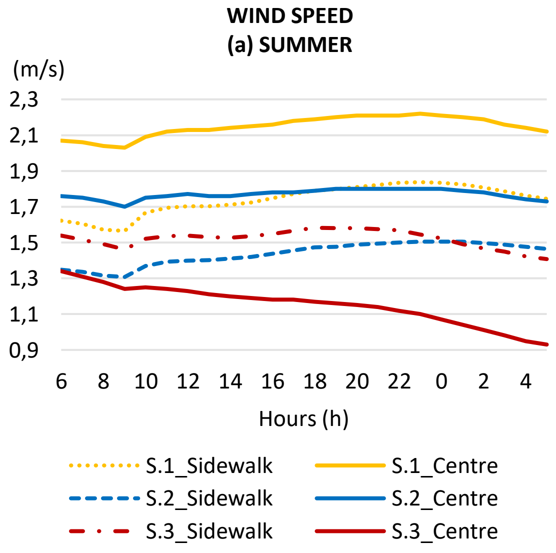
In the summer, the Tmrt from S.2 to S.1 dropped 4.73°C (at 8 a.m.) on the sidewalk and 15.05°C (at 7 a.m.) in the centre of the square. It occurred because of the long shadow from the buildings in S.2.

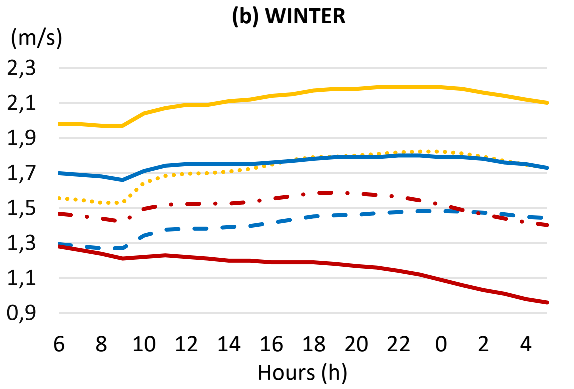
In the winter, the Tmrt was slightly warmer (at most times) in S.2, increasing at most 0.35°C on the sidewalk (at 1 p.m.) and 0.44°C (at 8 p.m.) in the centre. Although shadows from S.2 buildings are more extensive than S.1, S.2 has more facade area exposed to solar radiation. Therefore, the heat absorbed is reflected forward near open spaces, increasing the Tmrt.

The T_{mrt} results showed that for the studied case, the increase in density reduces the thermal amplitude for both the summer and winter. Our results align with a study in Campinas, Brazil [2]. The more expressive influence of density (and verticalization) was observed in the summer when the largest decrease in T_{mrt} happened.

Results indicate that for warmer climates (as in the Cfa), the increase in verticalization can promote thermal comfort at pedestrian level in open spaces. However, it's crucial to pay attention to the temperature decrease in the winter. In general, results showed a beneficial effect of shadings due to a T_{mrt} reduction in the summer. In addition, other effects of the verticalization should be considered, such as the drop in wind speed and modifications in wind direction. Figure 3 presents the results from wind speed, on 24 hours, for the summer and winter seasons.

Figure 3:
Wind speed on the sidewalk and in the centre of the square, for Scenarios 1, 2, and 3, in the summer (a) and winter (b) seasons





The wind speed in the winter and the summer had similar behaviour and values. The increase in building density and verticalization decreased wind speed. It can promote better thermal comfort in winter while contributing to thermal discomfort in the summer. The wind speed dropping was more intense in the centre of the square than on the sidewalk in all scenarios. S.2 to S.1 decreased up to 0.34m/s on the sidewalk and 0.42m/s in the centre of the square. S.3 to S.1 dropped 0.34m/s on the sidewalk and 1.19m/s in the centre.

On the sidewalk, the wind was speeder in S.3 than in S.2. It happened because, on S.3, the wind was channelled through the side clearances, accelerating it. Comparing the same scenarios in the centre, S.3 showed a lower speed due to the tower buildings' effect of partially blocking the wind flow. This effect of wind shading and canalization also was identified by Nogueira et al. [9]. Besides, S.3 was the one larger daily wind speed amplitude in the centre in the summer and winter. On the sidewalk at 1 a.m., the wind speed was the same in S.2 and S.3. Conversely, in the centre, they had the most expressive difference: 0.80m/s in the summer and 0.77m/s in the winter at 5 a.m.

The RH from S.1 to S.3 increased up to 1.2% on the sidewalk and up to 2.8% in the centre of the square in the summer. Similarly, in the winter, the RH increased up to 1.3% on the sidewalk and up to 3.6% in the centre. Thus, there is a direct correlation between RH and higher building density, similar to that identified in the study in Bandung, Indonesia [6].

Table 5 shows the Tmrt (24 hours averaged) for scenarios S.1, S.2, S.3, and two more: S.2.1 and S.3.1. (the initial air temperatures were increased by 3,1°C) that represents the climate change scenarios predicted by IPCC (2021) to 2060 [16].

Table 5:
Medium T_{mrt} (°C) for Scenarios S.1, S.2, S. 3 and the scenarios with an increase in their air temperature inputs (S.2.1 and S.3.1) in the summer

	S.1	S.2	**S.2.1**	S.3	**S.3.1**
Centre	34.02	33.08	**35.81**	31.60	**34.23**
Sidewalk	34.37	33.93	**36.65**	30.42	**33.15**

The S.2.1 and S.3.1 had a T_{mrt} increase compared with S.1, except on the Sidewalk in the highest scenario due to the biggest shading from the buildings.

4. CONCLUSIONS

This study analysed simulations of a current square for a city in Southern Brazilian and two scenarios denser and higher. We simulated all scenarios for the winter and summer seasons. We also run simulations considering the increase of climate change to 2060 in the summer.

The effect of density and verticalization to T_{mrt} was more expressive in the summer, improving the thermal comfort at the pedestrian level, as demonstrated in studies in hot climates. Although results for the winter had a less expressive effect on the variables, they cannot be underrated in subtropical climates. Higher verticalization can result in significant thermal discomfort in open spaces in the winter. Wind speed decreased from the current scenario to verticalized scenarios, mainly in the centre of the square, which can contribute to thermal comfort in the winter and discomfort in summer. In most results, the decrease by higher-rise was smaller than the increase by changing climate in the summer. Predicted studies are crucial to improving thermal comfort in open spaces.

We had a limitation in the configuration of clouds in the software ENVI-met 5.0.2. In this recent version, the software does not allow changing the value of high clouds. It did not commit the results. Furthermore, it is crucial to consider that verticalization affects other comfort aspects, such as the natural light and the thermal conditions inside the buildings. Also, other factors should be looked at, such as the landscape vegetation and surface materials. The further steps of this investigation will apply a thermal index to complement the results and simulate a larger area (nine squares).

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