

Article

Including Open Balconies in Housing Retrofitting: A Parametric Analysis for Energy Efficiency

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Abstract

Balconies are widely recognized for enhancing urban livability, making them attractive elements to incorporate in building renovation projects. However, their impact on energy performance remains insufficiently studied, particularly in temperate climates, like the Mediterranean, where both heating and cooling demands must be considered. This article evaluates the energy impacts of integrating open balconies into housing retrofits on the space conditioning demand of dwellings through spatialized analysis at the urban block scale. Focusing on Barcelona's Eixample district, a parametric Urban Building Energy Modeling (UBEM) was employed to assess how balcony design interacts with urban morphology (orientation, obstructions), building features (window-to-wall ratio, WWR), and balcony length. Results reveal a seasonal trade-off at the block scale: balconies increase heating demand (0.1–1.6 kWh/m²·yr) by reducing winter solar gain but decrease cooling demand (0.1–3.8 kWh/m²·yr) through summer shading. Net effects vary by unit position, with south-facing and moderately glazed dwellings benefiting the most. Deeper balconies (1.5–2 m) amplify both effects, while optimal depth depends on the window-to-wall ratio. Under future climates, retrofits combining insulation and balconies mitigate rising cooling demands more effectively than insulation alone, reducing block-level demand by up to 16%. Although balconies alone show modest energy savings at the block scale, they enhance localized thermal resilience. The study highlights the need for integrated retrofit strategies that balance thermal insulation with solar protection to address both current and future energy challenges while enhancing occupant well-being.

Keywords: balconies; urban building energy modelling; parametric energy analysis; cooling; heating; Mediterranean climate



Academic Editors: Giovanni Murano and Maria Grazia Giardinelli

Received: 18 June 2025

Revised: 19 September 2025

Accepted: 17 October 2025

Published: 24 October 2025

Citation: Garcia-Nevado, E.; Lopez-Besora, J.; Besuievsky, G. Including Open Balconies in Housing Retrofitting: A Parametric Analysis for Energy Efficiency. *Urban Sci.* **2025**, *9*, 439. <https://doi.org/10.3390/urbansci9110439>

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1. Introduction

The need for contact with the outdoors is inherent to the human condition. Urban public spaces provide a setting where communities can enjoy the benefits of being outdoors and connect with others, positively impacting health and well-being [1]. However, in dense and compact cities, this opportunity is limited due to the characteristics of urban morphology. Additionally, individuals with reduced mobility or certain health conditions must remain at home and cannot enjoy the outdoors as much as they would like [2].

Compact cities, such as the European ones, count on multi-family residential buildings that lack courtyards or vast private outdoor spaces. Therefore, balconies or terraces expand

the possibilities of outdoor living without leaving home. They provide the benefits of being outdoors: natural light, external views, access to fresh air, and contact with other people. In Mediterranean or temperate climates, open balconies are thermally comfortable many days a year [3,4] becoming spaces vibrant with life, growing plants, furniture, decorations, and various domestic elements. Many social interactions occur on the open balcony, as it is the part of the private realm where people socialize informally. For all these reasons, open balconies have a positive impact on the physical and psychological well-being of their users [5–7]. In addition, projecting balconies modify the façade geometry and generate shading, which influences the adjacent dwellings. On the one hand, they are beneficial in summer, as they reduce solar incidence and thermal load; however, on the other hand, during winter they may cause undesirable solar obstruction. The challenge lies in finding a balance between the benefits for occupants' well-being and the thermal performance of the building.

The open balcony, once considered a non-essential part of a dwelling, has experienced a significant shift in its value. In recent years, architects and developers have sometimes excluded balconies from new building designs to cut construction costs and increase the usable square footage. Moreover, many residents of homes with balconies have opted to convert these areas into indoor living areas to address the shortage of space. However, following the COVID-19 pandemic, open balconies have regained recognition as vital elements for promoting mental and physical well-being [8,9]. Today, open balconies are viewed positively by users and add economic value to residences [10].

Recent regulations come to light to foster the inclusion of open balconies and terraces in new buildings by exempting them from being classified as built areas [11,12], reflecting their increasing importance in contemporary architecture. There has also been growing interest in adding balconies to existing buildings as part of retrofitting efforts (Figure 1) [13,14], with renowned examples by architects such as Lacaton & Vassal and Frédéric Druot [15]. Even, the industry is introducing innovative prefabricated balcony solutions [16], including independent precast structures that can be assembled on-site [17], foldable prefabricated balconies and windows that can transform into balconies within seconds [18]. Beyond their relevance for physical and mental well-being, open balconies constitute an added value to housing prices and are increasingly sought after in the real estate market.

In 2020, the European Union launched a “renovation wave strategy” aiming at improving energy efficiency and enhancing living standards in existing buildings, which includes funding for renovations aligned with these targets. These renovations typically involve changes to the building's façade, such as the addition of external thermal insulation and the renovation of windows, which may create large-scale opportunities for adding balconies in consolidated urban areas. However, assessing the energy impacts of such decisions is crucial to ensure the overall efficiency of these interventions and achieve de-carbonization goals. In this line, special attention should be paid to the impact of balconies on space conditioning, an end-use accounting for nearly 70% of residential energy consumption in the EU [19].

The objective of this article is to quantify the impact of adding open balconies to existing residential buildings on heating and cooling demands, as part of typical energy retrofit interventions in Mediterranean cities. Using the *Eixample* district of Barcelona as a case study, the energy performance of an urban block in its original state with two façade retrofit approaches was compared: one following standard practice, based on increased thermal insulation, and another that incorporates balconies together with the addition of insulation. The thermal effects of balconies depend on their design, as well as extrinsic factors such as the characteristics of the building, the morphology of the surrounding urban environment, and climatic conditions. To address this complexity, a parametric study based

on Urban Building Energy Modeling (UBEM) simulations was conducted, analyzing model variations at different scales: balcony, building, block, and climate. Specifically, the impact of balconies on air-conditioning demands was examined, considering their depth and the building's glazing ratio, and the sensitivity of the results to façade orientation, floor level, and position within the urban block was analyzed. Additionally, the outcomes of balconies under current and projected climate scenarios were compared in order to discuss how this factor could affect their performance if cooling needs increased due to global warming trends. The key contribution of this study lies in its integration of parametric UBEM with climate projections to comprehensively evaluate balcony impacts across multiple spatial scales (from individual units to entire urban blocks) and temporal frames (present to 2050). Moving beyond conventional static models and single-building analyses, this approach employs systematic parametric simulations to assess design variables while capturing the complex relationships between urban morphology and energy performance—both for immediate effects and long-term climate resilience.

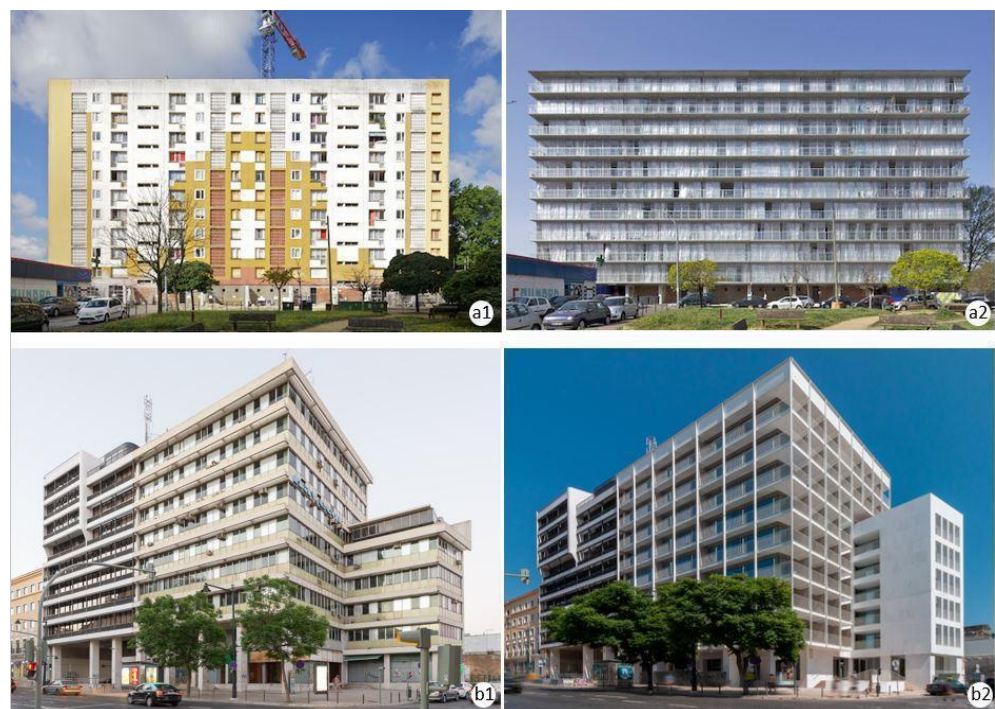


Figure 1. Examples of building retrofitting including balconies: (a1,a2) Collective housing in Bordeaux, by Lacaton & Vassal [15]. (b1,b2) Office building transformed into dwellings in Lisboa, by S. Torres de Carvalho (2019).

Review on the Effects of Open Balconies on Buildings' Energy Performance

The incorporation of balconies in newly built or retrofitted buildings is not only an architectural design decision but also a passive strategy with significant implications for the building's energy performance. Since the 1970s, research on the impact of balconies on the Indoor Environmental Quality (IEQ) of dwellings has predominantly focused on open balconies, with 68% of the studies dedicated to this topic [20]. However, most of these studies (81%) have concentrated on issues such as acoustic shielding and airflow patterns, while the thermal effects of balconies remain underexplored.

Existing literature demonstrates that balconies play a significant role in shaping the thermal performance of buildings. From a thermal perspective, the primary influence of balconies is the “overhang effect” [20]. As a protruding element of the façade, open balconies provide shade to the floors beneath, reducing solar gains. This shading effect can be either beneficial or detrimental, depending on the specific context and time of year [21].

In warm climates, open balconies generally have a positive impact on a building's thermal behavior, as they function as effective shading devices that can reduce cooling loads [20,22]. Numerous studies have assessed the impact of open balconies in cooling-dominated climates in tropical and subtropical regions [11,22–25]. These studies consistently show that balconies contribute to lower residential cooling demands across various orientations and floor levels, with the most noticeable effects observed on sun-facing façades. For instance, ref. [11] reported up to a 12.3% reduction in annual air-conditioning consumption for south-west-facing apartments in Hong Kong (22.3° N), compared to just 3.4% for north-facing ones. However, these benefits may be less pronounced in buildings with self-shading geometries and can vary between floors, with the upper levels experiencing the greatest impact [22].

Despite the potential reduction in natural ventilation [24,26,27], deeper balconies (≥ 2 m) in warm climates have demonstrated substantial potential to reduce cooling loads while improving daylight comfort in tropical climates [25]. Ref. [23] found that balconies greater than 2.5 m deep in highly glazed residential buildings (50–100% window-to-wall ratio) led to improvements in thermal comfort, with cooling reductions ranging from 21% to 31%. In office buildings, cooling load reductions were even more pronounced, with [24] reporting a 37% reduction in cooling thermal loads for the north façade in São Paulo (23.5° S, Brazil), while the decrease was much lower on the south façade (less than 10%).

In temperate regions, where both cooling and heating demands exist, the effect of open balconies on air-conditioning needs is more complex and highly dependent on local conditions. Balconies in these climates can reduce cooling loads while increasing heating requirements, with the net effect influenced by the trade-off between these opposing forces.

Some studies have explored this balance in residential buildings located near 30° latitude, in areas with hot summers and cold winters. For example, ref. [28] demonstrated in Shiraz, Iran (30° N, Bsh) that optimizing overhang dimensions based on orientation could reduce cooling loads by 13% on extreme summer days, with minimal increases in heating demands during winter (less than 1%). Similarly, in Changsha, China (28° N, Cfa), Ref. [29] found that deeper overhangs (0.3 to 1.5 m) provided net savings in annual air-conditioning consumption, although the reductions were generally modest (less than 2%). Ref. [30] observed that deep balconies (1.8 m) reduced annual air-conditioning consumption by 7–12% (for south- and west-facing living rooms), despite generating significant increases in heating demand (from 8% to 54% for north- and south-facing orientations, respectively). Overall, these studies consistently conclude that balconies provide annual energy savings in terms of air-conditioning, with the reductions in cooling loads systematically outweighing the increases in heating requirements.

However, despite this valuable body of research, there remains a notable gap in studies addressing the effects of open balconies in regions with cooler climates, particularly those at higher latitudes, where heating needs outweigh cooling requirements. In general terms, climates become cooler, and the cool season extends as latitude increases, altering the balance between cooling and heating demands. In contrast, climate change is reshaping this paradigm, and the warm season is becoming both longer and more extreme. This shift reveals a research gap that is particularly evident in Mediterranean and mild climates, an observation echoed by [20], who highlighted the lack of comprehensive studies on the impact of balcony design in such regions. This study aims to fill this gap and contribute to a more nuanced understanding of how open balconies can influence thermal comfort and energy demands in Mediterranean climates today, and in a future climate change scenario. The consideration of the morphological context, together with the challenges posed by the complexity of temperate climates, is central to the novelty and relevance of this study.

2. Materials and Methods

2.1. Case Study

The Eixample district in Barcelona (Figure 2) has been selected as a case study due to its unique urban and architectural character, as well as its potential for exploring the integration of balconies into façade retrofitting strategies within a dense urban context.

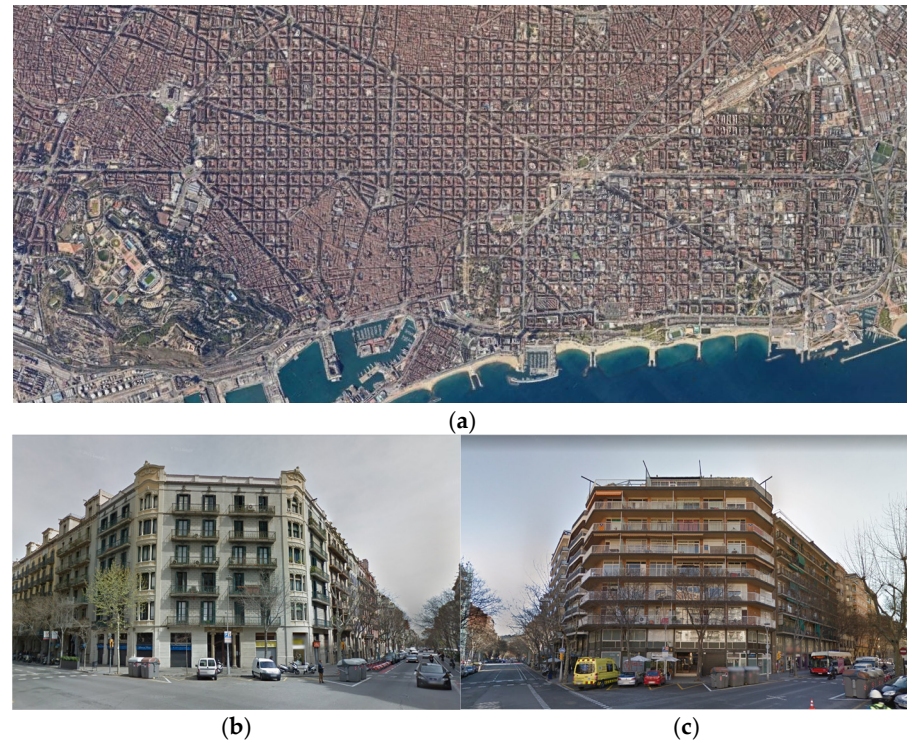


Figure 2. (a) Aerial view of Barcelona with the Eixample district; (b) Example of balconies in a 1900 building (Girona & Mallorca corner) and (c) a 1970 building (Calabria & Floridablanca corner).

Originally planned by Ildefons Cerdà in the 1860s, the Eixample was designed to address the demographic boom and unhealthy conditions of the walled 19th-century city. Cerdà's visionary plan proposed a 45°-rotated orthogonal grid, composed of chamfered square blocks measuring 113 by 113 m [31]. Over more than 160 years, this grid has been progressively filled in, resulting in a consolidated urban fabric where buildings from different architectural periods coexist [32]. Most of the building stock in the Eixample was constructed before 1980—before the implementation of Spain's first thermal regulations—making it a key target for energy retrofitting initiatives to improve energy performance and living conditions.

Balconies have been an integral part of Barcelona's urban identity since the 16th and 17th centuries [33]. In the Eixample, they were incorporated from the earliest phases of development, appearing as narrow street-facing ledges (approximately 0.5 m deep) and as wider terraces (1 to 2 m) facing inner courtyards [34]. With the rise of Rationalism and technological advancements in the 20th century, façades were no longer constrained by structural roles, enabling greater design freedom for balconies. Since then, the popularity of balconies has fluctuated, influenced by architectural trends, economic conditions, building codes, and real estate preferences. Some periods, such as the post-war era, saw a decline in balcony construction, while others, like the 1970s, saw their resurgence.

The Eixample exemplifies this shifting users' appreciation of balconies over time [35]. Once a status symbol, many balconies were later enclosed or absorbed into interior spaces due to a lack of usable indoor areas or challenging outdoor conditions such as noise

and pollution. However, in recent years, particularly since the COVID-19 pandemic—have renewed interest among residents and developers in private outdoor spaces such as balconies and terraces. Since façade retrofitting often involves substantial façade works, these interventions offer a timely opportunity to consider adding or reintroducing balconies.

As a result, the Eixample’s urban façade has become a mosaic of balcony types and configurations, making it an especially compelling setting for evaluating the architectural, energy, and habitability impacts of adding balconies within a dense and historic urban fabric.

2.2. Method Outlook

Urban stakeholders increasingly need to anticipate building interventions’ impact on energy use and occupant comfort. Urban Building Energy Models (UBEMs) are emerging as essential tools in this context, with a range of methodologies under development [36–38]. These models apply bottom-up physical simulations of heat and mass transfer to estimate indoor and outdoor environmental conditions, operational energy use, and the potential integration of local renewable energy sources.

A major challenge in urban energy modelling is the heterogeneity of the built environment, including variations in geometry, material properties, and occupant behavior. Parametric energy simulations provide a structured way to navigate this complexity. Tools like Ladybug and Honeybee [39], operated within the Rhinoceros and Grasshopper platforms as visual programming interfaces, support this approach. Several studies have demonstrated the usefulness of such tools for goals ranging from urban morphology analysis [40] to form optimization [41]. In our study, Honeybee [39] is employed to explore the effects of adding balconies on the heating and cooling demands of existing buildings through parametric energy modelling. Figure 3 illustrates the overall workflow, and the tools applied at each stage of the analysis.

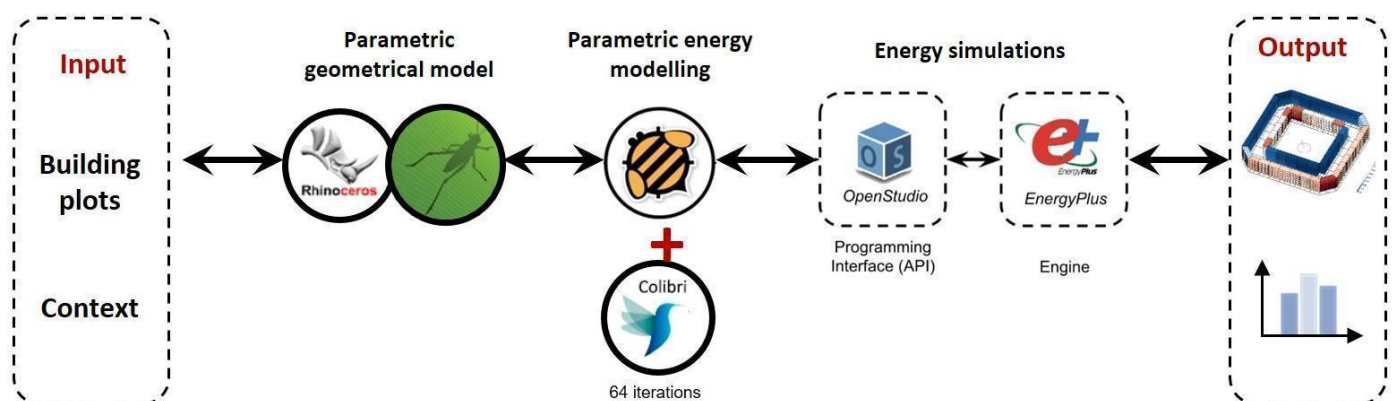


Figure 3. Study workflow and tools.

A parametric geometric model was developed in Rhinoceros 7.0 [42] and Grasshopper, consisting of a target urban block surrounded by its context. Balconies were included on all façades (except the ground floor) as protruding surfaces. The energy model was then built in Honeybee for simulations. Leveraging the efficiency of this tool in running parametric energy simulations through adjustable inputs, it was evaluated how three key parameters influence balcony effects on building energy performance:

- Window-to-wall ratio (WWR): 15%, 30%, 45%, 60%, 75%
- Balcony depth: 0 m (L0), 0.5 m (L50), 1.0 m (L100), 1.5 m (L150), and 2.0 m (L200)
- Façade thermal properties: Original vs. retrofitted (more insulated).

Using Colibri (a Grasshopper plugin), the Honeybee model was iteratively updated, running each configuration in OpenStudio/EnergyPlus and storing results in SQL format. Balconies' energy effects were also evaluated under both current and projected future climates by the Intergovernmental Panel on Climate Change (IPCC), using a representative 30% WWR block (matching the district average found in [43]). In total, 36 simulations were conducted: 30 for present conditions and 6 for future scenarios (Figure 4). Notice that simulations with balconies only happen in the retrofitted scenario, that is, with thermal insulation already added. This assumption is made considering that the main motivation for the retrofit operation would be the improvement of façade insulation to comply with current thermal regulations [44], while the incorporation of balconies would be optional.

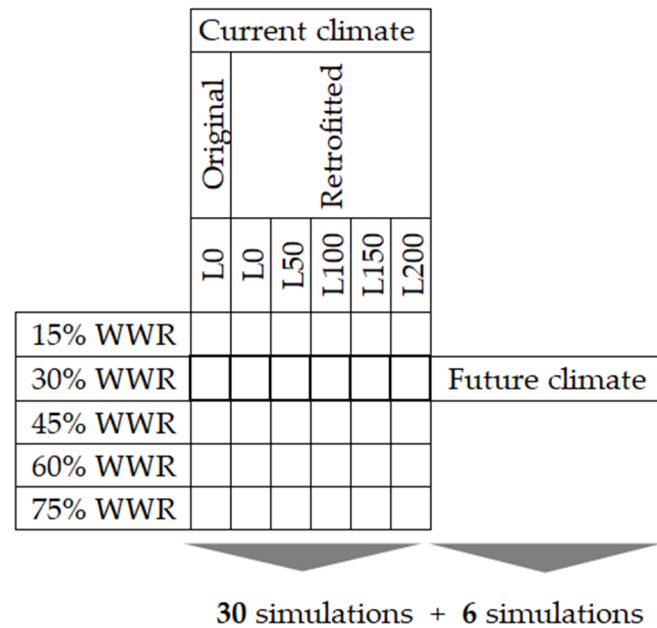


Figure 4. Matrix of simulation cases.

Finally, the results were analyzed using Grasshopper and Honeybee to generate 3D visualizations of cooling, heating, and total space conditioning demands. Simulation data were also exported to spreadsheets for further charting and analysis.

2.3. Urban Energy Model and Simulation Details

The energy simulations of this study were conducted using Honeybee v 1.6.0 [45], a Grasshopper-based interface that integrates with EnergyPlus as the simulation engine. EnergyPlus solves energy and mass balance equations at the zone level using a finite difference approach with fixed time steps. The thermal model calculates heat transfer through building envelopes using 1D conduction models, surface convection correlations (both interior and exterior), and steady-state moisture conditions (no moisture transfer through the built elements). Solar radiation gains through the envelopes are calculated based on algorithms that account for direct, diffuse, and reflected components on all exterior surfaces, using the Perez sky model and taking into account the dynamic shadowing effects of the balconies and the surrounding built environment.

This study is based on a typological urban model of the Eixample district in Barcelona. As shown in Figure 5, the urban model used for energy simulations comprises nine blocks arranged in a 3×3 array. The central one is designated as the analysis target, while the rest act as the built environment that creates shadows and reflections.

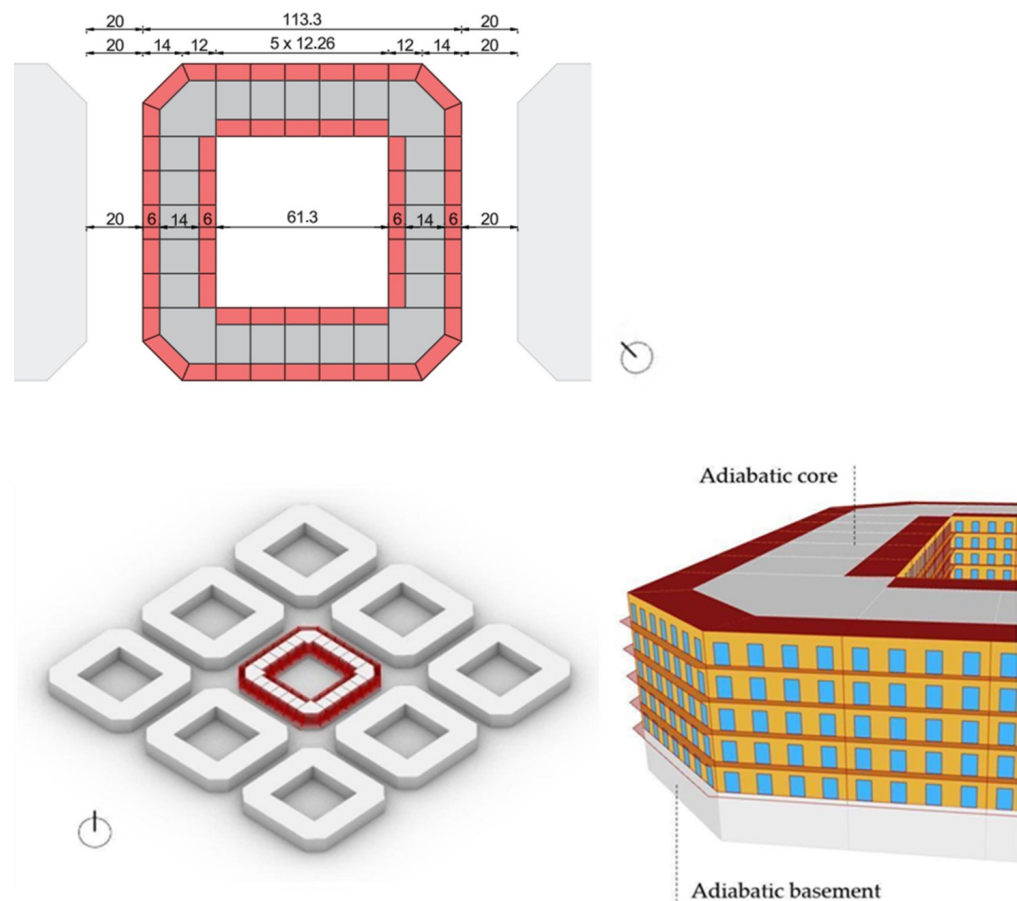


Figure 5. Block dimensions (up). 3D view of the urban energy model and detailed 3D view of the central block (WWR 30%, 1 m balcony) (down).

The central block consists of 24 buildings: 20 two-sided and 4 single-sided ones, located in the chamfers (see floor plan dimensions in Figure 5). All buildings have six floors: a 5 m-height commercial ground floor and five 3 m-height residential floors. The analysis focuses on the latter ones and, specifically, on the thermal zones closest to the building's outdoor perimeter, as the areas most affected by the changes in the facade design. Following this logic, a 6 m-deep "perimeter" zone and a "core" zone are defined [46]. Only the residential units in the perimeter are included in the simulations, whereas those in the core and the commercial ground floors are considered adiabatic volumes. On the long façades of the block, each floor accommodates two residential units—one oriented toward the street and the other toward the courtyard. In contrast, chamfer buildings contain three residential units per floor, all street-facing. In total, the model includes 260 residential units. Each unit is modelled as an empty prism measuring 3 m in height, 6 m in depth, and a variable width depending on its location (as shown in Figure 5). As units have no internal partitions, all residential units are treated as single thermal zones in energy simulations.

Balconies are a compositional resource in architecture and, as such, they may adopt multiple layouts and designs. For the present study, balconies were modeled in a simplified manner, as continuous slabs (flat surfaces, with no vegetation or enclosures) running along the complete building perimeter at each floor except for the ground level (Figure 5). Within the HoneyBee energy model, balconies are considered a shading element, able to cast shadows on the building and reflect the incoming solar radiation, but without thermal conduction exchange with the facade they are attached to. This assumption is based on the availability of technical solutions that can avoid or minimize thermal bridges when adding balconies to existing façades during energy renovations, thereby ensuring continuity of

the thermal insulation layer (e.g., self-supporting balconies, Isokorb connector systems, or similar solutions). Additionally, since the goal of our paper is to quantify the maximal effect of the balconies' shade, our model does not include any other local solar shading devices.

For this study, two building construction types representing the original state were defined, matching the typical characteristics of buildings dated between 1960 and 1980, in their original and retrofitted states. It has been considered that the original state of the buildings features a reinforced concrete structure, with a double-leaf brick façade including an uninsulated air cavity (cavity wall 15 + 5 + 7 cm), with outdoor mortar and indoor plaster finishings; windows with aluminum frames without thermal break and single glazing; floor slabs composed of concrete beams and ceramic infill blocks, with the top floor including an additional concrete layer for slope formation. In the rehabilitated state, it is assumed that the intervention affects only the façade and consists of replacing the window frames with aluminum units incorporating thermal break and low-emissivity double glazing (4/16/4 mm, Low-E), as well as adding external thermal insulation (6 cm EPS) using an ETICS system. Table 1 describes the thermal transmittance (U-value) for the main building elements in both states.

Table 1. Thermal transmittances of the energy model (U-value [$\text{W}/(\text{m}^2 \text{ K})$]).

Elements	Original U-Value	U-Value After Façade Retrofitting
Façade wall	1.54	0.44
Roof	1.80	1.80
Windows	5.73	1.69
Party floor	2.02	2.02
Party walls	2.12	2.12

The results presented in this paper are based on the analysis of space air conditioning demands. These demands were estimated using the Ideal Loads Air System mode (IdealAirLoads in EnergyPlus), which provides the exact heating or cooling needed to maintain setpoints, without the need to model physical HVAC equipment or energy use. The main simulation settings are summarized in Table 2.

The set-points and schedules used in this study were fixed according to the Spanish Energy regulations for residential buildings defined in [47]. A constant ventilation rate of 0.63 air changes per hour (ach) was assumed throughout the year, along with an infiltration rate of $0.0006 \text{ m}^3/\text{s}$ per m^2 of façade, according to [47]. Additionally, to prevent excessive indoor overheating during the warm season, free cooling was activated at a rate of 4 ach whenever indoor temperatures exceeded 21°C , outdoor temperatures were above 16°C , and indoor temperatures were higher than outdoor ones by at least 2°C .

Internal gains from occupancy, lighting, and appliances were defined following Spanish energy regulations ([44], Annex D). Occupancy-related gains were set at $3.51 \text{ W}/\text{m}^2$, based on a density of 0.036 persons/ m^2 performing light sedentary activity (≈ 1.2 met). The occupancy schedule varied by time and day: 100% during nighttime (23:00–07:59), 25% during working hours (08:00–15:59), and 50% in the late afternoon and evening (16:00–22:59), from Monday to Friday. On weekends and holidays, occupancy remained at 100% throughout the day. Lighting and appliance gains were capped at $4.4 \text{ W}/\text{m}^2$ and applied using a dynamic daily schedule: 10% from 00:00 to 07:59, 30% from 08:00 to 18:59, 50% at 19:00, 100% between 20:00 and 22:59, and 50% from 23:00 to 23:59. The load was set to 10% during the night (00:00–07:59), increased to 30% throughout the day (08:00–18:59), rose to 50% at 19:00, peaked at 100% between 20:00 and 22:59, and then decreased to 50% from 23:00 to 23:59.

Table 2. Settings for energy simulations.

Parameter	Setting
Heating set-point & schedule	From 1/10 to 31/04: 20 °C from 8:00 to 23:59 17 °C from 00:00 to 07:59
Cooling set-point & schedule	From 1/05 to 31/09: 25 °C from 16:00 to 23:59 27 °C from 00:00 to 07:59
Free-cooling	From 1/05 to 31/09: Whenever Tint > Text If: Tint > 21 & Text > 16 & Tint-Text > 2 °C
Ventilation rate	0.63 ach
Infiltration rate	0.0006 m ³ /s per m ² façade
Occupancy & schedule	3.51 W/m ² (0.036 people/m ² , 1.2 met) 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/m ² 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

The climatic files used for the simulations under the current climate scenario were taken from the EnergyPlus site [48]. To simulate the future impacts of balconies taking into account climate change, a climatic file provided by Meteonorm [49] was used, which was generated according to the IPCC projections for 2050 under the RCP8.5 scenario.

In the present climate scenario (Table 3a), average monthly temperatures range from about 8 °C in winter to 24 °C in summer, with relative humidity between 66% and 83% and wind speeds of 2.4–4.4 m/s. Global solar radiation varies from 6 to 24 MJ/m² per day, with diffuse radiation accounting for 37–56%. In the future scenario (Table 3b), minimum, mean, and maximum temperatures increase year-round by about 1–4 °C, particularly in summer, while humidity decreases slightly (around 3% on average). Wind remains stable, but global solar radiation increases, with a lower diffuse fraction likely linked to reduced ambient humidity.

Table 3. (a) Main data for the current climate scenario. (b) Main data for the future climate scenario.

(a)							
Current Scenario	T _{min}	T _{ave}	T _{max}	RH	WS	R _{glo}	% R _{dif}
January	4.1	8.2	13.2	72.0	3.1	6.9	51%
February	6.0	9.4	13.2	69.5	4.4	9.8	45%
March	6.9	11.1	15.8	75.3	2.4	13.3	51%
April	8.9	13.1	17.1	73.5	3.7	17.8	48%

Table 3. Cont.

May	13.2	17.0	20.4	75.3	3.6	21.1	46%
June	17.4	20.9	24.3	77.1	2.6	21.0	48%
July	19.6	23.5	26.9	69.6	3.7	24.1	37%
August	20.2	24.1	27.5	72.4	3.1	20.6	39%
September	17.5	21.6	25.6	75.3	3.6	14.5	54%
October	14.0	17.3	21.6	82.5	3.1	10.7	53%
November	8.3	12.1	16.5	79.7	2.8	6.9	56%
December	6.3	9.9	14.3	66.2	4.4	6.0	51%
YEAR	11.9	15.7	19.7	74.0	3.4	14.4	47%

(b)							
Future Scenario	T _{min}	T _{ave}	T _{max}	RH	WS	Rglo	% Rdif
January	7.4	10.7	14.7	70.2	4.2	7.6	36%
February	7.8	11.2	15.2	69.5	4.1	10.6	47%
March	9.8	13.3	17.0	70.2	4.1	15.5	37%
April	11.9	15.4	19.0	72.9	4.1	19.1	42%
May	15.9	19.3	22.6	72.3	3.8	23.4	36%
June	20.2	23.6	26.9	71.0	3.6	25.8	39%
July	23.8	27.2	30.5	68.7	3.6	25.4	38%
August	24.1	27.6	31.2	68.4	3.6	22.4	38%
September	20.5	24.0	27.8	72.6	3.6	17.0	39%
October	17.1	20.4	24.2	73.9	3.7	12.2	41%
November	11.3	14.6	18.7	70.8	4.0	8.0	45%
December	8.0	11.4	15.7	71.1	4.3	6.6	42%
YEAR	14.8	18.2	22.0	71.0	3.9	16.1	39%

T_{min}, T_{ave}, T_{max} (°C): average daily maximum, mean and maximum air temperatures; RH (%): average daily relative humidity; WS (m/s): average daily wind speed 10 m height; Rglo (MJ/m²): average daily global horizontal radiation; % Rdif: fraction of diffuse radiation.

3. Results

The analysis of the results is organized into four sections:

- Section 3.1 focuses on the demands of the reference case (WWR 30%) and compares the effects of the two façade retrofitting strategies studied here: adding only thermal insulation (retrofitting I) vs. adding insulation and a 1 m depth balcony (retrofitting I + L100).
- Section 3.2 analyzes how the outcomes of the retrofitting including thermal insulation vary with the size of the added balconies (retrofitting I + LXX).
- Section 3.3 investigates how the outcomes of the retrofitting with thermal insulation and different sizes of balconies are influenced by the size of the building windows (WWR).
- Section 3.4 discussed the future impact of balconies on air-conditioning demand considering climate projections for Barcelona by 2050.

The results are presented through synthesized charts and 3D visualizations of the analyzed urban block. For the 3D representations, graphic aids are included to facilitate the understanding of the results (Figure 6).



Figure 6. Graphical aid.

3.1. Demands of the Reference Case Before and After Retrofitting

Figure 7 depicts the space conditioning demands for each residential unit in the reference case in its original state, that is, before retrofitting, and Table 4 provides a summary of simulation results. According to our simulations, the average heating, cooling and total space conditioning demands are 44.3, 15.9 and 60.1 kWh/m²·yr. For all the residential units, heating energy needs exceed the cooling ones. This difference is more limited in S/SE/SW orientations, where higher winter solar exposures reduce heating demands.

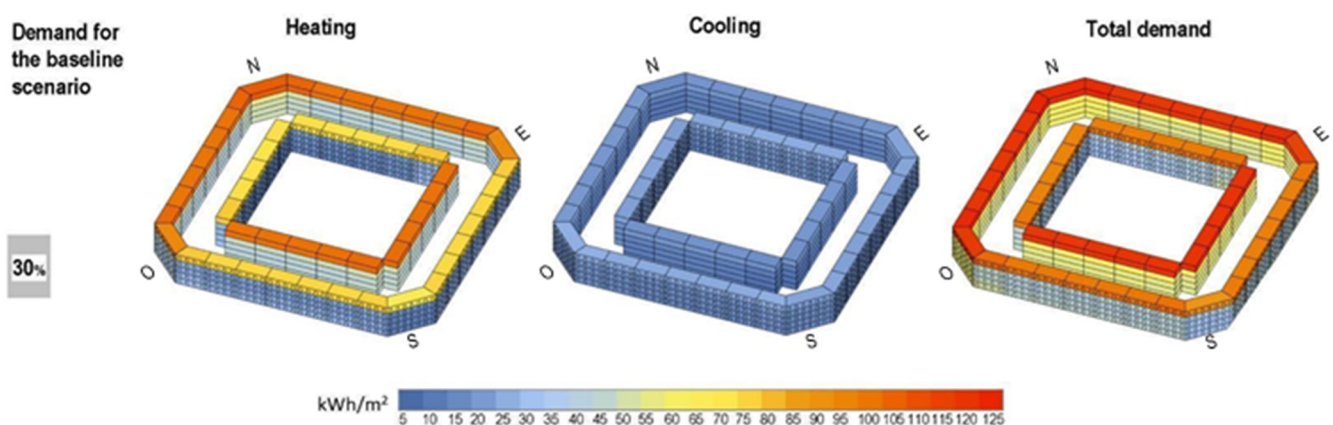


Figure 7. Heating, cooling and total air-conditioning demand (kWh/m²·yr) for the reference case before retrofitting.

Table 4. Unit-level space conditioning demands in kWh/m²·yr [MJ/m²·yr] for the reference case (WWR 30%) before and after retrofitting I.

		Heating	Cooling	Total
Original state	Maximum	106.0 [381.6]	25.6 [92.2]	124.3 [447.5]
	Average	44.3 [159.5]	15.9 [57.2]	60.1 [216.4]
	Minimum	14.2 [51.1]	7.1 [25.6]	28.8 [103.7]
After retrofitting I	Maximum	85.2 [306.4]	20.1 [72.4]	101.7 [366.1]
	Average	30.2 [108.7]	11.9 [42.8]	42.1 [151.6]
	Minimum	8.9 [32.0]	6.2 [22.3]	18.8 [67.7]

As shown in Figure 7, demand levels vary significantly by unit position. Top-floor units require substantially higher heating and cooling than intermediate floors, with total

space conditioning demands 5–6 times greater. On a given floor, differences between units are smaller (up to $2\times$ variation), driven primarily by orientation.

South-facing units exhibit lower heating demands ($S < SE < SW$) compared to east-, west-, and particularly north-facing units. Conversely, cooling demands are lowest in north-facing units ($N < NE < NW$) and progressively higher in southeast-, east-, south-, southwest-, and west-facing orientations. Although these orientation effects partially compensate for each other, south-, southeast-, and southwest-facing units maintain marginally lower total space conditioning demands.

Residential units with greater obstructions (such as street-facing lower floors or those near patio corners) demonstrate higher heating but lower cooling demands compared to those unobstructed with identical orientations. These findings highlight that exposed surface area is the primary determinant of space conditioning demands, with secondary influences from orientation and surrounding obstructions.

Table 5 and Figure 8 evidence the impact of façade insulation retrofitting, showing consistent reductions in space conditioning demands across the block. Heating demand decreases range from 2.4 to 23.1 kWh/m²·yr, while cooling demand reductions vary between 1.0 and 6.7 kWh/m²·yr, depending on unit position. At the block scale, once buildings are insulated, the average heating, cooling and total space conditioning drop to 30.2, 11.9 and 42.1 kWh/m²·yr (Table 4).

Table 5. Decrease in unit-level demands from retrofitting I, shown in relative (%) and absolute terms (kWh/m²·yr [MJ/m²·yr]), for the reference case (WWR 30%).

Decrease in		Heating	Cooling	Total
Absolute terms	Maximum	23.1 [83.2]	6.7 [24.1]	24.8 [89.3]
	Average	14.0 [50.4]	3.4 [12.2]	18.0 [64.8]
	Minimum	2.4 [8.6]	1.0 [4.3]	6.7 [24.1]
Relative terms	Maximum	48%	35%	43%
	Average	36%	25%	33%
	Minimum	4%	8%	8%

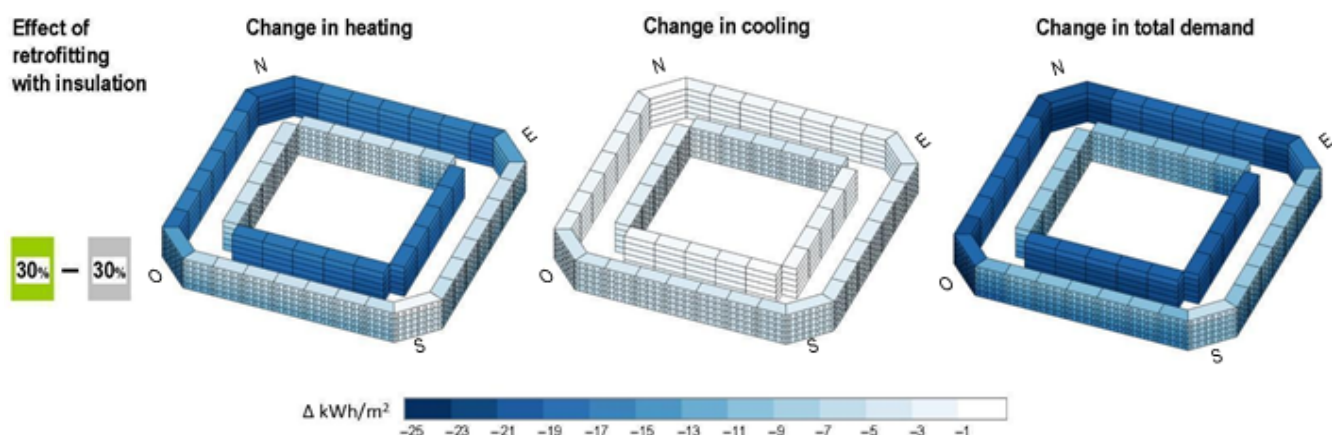


Figure 8. Change in heating, cooling and total space conditioning demand (kWh/m²·yr) after retrofitting with thermal insulation (retrofitting I).

The most noticeable reductions in heating—both in absolute and relative terms—happen in the N buildings (up to 23.1 kWh/m²·yr or 48%), followed by those in NE and NW buildings (up to 21.8 kWh/m²·yr or 48%). These reductions are up to 9.6 times higher than those achieved in the S-oriented building, where the decreases in heating demand range from 2.4 to 5.4 kWh/m²·yr (or from 4 to 37%). And up 4.1 times higher than those in SE/SW buildings, with decreases not exceeding 13.5 kWh/m²·yr or 45%. As for E/W

buildings, savings in heating lie between the north and south-oriented buildings, with values up to $17.2 \text{ kWh/m}^2\cdot\text{yr}$ or 45%.

Among buildings with the same orientation, higher energy savings in heating after retrofitting with insulation appear in the residential units with a higher level of obstructions, such as those on the lower floors or close to the patio corners. This effect is especially evident in the SW and SE buildings, where savings on the lower floor can even double those on the top floors in the buildings overlooking the street, and between those close to the patio corners.

As for cooling, the highest reductions in demand occur in SW and W buildings (up to $6.7 \text{ kWh/m}^2\cdot\text{yr}$ or 35%), followed by the SE, E and S ones. Conversely, the least significant demand decreases are found on average in the N building (not exceeding $\text{kWh/m}^2\cdot\text{yr}$ or 20%).

Accounting for the aggregated effect on cooling and heating, the reduction in total space conditioning demands after retrofitting with insulation is between 6.7 and $24.8 \text{ kWh/m}^2\cdot\text{yr}$. The most remarkable effects take place on the north-oriented buildings (N/NE/NW between 19.9 and $24.8 \text{ kWh/m}^2\cdot\text{yr}$), followed in order by the E/W, the SE/SW, and, finally, the S ones.

Table 6 and Figure 9 show the effect of adding 1 m depth balconies to buildings once retrofitted. The presence of balconies generates higher solar obstructions, which have opposing effects in the warm and cold seasons. Results show that, due to the balconies, the unit's heating demand in buildings retrofitted with insulation increases between 0.1 and $1.6 \text{ kWh/m}^2\cdot\text{yr}$ in absolute terms (between 0 and 15% in relative terms). In contrast, cooling demand decreases between 0.1 and $3.8 \text{ kWh/m}^2\cdot\text{yr}$ in absolute terms (between 1 and 47% in relative terms).

Table 6. Changes in unit-level demands after adding 1 m balconies to insulated retrofitted buildings, in relative (%) and absolute terms ($\text{kWh/m}^2\cdot\text{yr}$ [$\text{MJ/m}^2\cdot\text{yr}$]), for the reference case (WWR 30%).

Change in		Heating	Cooling	Total
Absolute terms	Maximum	+1.6 [5.8]	−3.8 [13.7]	−2.7 [9.7]
	Average	+0.8 [2.9]	−1.2 [4.3]	−0.4 [1.4]
	Minimum	+0.1 [0.4]	−0.1 [0.4]	±0.1 [0.4]
Relative terms	Maximum	+15%	−47%	−15%
	Average	+4%	−13%	−2%
	Minimum	0%	−1%	0%

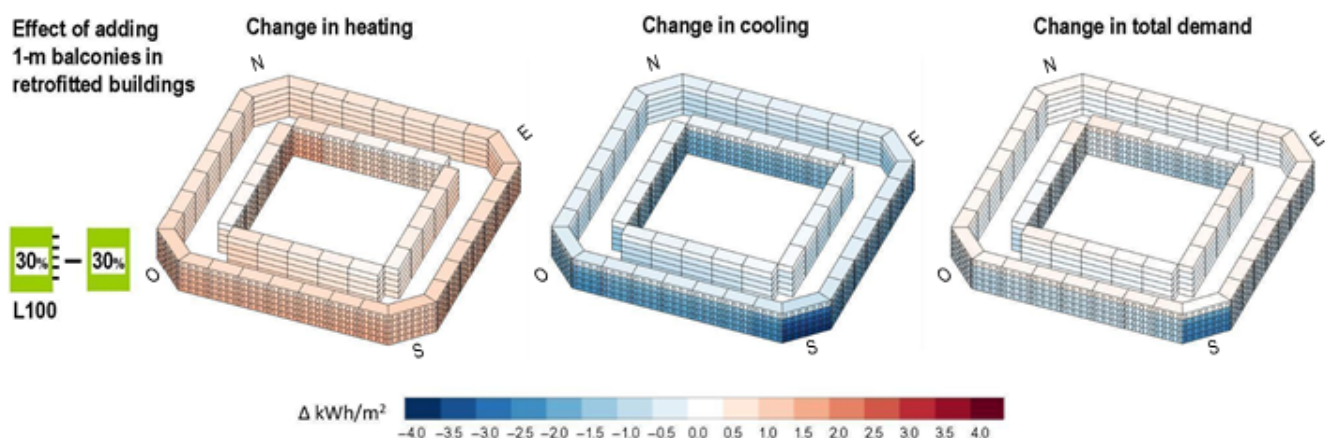


Figure 9. Change in heating, cooling and total space conditioning demand ($\text{kWh/m}^2\cdot\text{yr}$) when adding 1 m balconies to the buildings retrofitted with insulation.

The trade-off between the positive and negative effects of balconies between the cooling and the heating season results in changes in total space conditioning demand ranging from a 0.4 increase to a 2.7 kWh/m²·yr decrease in absolute terms (−2% on average). Overall, the balcony's impact on the total space conditioning of retrofitted buildings is modest but generally beneficial (except for the units on the top floor that exhibit a slight demand increase). The residential units on the first to the fourth floor of the S-chamfer, followed by those on the SE and SW street facades, experience the most significant reductions in total air-conditioning demand (up to −15%), mostly associated with higher effectiveness of balconies as solar protection in these orientations.

3.2. Sensitivity of Results to the Balcony Size

On average, at the block scale, the larger the balcony, the higher the heating and the lower the cooling demands (Figure 10). Depending on the balcony size (L), the normalized demand of the retrofitted block for heating exceeds by up to 0.3 (L50), 0.8 (L100), 1.6 (L150), and 2.5 (L200) kWh/m²·yr the one of the same block without balconies. As for cooling, the demand lowers by up to 0.4 (L50), 1.2 (L100), 2.0 (L150), and 2.7 (L200) kWh/m²·yr. Since the increase in heating and the decrease in cooling largely offset each other, the change in total space conditioning demand due to the balcony size variation is virtually null at the block scale (between 0.1 and 0.5 kWh/m²·yr).

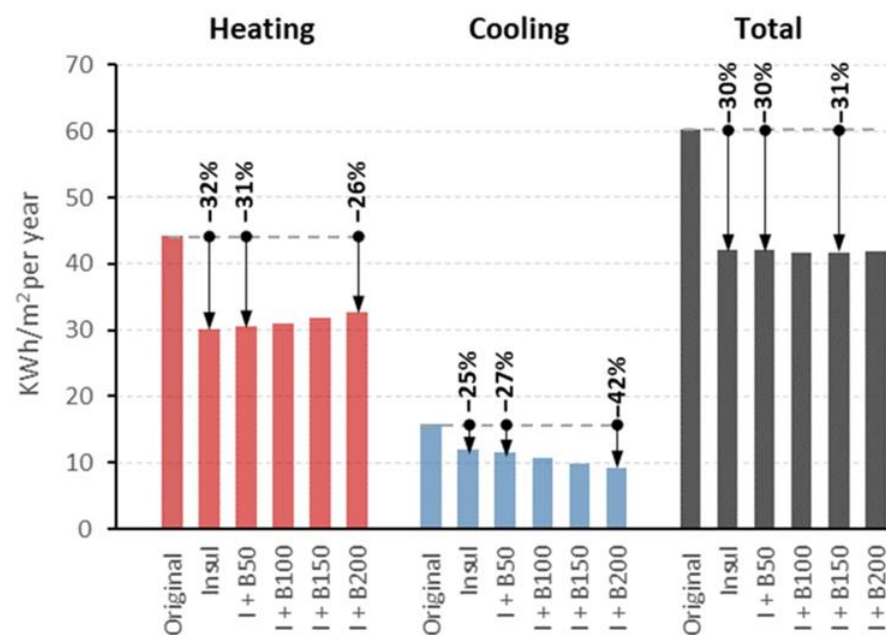


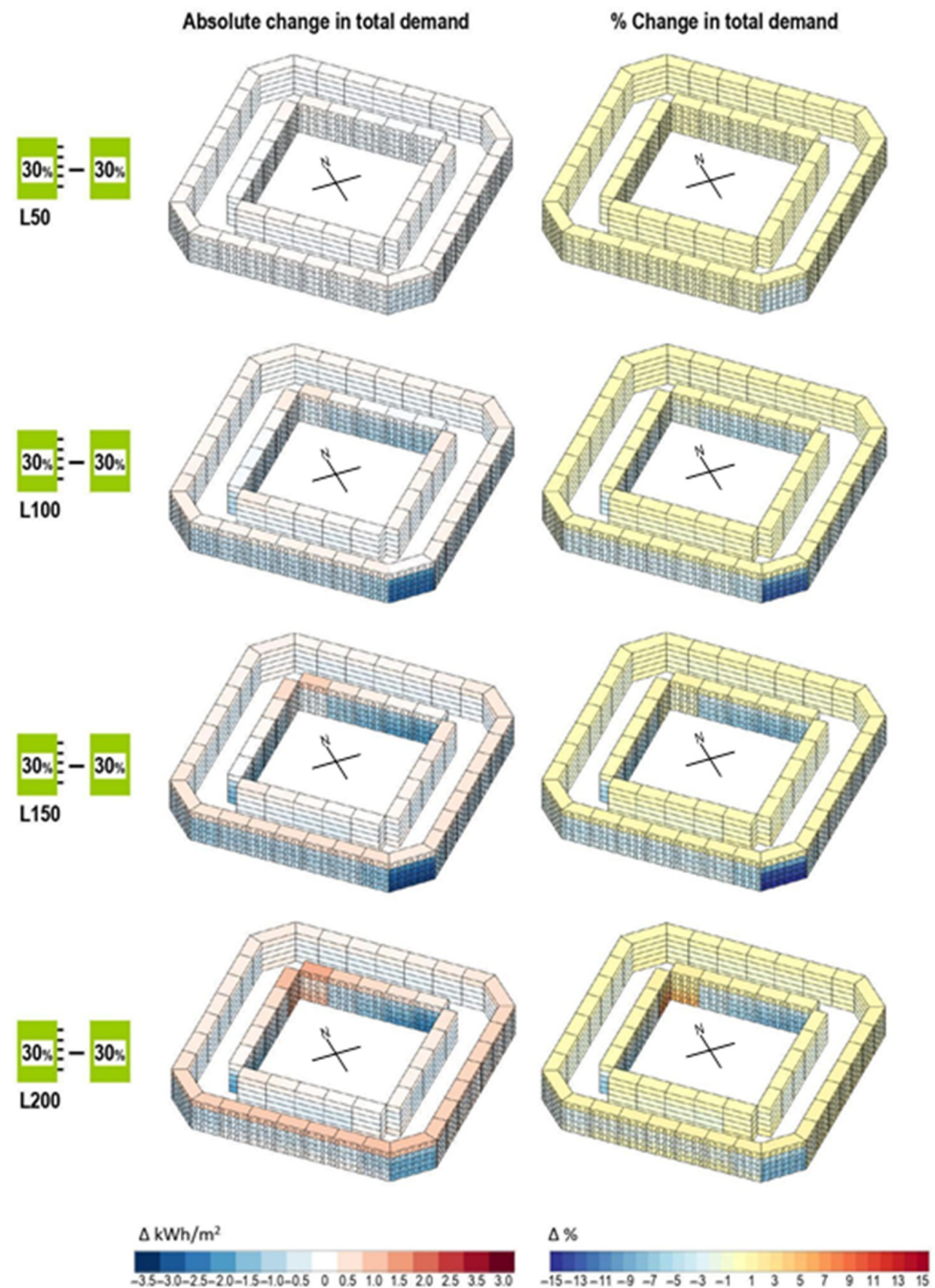
Figure 10. Heating, cooling and total space conditioning demand normalized per area of the block with 30% WWR (kWh/m²·yr) before and after retrofitting with different balcony sizes.

The results indicate that when insulation is incorporated during the retrofit process, the net reduction in air conditioning demand at the block scale remains consistent across different balcony sizes (Table 7). The net annual savings range from 18.0 to 18.5 kWh/m²·yr, corresponding to a 30–31% decrease in demand compared to the non-retrofitted case. The highest savings are observed in the case with 1.5 m-deep balconies, although the differences between balcony configurations are minimal.

The local effect of balcony size on demand differs across residential units, depending on their position (orientation, floor level, etc.). Figure 11 illustrates these variations by showing changes in total space conditioning demand (both absolute [kWh/m²·yr] and relative [%]) for the retrofitted block with progressively deeper balconies.

Table 7. Net savings for the reference case before and after retrofitting at the block scale.

Under PRESENT Climate Scenario	Net Savings [kWh/(m ² ·yr)]	Net Savings [MJ/(m ² ·yr)]	Net Savings [%]
Original	0	0	0
Insulated (I)	18.0	64.8	30%
I + Balcony L50	18.1	65.2	30%
I + Balcony L100	18.4	66.2	31%
I + Balcony L150	18.5	66.6	31%
I + Balcony L200	18.2	65.5	30%

**Figure 11.** Change in the total space conditioning demand (kWh/m²·yr or %) for retrofitted buildings depending on the balcony size.

On the last floor, including balconies in the retrofitting leads to small increases in the total space conditioning demand regardless of their size ($\leq 1.3 \text{ kWh/m}^2\cdot\text{yr}$ or 1.5% for 2 m balconies). This effect is due to a slight increase in the heating needs that is not compensated by the decrease in cooling since the last-floor units lack overhead balcony shading.

For residential units on floors 1–4, there are either reductions or increases in demand depending on their position and the balcony size:

- 0.5 m balconies: Negligible impact on total space conditioning demand ($< -0.8 \text{ kWh/m}^2\cdot\text{yr}$ or -3.5%).
- 1 m balconies: Modest reductions overall, most significant for south-facing units (-12.8% or $2.7 \text{ kWh/m}^2\cdot\text{yr}$), with minimal effects ($< 2\%$, $< 0.4 \text{ kWh/m}^2\cdot\text{yr}$) on N/NE/NW/E/W orientations.
- 1.5 m balconies: Peak benefits for S/SE/SW units (reductions of 14.8%, 6.9%, and 7.9%, equivalent to 3.1, 1.7, and $2.0 \text{ kWh/m}^2\cdot\text{yr}$), while other orientations showed limited effects ($< 2.3\%$, $< 0.8 \text{ kWh/m}^2\cdot\text{yr}$).
- 2 m balconies: Benefits diminished overall, with slight negative impacts ($\leq 1.3 \text{ kWh/m}^2\cdot\text{yr}$ or 6.9%) for some SE/SW units on lower floors or near street corners.

3.3. Impact of Balconies on the Energy Demand of Retrofitted Buildings Depending on Window Size

The amount of glazed surface in buildings significantly affects the energy exchanges through its envelope, hence, their air-conditioning demands. For the retrofitted *Eixample* block, the higher the window-to-wall ratio (WWR), the higher the average heating and cooling demands, especially the latter. Likewise, the more glazed surface there is, the more significant the effects of balconies are, as shown in Figure 12.

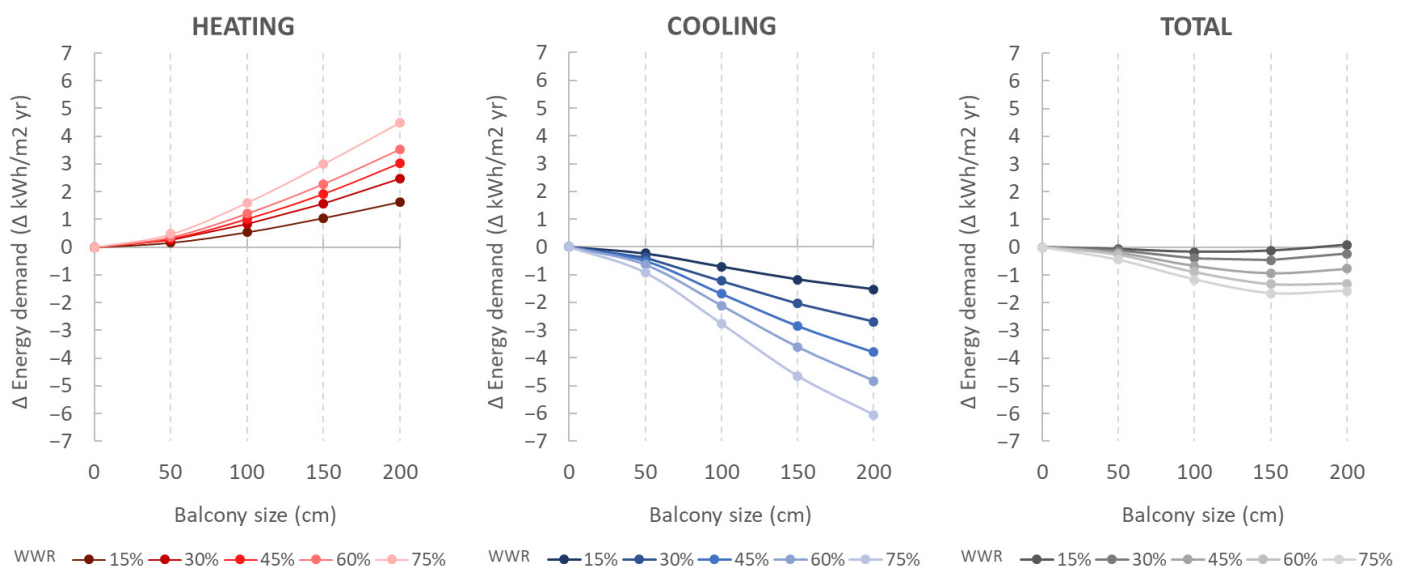


Figure 12. Change in the average heating, cooling and total space conditioning demand at the block scale depending on WWR (%) of the retrofitted buildings for different balcony sizes.

For each balcony size, the increase in heating needs is associated with the presence of balconies roughly triples between a block with 15% WWR and 75% WWR, whereas the decrease in cooling needs roughly quadruples. As a result, the net reduction in the total space conditioning demand achieved thanks to a certain balcony increases as WWR grows.

Results in Figure 12 also show that the balcony size that allows for lower total space conditioning demands varies depending on window size. For the block with a 15% WWR,

the lowest average total space conditioning demands happen with 1 m balconies, but for the blocks with a 30% WWR and beyond, it happens with 1.5 m balconies (Figure 13).

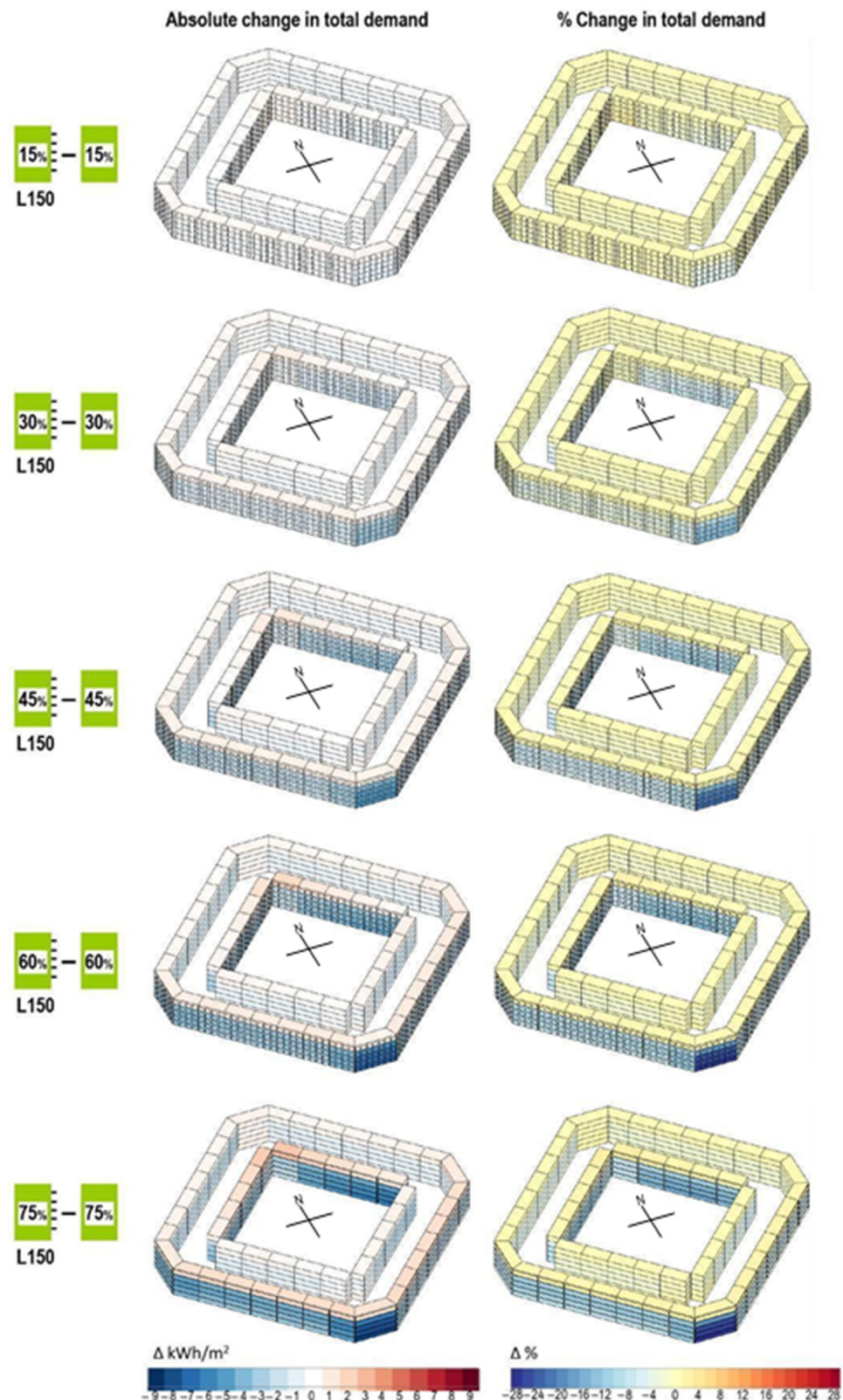


Figure 13. Absolute (left) and relative (right) changes in the total space conditioning demand of retrofitted buildings when adding 1.5 m balconies depending on WWR.

No matter the window size, the global impact of balconies remains limited at the block scale, with a maximum reduction of 1.7 kWh/m²·yr for the block with a 75% WWR when

adding 1.5 m balconies, which represents a 3% fall in demand compared with the block without balconies. At a local scale, the reduction in the total space conditioning demand can be more significant, arriving up to an 8.3 kWh/m²·yr in the residential units on the south chamfer, which represents a 28% decrease (Figure 13).

3.4. Performance of Energy Retrofitting Including Balconies by 2050

An important aspect regarding the energy retrofitting of buildings is the effectiveness of the measures in the foreseeable future if the current trends of global warming remain. Climate prospects for the Mediterranean region anticipate a rise in the average monthly temperature and an increase in the number and severity of extreme heat episodes throughout the year. As a result, a decrease in heating and a rise in cooling demand is expected in general terms.

Figure 14 depicts the impact of climate change on the average air-conditioning demand for the specific case of the *Eixample* under three different retrofitting scenarios: no intervention, façade thermal insulation, and façade insulation with balconies.

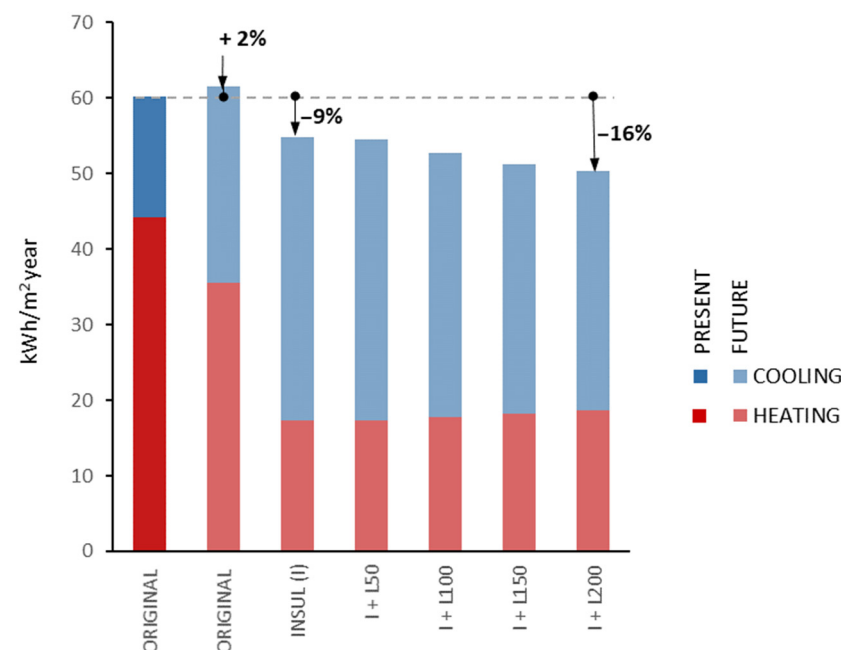


Figure 14. Current air-conditioning demand and prospect air-conditioning demand by 2050 under three retrofitting scenarios 30% WWR, for different balcony sizes.

Simulations show that, without any retrofitting intervention, the total space conditioning demand by 2050 would slightly grow (+2%, +1.4 kWh/m²·yr) compared to the current one, due to a significant cooling increase (+63%) not fully compensated by the decrease in heating (−20%). In contrast, by implementing any of the two retrofitting strategies studied here, the total space conditioning demand would decrease thanks to a significant fall in heating needs. If the intervention only consisted of adding thermal insulation, the reduction in the total space conditioning demand would be 9% (−5.4 kWh/m²·yr). If balconies were also included, higher decreases in the total space conditioning demand would be expected, ranging between 9% (−5.7 kWh/m²·yr) with 0.5 m balconies up to 16% (−9.9 kWh/m²·yr) with 2 m balconies.

However, despite the decrease in total space conditioning demand, retrofitted buildings would have significantly higher cooling needs than the un-retrofitted ones (between 1.9 and 2.4 times). So much so that cooling even becomes the predominant energy use for air-conditioning. These results evidence the possible counterproductive effects of

insulation-based energy rehabilitations under a warming climate scenario and highlight the need for additional solar protection, such as the one provided by the balcony slab.

The net savings in space conditioning demand under the future climate scenario are summarized in Table 8. If current climate projections are realized, annual savings would range between 6.7 and 11.2 kWh/(m²·yr), representing a 11–18% reduction compared to the non-retrofitted case. These values are significantly lower than those obtained under the present climate scenario (18.0–18.5 kWh/(m²·yr), or a 30–31% reduction), indicating a diminished effectiveness of retrofitting measures in a warmer future. However, unlike in the present climate, results show a stronger influence of balcony depth: deeper balconies are associated with greater energy savings, suggesting that their integration into retrofit strategies may become increasingly beneficial as temperatures rise.

Table 8. Net savings for the reference case before and after retrofitting at the block scale under the future climate scenario.

Under FUTURE Climate Scenario	Net Savings [kWh/(m ² ·yr)]	Net Savings [MJ/(m ² ·yr)]	Net Savings [%]
Original	0	0	0
Insulated (I)	6.7	24.1	11%
I + Balcony L50	7.0	25.2	11%
I + Balcony L100	8.8	31.7	14%
I + Balcony L150	10.2	36.7	17%
I + Balcony L200	11.2	40.3	18%

4. Discussion

This study assessed the impact of open balconies on the energy performance of retrofitted residential buildings in Barcelona through energy simulations using climate files generated from data collected at AEMET’s official weather station, located at the city’s airport, approximately 12 km from the Eixample district. As a result, local climatic phenomena such as the Urban Heat Island (UHI) effect are not captured. Previous research [50] reported an average annual UHI intensity of approximately 2 °C in Barcelona, a value consistent with another study that specifically simulated UHI conditions in the Eixample district [51]. Both studies found a clear seasonal pattern, with higher UHI intensities recorded during winter than in summer. Increased urban temperatures compared to surrounding areas are expected to result in lower heating and higher cooling demands than those originally simulated. Since balconies tend to have a negative impact during the heating season and a positive one during the cooling season, accounting for the UHI effect would further reinforce the findings of this study. This tendency is further supported by the fact that the anticipated reduction in heating demand is likely to outweigh the increase in cooling needs.

The present study focuses on Barcelona, a mid-latitude city with a Mediterranean climate. The results may serve as a reference for other locations with similar characteristics—not only in terms of climate, but also latitude, which is a key factor influencing the shading effects of balconies. Several major cities within the Mediterranean basin and beyond fall into this category, defined by a Csa climate and a latitude of approximately 41° ± 2°. These include Madrid (Spain), Rome (Italy), Tirana (Albania), Thessaloniki (Greece), Skopje (North Macedonia), and Podgorica (Montenegro), as well as Sacramento and Redding (California, USA), among others.

Future investigations should address how changes in latitude and climatic conditions will affect the impacts of balconies on indoor comfort. To this end, we propose that those future studies should be grounded on three interrelated concepts. First, the potential hours of balcony use throughout the year under the analyzed climate. This would require

determining the percentage of hours during which the balcony is habitable, as defined within predetermined comfort thresholds. Second, the impact of balconies on the indoor environment, considering the climate, building characteristics, and urban morphology. Third, a life cycle assessment (LCA) should be conducted to calculate the environmental payback of balconies in terms of embodied energy over time. Together, these three aspects would provide a more integrated perspective on the suitability of incorporating balconies in a given context and could support recommendations for their implementation.

In this study, open balconies were modeled in a simplified manner, excluding elements such as vegetation, blinds, balustrades, or partial enclosures. While this approach is justified by the urban scale of the analysis, it inevitably departs from real-world conditions. In practice, such features can alter solar gains and thermal exchanges, potentially increasing heating and decreasing cooling demands depending not only on their configuration and use, but also the features of the building. Exploring these influences in greater detail represents a promising direction for future research. Sensitivity analyses addressing design parameters (e.g., balustrade features, lateral walls) and operational aspects (e.g., use of shading devices, incorporation of vegetation) could yield valuable insights into how balcony design and management strategies affect building performance across diverse urban contexts.

5. Conclusions

This study evaluated the impact of incorporating open balconies into energy retrofits of residential buildings in Mediterranean climates, using Barcelona's Eixample district as a case study. The effects on heating and cooling demands under both current and projected climate conditions were analyzed by comparing traditional insulation-based retrofits with an alternative strategy combining thermal insulation and balconies.

The main findings of the study can be summarized as follows:

- Balconies introduce a seasonal trade-off: heating demand increases slightly in winter (+0.1 to +1.6 kWh/m²·yr) due to reduced solar gain, while cooling demand decreases in summer (−0.1 to −3.8 kWh/m²·yr for 1 m balconies added to insulated buildings with 30% WWR) thanks to shading.
- At the block scale, these effects nearly cancel out, but at the unit scale differences are more pronounced: south-, southeast-, and southwest-facing units achieve the highest reductions (up to −2.7 kWh/m²·yr or 15%, for 1 m balconies added to insulated buildings with 30% WWR), while top-floor units may face increases due to missing overhead shading.
- The depth of balconies plays an important role in energy performance: larger ones (1.5–2 m) strengthen both the heating penalty and cooling savings. Optimal size depends on glazing: for WWR ≥ 30%, 1.5 m balconies provide the best results; for WWR = 15%, smaller 1 m balconies perform better.
- Interesting results were obtained for future predictions. Under 2050 climate projections, both insulation-only and combined retrofits reduce demand compared to un-retrofitted buildings, but insulation alone nearly doubles cooling demand. Retrofits with balconies offset this, lowering block-scale demand by up to 16% with 2 m balconies. This underscores the importance of solar protection measures in future retrofits, as cooling demands are expected to dominate in warmer climates.
- Although block-level reductions remain modest, balconies deliver localized benefits in highly glazed and south-facing units, and parametric simulations allow identifying where these interventions are most effective. It also supports evidence-based decision-making in the implementation of localized rehabilitation interventions according to their anticipated impact, thus assisting designers and urban planners in their professional practice.

In conclusion, the integration of balconies into retrofits can enhance not only dwelling livability but also its resilience to climate change by offsetting rising cooling needs. Future energy policies in Mediterranean regions should consider balcony design as a complementary measure to insulation, balancing winter heat retention with summer solar protection to optimize long-term performance.

Author Contributions: Conceptualization, E.G.-N., G.B. and J.L.-B.; methodology, E.G.-N. and G.B.; software, E.G.-N.; validation, E.G.-N. and G.B.; formal analysis, E.G.-N., G.B. and J.L.-B.; investigation, E.G.-N., G.B. and J.L.-B.; resources, G.B.; data curation, E.G.-N.; writing—original draft preparation, E.G.-N. and G.B.; writing—review and editing, E.G.-N., G.B. and J.L.-B.; visualization, E.G.-N.; supervision, E.G.-N., G.B. and J.L.-B.; project administration, G.B.; funding acquisition, G.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by Grant PID2021-122136OBC22 funded by MICIU/AEI/10.13039/501100011033, Spain. Also by ERDF A way of making Europe and AGAUR research support grant (ref. 2021 SGR 01035) funded by the Department of Research and Universities of the Generalitat of Catalunya.

Data Availability Statement: The data supporting reported results may be publicly available upon request from the authors.

Acknowledgments: The authors acknowledge any support given which is not covered by the author contribution or funding sections.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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