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Evaluating Resilience and Thermal Comfort in Mediterranean Dwellings: A Level(s) Framework Approach

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Abstract: The construction sector plays a pivotal role in urban development, providing a critical opportunity to foster a cultural shift towards the regeneration of housing stock. This shift focuses on sustainable and resilient urban interventions to extend the lifespan of buildings, starting from the design phase. In this context, the European Union's Level(s) framework, which establishes sustainability indicators, is particularly relevant to this research, as it promotes circular economy principles and building resilience. The framework provides a comprehensive set of indicators that guide resilient housing rehabilitation methodologies. Indicator 2.3 supports the design and renovation of obsolete housing, emphasizing the maximization of resilience against climatic, functional, and socio-economic impacts. Meanwhile, Indicator 4.2 evaluates the thermal comfort of building occupants concerning indoor conditions throughout the year. The primary aim of this study is to develop a resilient housing rehabilitation methodology based on Level(s), which includes (i) assessing the current resilience of a pilot case, (ii) designing new resilient housing configurations, (iii) evaluating thermal comfort duration for older adults, and (iv) analyzing cost amortization. The research findings indicate that the proposed rehabilitation approach significantly improves occupants' resilience to climate-related stressors and thermal comfort, particularly vulnerable populations such as older adults. Additionally, the study highlights the importance of adapting thermal comfort standards for these populations and demonstrates the cost-effectiveness of resilience strategies. The outcomes contribute to a flexible and accessible refurbishment model that meets diverse tenant needs, offering a scalable solution for sustainable urban interventions.

Keywords: resilience; sustainability; housing; rehabilitation; thermal comfort; level(s)

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1. Introduction

The accelerated construction expansion in urban areas has profound implications for the environment, the economy, public health, and the overall well-being of cities. In the European Union (EU), buildings account for 40% of energy consumption and 36% of greenhouse gas (GHG) emissions [1]. Alarmingly, approximately 15% of the EU population lives in inadequate housing conditions. Factors such as rising energy prices, low incomes, poor insulation, poor air quality, and overcrowded homes have contributed to an increase in energy poverty, negatively affecting the quality of life for many individuals.

Energy poverty in Europe has risen significantly due to recent economic crises, such as the global financial crisis 2008 and the COVID-19 pandemic [2]. During these periods, energy prices increased dramatically while many people in Europe faced economic difficulties due to recession and financial uncertainty.

It is estimated that around 54 million Europeans suffer from energy poverty, meaning they cannot afford essential energy services such as heating, cooling, and electricity due to high energy costs and low incomes. Between 2020 and 2021, energy prices in the EU increased by approximately 30% due to the pandemic and global supply chain disruptions, significantly increasing household economic burden [3].

Over the past decade, electricity prices in the EU have risen considerably. This trend, combined with recent economic and financial crises and the energy inefficiency of the existing housing stock, has heightened concerns about energy poverty, which now affects around 54 million Europeans. Energy poverty is defined as the inability of a household to pay for essential energy services necessary to maintain an adequate standard of living, which results from a combination of low-income, high-energy costs, and the low energy efficiency of their homes. Additionally, many homes in the EU do not provide adequate thermal comfort due to various issues, such as lack of insulation, low-quality windows, thermal leaks in building structures, excessive air infiltration, and poorly maintained heating systems [4].

On the other hand, advances in medicine have led to an increase in life expectancy worldwide. Between 2020 and 2021, the European population aged 80 and over nearly doubled. By 2050, 16% of the global population is estimated to be over 65 years old. This demographic shift has far-reaching implications for all sectors of society, including architecture, urban planning, and related services. It also poses challenges for intergenerational relationships, as the accumulated experience of older generations can foster positive outcomes and create collaborative environments that minimize the impact on users and public spending [5].

The construction sector presents a unique opportunity to foster a transformative change in urban culture, emphasizing the regeneration and resilience of the existing housing stock in response to the challenges posed by urban growth and the expansion associated with new developments. Promoting urban interventions that extend the life cycle of buildings and facilitate sustainable rehabilitation is essential. It is critical to incorporate considerations of active ageing from the design phase of projects [6]. The expected lifespan of a building significantly influences its functional utility, which is directly related to the initial investment of resources assigned to its construction. Extending the lifespan of a building can generate substantial environmental benefits. However, the actual lifespan may end earlier than anticipated due to market dynamics contributing to obsolescence, such as evolving user needs and demands. This underscores the need to address future flexibility and adaptability requirements during the design process.

Adopting this strategic approach will allow the construction sector to align with the commitments outlined in the Urban Agenda 2030 [7], the European Green Deal [8], the New European Bauhaus [9], and the principles of the circular economy, which have become key policies for developing more efficient resource conservation strategies. In response to these challenges, Level(s) has been established as a common EU framework that includes key indicators to assess the sustainability of residential and office buildings [10]. This framework can be applied from the early stages of conceptual design to the planned end-of-life phase of a building. Beyond its primary focus on environmental performance, Level(s) also facilitates the evaluation of other critical performance-related aspects through indicators and tools that address health and well-being, life cycle costs, and future performance risks. Specifically, Indicator 2.3, which focuses on design for adaptability and renewal, proposes a process that assists in designing and renovating currently obsolete housing, maximizing resilience to climate, functional, and socioeconomic challenges. Additionally, Indicator 4.2 measures the duration during which building occupants experience thermal comfort and assesses a building's ability to maintain predefined thermal comfort specifications during warm and cold weather conditions.

Consequently, this research aims to establish a resilient housing rehabilitation methodology based on the Level(s) framework. To achieve the objectives of this study, the following method has been outlined (see Figure 1): (i) assessment of the current resilience of the pilot case using Level(s); (ii) design of innovative and resilient housing configurations, along with an analysis of opportunities and constraints of the project based on **Level(s)**; (iii) evaluation of the duration outside the thermal comfort range for older adults; and (iv) cost amortization analysis.

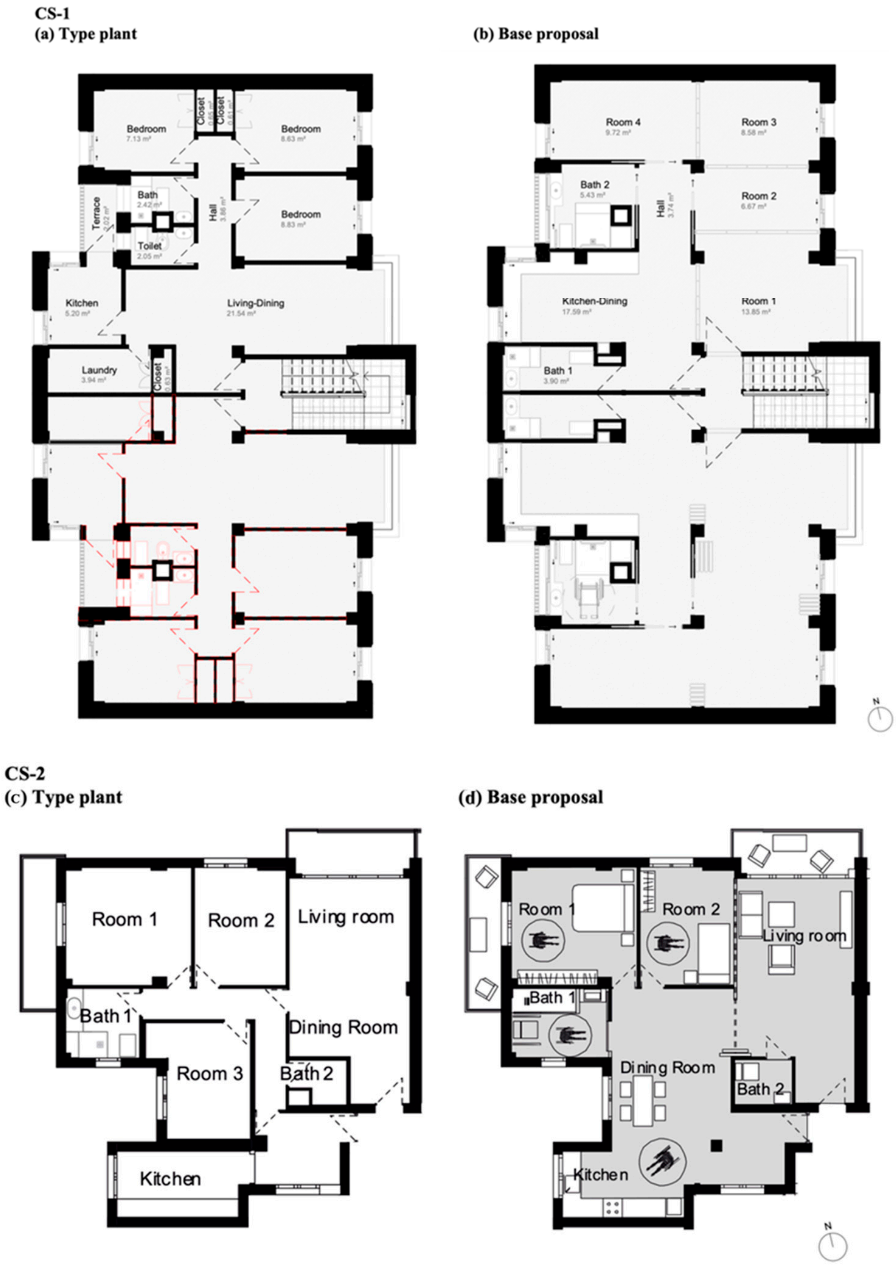

Figure 1. Case study (CS). CS-1, model plant (**a**) and base proposal (**b**); CS-2 model plant (**c**) and base proposal (**d**). The red lines correspond to the mobile panels.

The manuscript highlights the urgent need to rethink traditional construction practices to create a more sustainable, flexible, and accessible future. This shift is particularly critical considering growing challenges such as the ageing population and increasing energy poverty—issues affecting citizens' quality of life and threatening urban environments' long-term sustainability.

The research focuses on developing an integrated, adaptable, resilient housing rehabilitation model. This model, derived from a comprehensive research process, aims to accommodate a wide range of tenant needs, considering thermal comfort, cost-effectiveness, durability, and return on investment. By analyzing the metabolic energy index in older adults, the study will help adapt housing solutions and review comfort standards to better meet the needs of vulnerable populations.

The manuscript explores the primary impacts, theoretical foundations, and statistical data related to the rapid growth of urban construction and its effects on the environment, the economy, public health, and social well-being. It identifies:

Environmental Impacts: Urban construction accounts for 40% of energy consumption and 36% of GHG emissions in the EU, highlighting the sector's substantial environmental footprint.

- Economic and Social Impacts: Approximately 54 million Europeans are affected by energy poverty, struggling with high energy costs and inefficient housing. Furthermore, 15% of the EU population lives in inadequate housing conditions [11].
- Demographic Impacts: With 16% of the global population projected to be over 65 years old by 2050, the ageing population creates a need for adaptable housing solutions [5].
- Energy Poverty: Defined as the inability to afford essential energy services, it affects millions in the EU.
- Active Aging: Promotes housing designs that meet older adults' needs based on universal design principles and age-friendly cities.
- Circular Economy and Sustainability promotes construction practices that extend buildings' life cycles, reduce waste, and improve resource efficiency [12].
- Energy Consumption: Buildings in the EU account for 40% of energy consumption and 36% of GHG emissions [13].
- Energy Poverty: 54 million Europeans are affected by energy poverty [14].
- Demographics: The European population aged 80 and over nearly doubled between 2020 and 2021; by 2050, 16% of the global population will be over 65 [15].

1.1. Alignment with Key Theories

The research aligns with several key global sustainability frameworks, particularly the Urban Agenda 2030, which advocates for the regeneration of existing buildings to enhance social inclusion, environmental sustainability, and quality of life, especially for vulnerable groups. By focusing on the adaptive reuse of buildings, the study follows circular economy principles, reducing waste and improving long-term resource efficiency through sustainable renovations. Additionally, the research reinforces strategies centred on resource conservation, emphasising improving energy efficiency and ensuring the longevity of buildings—critical factors for reducing resource consumption and waste.

The study emphasises building sustainability by promoting sustainable rehabilitation methods that improve energy performance and climate resilience. This approach aligns with creating environmentally responsible and adaptable buildings capable of meeting the challenges of future urban environments. Through these strategies, the research directly promotes sustainable urban development, improves energy efficiency, reduces environmental impact, and ensures long-term adaptability. It supports creating inclusive, resilient, and socially equitable urban spaces aligned with global sustainability agendas.

1.2. Innovative Aspects of the Study

The study presents an innovative approach to urban sustainability by prioritizing the rehabilitation of existing housing stock over constructing new buildings. This shift aligns with the principles of the circular economy, promoting resource conservation and reducing waste while improving the resilience and functionality of ageing buildings. Urban regeneration through housing rehabilitation not only has the potential to reduce the environmental impact of construction but also contributes to revitalizing communities and creating more inclusive and accessible spaces.

The research employs the Level(s) framework, a comprehensive EU sustainability tool, to guide the development of adaptable and energy-efficient housing solutions. By integrating key Level(s) indicators such as adaptability (Indicator 2.3) and thermal comfort (Indicator 4.2), the study presents an innovative methodology for assessing both the environmental and social dimensions of building performance throughout its lifecycle. This integration enables a holistic approach that considers not only energy efficiency but also the capacity of buildings to adapt to changing occupant needs, particularly in the context of an ever-evolving urban environment.

A key innovation of the study is the thermal comfort assessment for older adults, a demographic increasingly affected by energy poverty and inadequate housing. The study explores how poor thermal conditions negatively impact this group and provides a framework for improving housing solutions to meet their specific needs better. This contributes to the development of age-friendly housing, ensuring energy efficiency and a healthy and comfortable living environment for this vulnerable population.

1.3. Adaptive Housing Configurations

The research proposes innovative, adaptive housing configurations considering changing social, economic, and environmental conditions. This approach is critical for addressing the needs of an ageing population and responding to challenges posed by fluctuating energy prices, low incomes, and climate change. By incorporating flexibility into the design process, the study promotes the long-term resilience of buildings.

Cost Amortization Analysis.

A significant aspect of the study is its focus on the economic feasibility of the proposed interventions. It incorporates a cost amortization analysis to ensure energy-efficient renovations are financially sustainable. This approach ensures that energy-efficient upgrades provide environmental and social benefits and long-term cost-effectiveness.

Addressing Energy Poverty and Sustainability.

The research tackles the urgent issue of energy poverty in Europe, which affects millions due to high energy costs and inefficient housing. By promoting energy-efficient housing rehabilitation, the study seeks to mitigate energy poverty, improve thermal comfort, and enhance the economic stability of vulnerable groups, contributing to the social equity goals of the European Green Deal and the Urban Agenda 2030.

1.4. Alignment with Global Sustainability Agendas

The study directly supports several global sustainability frameworks, including the European Green Deal, the Urban Agenda 2030, and the circular economy principles. By focusing on sustainable building rehabilitation, the research contributes to resource conservation, energy efficiency, and climate resilience, aligning with international social inclusion and environmental sustainability objectives.

The manuscript argues that transforming construction practices toward more sustainable and resilient models—centred on urban regeneration—is essential to addressing the challenges of an ageing population and energy poverty. Regeneration offers numerous benefits: it reduces the environmental impact of new developments, promotes affordable and energy-efficient housing, and enhances social and economic well-being, especially for vulnerable groups. Regenerating existing urban spaces can also revitalize deteriorated areas, fostering inclusive and socially cohesive communities.

In conclusion, the research underscores the importance of regenerating existing buildings to meet environmental and social goals and create more adaptable, accessible, and equitable urban spaces for future generations.

1.5. Comparison Between Existing Literature, Level(s) Framework and Current Study on Building Resilience and Thermal Comfort

Building resilience and thermal comfort have been recurring themes in research on urban sustainability and climate change adaptation. Building resilience understood as the ability of buildings to withstand and adapt to extreme conditions without losing functionality, has been extensively explored in previous studies. Numerous studies have focused on adaptive design strategies as key mechanisms for enhancing building resilience in the face of extreme weather events. These strategies include using innovative technologies and building materials, enabling adaptability over time [16–21].

On the other hand, thermal comfort in the built environment has primarily been studied from the perspective of occupant health and well-being, particularly in contexts of energy poverty. Research has examined how indoor temperature, relative humidity, and natural ventilation affect residents' thermal perceptions. Furthermore, several studies have linked inadequate thermal conditions to adverse health outcomes, particularly for vulnerable groups such as older adults and low-income individuals, for whom poorly insulated homes and ineffective heating systems exacerbate issues related to energy poverty [22–25].

Within the context of urban sustainability, the Level(s) framework has emerged as a pivotal tool for the comprehensive assessment of building sustainability. Developed by the European Commission, this framework introduces a set of indicators designed to evaluate the environmental, social, and economic impact of buildings throughout their entire life cycle. Specifically, Indicators 2.3 and 4.2 are of relevance for addressing crucial aspects of thermal resilience and thermal comfort in buildings.

Indicator 2.3 of Level(s) focuses on design for adaptability and renovation, assessing the ability of buildings to adapt to future changes in use or climatic conditions. This approach enhances the resilience of buildings to climate change, ensuring they can efficiently adapt over their life span.

Indicator 4.2, which specifically addresses thermal comfort and the building's ability to maintain suitable thermal conditions, is closely aligned with the need to ensure that buildings are not only energy-efficient but also provide a healthy and comfortable indoor environment for occupants, regardless of external climatic variations.

The present study, which focuses on developing a model for resilient housing rehabilitation using the Level(s) framework, differs from previous research in several key aspects. While the existing literature has predominantly concentrated on the construction of new buildings or the adaptation of buildings to extreme conditions, this research places a particular emphasis on the rehabilitation of the existing building stock. This approach aligns with European policies on urban regeneration and the principle of the circular economy, which promote extending the life span of existing buildings through sustainable interventions.

A central aspect of this study is the integration of thermal comfort within a broader resilience framework, which represents a novel approach compared to previous studies that address these concepts separately. Rather than focusing solely on energy efficiency or strategies to reduce environmental impact, this study explores how building rehabilitation interventions can simultaneously improve both thermal comfort and resilience. This is especially relevant in the context of energy poverty, an increasingly prevalent issue in many urban settings, particularly among vulnerable groups such as the elderly.

Furthermore, the use of the Level(s) framework in this study enables a more structured and measurable assessment of key indicators related to thermal comfort and adaptability. Unlike other studies that have focused on implementing technological solutions without considering the entire life cycle of buildings, the Level(s) framework offers a robust tool for measuring the environmental and social performance of buildings over time, which is crucial for designing solutions that are sustainable in the long term.

2. Materials and Methods

2.1. Methodology Overview

The following methodology has been established to achieve the objectives of this research: (I) Assessment of Resilience Using Level(s): Analyze the current resilience of the pilot cases using the Level(s) framework. (II) Design of Innovative Housing Configurations: Develop resilient and adaptable housing configurations; Analyze opportunities and constraints of the design based on Level(s). (III) Evaluation of Thermal Comfort for Older Adults: Assess the amount of time older adults spend outside the thermal comfort range within the selected housing environments. (IV) Cost Amortization Assessment: Evaluate the cost-effectiveness of the refurbishment strategies, focusing on their long-term financial viability.

2.2. Selection Criteria for the Case Studies

Geographical Location and Climatic Context: The location of the housing is crucial, as each area's climate significantly influences the buildings' thermal and energy requirements. The selected cases are in two cities in southern Spain, Seville and Malaga, which share a Mediterranean climate. This climate is characterized by very hot, dry summers, which present a significant challenge for the thermal comfort of residents, particularly older adults, who are more vulnerable to thermal variations. The selection of these two cases allows for exploring how different climatic conditions affect energy efficiency and thermal comfort.

Building Age: Both buildings were constructed between the 1950s and 1980s, making them representative examples of the post-war housing stock in Spain. These older buildings commonly exhibit poor insulation, inadequate heating and cooling systems, and deteriorating structures—factors contributing to high energy poverty rates in Europe.

Representativeness of the Housing Typology: Case Study 1 (CS-1) in Barriada Juan XXIII, Seville, represents a typical social housing area built during an urban expansion period, which, over time, has undergone socio-urban changes and some degree of marginalization. This type of housing is particularly relevant for studying the impact of energy poverty on vulnerable segments of the population. On the other hand, Case Study 2 (CS-2) in the Gamarra neighbourhood of Malaga, a mixed-use building (residential and offices), was selected for its typological diversity and relevance in exploring how rehabilitation can impact multi-functional buildings.

Structural and Spatial Conditions: Both cases were selected based on their structural and spatial characteristics, which present significant potential for energy rehabilitation interventions. Specifically, Barriada Juan XXIII, with its symmetrical layout and generous spaces, and the Gamarra building, with its mixed-use design, offer a variety of configurations that allow for the study of rehabilitation solutions applied to different residential typologies.

Relevance of Vulnerable Populations: Both case studies were also selected due to the presence of vulnerable populations, particularly older adults, who are more susceptible to issues arising from energy poverty and poor thermal quality in their homes. This factor is critical to the research, as it enables an evaluation of how the proposed interventions can improve the living conditions of the most disadvantaged groups.

Case Studies:

Barriada Juan XXIII, Seville (CS-1):

- Year of Construction: 1967.
- Building Type: Double-aisle, with two ground-floor flats and four additional floors.

- Living Area: 68 m^2.
- Common Areas: The residents maintain shared spaces, including storage rooms and gardens.
- Climate: Mediterranean, with very hot summers (temperatures exceeding 35 °C) and mild winters (around 10 °C), providing ideal conditions for studying the impact of climate on thermal comfort.

Gamarra Neighborhood, Malaga (CS-2):

- Year of Construction: 1970.
- Building Type: Mixed-use, residential and offices.
- Total Area per Residential Unit: 97 m^2.
- Structure: 17-story building, with offices on the first floor and residential units on the upper levels.
- Climate: It is also Mediterranean, with hot summers (temperatures exceeding 30 °C), mild winters (around 12 °C), and moderate sea breezes influence the coastal area.

These case studies provide a basis for evaluating the feasibility and impact of potential refurbishment strategies, focusing on improving resilience, energy efficiency, and adaptability to future challenges, particularly for vulnerable groups like older adults.

2.3. Assessment of the Current Resilience of the Pilot Case Using Level(s)

The initial phase of the methodology involves a thorough analysis of the current state of the pilot case, utilizing indicator 2.3 from the Level(s) framework (see Table 1). This indicator provides a structured approach to evaluate the opportunities and constraints associated with the housing refurbishment project. By applying these criteria, we aim to identify a comprehensive refurbishment strategy that maximizes the adaptability of the space, ensuring it can accommodate a diverse range of configurations for the most significant number of tenants over time.

Table 1. Level(s) indicators.

Thematic Area	Macro Objective	Indicator			
Resource use and environmental performance	1. Greenhouse gas emissions throughout the life cycle of a building	1.1 energy performance of the use stage (kwh/m^2/year)	1.2 life cycle global warming potential (co_2 eq./m^2/yr)		
	2. Circular and resource-efficient material life cycles	2.1 list of quantities, materials and shelf life	2.2 construction and demolition waste	2.3 design for adaptability and renewal	2.4 design for deconstruction
	3. Efficient use of water resources	3.1 water consumption in the use stage (m^3/occupant/year)			
Health and comfort	4. Healthy and comfortable spaces	4.1 indoor air quality	4.2 time outside the thermal comfort range	4.3 lighting	4.4 acoustics
Cost, value and risk	5. Adaptation and resilience to climate change	5.1 life cycle tools: Scenarios for projected future climate conditions	5.2 increased risk of extreme weather	5.3 increased risk of flooding	
	6. Optimized life cycle cost and value	6.1 life cycle costs (€/m^2/year)	6.2 value creation and risk factors		

2.4. Design of Innovative Resilient Housing Configurations: Analyzing Project Opportunities and Constraints Based on the Level(s) Framework

In the second phase of our methodology, guided by Indicator 2.3, we focus on identifying the most appropriate housing configurations tailored to tenants' diverse needs and living arrangements. We explore various cohabitation models, categorized by the number of residents, their relationships' nature, and the dwelling's intended use.

We propose a Basic Refurbishment Plan for the case study to maximize the building's lifespan and accommodate a wide range of tenant types. This plan is designed to allow for flexible spatial configurations that can adapt over time. The Basic Refurbishment Proposal is grounded in the following principles, aligned with the criteria outlined in Indicator 2.3:

(a) Accessibility: Ensure that access points and internal passages are appropriately sized and adapt the bathroom to accommodate wheelchair users in compliance with European regulations.
(b) Flexibility: Incorporating movable panels that enable tenants to adjust the living space according to their specific needs, whether expanding or reducing the area.
(c) Independence: Adding a second bathroom and an additional entrance to the dwelling, allowing for greater privacy and autonomy for different tenant arrangements.
(d) Economy of Means and Materials: Striking for maximum resilience while minimizing investment ensures that the refurbishment is both cost-effective and sustainable.

This comprehensive approach aims to create resilient housing configurations that can evolve with tenants' changing needs over time.

2.5. Assessment of Time Outside of Thermal Comfort Range for Elderly People

The third phase of our methodology focuses on applying Indicator 4.2, which evaluates the proportion of time throughout the year that occupants experience comfortable indoor thermal conditions. This indicator explicitly measures the percentage of time indoor temperatures fall outside the established comfort range. While the primary emphasis is on ensuring thermal comfort during the summer, assessing how well residents can maintain warmth in their homes during winter is equally important.

When analysing this indicator, we adhere to the Level(s) framework requirements. For buildings equipped with mechanical HVAC systems, it is crucial to evaluate the performance of the building envelope when the HVAC system is not in operation. This assessment aims to determine the inherent thermal resilience of the building envelope. The performance metrics are derived from dynamic energy simulations, following the methodology outlined in Annex A.2 of EN 16798-1 [26].

For our thermal comfort calculations, we utilize DesignBuilder Software, version 5.5.2.007 and the CBE Thermal Comfort Tool (an online resource for thermal comfort calculations and visualizations, SoftwareX 12, version 2.4.7). The thermal comfort criteria are based on the standards outlined in EN 16798, which utilize the PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) calculations developed by Fanger. His research, grounded in empirical studies of skin temperature, provides a framework for defining comfort levels [27].

PMV (Predicted Mean Vote): This metric assesses hygrothermal comfort by asking participants to rate their thermal sensation on a seven-point scale, ranging from cold (-3) to hot (+3). The Fanger equations are employed to estimate the mean vote of a diverse group of individuals based on various factors, including air temperature, mean radiant temperature, relative humidity, air velocity, metabolic rate, and clothing.

PPD (Predicted Percentage Dissatisfied): this parameter estimates the percentage of individuals likely to experience discomfort based on the comfort conditions defined by the PMV.

The *PMV* is calculated based on the following equation, which predicts the mean thermal sensation vote of a large group of people. It uses several parameters like air temperature, radiant temperature, air velocity, humidity, metabolic rate, and clothing insulation.

$$PMV = (0.303\ e\hat{}(-0.036\ M) + 0.028) \times ((T\_a - T\_r) + (M - W) \times (1 - F\_cl))$$

where:

- M = Metabolic rate (in watts per square meter, W/m^2)
- W = External work (typically assumed to be zero in normal conditions)
- T_a = Air temperature (°C)
- T_r = Mean radiant temperature (°C)
- F_cl = Clothing area factor
- e = Exponential function

The formula considers both the heat exchange between the body and the environment and the level of comfort that is predicted based on these variables.

PPD quantifies the percentage of people dissatisfied with the thermal environment. It is calculated using the following equation:

$$PPD = 100 - 95 \times e\hat{}(-0.03353\ (PMV)\hat{}4 - 0.2179\ (PMV)\hat{}2)$$

where:

- *PMV* is the Predicted Mean Vote (from the previous formula).

The *PPD* provides a useful metric for gauging the discomfort of building occupants in terms of thermal satisfaction.

By thoroughly assessing these factors, we aim to ensure that elderly residents can enjoy a comfortable living environment year-round and minimize the time spent outside their thermal comfort range.

2.5.1. Determining Thermal Comfort for the Elderly

Research indicates that the thermal comfort zone for seated or quiet adults, typically between 20 °C and 24 °C, is inadequate for older adults, who generally prefer a higher comfort temperature than the normotype [28]. Several studies have estimated that the optimal thermal comfort range for older individuals lies between 24 °C and 32 °C [29]. As people age, their metabolism slows down, physical activity becomes more sedentary, and muscle mass decreases, significantly reducing the energy metabolic rate, ranging from 37 W/m^2 to 40 W/m^2 [30]. Based on these data, an energy metabolic rate of approximately 0.7 met has been established for older adults (compared to 1.0 met for quiet adult men and 0.85 met for quiet adult women), where 1 met equals 58.2 W/m^2.

2.5.2. Simulations and Calculation of Time Outside the Thermal Comfort Range for the City of Málaga

Once the metabolic rate parameters for older adults have been established and the climate file (EPW) [31] has been obtained from the EnergyPlus database [32], we can calculate the metabolic rate parameters specific to the elderly population in Málaga. The specified tools are used to simulate and calculate the time spent outside the comfort range.

Thermal comfort is analyzed through simulations using DesignBuilder [33] with the EnergyPlus engine. Several scenarios were simulated (including different types of dwellings, with and without HVAC systems, and various orientations), resulting in operative indoor temperatures for each situation. The CBE Thermal Comfort Tool [27] was also employed to establish appropriate thermal comfort ranges for the target population profile. For this purpose, the metabolic energy index of older adults was input into the tool.

2.6. Assessment of Cost Amortization

Finally, the costs and benefits derived from the Base Proposal are quantified, identifying construction and material costs and rental benefits across different configurations based on Level(s) Indicator 6.1 (Table 1).

3. Results

The following sections present and analyze the results derived from applying the methodology.

3.1. Resilience Evaluation of the Current State of the Pilot Cases Based on Level(s)

This section analyzes CS-1 and CS-2 using Level(s) indicator 2.3.

CS-1 (see Figure 1 and Table 2) is located on the third floor and has a northeast-southwest orientation, with the south façade being completely opaque. The compact layout includes a kitchen, dining room, living room, bathroom, toilet, laundry room, and three bedrooms. Feedback from users indicates that it has undergone significant modifications over time. However, the space's flexibility is limited due to the structural rigidity of the building, along with accessibility issues in the communication core and within the individual units. Furthermore, the small space, low ceilings, and minimal usable surface area restrict the possibility of implementing substantial improvements to the building's facilities. Given these constraints, which are influenced by tenants' lifestyle and needs, a comprehensive refurbishment is proposed to meet both the current and future demands of residents in this social neighborhood.

Table 2. Residential building checklist of adaptability design concepts.

Adaptability Design Concept	**Specific Design Aspect to Address**	**How the Design Aspect Can Contribute to Adaptability**		
		Original (SC-1, SC-2)	Basic Proposal (SC-1, SC-2)	Weighted score (SC-1, SC-2)
1. Changes to the internal space distribution	1.1 Wall systems that support layout changes	The design of the internal walls is fixed, limiting the ability to transform the space.	The use of movable panels to increase space flexibility.	13.5
	1.2 Greater ceiling heights for surface routes	Due to the absence of a suspended ceiling, it is not possible to install air-conditioning ducts or expand the space.	No changes have been made, as increasing the ceiling height is not possible.	0
2. Changes to the buildings servicing	2.1 Ease of access to the building services	The building's services are accessible from the ground floor.	No changues were made.	-
	2.2 Ease of adaptation of the distribution networks and connectors	The building's structure does not support the adaptation of distribution networks.	To make each studio independent, the distribution networks and connectors for a new downspout have been adjusted to accommodate an additional bathroom.	0
3. Change to the use of units or floors	3.1 The potential for a segregated home working spaces	It is possible to make independent a space with adequate dimensions, light and services within the home.	The addition of new movable panels, a new bathroom, and an alternative entrance allows for part of the flat to be privatized as a studio, office, or similar space, while also creating a new living area.	9
	3.2 The potential for ground floor conversion to a contained unit	It is possible to make independent a space with adequate dimensions, light and services on the ground floor.	No changes were made.	9
4. Changes in access requirements	4.1 Ease of access to each residential unit	A complete modification of the vertical communication core would be required to comply with regulations.	The width of the new entrance door to the house was changed to 1 m.	9
	4.2 Access to and manoeuvrability within rooms	A complete restoration of the communication core and dwellings would be required to enable wheelchair access and improve maneuverability.	The passage widths throughout the house have been modified to ensure wheelchair accessibility in all rooms.	9
		Total, weighted score 49.5		49.5

CS-2 (see Figure 1 and Table 2) is located on the eighth floor, with a southeast orientation, and is characterized by a clear division of spaces. This larger dwelling features a kitchen-dining area, living room, two bathrooms, a laundry room, and three bedrooms. User data suggests that it has undergone minimal modifications over time. However, the pronounced separation between spaces leads to functional issues; for example, the dining room is located a considerable distance from the kitchen, often resulting in its repurposing for other uses. The long layout suggests that the space could be better utilized. Despite these challenges, the home has excellent spatial potential, with its generous size, two independent entrances, and two balconies.

3.2. Designing New Resilient Housing Configurations: Analyzing Project Opportunities and Constraints Using the Level(s) Framework

This section presents the Base Proposal (BP) and potential configurations for each case study (CS). In both CSs, the BP aims to maximize the intervention's effectiveness by promoting flexibility and efficient space utilization. Areas such as the living room, study, and bedrooms are transformed into dynamic spaces that offer a range of creative possibilities and enhanced versatility in their use.

Each of the three configurations provides distinct rental options, catering to the needs of both the owner and the tenant. Notably, in all configurations, the home can serve solely as a residential space for a family unit or as a combined living and workspace for the owner or tenant, highlighting the innovative and dual-purpose nature of the design.

3.2.1. Resilient CS-1 Configurations

Regarding CS-1, as shown in Figure 2, the preliminary proposal seeks to optimize the intervention by enhancing flexibility and maximizing space utilization. Areas such as the living room, study, and bedrooms are designed to be adaptable, offering a high degree of versatility.

Configuration 1 (Figure 2): This layout features two independent rooms with movable partitions that can function as either a bedroom or a study. It accommodates 3 to 4 users, with easy access to shared areas and the main bedroom. Potential users include:

- Families of 1 to 3 members, where the two independent rooms can be used as bedrooms or studios.
- Families caring for a dependent individual, allowing the dependent person and their caregiver to share common spaces while maintaining privacy in their respective bedrooms and bathrooms.

Configuration 2 (Figure 2): This configuration also includes two independent rooms that can serve as a bedroom, study, or office, using movable partitions. It supports 3 to 4 occupants, with common areas oriented to the northwest, offering the option to privatize the living room. The main bedroom and study are easily accessible, promoting smooth circulation between the kitchen-dining area and living room. Over time, potential users could include:

- A family of 1 to 2 members with a studio or office space.
- A family of 1 to 2 members who may decide to rent out a part of the dwelling, such as a 14 m^2 studio with a separate bathroom.

Configuration 3 (Figure 2): This layout also features two independent rooms with movable partitions that can be adapted as a bedroom, study, or office. It accommodates 2 to 3 users and maximizes privacy by eliminating the living room and minimizing shared space to the kitchen-dining area. Potential users might include:

- An individual who works from home.
- An individual who rents part of their dwelling, such as a studio with an independent bathroom.

Figure 2. New configurations of SC-1 and SC-2.

3.2.2. Resilient Configurations of CS-2

Configuration 1 (Figure 2): This layout features two rooms and a separate living area with movable partition walls, accommodating 3 to 4 users. Potential users may include:

- Families of 2 to 4 members.
- Families caring for a dependent individual, where the dependent person and caregiver share a close relationship and common spaces.

Configuration 2 (Figure 2): This configuration includes two rooms and a separate office area with movable partitions, allowing for one of the spaces to be rented. Potential users could include:

- Families of 1 to 3 members, with an office suitable for one or two workers.
- Families caring for a dependent individual, where the dependent person and caregiver maintain a close relationship and share common areas, while also having an office for one or two workers.

Renting part of the dwelling, measuring 12.80 m^2.

Configuration 3 (Figure 2): The third proposal offers the option to rent a studio apartment independent of the main dwelling. Two independent living spaces can be created by adjusting the partition panels. Potential users over time may include:

- Families of 1 or 2 members, with an additional studio that can accommodate one or two individuals.
- Families caring for a dependent individual, where the dependent person and caregiver share common areas, and the studio can accommodate one or two individuals.
- Renting part of the dwelling, measuring 23.60 m^2.

3.3. Assessment of Time Outside the Thermal Comfort Range for Elderly Individuals

This section provides a comprehensive analysis of the simulation and calculation results aimed at evaluating the thermal comfort zone for elderly individuals and predicting the duration of time spent outside this comfort range in the specific case study.

Figure 3 illustrates the comfort range graph generated by the CBE Thermal Comfort Tool, which is based on a metabolic energy index of 0.7 met. This index is particularly relevant for elderly or vulnerable populations, considering Malaga's specific climatic conditions. The resulting comfort range is identified as being between 24.5 °C and 32 °C.

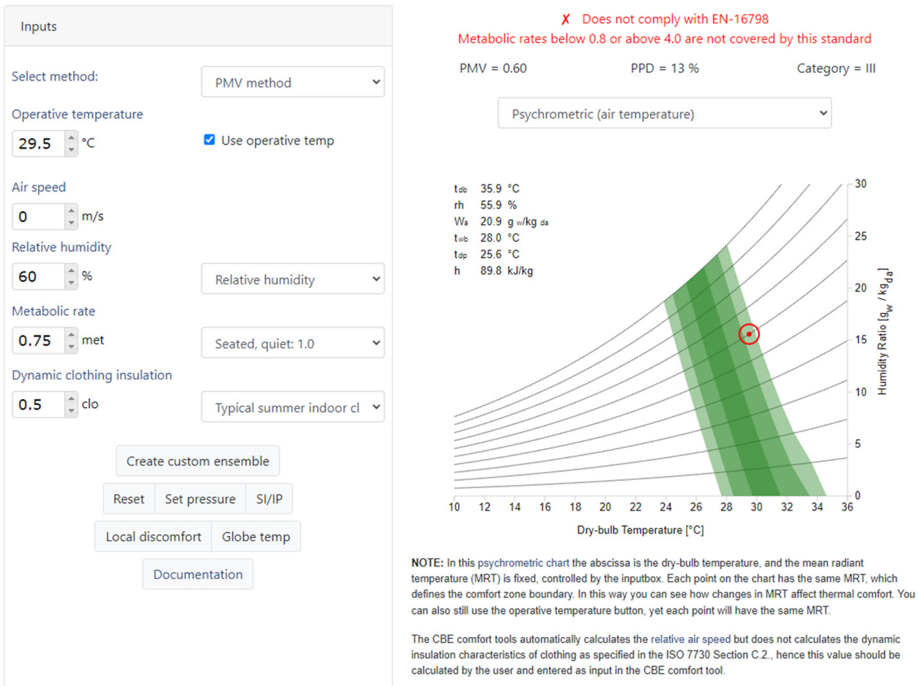

Figure 3. Thermal comfort range for the elderly.

However, it is important to note that the findings from the simulation indicate that this comfort range does not align with the EN-16798 standard [34]. The EN-16798 standard specifies a minimum metabolic rate of 0.8 met, which needs to be adequately covered by the current comfort range derived from the simulation. This discrepancy highlights a significant concern regarding the thermal comfort of elderly individuals in Malaga, as the established range may not provide sufficient comfort or safety for this demographic.

In conclusion, the assessment underscores the necessity for further investigation and potential adjustments to the thermal comfort parameters to ensure they meet the standards required for the well-being of elderly populations. Addressing these gaps is crucial for enhancing vulnerable groups' living conditions and overall health in varying climatic contexts.

An analysis was conducted to evaluate a winter scenario in which the dwelling was heated according to the heating setpoints outlined in the Spanish Technical Building Code (2019). This analysis was compared to a setpoint temperature derived from the previously established comfort range.

Figure 4 illustrates the predicted percentage of discomfort experienced by occupants at two distinct heating setpoints: 21 °C, the maximum permitted by the Spanish Technical Building Code, and 24.5 °C, the minimum within the identified comfort range.

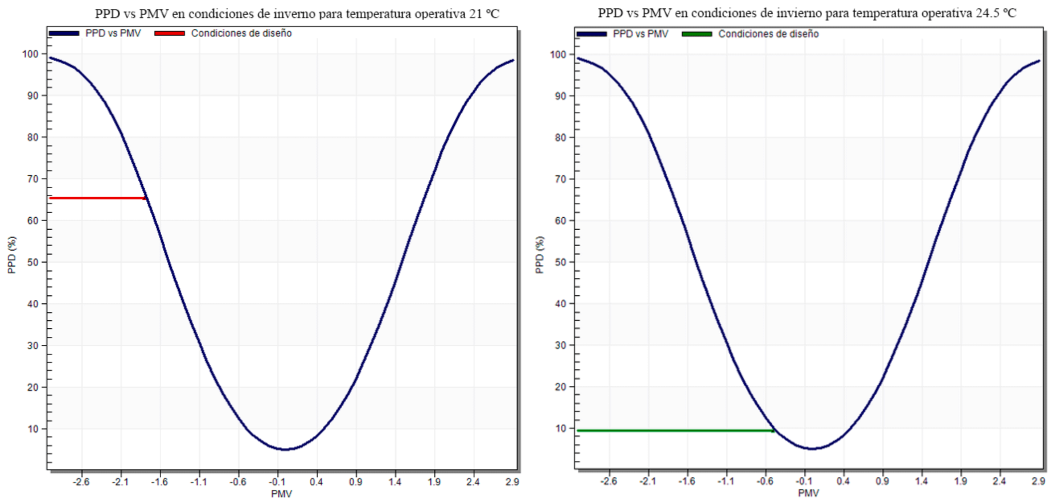

Figure 4. Comparison of predicted percentage of discomfort under heating temperature set points of 21 °C and 24.5 °C.

The findings reveal a significant disparity in occupant comfort levels at these two temperatures. Specifically, 73% of individuals reported experiencing discomfort at the 21 °C setpoint. In contrast, only 9.5% of individuals reported discomfort when the temperature was set to 24.5 °C.

These results underscore the importance of aligning heating practices with comfort standards, particularly for vulnerable populations such as the elderly. The data suggest that adhering to the higher comfort setpoint not only enhances the overall well-being of residents but also significantly reduces the percentage of individuals who experience discomfort during the winter months. This analysis highlights the need to reevaluate current heating regulations to accommodate the thermal comfort requirements of occupants better, ultimately promoting healthier living environments.

A comparable analysis was conducted for a summer scenario, focusing on the cooling setpoint temperatures as a benchmark for occupant comfort. Figures 4 and 5 present the predicted percentage of discomfort experienced by individuals at two specific cooling setpoints: 25 °C, the minimum temperature mandated by the Spanish Technical Building Code, and 27.5 °C, which falls within a more comfortable range.

This analysis reveals a significant difference in discomfort levels between the two temperatures. At the 25 °C setpoint, 65.5% of individuals reported experiencing discomfort. This high percentage indicates that the minimum cooling temperature established by the code may not adequately address the thermal comfort needs of occupants during the hotter months. In contrast, when the cooling setpoint is raised to 27.5 °C, the predicted percentage of discomfort drops dramatically to just 8.5%.

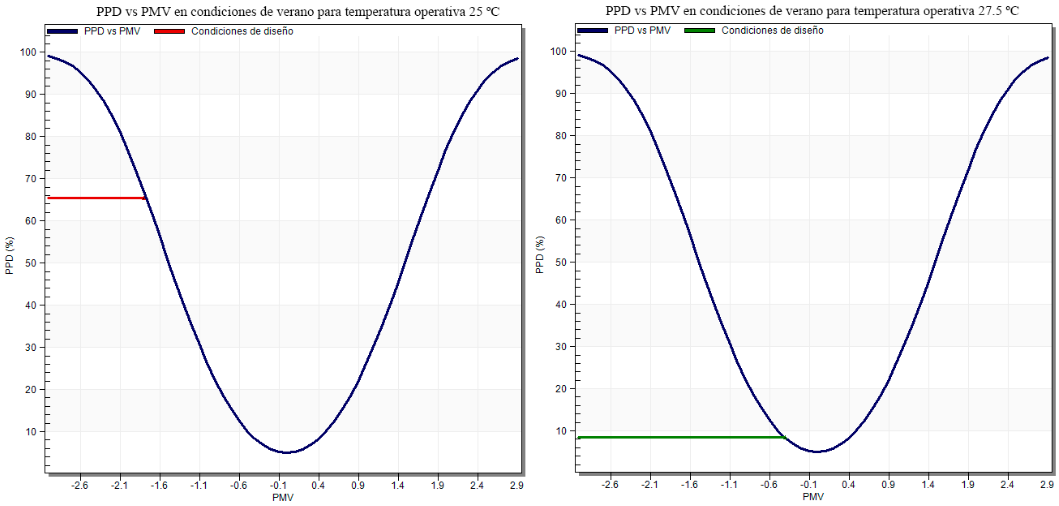

Figure 5. Comparison of predicted percentage of discomfort under cooling temperature set points of 25 °C and 27.5 °C.

These findings highlight the importance of optimizing cooling strategies to enhance occupant comfort in residential settings. The stark contrast in discomfort levels suggests that a higher cooling setpoint can lead to a more pleasant indoor environment, significantly reducing the number of individuals who feel uncomfortable during the summer heat.

This analysis emphasizes the need to reassess current cooling regulations and advocates for a more nuanced approach to temperature settings that prioritizes occupant well-being. By aligning cooling practices with comfort standards, we can create healthier and more enjoyable living spaces, particularly during the sweltering summer months.

3.4. Assessment of Cost Amortization

In this section, we comprehensively analyse the costs and benefits associated with the three resilient configurations. This analysis includes a detailed breakdown of the construction and material costs for the Base Proposals and the potential rental income generated from each configuration.

We have identified several key improvement measures to calculate the refurbishment costs accurately. These include the insufflation of a 4 cm rock wool air chamber, which enhances insulation, and installing double-glazed windows with specifications of 4-16-6, paired with Class 3 PVC frames. These upgrades are designed to improve significantly in energy efficiency and occupant comfort.

As illustrated in Table 3, the payback period for Configurations 2 and 3 is estimated to be a maximum of four years. This estimation is based on the average rental price per square meter derived from local real estate databases. Such a relatively short payback period indicates that these configurations not only recoup their initial investment quickly but also offer a sustainable financial model for property owners.

Moreover, a long-term perspective on housing lifespan reveals numerous opportunities for extending the value of these properties. Property owners can expect a higher return on investment over time by investing in resilient configurations. Additionally, these improvements contribute to significant environmental benefits, such as reduced energy consumption and lower carbon emissions, aligning with broader sustainability goals.

In summary, the assessment of cost amortization for these resilient configurations underscores their financial viability and environmental advantages, making them attractive options for current and future housing developments.

Table 3. Identification of costs and depreciation of the investment.

	CS-1			CS-2		
	C1	**C2**	**C3**	**C1**	**C2**	**C3**
m^2 available	-	14 m^2	21.20 m^2	-	13.40 m^2	24 m^2
rental price m^2		21 €	21 €		22 €	22 €
estimated rental price	-	294 €	445 €	-	295 €	528 €
economic cost of refurbishment	15,456 €	15,456 €	15,456 €	18,165 €	18,165 €	18,165 €
amortisation time (years)	-	4–5	2.5–3.5	-	5–6	2.5–3.5

4. Discussion

The resilience assessment of pilot cases CS-1 and CS-2 provides valuable insights into their current conditions and adaptability. However, not considering previous research loses the opportunity to place the findings within a broader context. Relevant studies that could complement the results and improve understanding of the challenges and solutions raised are reviewed below [35].

Flexibility in Housing Design

CS-1′s structural rigidity can benefit from adaptive approaches such as those proposed by Leder et al. (Simões et al., 2025), who highlight the importance of flexibility in housing to meet changing needs. Solutions such as movable walls and modular spaces could improve adaptability without major structural reforms.

Space Optimization and Functional Design

The CS-2 case faces distribution problems, addressed in studies such as Zou et al.'s (Zou et al., 2021) on optimizing optimal homes. Reconfiguring the spaces of CS-2 with multifunctional areas would improve the home's functionality and use.

Thermal Comfort for Vulnerable Populations

The gap in thermal comfort standards, especially for older people, could be addressed by following research like that of Kanchwala (Kanchwala, 2025) that provides guidelines for improving thermal comfort through more efficient systems and insulating materials that reduce reliance on heating.

Participatory Design and User Feedback

Participatory design, such as that proposed by Kowaltowski et al. (Kowaltowski et al., 2024), ensures that designs are better adapted to users' needs. Including residents in the design process in cases CS-1 and CS-2 would increase the effectiveness and acceptance of the reforms, improving their quality of life.

Social Sustainability and Community Resilience

Studies on social sustainability and community cohesion, such as those by Stenberg et al. (Stenberg, 2018), highlight how design can foster interaction and strengthen social resilience in urban neighbourhoods. Accessible, communal spaces could improve integration and well-being in neighbourhoods such as CS-1.

Climate Change Resilience

Based on EU-level Technical Guidance on Adapting Buildings to Climate Change BEST PRACTICE GUIDANCE, the climate-resilient design suggests integrating green roofs and rainwater harvesting systems. This would not only improve thermal comfort but also contribute to the environmental sustainability of homes.

Integrating previous research on flexibility, thermal comfort, energy efficiency, participatory design and social sustainability would strengthen the proposals for CS-1 and CS-2. These solutions would allow for the creation of more resilient, adaptable and sustainable homes aligned with international best practices.

5. Conclusions

This research highlights the urgent need for resilient housing solutions in urban environments, particularly in the European Union, where a significant portion of the population lives in inadequate housing conditions. The findings underline the construction sector's critical role in addressing energy poverty, improving thermal comfort, and promoting sustainable living environments.

Resilience and adaptability: The evaluation of the pilot cases, CS-1 and CS-2, reveals that both homes face unique structural rigidity and spatial configuration challenges. The proposed comprehensive retrofit strategies aim to improve flexibility and adaptability, allowing these homes better to meet the changing needs of diverse tenant populations. By incorporating movable panels and additional facilities, the designs promote a more dynamic use of space, which is essential in modern housing.

Thermal comfort for vulnerable populations: The thermal comfort analysis, particularly for elderly residents, indicates a significant gap between current housing standards and the actual comfort needs of this demographic. The comfort range established for Malaga does not align with the EN-16798 standard, suggesting that many older people may experience discomfort due to inadequate heating and cooling practices. This finding emphasizes the need to re-evaluate thermal comfort parameters to ensure the well-being of vulnerable populations.

Economic feasibility: The cost-recovery assessment demonstrates that the proposed resilient configurations provide substantial environmental benefits and present a financially viable model for property owners. With relatively short payback periods for retrofit investments, these configurations can generate higher returns while contributing to reduced energy consumption and carbon emissions.

Policy alignment: The research aligns with broader EU commitments, including the Urban Agenda 2030 and the European Green Deal, which advocate for sustainable urban development practices. By integrating the Level(s) framework into design and retrofit processes, the construction sector can effectively contribute to achieving these policy goals.

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