ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

D4.3 DESIGN GUIDELINES FOR REFURBISHED AND NEW BUILDINGS IN THE POSITIVE CIRCULAR COMMUNITY IN PALMA

WP4 SUSTAINABLE BUILDING (RE) DESIGN

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[1] *ARV is a Norwegian word meaning "heritage" or "legacy". It reflects the emphasis on circularity, a key aspect in reaching the project's main goal of boosting the building renovation rate in Europe.*

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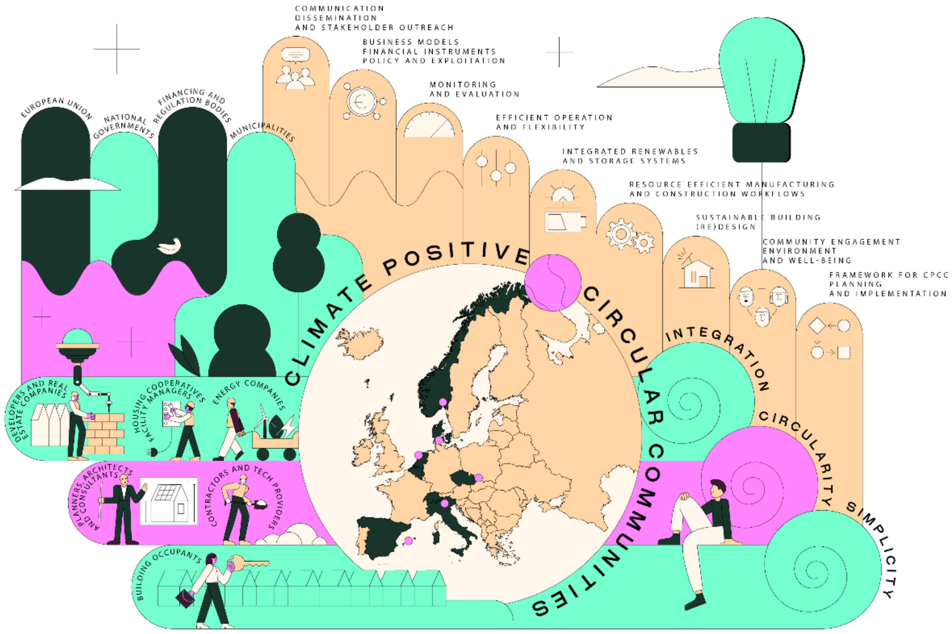
ABOUT THE ARV PROJECT

The vision of the ARV project is to contribute to speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come. The overall aim is to demonstrate and validate attractive, resilient, and affordable solutions for CPCC that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries. To achieve this, the ARV project will employ a novel concept relying on a combination of 3 conceptual pillars, 6 demonstration projects, and 9 thematic focus areas.

The 3 conceptual pillars are integration, circularity, and simplicity. **Integration** in ARV means the coupling of people, buildings, and energy systems, through multi-stakeholder co-creation and use of innovative digital tools. **Circularity** in ARV means a systematic way of addressing circular economy through integrated use of Life Cycle Assessment, digital logbooks, and material banks. **Simplicity** in ARV means to make the solutions easy to understand and use for all stakeholders, from manufacturers to end-users.

The 6 demonstration projects are urban regeneration projects in 6 locations around Europe. They have been carefully selected to represent the different European climates and contexts, and due to their high ambitions in environmental, social, and economic sustainability. Renovation of social housing and public buildings are specifically focused. Together, they will demonstrate more than 50 innovations in more than 150,000 m^2 of buildings.

The 9 thematic focus areas are 1) Effective planning and implementation of CPCCs, 2) Enhancing citizen engagement, environment, and well-being, 3) Sustainable building re(design) 4) Resource efficient manufacturing and construction workflows, 5) Smart integration of renewables and storage systems, 6) Effective management of energy and flexibility, 7) Continuous monitoring and evaluation, 8) New business models and financial mechanisms, policy instruments and exploitation, and 9) Effective communication, dissemination, and stakeholder outreach.



The ARV project is an Innovation Action that has received funding under the Green Deal Call LC-GD-4-1-2020 - Building and renovating in an energy and resource efficient way. The project started in January 2022 and has a project period of 4 years, until December 2025. The project is coordinated by the Norwegian University of Science and Technology and involves 35 partners from 8 different European Countries.

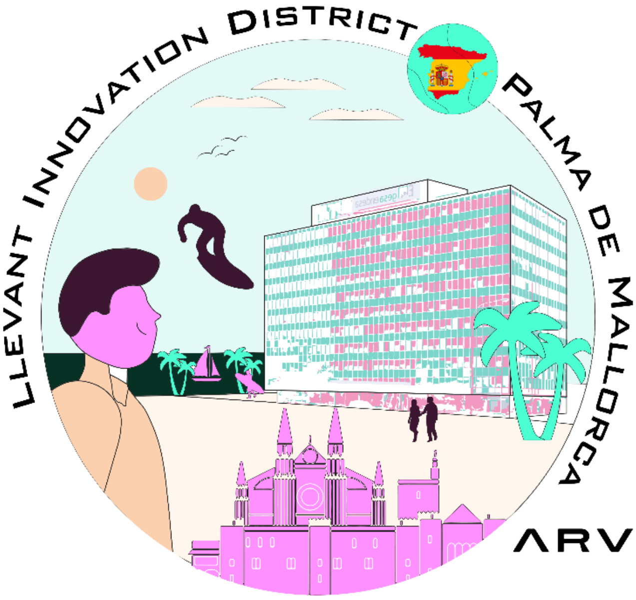
EXECUTIVE SUMMARY

The main objective of this report is to describe the design process of the three principal actions involved in the demo in Palma de Mallorca. The principal goal is the integrated circular design, evaluation and implementation of Climate Positive Circular Communities (CPCCs). The CPCCs design includes concepts of scalability, flexibility, durability and maintainability throughout the whole life cycle of the buildings.

The report involves the main stakeholders in the three actions whose focus is to explain the decision-making process in the design phase by analysing qualitatively and quantitatively the most relevant aspects taking into account the spatial, economic, technical, environmental, regulatory and social context of the district.

Actions described in this document are:

- Large scale retrofitting in La Soledad Sud of 250 private dwelling by means of a novel Public-Private-Partnership.
- New positive energy social housing building with 36 apartments.
- Energy Renovation of a flagship heritage protected building from the 70's modern movement.



The design and evaluation processes are different for each action. Therefore, the report is divided into three distinct sections:

1. Design in large scale retrofitting process.
2. Design in new social housing buildings.
3. Design in GESA building.

TABLE OF CONTENTS

1. INTRODUCTION

The goal of the ARV project is to contribute to speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come.

A Climate Positive Circular Community **(CPCC)** is an urban area, which aims to achieve net zero greenhouse gas emissions, enables energy flexibility, and promotes a circular economy and social sustainability. The CPCC concept focuses strongly on the **interaction** and **integration between new and regenerated buildings, users,** and **energy systems, facilitated by ICT to provide attractive, resilient, and affordable solutions** for citizens**.**

In this context, Work Package (WP) 4 addresses the (re)design of new and retrofitting of existing buildings as zero-emission positive energy-buildings in sustainable CPCC. Therefore, the main objectives can be summarised as follows:

- Reduction of embodied energy and emissions.
- Increasing energy efficiency.
- Reconciling sustainability with aesthetics and quality of life through integrated circular design processes.

ARV's integrated circular design includes adaptation to local climate conditions, in-depth renovation with minimal disruption to the building's occupants, significant reduction of CO_2 emissions, and high energy efficiency with active and passive solutions. In addition, a strong focus should be given on the circular economy, i.e., the reduction, reuse and recycling of materials, elements and modules, value addition and resource and energy efficient integration of photovoltaic systems, i.e. Building-Integrated Photovoltaics (BIPV) and Building Applied Photovoltaics (BAPV), while considering occupant wellbeing and architectural aspects.

Design considerations include scalability, flexibility, durability, ease of maintenance, fire and seismic safety of the buildings. The circular positive energy buildings and neighbourhoods will be embedded in the spatial, economic, technical, environmental, regulatory and social context of the demo sites. The ultimate goal of WP4 is an integrated circular design that cultivates aesthetics and enhances the amenities of the building's occupants, while increasing the performance of the buildings in line with the new European Bauhaus strategy [1].

The activities in WP4 are divided into six main tasks that address design strategies of buildings integrated in CPCCs. The main goal of Task 4.4 is the integrated circular design and evaluation of different concepts for zero-emission and positive energy buildings within sustainable climate positive circular districts in Palma. The key actions in the district can be summarized as:

- Large scale retrofitting action in La Soledat Sud and Nou Llevant of 250 private dwellings by means of a novel Public Private Partnership (PPP) mechanism.
- New positive energy social housing building with 36 apartments.
- Energy Renovation of a flagship heritage protected building from the 70's modern movement.

The first version of this report is dedicated to documenting the planning, design and construction activities of these three actions. The main methodologies used in this report are data collection, building energy simulation in Transient System Simulation (TRNSYS) software and other tools, post-processing of the simulation results in Python, energy and economical calculations and reporting. Further revisions (December 2023 and December 2024) will describe and report the further results of the scenarios analyses.

In order to benchmark against the general ARV objectives set out in the Grant Agreement (GA) (**Table 1**), the following factors were analysed:

- Design and architectural qualities.
- Social qualities.
- Environmental sustainability (energy use, emissions, recyclability, circularity, etc.).
- Economy (global cost and investment cost).

Table 1. *Overview of target values for new and renovated buildings in ARV CPCCs.*

Assessment criteria	New construction	Renovated buildings
Energy	**At least 50% reduction in energy needs** compared to current country building code. **Positive energy** level based on primary energy.	**At least 50% reduction in energy needs** compared to pre-renovation levels. At least Nearly Zero Energy Building (**NZEB**) standard.
IEQ	High levels of indoor environment quality according to EU norms.	**At least 30% improvement** compared to pre-retrofitting levels according to EN 16798-1:2019.
Noise and dust levels	According to the EU health, safety, and environment standards.	**At least 30 % reduction** in occupant disruption during retrofitting compared to local current practice.
Embodied emissions	**At least 50% reduction** compared to local current practice.	
Construction/retrofitting time	**At least 30% reduction** compared to local current practice.	
Life Cycle Costs	**At least 20% reduction** for the community compared to local current practice.	
Construction/retrofitting costs	**At least 30% reduction** compared to local current practice.	

2. EXECUTIVE SUMMARY OF THE PROJECTS IN PALMA

2.1. VISION AND GOALS

The Spanish demo case is the *Llevant Innovation District* (DILL) in Palma de Mallorca. It encompasses a mixed used development area including residential, tertiary, and educational buildings, with both new construction and renovation activities. The set of actions that will be undertaken by the ARV project will encompass resource efficient renovation processes at large scale and district energy analysis and operation, highlighting social, educational, and digital aspects to enhance citizens involvement.

The main goal of the sustainable design is to provide an integrated circular design and evaluation of different concepts for zero-emission and positive energy buildings within sustainable climate positive circular districts in Palma. The key actions in the district can be summarized as:

- ***Action 1*: Large Scale retrofitting action** in La Soledat Sud and Nou Llevant of 250 private dwellings (26 800 m^2) by means of a novel Public Private Partnership mechanism. **Cost-optimal solutions for retrofitting** of buildings in large-scale renovation process aiming to achieve 50% reduction in the energy demand and a significant improvement in the thermal comfort conditions.

- ***Action 2:*** New Positive Energy **Social Housing Building** promoted by IBAVI: 36 apartments with a total area of 1750 m^2. Design, construction, and monitoring of 36 apartments multifamily building with the ambition level of being a Positive Energy Buildings in 2023 by a Public Social Housing promoter. Strong focus on the use of **innovative local materials and resilience against climate change.**

- ***Action 3:*** Proposal of **Energy Renovation of a flagship heritage protected office building** from the 70's modern movement (Antic Edifici GESA) along with testing and monitoring of several BIPV solutions regarding aesthetics aspects and energy production.

Figure 1 demonstrates a map of the three principal actions in sustainable design involved in the demo in Palma de Mallorca.

Figure 1. *A map of the principal actions in sustainable design involved in the demo in Palma de Mallorca.*

The vision and goals of the project are intended to demonstrate how the project will impact various aspects such as architectural, social and environmental.

Architectural vision and goals:
One of the main goals of the project is to reduce embodied energy in buildings by 50%. Therefore, the architectural vision of the large-scale retrofitting *(Action 1)* is to provide cost-optimal retrofitting solutions for large and medium multi-family buildings constructed before 1980, while in addition using local building materials.

The integrated energy design for the retrofitting will be proposed for the protected and iconic heritage GESA office building from the Modern Movement (1970) *(Action 2).* GESA building is characterized by a glass curtain wall, therefore, an integrated design solution for the envelope is a necessity to reduce the energy demand to 50% compared with the pre-retrofit status. In order to achieve architectural vision of the project, the design concept includes a pre-testing of several last generation BIPV solutions. Designing an optimal solution for high glazed office buildings will not only affect aesthetics aspects, but also has an impact to the heating and cooling loads and energy production. Several Heating, Ventilation, and Air Conditioning (HVAC) solutions and strategies will be analysed and designed adapted to the local climate by means of integrated design linked with the envelope solutions in the façades.

Lack of ventilation significantly affects people's health by causing various building-related health symptoms such as respiratory diseases, allergies, headaches, and others [2]. Therefore, Integrated Design for social housing *(Action 3)* will consider hybrid ventilation solutions driven by Indoor Air Quality (IAQ) metrics for cooling and heating, which are intended to provide also a high architectural quality.

Environmental vision and goals:
Another principal goal of the project is to reduce Greenhouse Gas (GHG) emissions towards zero for the total life cycle compared to the current situation shown through cradle-to-cradle Life Cycle Assessment (LCA). In this regard, in order to reduce GHG emissions in the product stage, solutions based on the recovery of eco-friendly local artisan industries with km 0 raw materials are planning to be tested. Increased use of local materials will in addition contribute to the ARV´s circularity pillar, which aims at durability, flexibility, adaptability, reuse, and recycling of materials.

Social vision and goals:
Cost-optimal solutions for large-scale retrofits aim not only to reduce energy demand by 50%, but also to significantly improve thermal comfort conditions. The social vision of the *Action 1* is thus to provide optimal thermal comfort to the residents while keeping houses affordable. A catalogue of technical solutions for replicability will be derived, which guarantees a high level of replicability for other projects, which will lead to an improvement in thermal comfort and affordability for other residents.

The vision of *Action 2* is a design of a new Energy Positive Social Housing with 36 apartments. Utility bills account for a large portion of the operating costs for a multifamily building, so reducing energy costs is one of the primary solutions to preserve affordable housing.

3. URBAN PLANNING CONTEXT: THE LLEVANT INNOVATION DISTRICT

Until 1851, the area was a vegetable garden called “S’Hort del Ca”, with few constructions, one of them, a convent and a church that after would give the name to the neighbourhood “La Soledat” in reference to ”Nuestra Señora de la Soledat”.

The landscape of the area was characterized by the existence of windmills placed in a linear way **(Figure 2)**. The mills were located from the urban center of "Es Molinar" to the sector of "Llevant de Palma", taking advantage of the wind called "s'embat". During centuries the sector of Levant was the main point of transformation of the cereal that supplied the city of Palma.

Figure 2. *Pre-industrial windmills [3].*

Since then, the Llevant Innovation District (DILL) has developed in three different stages.

First stage of development: La Soledat Sud. A history associated to industrial development

The first development of La Soledad neighbourhood was directly associated to the industrialization process in the island. The first Industrial Revolution led to demographic growth that triggered the need for new urban space.

After the restrictions established in the city of Palma, in which steam engines were prohibited inside the walled city, the Can Ribas blanket factory sought a new location in the surroundings of the city, outside the military protection zone, which was located at a distance of 1,000 meters from the walled boundary.

In the 19th century, La Soledat became an industrial hub hosting the development of the industrial economy on the island. The main factories were Can Ribes, a blanket factory, established in 1851 in the center of the actual neighbourhood of La Soledat, and decades later, at 1938, it was established Can Salom, a shoe factory. During the following decades, the area was urbanized in order to provide housing to the factory workers in the surroundings of the factory.

These was the typical housing of Mallorca at that time (**Figure 3**): one or two flours housing with sand stones structural walls, wooden beams cealings and tild roof with the also common ceramic tiles and it is located out of the old city walls.

Figure 3. *Aerial view of Can Ribes factory and the typical housing [3].*

In 1943, the area south of La Soledat were qualified as industrial (**Figure 4**). Later, in 1962, the Son Molines power plant was installed. The factories contributed to the development of the working-class in the neighbourhood.

Figure 4. *Denomination of residential and industrial zone (Plan of 1943). Adopted from [3].*

After the approval of the 1963 urban plan, it was allowed to increase the building density without allocating hardly any space for equipment and green areas. At that time, industries tended to be located outskirts of the city. As a result, empty lots were left, and small residential buildings were replaced by large residential buildings.

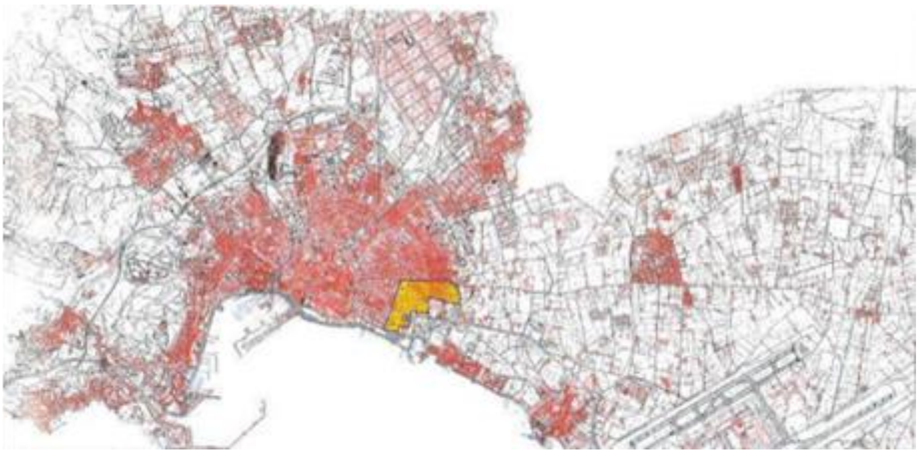


Figure 5. *"La Soledat" and "Polígono de Levante" in the city. Adopted from [3].*

Second stage of development: Polígono de Levante

During the 1970s, the increase in Mallorca's population due to its consolidation as a tourist destination generated the need to build low-cost housing.

Several social housing units were built around the traditional area, and others also to the south of the district. This fact gave rise to the creation of the "Poligono de Levante", which today is called "Nou Llevant".

Figure 6. *Formation of La Soledat and the Industrial Park. Adopted from [3].*

Third stage of development: Llevant Innovation District

The current world economic situation has highlighted the economic dependence of the Balearic Islands, based on the **tourism sector**. On the other hand, the **climate emergency** that affects us all forces us to act to curb its effects. At the same time, in recent years we are seeing how **social inequality** is growing and more and more vulnerable groups. Therefore, we need tools to offer opportunities to citizens, and the creation of an **innovation district** is one of them, as it is a geographical area where they converge housing, offices and shops that will serve as a technological base oriented to innovation.

In this context, the area of **Nou Llevant** has the development potential that can respond to these needs and can also contribute to the urban regeneration of the neighbourhood of La Soledad Sud, which requires interventions to alleviate the social vulnerability of the area.

The **Palma Council**, together with the **Government of the Balearic Islands**, the **Conseil of Mallorca**, the **Balearic Islands Authority,** and **the University of the Balearic Islands** will take advantage of this opportunity offered to them and promote the project of the District of Innovation of the Levante.

The project is developed in 5 lines of work, which could be classified into two stages:

Medium term (2020-23)

Innovative Hub - Campus Palma Tech

It is planned to generate an urban campus (**Figure 7**) belonging to the University of the Balearic Islands, which will bring the university closer to the city and its economic fabric.

Figure 7. *Project of Campus Palma Tech.*

Living lab "Es Laboratori" at Fábrica Gorilla

Palma citilab is a collaborative co-creation space, structured in 4 initiatives:

- **FABLab**: digital creation workshop with technological tools that promote the culture of own creation.
- **PalmaLab**: space for technological dynamization of the city to boost the talent of citizens.
- **TecnoLab**: **laboratory/workshop** to start a technology school.
- **SmartDestinationLab**: observatory of Palma's smart tourist destination.

Figure 8. *Branding image of the Living Lab in Palma.*

Long-term (2024-33)

They are projects that aim to promote the development of new productive sectors, to attract companies and talent. This would be achieved by creating hubs and clusters focused on specific economic activities.

Energy Hub – Cluster of Energy transition (TE21)

The main objective of the innovation centre for the energy transition is to turn Palma, Mallorca, and the Balearic Islands into an international benchmark in terms of energy model based on energy efficiency and renewable energies. Its main objective will be to promote projects and facilities related to the transition of energy model based on the use of renewable energies. To do this, it will use the spaces created by projects such as Citilab or the innovative HUB to generate synergies with the innovation district as a whole.

Digital hub for creative cultural industries

The objective of the Digital Hub is to create a tool to promote new opportunities for creative cultural industries related to the audio-visual sector, cultural creation, and dissemination. In this sense, the attraction of talent related to audio-visual and creative activities will be promoted and alternatives will be opened to sectors complementary to tourism in Mallorca.

Tourism and Innovation Hub

Tourist activity in the city, as well as in the rest of the Balearic territory is the main economic engine of Palma. The application of a tourism hub will implement the application of technology to this sector.

Finally, to reduce social inequality and fight against the vulnerability of the area, the city council has launched urban transformation initiatives through the following actions:

Cooperation project of the PERI of La Soledat. Cooperative reparcelling and redevelopment of the area.

Figure 9*. Plan of proposed image from actual urban planning.*

Construction of **housing and the equipment of** the **Ciutat de Queretaro.** Increase in the public stock of housing and emergency accommodation.

Opening of Brotad Street (La Soledat). For integration between neighbourhoods of La Soledad and Nou Llevant and of these with the rest of the city. One particular factor that led to the degradation of La Soledat was its isolation from the city due to urban development, in which the main streets of the neighbourhood did not connect with the main streets of the city. Therefore, La Soledat functioned as a separate city, which led to the development of the ghetto.

Figure 10. *Actions to connect with the centre of the city.*

4. DESIGN IN LARGE SCALE RETROFITTING PROCESS

One of the Expected Impacts of the Call[2] (EICs) of the ARV project is to achieve at least 50% reduction in energy needs compared to pre-renovation levels. At the same time, the socio-economic vulnerability of residents is one of the current growing challenges for CPPCs in addressing the interaction between the vulnerable residential population and the need to improve the building stock.

With an aim of addressing the issue of low energy renovation rates and vulnerable neighbourhoods, the purpose of the large-scale retrofitting process in the Spanish demo is to access funding through the Neighbourhood Retrofit Assistance Programme defined in Article 9 of Royal Decree 853/2021 [4]. The purpose of the program is to finance the joint implementation of retrofitting works in predominantly residential buildings and dwellings, including single-family houses, and the urbanization or redevelopment of public spaces within action areas called Residential Environments of Programmed Rehabilitation (ERRP).

In accordance with the objectives set out in the Annex to the Council Implementing Decision (CID) of 16 June 2021, approving the evaluation of Spain's recovery and resilience plan, the granting and execution of assistance under this programme will support the fulfilment of the following objectives:

- *CID Objective No. 27:* Complete the renovation of dwellings with an average saving of at **least 30% of primary energy** (**231 000 renovations in at least 160 000 dwellings**) by the fourth quarter of **2023.**
- *CID Objective No. 28:* Hectares of renovated areas or districts with an average saving of at **least 30% of primary energy (600 ha)**, second quarter of **2026.**
- *CID Objective No. 29:* Completion of renovation measures in residential buildings with an average saving of at **least 30% of primary energy (510 000 renovation measures in at least 355 000 residential buildings)** by the second quarter of **2026.**

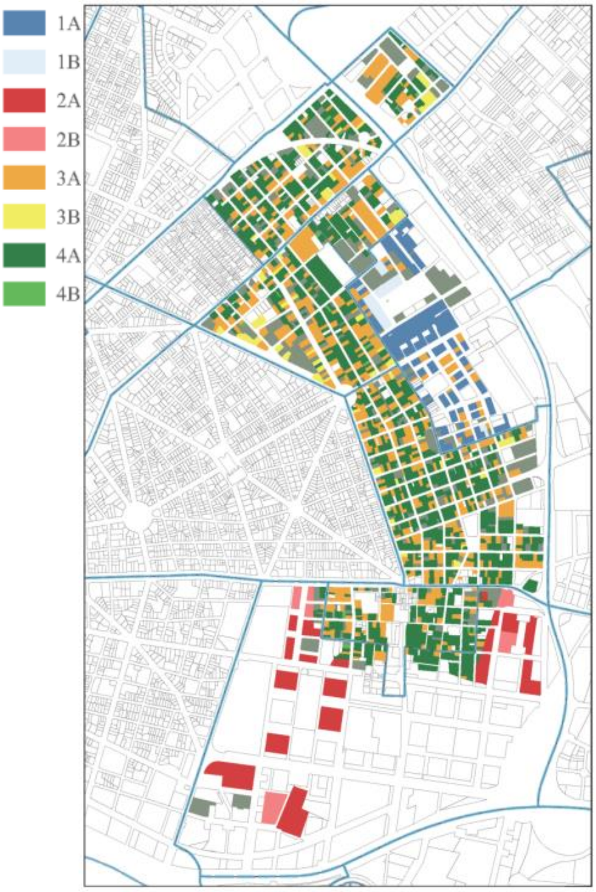
Therefore, the main objective in the large-scale renovation of existing buildings is to reduce the energy consumption of houses to at least 30% of non-renewable primary energy consumption, referring to the Energy Performance Certificate (EPC). For residential buildings, this goal can be achieved by improving the thermal envelope of the building and improving the energy efficiency of the heating and ventilation systems. The maximum amount of the subsidy is determined on the basis of the energy savings achieved by the measure and the total cost of the measures to be implemented. **Table 2** shows how access to this programme contributes to tackling energy poverty by reducing the price of housing and making it affordable for households.

Table 2. *Correlation between energy savings achieved with the action and the percentage of the subsidy. Adopted from [4].*

Energy savings achieved with the action	Maximum percentage of the subsidy of the cost of the action	Dwelling	Commercial premises or other uses
		Maximum amount of housing grant (euros)	Maximum amount of aid per m² (euros)
$30\% \leq \Delta E_{p,nren} < 45$	40	8 100	72
$45\% \leq \Delta E_{p,nren} < 60\%$	65	14 500	130
$\Delta E_{p,nren} \geq 60\%$	80	21 400	192

[2] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-gd-4-1-2020

In order to generate the ERRP zone, a study has been carried out by the city council according to building typology. A code system was created to identify buildings by size, year of construction and, in some cases, area.



Code	Building type	Year of construction	Area
1A	Multifamily	Before 1981	Son Gotleu Son Ximelis Mare de Deu
1B	Multifamily	1981-1990	Son Gotleu Son Ximelis Mare de Deu
2A	Multifamily	Before 1981	Nou Llevant
2B	Multifamily	1981-1990	Nou Llevant
3A	Multifamily	Before 1981	Rest of the area
3B	Multifamily	1981-1990	Rest of the area
4A	Single family Multifamily with (< 3 dwellings)	Before 1981	Rest of the area
4B	Single family Multifamily with (< 3 dwellings)	1981-1990	Rest of the area

Figure 11. *Groups of buildings throughout the ERRP area.*

The area of the city studied for the ERRP document is larger than the district covered by the ARV project. Focusing on the DILL district, the typology of buildings can be seen in **Figure 12**.

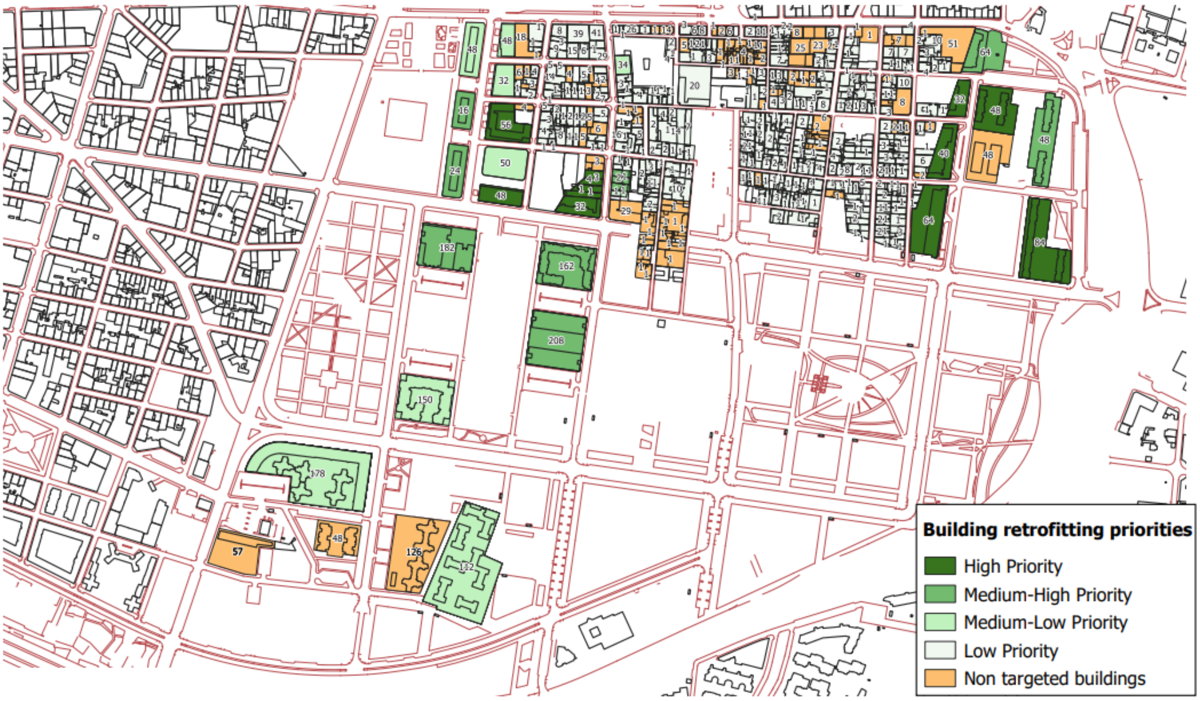
Figure 12*. Building codes according to assignment in ERRP document.*

Two areas can be clearly identified: one centered on the Soledad neighbourhood with small single-family and multi-family buildings and a periphery of large blocks of multi-family buildings.

Similarly, the revision of the Palma General Plan establishes in Article 4.5.8 of the Neighbourhood Improvement and Revitalisation Program (Programa de Millora i Revitalització de Barri), with the aim of adopting a coordinated and complementary set of measures to revitalise and improve the urban quality of the existing city and consequently designate statistical areas of greater vulnerability.

With the aim of concentrating efforts, priority areas within the district have been proposed by the city council to start the work of awareness and citizen engagement (**Figure 13**).

Ajuntament de Palma



Numbers indicate de quantity of dwellings per plot or building

***Figure 13**. Priority areas and number of dwellings per building in DILL area.*

If the public sector is leading the renovation project, end-users are eligible for a larger share of grants and soft loans [5]. Therefore, Palma City Council proposes to carry out the large-scale energy retrofit of the Soledat Sud and Nou Llevant neighbourhoods through a Public-Private Partnership between the city council and several private actors, including financial companies, while implementing a participatory strategy that involves the end users (i.e., the neighbourhood residents) in the project. In addition, the ARV project foresees the external support of a *rehabiltation agent* through a public-private cooperation model based on a single public tender where a private company is selected to manage the entire project (**Figure 14**).

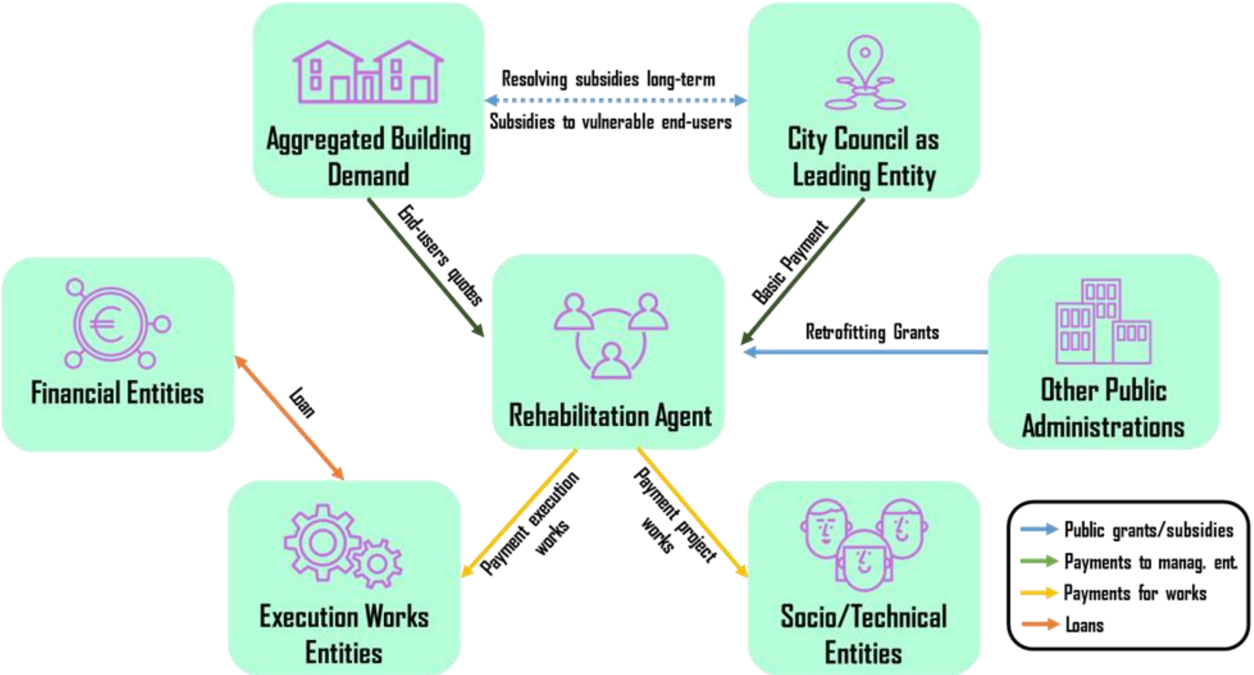


Figure 14. Monetary and financial fluxes for the PPP model. Adopted from [5].

4.1. SELECTION OF THE BUILDING ARCHETYPES

As a first step, the general priority area for retrofitting measures was defined in cooperation with the Palma City Council. Secondly, several selection criteria were applied to the defined area to identify potential building archetypes for the application of sustainable design concepts.

The first criterion applied to the selected priority area is the year of construction of the building. **Figure 15** shows a map of the selected area with different colour codes for the buildings based on their year of construction. It is worth noting that most of the buildings were built before 1980, specifically in the period of 1961-1980, so the areas marked light blue could be potential candidates for retrofitting as they represent the majority of the buildings in the area.

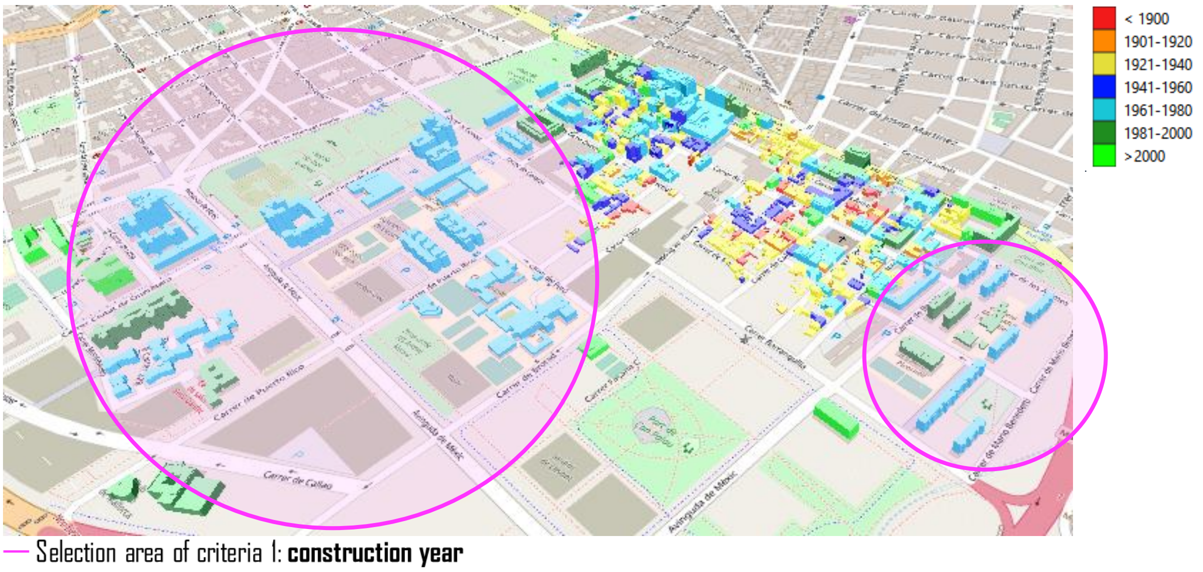


Figure 15. A map of the selected area with different colour codes for the buildings based on the construction year.

With this first criterion the focus is on the typology of buildings with code B by year of construction (before 1981).

The second criterion that has been applied is the typology of the building. **Figure 16** shows a map of the selected area with different colour codes for the buildings based on their typology – single family, small and large multifamily buildings. Typology of the buildings have been selected based on the size of constructed area (**Table 3**).

Table 3. *Correlation between the construction area of the building and corresponding building typology.*

Typology	Construction area - S (m²)	Number of buildings
Single family	S ≤ 300	173
Small multifamily	300 < S ≤ 1 400	111
Large multifamily	S > 1 400	60

Based on the **Figure 16**, small and especially large multifamily buildings are representing most of the dwelling stock of the priority areas (**Figure 15**), that make them potential building archetypes. In addition, the economy of scale is one of the biggest advantages of multifamily housing versus single family housing. As land costs rise, developers must fit more housing units on a single lot. The costs of design, regulation and operation do not vary much by building size, so larger buildings allow developers to spread these fixed costs over more dwellings.

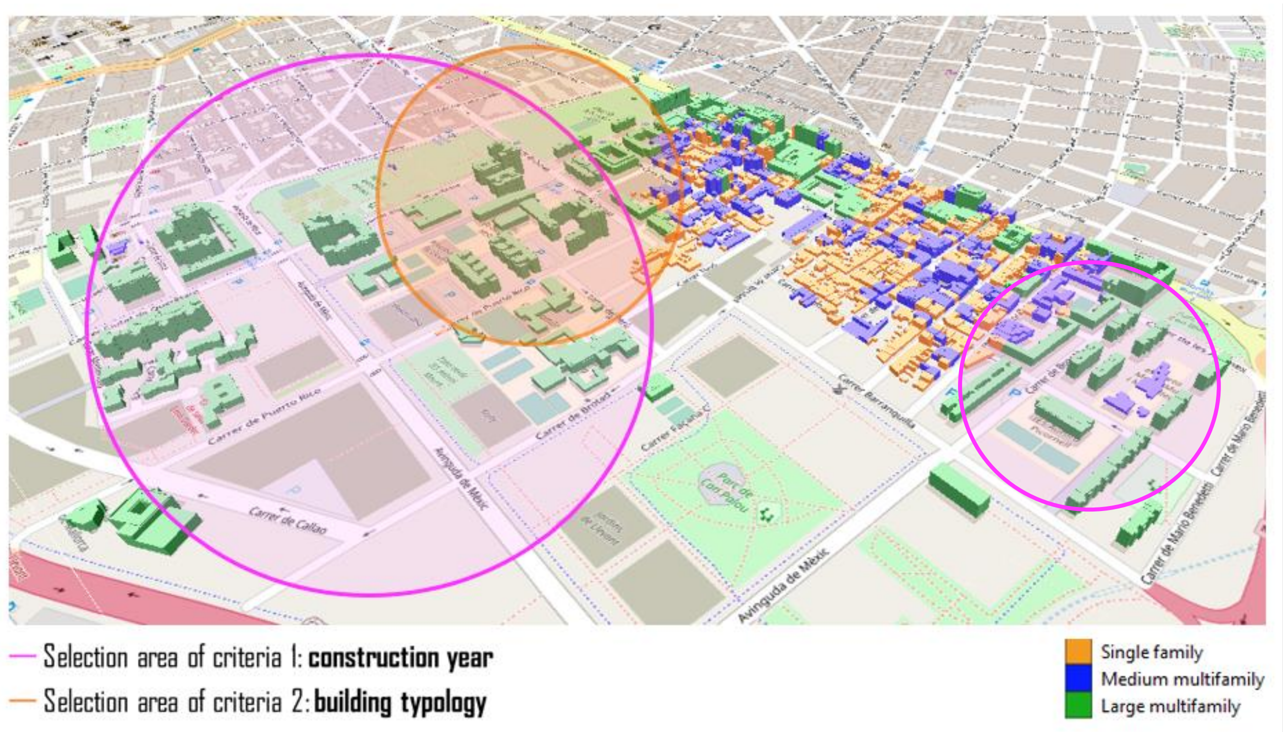


Figure 16. *A map of the selected area with different colour codes for the buildings based on the construction year (criteria 1) and building typology (criteria 2).*

A second circle has been marked in the area with a concentration of large multi-family buildings, as the economies of scale and the impact on the district will be greater.

As a result, the selected building archetypes should be located in the intersection of the areas with the following criteria: construction year in the period of 1961-1980 and be a small and a large multifamily building. **Figure 17** and **Figure 18** show two building archetypes that were chosen for the further analysis:

Archetype 1: Large multifamily building – code 2A (**Figure 17**).
Archetype 2: Small multifamily building – code 3A (**Figure 18**).

Figure 17. *Selected building archetype: large multifamily building 2A (Carrer de Caracas 1).*

Figure 18. *Selected building archetype: medium multifamily building 3A (Carrer de la Fe 36).*

One of the most relevant aspects, as already mentioned, is the commitment of the owners to undertake the energetic retrofitting of their building. With this in mind, it is expected that there will be an easier entry if the owners are residents. Therefore, a study of this aspect has been carried out (**Figure 19**), obtaining the resident owners, the non-resident owners, and the legal entities of priority areas according to **Figure 13**.

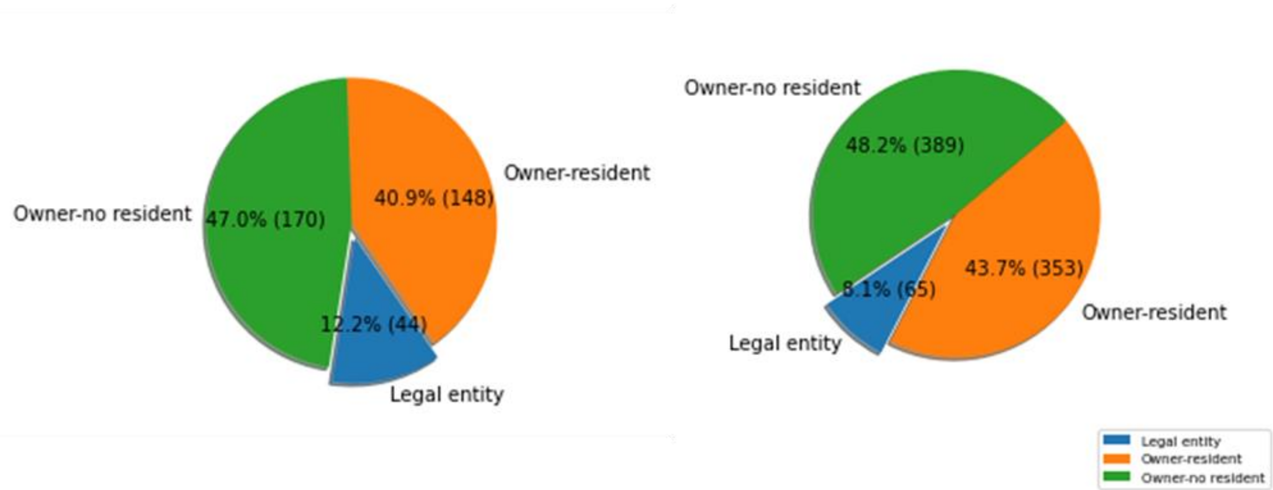


Figure 19. *Pie chart with the distribution of high priority (left) and medium-high priority area (right) of the typology of owners.*

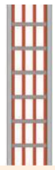
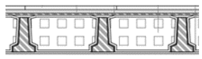
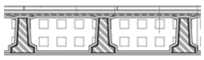
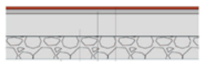
It is expected that the legal entities are open to the retrofitting process because the value of the houses would increase, together with the owners that are living within the buildings. Therefore, in the case of high priority area we obtain 53.1% of owners who could be more open for retrofitting and in the case of medium-high priority area it would be 51.8%. In any case, the engagement process under a PPP mechanism aims to overcome barriers and engage owners in the retrofitting actions.

4.1.1. DESCRIPTION OF LARGE MULTIFAMILY BUILDING ARCHETYPE

The first typology selected for sustainable design is a large multifamily building at Carrer de Caracas 1 (**Figure 17**), which is the representative building type in the area of Nou Llevant. It is a 4-storey building, where each floor consists of twelve flats. Each flat consists of a living/dining room, a kitchen, a bathroom, two bedrooms, and a balcony. In addition, one of the main features of this building is an open ground floor. The main façade connecting the building to the street faces southwest and another main façade faces the green space to the northeast. The side façades face northwest and southeast respectively.

The building was constructed before 1980, when energy regulations for buildings were very limited. Therefore, buildings from this construction period can be characterised by minimal thermal performance requirements for the building envelope, less efficient cooling and heating systems, older windows and other energy consuming features. The description of the structural elements of the building such as walls, floors, windows and ceilings are summarised in **Table 4**.

__Table 4.__ The description of the structural elements of the building.

Element	Layers	Thickness [m]	U-value [W/m²K]	Image
External walls	Plaster coating	0.01	2.207	
	Concrete block	0.20		
	Plaster coating	0.01		
Internal walls	Plaster coating	0.01	2.603	
	Perforated masonry brick wall	0.07		
	Plaster coating	0.01		
Roof	Plaster coating	0.01	1.926	
	Unidirectional slab of prestressed concrete beams	0.003		
	Roofing tar	0.01		
Ceiling	Terrazzo pavement	0.03	1.866	
	Cement mortar	0.02		
	Unidirectional slab of prestressed concrete beams	0.20		
	Plaster coating	0.01		
Ground floor	Terrazzo pavement	0.03	0.921	
	Cement mortar	0.01		
	Filler concrete	0.15		
	Compacted soil	0.15		
Windows	Glass: simple glass	0.006	5.69	-
	Frame: aluminium no thermal break	-	2.26	

The building model has been performed to provide energy and thermal comfort performance predictions. The energy simulations of the building with impacts of shading effects from nearby buildings are carried out with TRNSYS, using SketchUp as a 3D interface (**Figure 20**).

Figure 20. *The building model with a shading effect from nearby buildings (Archetype 1).*

The first floor, an intermediate and the top floor were selected for the simulation in order to observe critically behaving zones. The internal distribution of each floor with three representative dwellings is presented in **Figure 21**. Distribution of day and night zones is proposed as following: each dwelling has two day zones (D1 and D2) and two night zones (N1 and N2). Zone D1 consists of a living and a dining room with a balcony and zone D2 consists of a kitchen and a bathroom with a corridor. Zone N1 consists of two bedrooms and zone N2 consists of one bedroom.

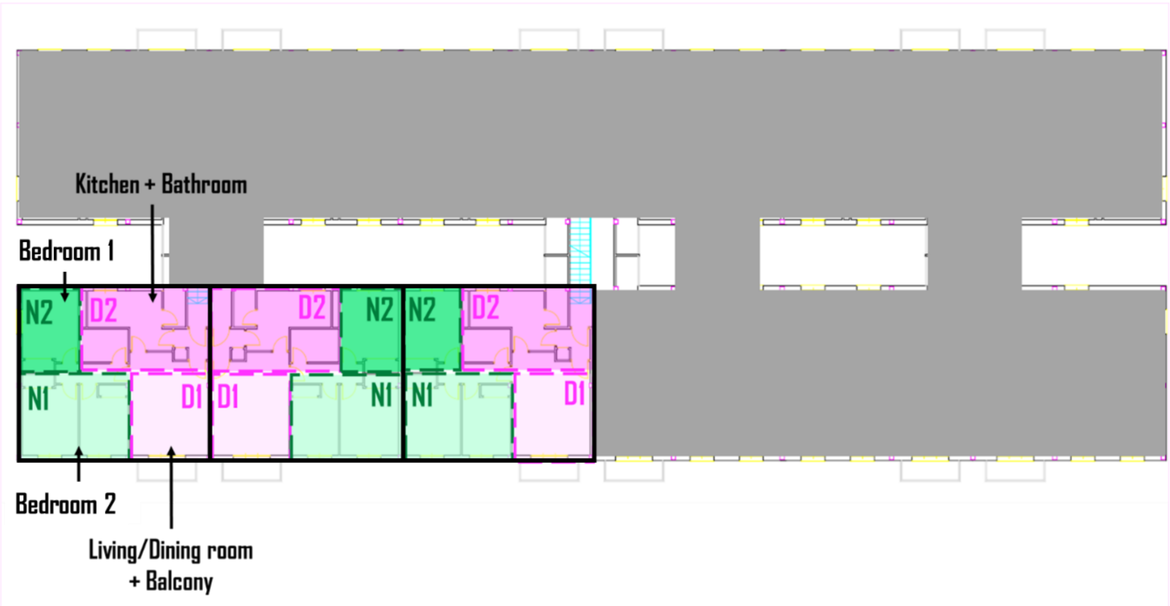


Figure 21. *The internal distribution of the floor with thermal zones proposal (Archetype 1).*

4.1.2. DESCRIPTION OF MEDIUM MULTIFAMILY BUILDING ARCHETYPE

The second typology selected for sustainable design is a medium multifamily building at Carrer de la Fe, 36 (**Figure 18**), which is another representative building type in the area of Nou Llevant. It is a 4-storey building, where each floor consists of one flat and the first floor in addition consists of the shop and the attic. Each flat consists of a living/dining room, a kitchen, two bathrooms, four bedrooms, and a balcony. The main façade connecting the building to the street faces southeast and another main façade faces other buildings to the northwest. The side façades face northeast and southwest respectively.

Similar to the first typology, the building was constructed before 1980 and is characterized with the same materials presented in **Table 4**. The energy simulations of the building with impacts of shading effects from nearby buildings is presented in **Figure 22**.

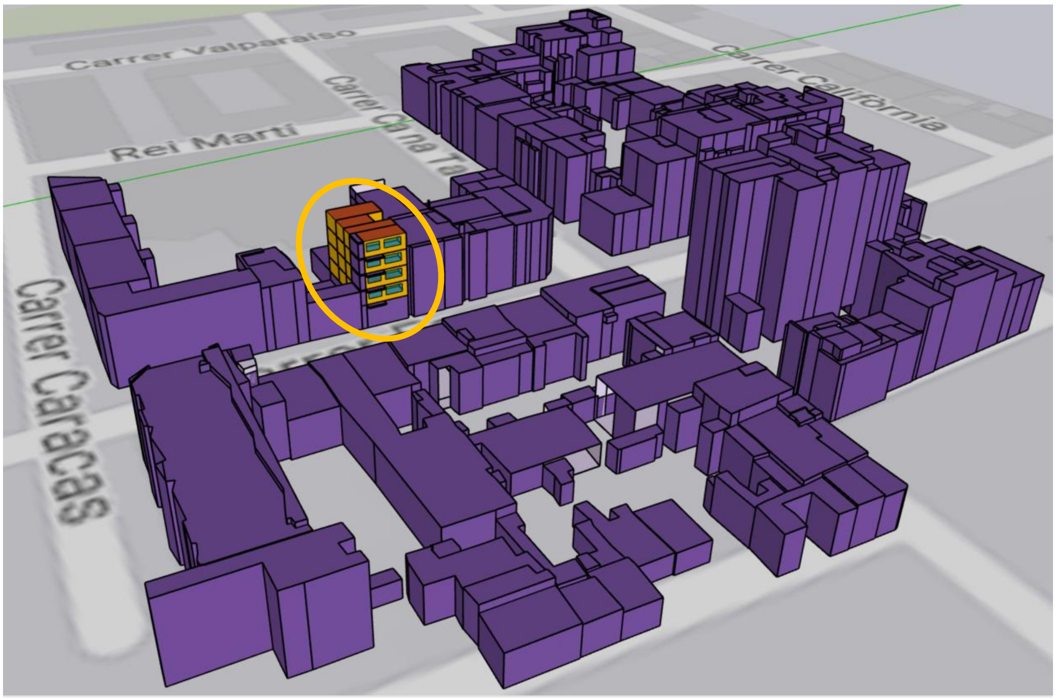


Figure 22. *The building model with a shading effect from nearby buildings (Archetype 2).*

The internal distribution of the floor is presented in **Figure 23**. Distribution of day and night zones is proposed as following: each dwelling has two day zones (D1 and D2) and two night zones (N1 and N2). Zone D1 consists of a living/dining room and zone D2 consists of a kitchen, a bathroom and a hall. Zone N1 consists of one bedroom and a bathroom and zone N2 consists of three bedrooms.

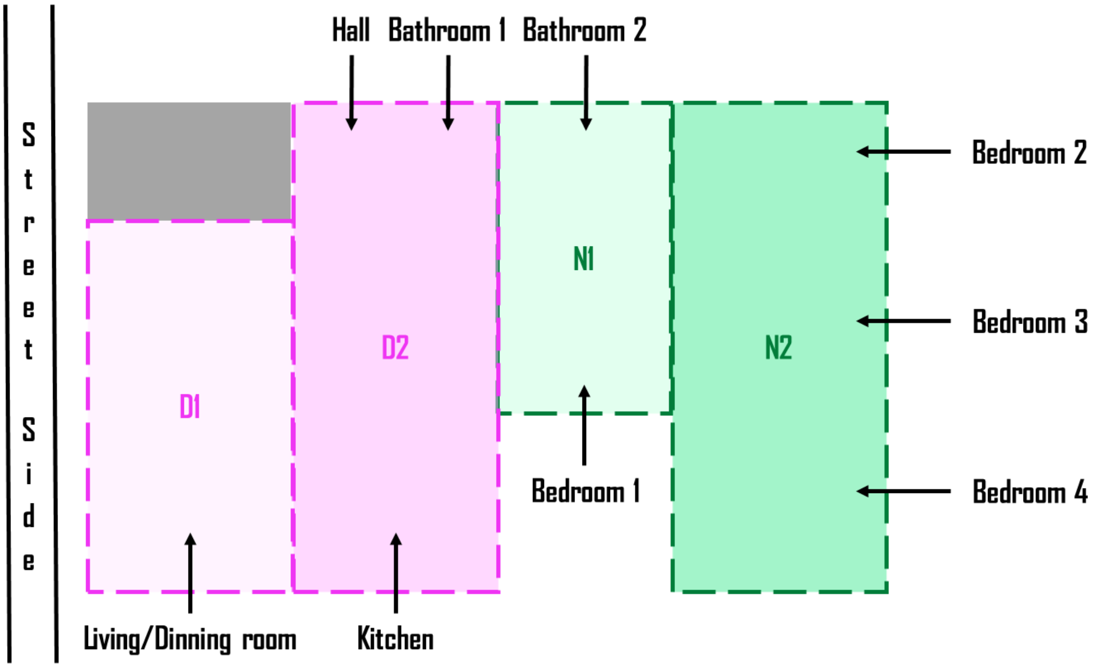


Figure 23. *The internal distribution of the floor with thermal zones proposal (Archetype 2).*

4.2. CONCEPT DESIGN

The integrated energy design process has been done based on a multicriteria analysis, considering energy, environmental, indoor comfort, and economic parameters. Overall, the design process should apply several steps (**Figure 24**), starting from acting in the design phase by integrating passive measures to implementing Renewable Energy Systems (RES).

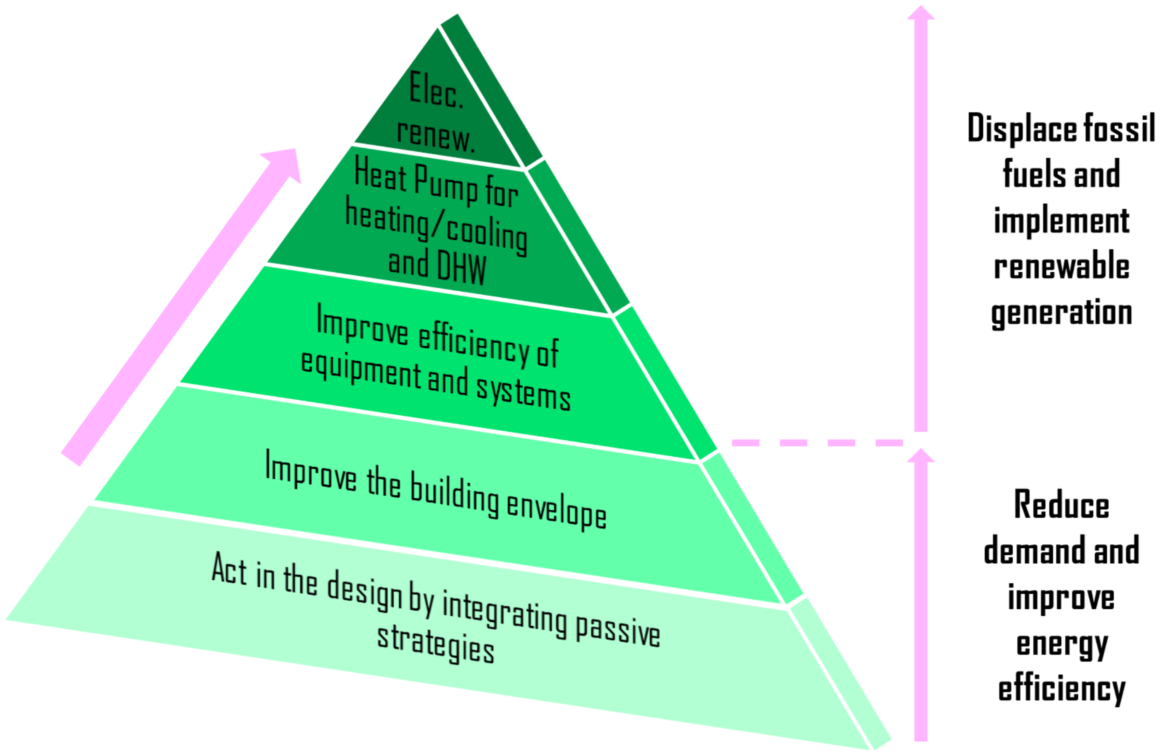


Figure 24. *The integrated energy design process strategy.*

Therefore, the integrated energy design process of the building includes both passive and active energy saving solutions.

From a simulation point of view, above the previously mentioned distinction between critically behaving zones such as first floor, intermediate and top floor, several additional factors have been taken into consideration.

One of the driving factors to energy consumption in the buildings is the incoming solar irradiation. Changing the orientation of the building and its surroundings regarding its position to the sun dictates a higher or lower heating/cooling demand. Therefore, the two archetypes described were simulated both at its current real orientation and turning them on 90º, 180º and 270º from its original position.

In addition to human behavioural patterns, another parameter that affects energy consumption is how building occupants perform the natural ventilation of their dwellings. The type of behaviour chosen is mainly based on natural ventilation during summer nights.

From passive design measures, the chosen dwellings have undergone a process of testing different design parameters for the insulation for different parts of the building envelope depending on the building archetype:

- The conventional retrofitting solution using materials such as Extruded Polystyrene (XPS), Expanded Polystyrene (EPS) and Polyvinyl Chloride (PVC).
- The low environmental impact solution based on the use of the local eco materials for insulation such as expanded cork and wood panels.

The aim of giving preference to local materials is to reduce GHG emissions and the non-renewable primary energy consumption of the building during its life cycle. From the perspective of sustainable development, it is important to choose easily recyclable, renewable, locally available and environmentally friendly raw materials.

From active design measures, the chosen dwellings have undergone a process of testing different facilities improvement scenarios such as installation of Heat Pumps (HP) for Domestic Hot Water (DHW) and air conditioning and photovoltaic (PV) panels for electricity generation. The selected technical system allows covering the low thermal demands of the building with an innovative and highly efficient solution.

The conceptual scheme of applied packages of passive measures is demonstrated in **Figure 25**.

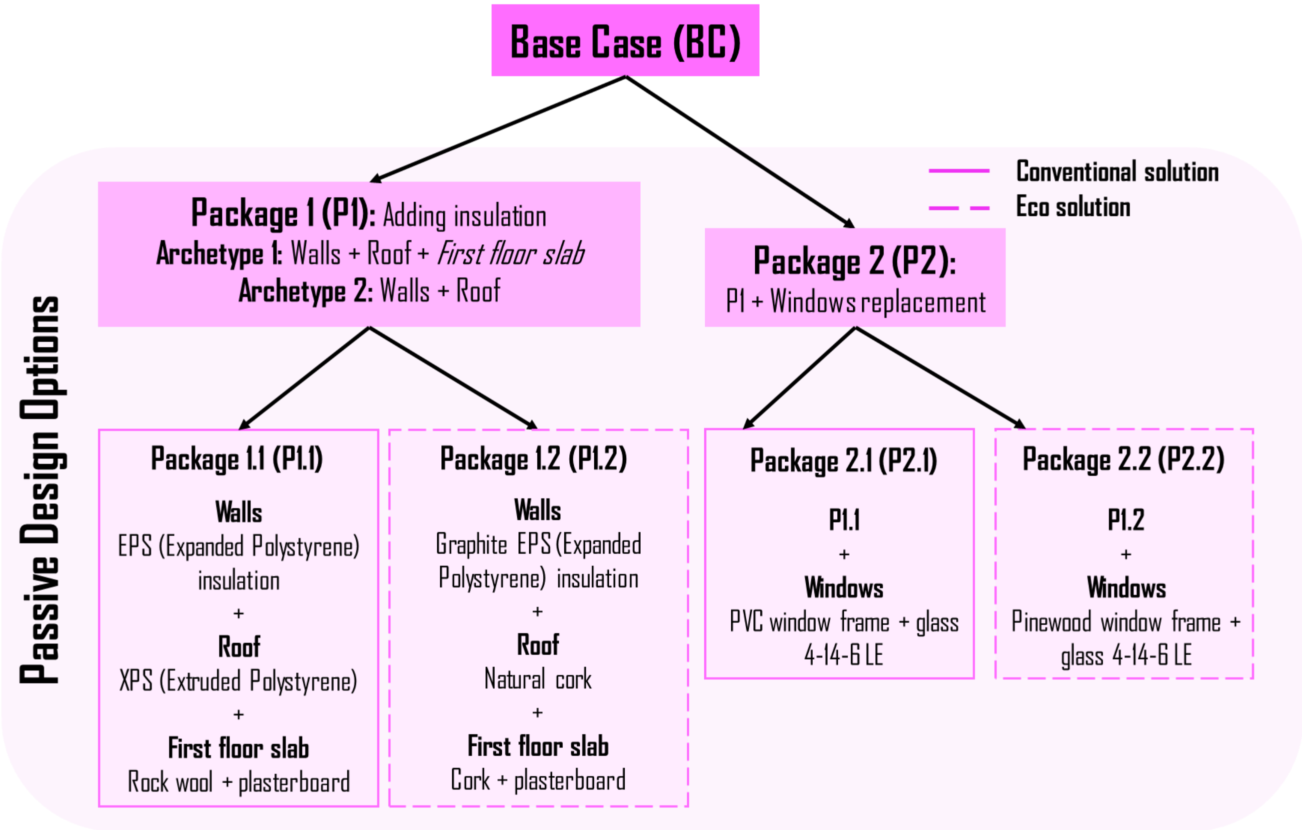


Figure 25. *Passive measures packages.*

More specifically, each of the solutions included in the previous packages, have been simulated using the following insulation thicknesses (**Table 5**).

Table 5. *Scenarios of the insulation thicknesses.*

Scenario	Insulation	Thickness (m)
Conventional	Walls - EPS	0.06 / 0.08 / 0.1 / 0.12 / 0.14
	Roof - XPS	0.08
	First floor slab - Rockwool	0.06
Eco	Walls – EPS local	0.06 / 0.08 / 0.1 / 0.12 / 0.14
	Roof – natural expanded cork	0.08
	First floor slab – natural expanded cork	0.06

Also, the two types of windows introduced in the solutions, create the following changes in the packages scenarios (**Table 6**).

Table 6. Scenarios windows features.

Scenario	Frame	U_value (W/m^2)	Glass configuration	U_value (W/m^2)
Conventional	PVC	0.9	4/14/6	1.69
Eco	Pine wood	1.43	4/14/6	1.69

In order to complete the study, active measures have been considered with the aim of checking whether by reducing the consumption of the dwellings, it is possible to reach higher levels of subsidies and thus reduce the initial investment.

To perform the calculations, simulations will be performed that most closely represent the average results of the complete building (average between orientations and flats). Then, all combinations of installations will be applied to check which of them have more favourable result.

The proposed measures are:

1. Change the air conditioning system of the house for a high efficiency 3x1 multisplit.
2. Implementation of a photovoltaic installation in the roof.
3. Change of the domestic hot water production equipment for a dedicated heat pump.

The number of scenarios for each of the chosen simulations will be 7, and these will be analysed in terms of initial investment and in terms of global cost over 50 years. Lastly, technical details of the specific equipment can be found in **Section 4.3.1,** including the results of the analysis.

4.3. PERFORMANCE ANALYSIS

Cost-optimal solutions for retrofitting of buildings in large-scale renovation processes are aiming to achieve 50% reduction in the energy demand and a significant improvement in the thermal comfort conditions. The conceptual scheme of the performance analysis is illustrated in **Figure 26.**

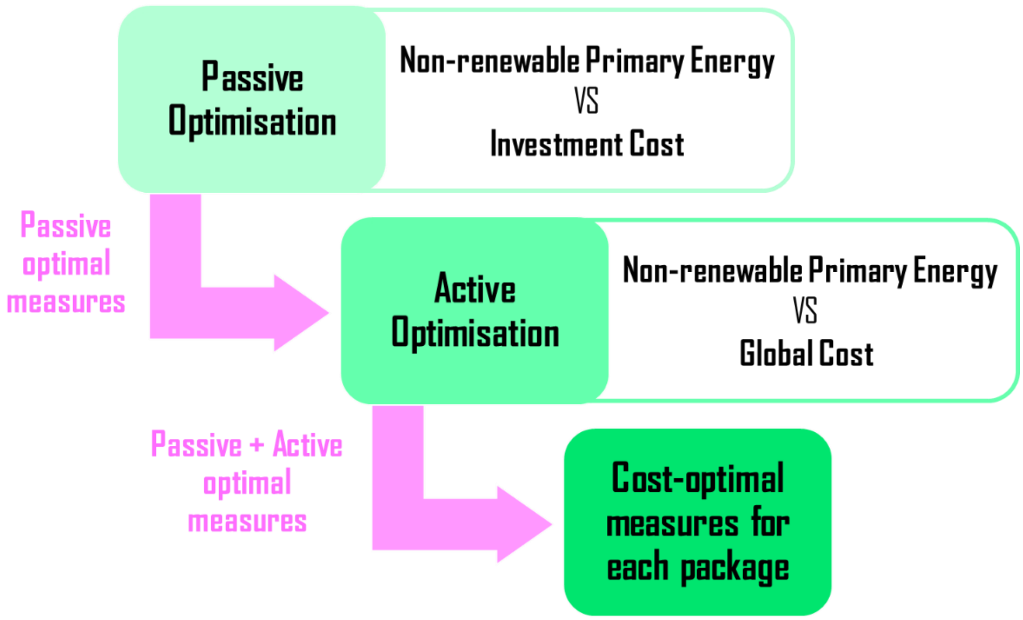


Figure 26. *The conceptual scheme adopted for the integrated energy design.*

4.3.1. ENERGY PERFORMANCE ANALYSIS

The main objective of the study is to obtain the most favourable scenarios for the retrofitting of the district's buildings in order to support decision-making process.

A relevant aspect to be taken into account when comparing rehabilitation scenarios, is the possibility of obtaining subsidies according to **Table 2.** This fact has the consequence that scenarios with a higher investment cost can be a more economical option thanks to the reduction of energy consumption.

For the calculation of the primary energy in the different simulation scenarios, the same profile of installations [6] has been used to cover the total demand according to **Table 7**.

Table 7. *Penetration index, efficiency ratio and primary energy coefficient of each technology (Base Case).*

Scenario	Technology	Penetration index (%) [6]	Seasonal Performance Factor (SPF) (kWh demand/kWh consumption)
Heating	Joule	32%	1
	Heat pump	31%	2 [7]
	Natural gas boiler	27%	0.7 [8]
	Butane	6%	0.7
	No system	4%	0.7 [7]
Cooling	Heat pump	57 %	2 [7]
	No system	43 %	2 [7]
DHW	Natural gas boiler	86%	0.7
	Butane	14%	0.7

The energy performance simulations of the case studies are carried out with TRNSYS. **Figure 27** and **Figure 28** demonstrates average non-renewable primary energy and average heating and cooling demand of the dwellings for the first, intermediate, and the top floor in the case of archetype 1, and all dwellings in the case of archetype 2. The four orientations have also been simulated, as mentioned above. The insulation thickness selected for this first graph is 6 cm.

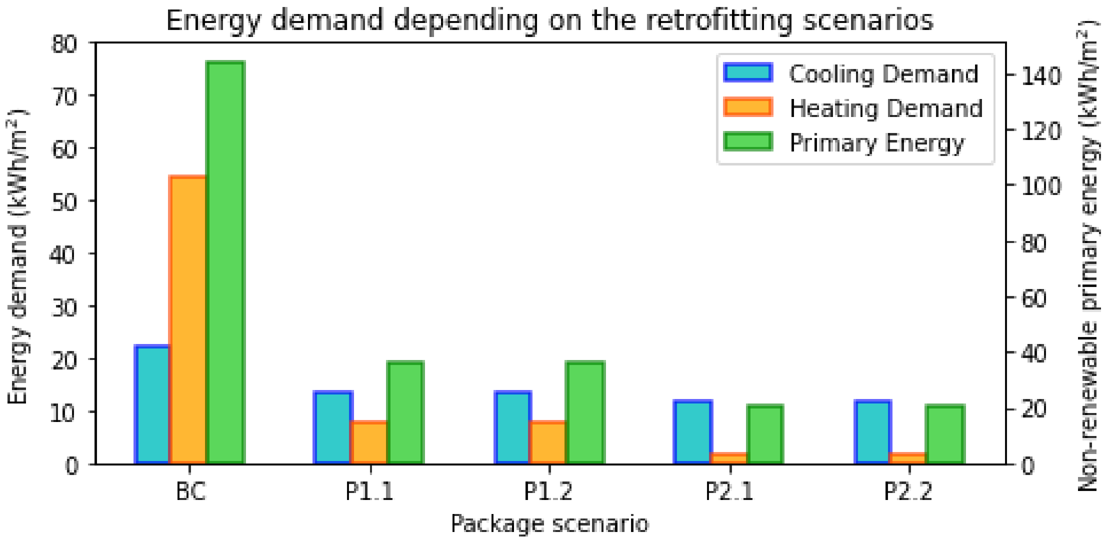


Figure 27*. Energy demand and non-renewable primary energy in the analysed scenarios (Archetype 1).*

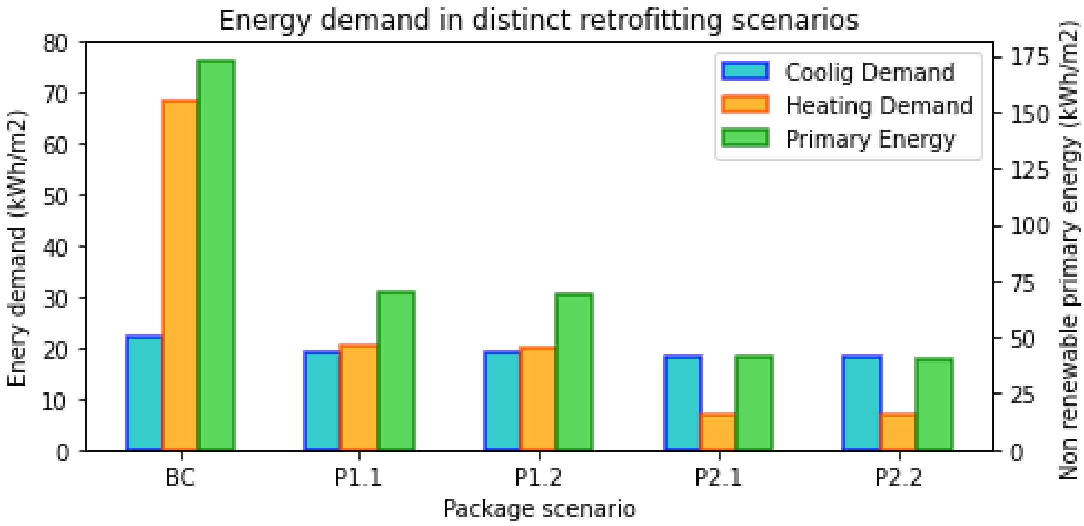


Figure 28*. Energy demand and non-renewable primary energy in the scenarios analysed (Archetype 2).*

The annual heating demand in non-renovated scenarios takes a value of almost 70 kWh/m², a demand that is mostly not covered by the tenants of the dwellings, thus affecting the decrease in comfort. When renovating the building envelope, the heat produced by the internal loads or the heating system is stored inside the dwelling, thus the decrease reaches a value of 70%. This is even more in the case of package 2, where the windows are renewed, making the building more airtight and reducing infiltration, which is most affected at night.

On the other hand, cooling demand behaves differently. As a consideration, natural ventilation is allowed in the dwelling at night, therefore, a better building envelope or more airtight windows do not cause a significant decrease in demand as the dwelling is ventilated almost every night. This is common in Mediterranean climates [8]. In addition, as infiltration decreases and the building becomes more airtight, internal loads are kept inside the house, and therefore cooling demand increases.

4.3.2. ECONOMIC ANALYSIS

Despite the opportunity to obtain subsidies to rehabilitate housing, there will always be a part that will have to be paid for by the owners. Financing is therefore a key aspect of the retrofitting process at the neighbourhood level, where two aspects become important:

- The private entity must have sufficient financial capacity to support the financing of a large number of owners.
- The final payments to the owners must be reasonable in order to be able to carry out the refurbishment.

Investment calculation

For the calculation of the initial investment, the parameters in **Table 8** have been taken into account. Detailed prices for all materials can be found in **Appendix E – Detailed data for economic calculations.**

Table 8. *Economic parameters for calculating investment*

Concept	Value (%)
Material execution budget including General costs and Industrial profit (9%+6%)	-
Project fees	9%
Management fees	2%
Cost reduction per large scale retrofitting	11% [5]
Taxes	21%

In addition, knowing the state of the buildings, an economic item has been taken into account for the renovation of the electrical installation of the common areas of the building, for which a value of 1.48 €/m² [9] has been taken, including a forecast of the material and the necessary workforce.

For the calculation of the surface areas, the generated 3D models (**Figure 20** and **Figure 22**) have been used together with the information from the cadastre to obtain the quotation by multiplying the unit costs by the surface area of the building. The results of the operation can be seen in detail in **Appendix E – Detailed data for economic calculations**, the global cost take into account the taxes.

Table 9 and **Table 10** are also shown with some examples in order to understand the specific weight of each surface in the overall computation, the results are shown for all the wall insulation possibilities.

Table 9. *Extraction of global retrofitting cost per dwelling without grants (Archetype 1).*

Package	Insulation Thickness (mm)	Total cost (€)	Wall cost (€)	Floor cost (€)	Roof cost (€)	Windows (€)	Electrical renovation (€)
P1.1	60	15 361	8 613	2 363	4 214	0	170
P1.2	60	16 517	8 874	2 331	5 142	0	170
P2.1	60	19 788	8 613	2 363	4 214	4 428	170
P2.2	60	24 838	8 874	2 331	5 142	8 322	170

Comparing some results obtained, in the case of packages P1.1 and P1.2 the costs are distributed between walls, roof and floor for an insulation thickness of 6 cm is 56%, 15% and 27% respectively, while in the case of packages P2.1 and P2.2 the specific weight is affected by the change of windows obtaining a distribution of 44%, 12% and 21% respectively and 22% for the windows. Even increasing to 33% in the case of applying an ecological window frame solution with pinewood.

Table 10. *Extract of global retrofitting cost per dwelling without grants (Archetype 2).*

Package	Insulation Thickness (mm)	Total cost (€)	Wall cost (€)	Roof cost (€)	Windows (€)	Electrical renovation (€)
P1.1	60	25 984	15 582	10 002	0	400
P1.2	60	28 659	16 054	12 205	0	400
P2.1	60	25 984	15 582	10 002	3 599	400
P2.2	60	28 659	16 054	12 205	6 764	400

The main differences between the buildings are the proportion of windows, the existence of uncovered party walls and the absence of a slab in contact with the exterior. For this reason, the weight of the walls in any of the options reaches higher values of up to 64%, while the windows remain at 14% in the conventional solution or 24% in the eco solution. Therefore, in the energy simulations of the following section, this will have an impact on the final results.

Further to the measures, the costs are divided into investment, maintenance, and replacement. The last two categories will be explained later in the life cycle costing process. In the case of investment, the market prices of different equipment have been obtained. These prices are summarised in **Table 11** taking into account the total cost.

Table 11*. Active measures costs.*

Active measure	Model	Budget
Multisplit for heating and cooling	DAIKIN 3MXM52N R32 (3x1)	3 000 € [10]
PV field	PV module Sunrise SR-725MHLPro Huawei SUN2000L-33KTL (archetype 1) Huawei SUN2000-8KTL M1(archetype 2)	1.8 €/Wp 59 400 € - Archetype 1 (3 784 € inverter) 13 860 € - Archetype 2 (2 000 € inverter)
Heat pump for DHW	BAXI BC 200 IN	3 088 € [11]
Gas natural Boiler	Existing (Base Case)	1 764 €

The inverter part of the budget is shown because the lifetime of the inverter and the PV panels are different, and this affects the calculation of the next section.

Life cycle and global cost calculation

The global cost consists of all the expenses that the owner of the house will have to pay over a period of time. In this case, a 50-year life cycle study is carried out. The associated costs are divided into four categories, initial investment, maintenance, equipment replacement and energy costs.

The maintenance costs take into account the revisions that the installations need, repairs to be carried out and replacement of parts throughout the life of the equipment.

In relation to replacement costs, the lifetime of each piece of equipment is taken into account, and at the end of this life, the investment will have to be made again according to **Table 11**.

The summary of the values taken can be seen in **Table 12**.

Table 12*. Replacement and maintenance costs of active measures*

Active measure	Lifetime (years)	Maintenance per dwelling [9]
PV Inverter	10 (5 replacements)	11.81 €/year (archetype 1) 43.6 €/year (archetype 2)
PV modules	25 (1 replacement)	6.87 €/year (archetype 1) 15.4 €/year (archetype 2)
Multisplit for heating and cooling	20-25 (1 replacement)	85 €/year
Heatpump for DHW	20-25 (1 replacement)	205 €/year
Gas natural boiler	25 (1 replacement)	167 €/year

In addition to the costs related to the entire life cycle, the factors of facility degradation and electricity price inflation have also been taken into account.

On the one hand, the degradation of the installations leads to a decrease in performance, thus the overall electricity consumption of the building increases by 0.5% per year. As an example, a photovoltaic system at the end of its lifetime would produce 12.5% and in the case of heat pumps 10% less efficiency.

On the other hand, in the case of electricity price inflation (1% annual) there is a double impact. In relation to the cost of energy it is prejudicial because as the years go the cost of energy rises, however in cases where a photovoltaic installation is implemented this increase of price is positive for two reasons. Self-consumed energy avoids more costs and the energy exported to the grid has a higher price.

The costs chosen for each of the demands occurring in the different scenarios calculated can be seen in **Table 13**.

Table 13*. Prices chosen for each type of energy demand.*

Demand type	Cost per €/kWh

Electricity	0.23 [12]
Natural Gas	0.10 [13]
Butane	0.13

Parameters for the calculation of monthly payments
The business model will be carried out through a public-private relationship, and the cost of the investment will be financed to enable the owners to pay the investment in monthly quotas and not to have to pay off the investment all at once.

Therefore, this aspect has been taken into account when calculating the monthly instalments to be paid by the owners to the rehabilitation agent. The financing period is preliminarily set at 10 years at an interest rate of 2% per annum in the French amortisation method.

4.3.3. PASIVE MEASURES ANALYSIS

Archetype 1
The results of applying the package scenarios to the demand shown in **Figure 27** can be seen in **Figure 29**. Each point colour corresponds to the implementation of a building envelope improvement package. Each point corresponds to an insulation thickness according to the options proposed in **Table 5**. The average between the different orientations (4) and simulated floors (3) has also been carried out. The background colours correspond to the Energy Performance Certificate (EPC) set by the Spanish energy legislation in relation to the energy labelling.

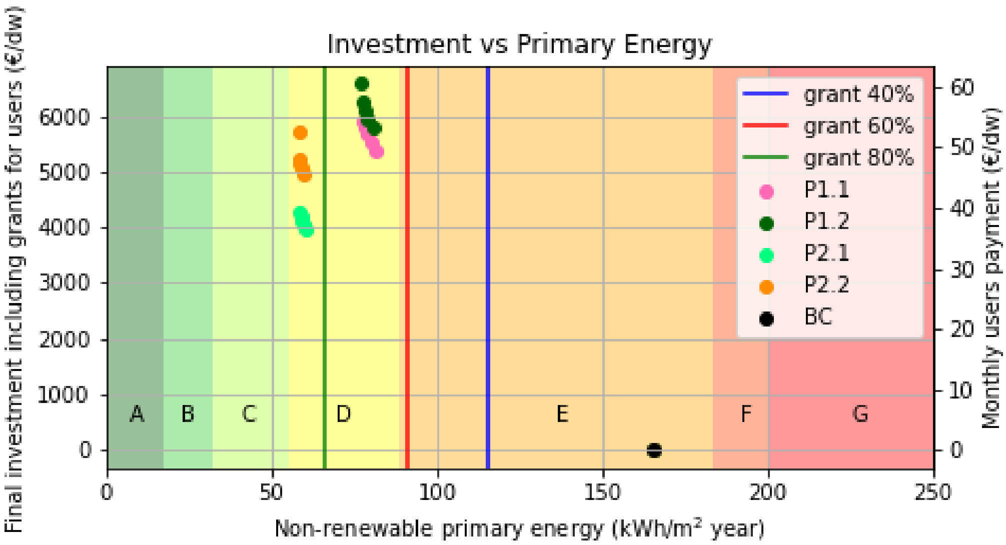


Figure 29. *Investment per dwelling vs Non-renewable primary energy*

The first relevant result of the study is that the second subsidisable segment (65% for reducing primary energy consumption by 45% to 60%) is achieved. In addition, it is found that the improvement of the windows would be enough to pass to the final segment. This is due to the fact that in the case of the Archetype 1, the cost of retrofitting for the first-floor slab has a large influence on the initial investment. Therefore, modifications to façades have less specific weight in the overall computation.

On the other hand, if one compares the difference between eco materials for façades, roofs, and floors with the difference between windows in economic terms, there is a higher investment gap for windows.

In this case, it is found that the building materials of the base case compared to the materials that would be used for retrofitting have a different thermal behaviour. This is because the regulations on building requirements in the 1970s did not consider energy efficiency as a priority, in contrast to today's building codes.

Relating the results in terms of the energy labelling bands all points are in the range of a D rating. in the scenarios with window changes would be close to the step up to the next level of labelling with a C label. Finally, in improvement packages that include the replacement of windows, an increase in energy demand can be seen as the insulation thickness of the façades increases. This effect is common in hot climates such as Palma de Mallorca, where the demand for cooling is high and the decrease in air infiltration as a result of changing the windows makes the houses more sealed and they lose that part of the cooling. However, in the case of archetype 1, the points are very close to each other, so this effect is almost negligible because the increase in insulation due to the characteristics of the building has less influence as mentioned above (**Figure 30**).

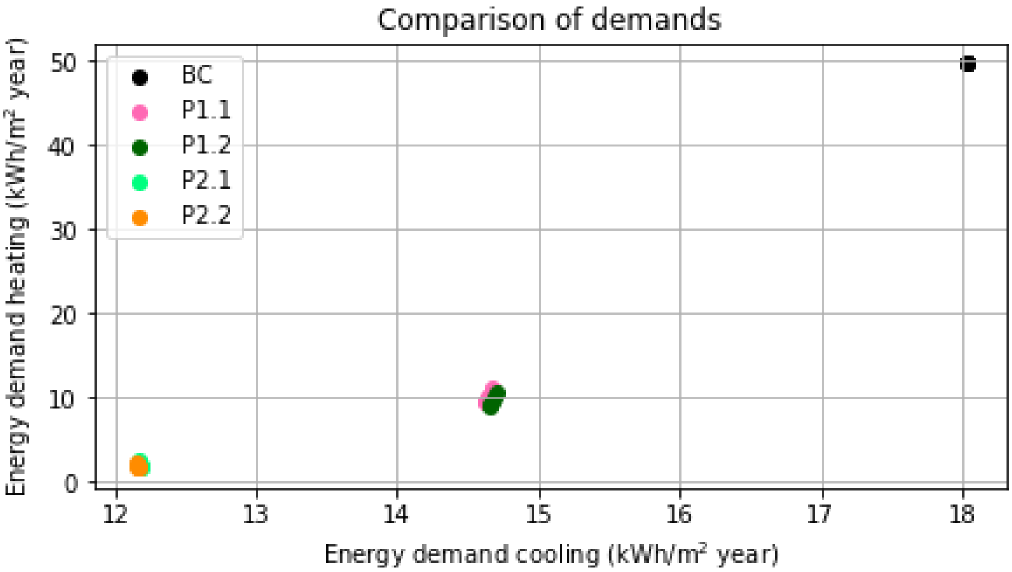


Figure 30. *Comparison between cooling and heating energy demand.*

The following analysis aims to further evaluate the increase in cooling demand in the building retrofitting scenarios and how it affects summer comfort in dwellings. Therefore, following the Key Performance Indicators (KPIs) of the document D2.1 (Assessment Framework for CPCC) there is an increase in summer discomfort and an increase in the hours during which this discomfort can be harmful to health.

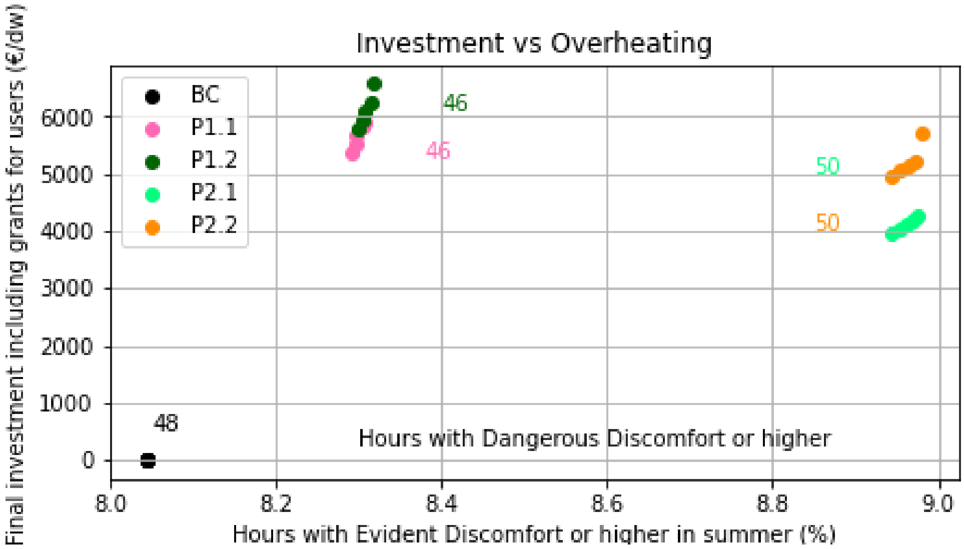


Figure 31. *Investment per dwelling vs Overheating analysis.*

As can be seen from the previous results, in the archetype 1 building the cooling effect of the increase in the airtightness of the building is not very high and this aspect is noticeable in the calculation of the overheating. As it is possible to have natural ventilation, especially at night, this leads to a daily discharge of thermal loads, so heat accumulation inside the building does not occur. In fact, the number of hours with a discomfort dangerous to health does not vary significantly and remains low in proportion to the total hours of the year.

Archetype 2

The same analysis was carried out for the second archetype. The main difference in this case is the effect of the change of the insulation thicknesses, as in this building it has a greater effect for two reasons: firstly, the surface of the façade is much larger compared to the total surface of the envelope. Secondly, the ground floor is not empty, there is a commercial space.

A greater effect of the insulation thickness can be seen in **Figure 32**, where in packages P1.1 and P1.2 there is a greater distance between points, and even a curvature can be seen which indicates that as the thickness of the insulation increases, the primary energy consumed decreases.

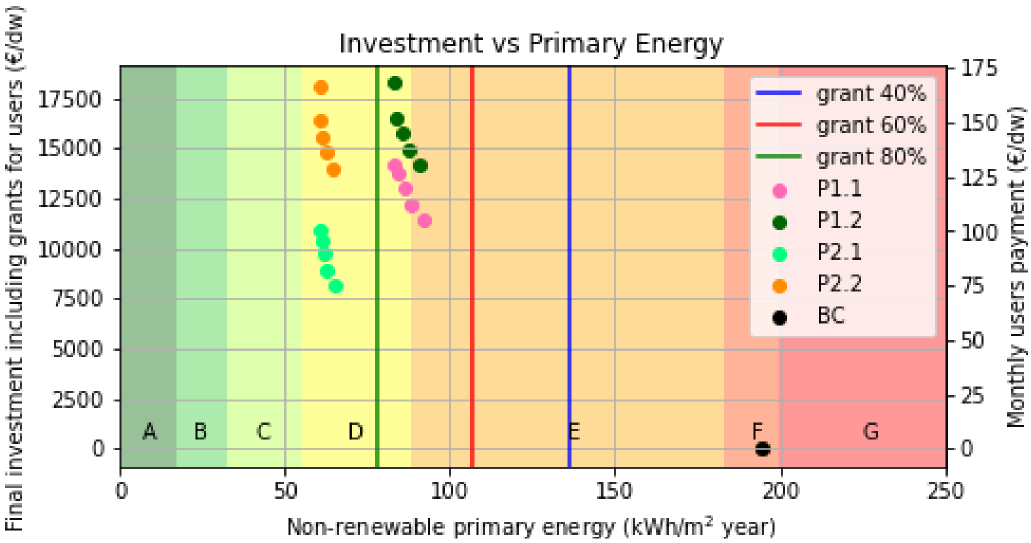


Figure 32. *Investment per dwelling vs Non-renewable primary energy.*

Similar to the previous case, changing the windows does allow to pass to the second segment of subsidy and this makes the investment in the P2.1 package more economical compared to the P1.1 package. Something similar happens with the packages with ecological materials (P1.2 and P2.2), however, to a lower extent given the price of the window with a pine frame.

The year of construction of the building in archetype 2 is similar to the one in archetype 1, therefore the same applies to the difference between the base case and the retrofit scenarios in relation to the primary energy consumption. Obtaining a substantial improvement in energy consumption and allowing to reach the subsidised scenarios with only passive actions. In this case, the energy labelling that could be obtained by passive measures would depend on whether the windows are modified. In the case of not changing the windows the rating obtained would be a D and in the case of changing the windows the rating would be a C.

Comparing the results with the windows replacement in the previous case, the effect of the increase of the total energy consumption due to the higher cooling demand can be seen. **Figure 33** demonstrates a comparison between cooling and heating demand. It is worth noting that the effect is greater than in the other archetype.

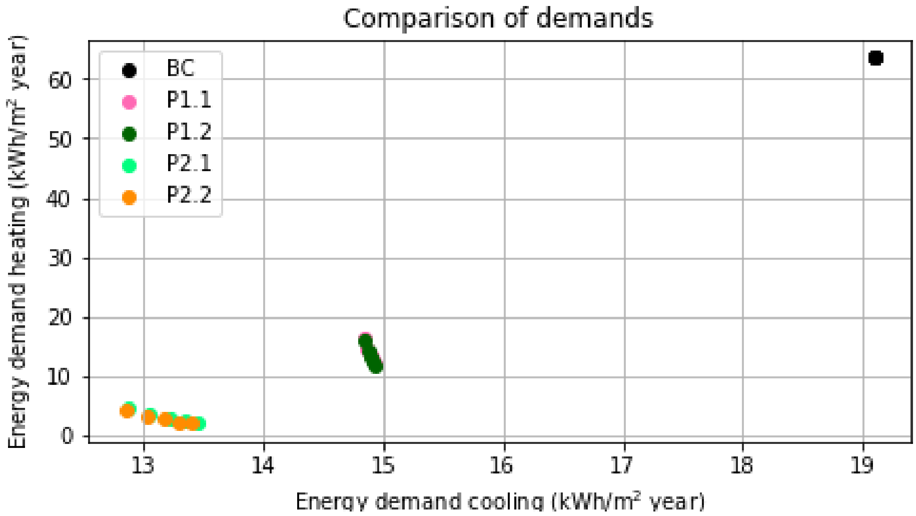


Figure 33. *Comparison between cooling and heating energy demand.*

The overheating parameter is calculated for the building Fe (**Figure 34**). As mentioned above, the main effect of the possibility of natural ventilation is to dissipate the loads inside the house, so the comfort is slightly affected by the increase of the insulation of the building.

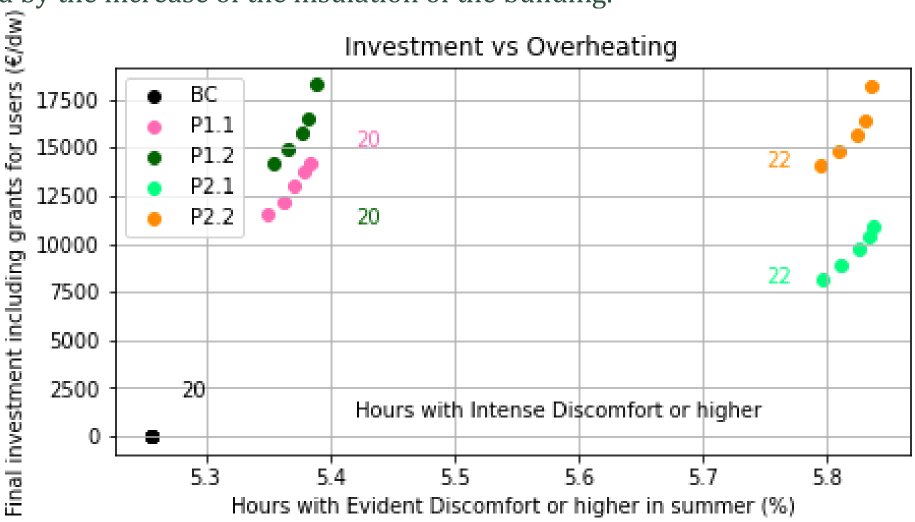


Figure 34. *Investment per dwelling vs Overheating analysis.*

4.3.4. ACTIVE MEASURES ANALYSIS

Archetype 1

Continuing with the analysis of the different solutions, some scenarios resulting from the passive part have been chosen for the study of the active measures. In the case of archetype 1, the following scenarios have been chosen:

- 4th floor Base Case.
- 4th floor P1.1 with 6 cm of insulation with the real orientation of the building.
- 4th floor P1.2 with 6 cm of insulation. with the real orientation of the building.
- 4th floor P2.1 with 6 cm of insulation with the real orientation of the building.
- 4th floor P2.2 with 6 cm of insulation. with the real orientation of the building.

Scenarios with 6 cm of insulation have been chosen because in none of the scenarios, increasing the insulation leads to an improvement of the subsidy scenario, on the other hand, the floor selected for active measures would be the fourth floor. The reason for this is that the results of the averages between floors and orientations are more equal for the fourth floor than for the other two floors.

The facilities proposed for the archetype 1 building are shown in **Table 14.**

Table 14. *Proposed facilities for the analysis of active measures.*

Technology	Power (kW]	Efficiency ratio (kWh demand/kWh consumption)	Primary energy coefficient (kWh primary energy/kWh final energy)
Heat pump	6.8 (Heating) 5.2 (Cooling)	4.6 (Heating) 5 (Cooling)	2.968
PV field	33 kWp (687 Wp/dw)	-	2.968
Heat pump	1.7 kW	3.16	2.968

All possible combinations between the different facilities options have been realised, which results in 7 cases to be analysed. The results of applying the active measures to the chosen scenarios are shown in **Figure 35.**

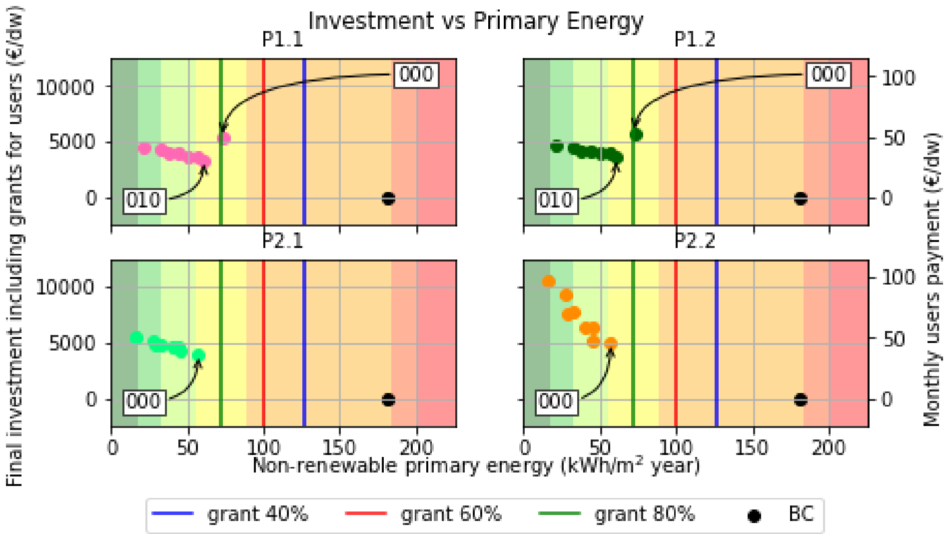


Figure 35. *Investment per dwelling vs Non-renewable primary energy.*

It can be seen that the dots have moved to the left due to the decrease in primary energy consumption. In addition, there are cases where it is possible even to reach the last section without retrofitting the windows.

A coding of zeros (0) and ones (1) of active measures that minimise the initial investment and also which of them would be the most costly in terms of investment have been labelled. The first digit being the change of the air-conditioning system, the second digit the implementation of a PV system and the third digit the installation of a heat pump for domestic hot water.

In terms of energy labelling there is a variety of results, such as obtaining an A rating in the cases of a global envelope renovation and the application of all active measures. In the case of the most economical solutions in relation to investment, the resulting letter in all cases would be D.

If only the initial investment is taken into account, there is a significant differentiation between changing the windows and not. It is more economical to implement a PV system when changing the windows and do not invest in active measures when changing the windows because the last level of subsidy is already obtained.

However, in order to define the most favourable scenario, it is also representative to analyse a dynamic scenario and not a static scenario. For this reason, a 50-year analysis of the active measures has been carried out to access whether the decrease in energy consumption and associated costs are enough to compensate for the higher initial investment.

In order to calculate the global costs, electricity inflation, facilities deterioration, maintenance costs, replacement costs, the cost of investment (including subsidies) and the cost of energy for each of the technologies have been taken into account, concepts detailed in **Section 4.3.2**. The cost of energy takes into account the market selling price of the surplus produced by the photovoltaic solar field.

The codes that appear on the X-axis of **Figure 36** correspond to the package of passive measures used and the following digits correspond to the application or not of the active solutions being in order of digit change of the air conditioning system, installation of a photovoltaic production system and change of the domestic hot water system.

For example, the first column (P2.2-111): P2.2 (number of the package applied) – 1 (change of air conditioning system) 1 (installation of PV) 1 (change of domestic hot water).

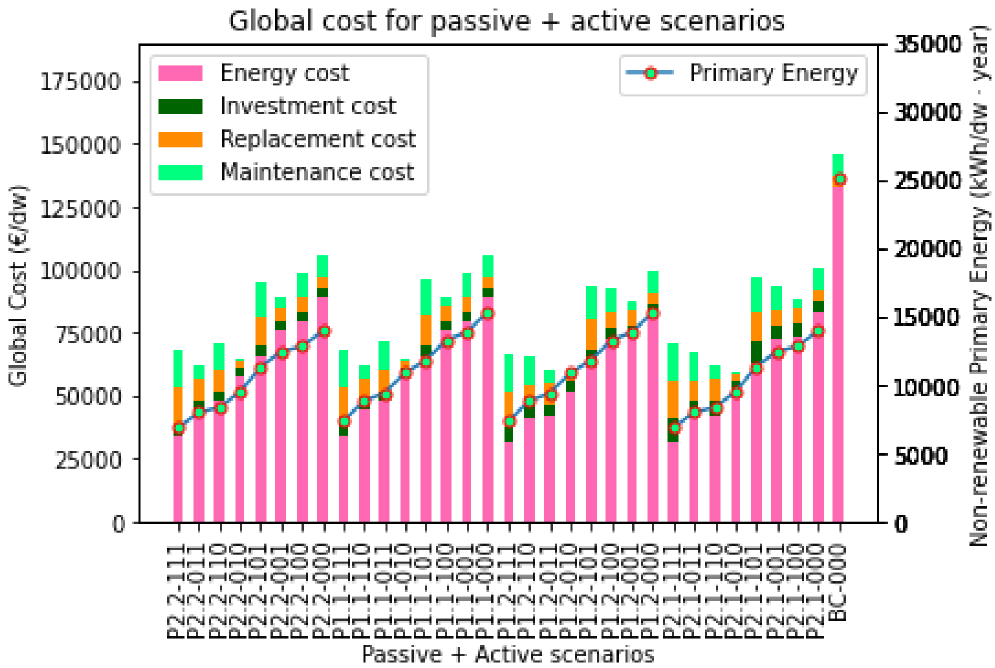


Figure 36. *Global cost vs Passive + Active measures and Non-renewable primary energy consumption.*

Based on the results obtained from the study of the optimization scenarios of the passive and active measures, there are differences comparing initial investment or global costs. For example, in the case of package 1.1, in the previous case where only the initial investment was taken into account, the most cost-effective case is the one that only implements a PV system. However, taking into account the global costs, the most cost-effective case is to change the air conditioning system and add a photovoltaic system.

In relation to the choice of conventional or ecological materials, it is found that the initial investment difference compared to the energy use in a 50-year calculation is significant. Therefore, taking into account that the thermal behaviour between the materials is similar, choosing an ecological material for the construction does not lead to a significative increase in the cost over the lifetime of the building.

Finally, a complete refurbishment scenario would consume the least energy and, therefore, results in the lowest energy cost. However, the facilities must be maintained and replaced, if necessary, a cost that does not make it the best scenario in terms of cost-effectiveness.

Archetype 2

The scenarios chosen for archetype 2 are:

- All the building Base Case.
- All the building P1.1 with 6 cm of insulation with the real orientation of the building.
- All the building P1.2 with 6 cm of insulation with the real orientation of the building.
- All the building P2.1 with 6 cm of insulation with the real orientation of the building.
- All the building P2.2 with 6 cm of insulation with the real orientation of the building.

Equal to archetype 1, scenarios with 6 cm of insulation have been chosen because in none of the scenarios did increasing this insulation lead to an improvement of the subsidy scenario. In this case, the simulation take into account all the building. The facilities proposed for the archetype 2 building are as shown in **Table 15.**

Table 15. Proposed facilities for the analysis of active measures.

Demand	Technology	Power (kW)	Efficiency ratio (kWh demand/kWh consuption)	Primary energy coefficient (kWh primary energy/kWh final energy)
Heating & Cooling	Heat pump	6.8 (Heating) 5.2 (Cooling)	4.6 (Heating) 5 (Cooling)	2.968
Electrical	PV field	7.7 kWp (1.54kWp/dw+local)	-	2.968
DHW	Heat pump	1.7 kW	3.17	2.968

All possible combinations between the different facilities options have been realised, which means that 7 cases have been studied. The results of applying the active measures to the chosen scenarios are shown in **Figure 37**.

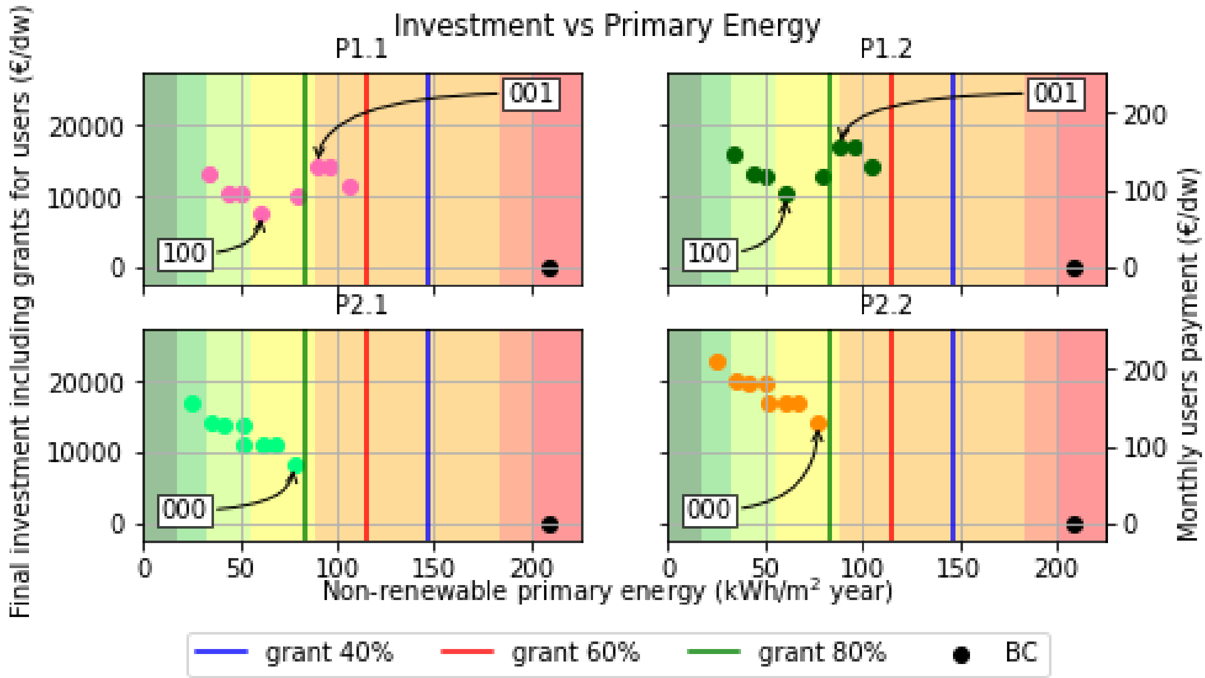


Figure 37. *Investment per dwelling vs Non-renewable primary energy.*

In relation to the active measures, the main difference is in the photovoltaic installation. In this case, the roof of the building does not have good conditions (small total area, shadows between roof elements, perimeter wall, etc.) for its installation, so the capacity is lower.

For this reason, in the case where only the initial investment is taken into account, modifying the air conditioning system is the most cost-effective measure in the scenarios where windows are not changed. In addition, only by applying the previous measure, the last segment of subsidy is reached. Similar to the previous case, by changing the windows the last level of subsidy is obtained, therefore adding new active measures do not improve the scenarios in terms of investment cost.

Further analysis, taking into account overall costs, is demonstrated in **Figure 38**.

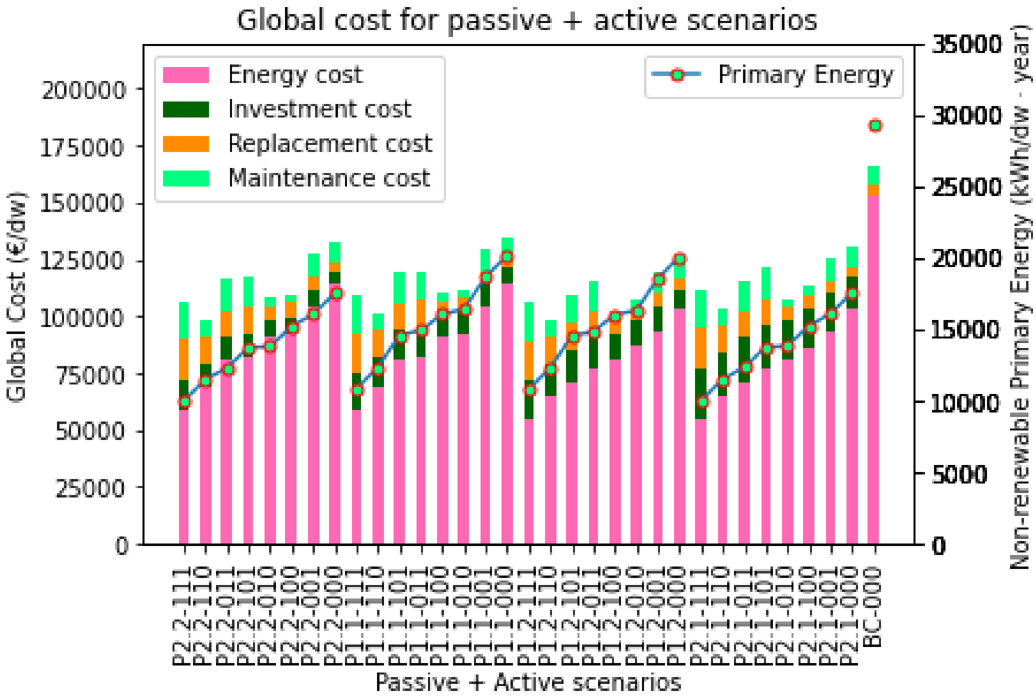


Figure 38. *Global cost vs Passive + Active measures and non-renewable primary energy consumption.*

In contrast to the previous case there is a combination of passive and active measures is more favourable. The optimal combination is the modification of the air conditioning system with an installation of a photovoltaic system. The extra cost of maintenance and replacement of the photovoltaic system is approximately equal to the energy cost that would be avoided and the improve of the air conditioning system helps to achieve better performance in the long term.

Therefore, the decision of some measures or others will depend on the economic capacity of the community of neighbours to make a greater investment or not.

4.3.5. ENERGY LABELLING

Throughout this section, the results of a detailed energy simulation of two archetypes have been shown with the aim of jointly optimise possible passive and active measures to improve the efficiency of the residential environment with the characteristics found in the DILL. Always considering that the main opportunity to finally realise the refurbishment at district level is the available subsidies to help the owners to afford the investment.

In order to be able to access the subsidies there is an official procedure to demonstrate the reduction of primary energy consumption, which is articulated by the energy certificate. This energy certificate has to be calculated by using official programs certified by the Spanish state that have a set of calculation mechanisms based on the Spanish Technical Building Code.

The technicians who are authorised to perform the energy certificates must register them in the corresponding department of the city council. **Figure 39** shows a histogram plotting the results of the analysis of the energy auditors who have performed it in the scope of the ERRP.

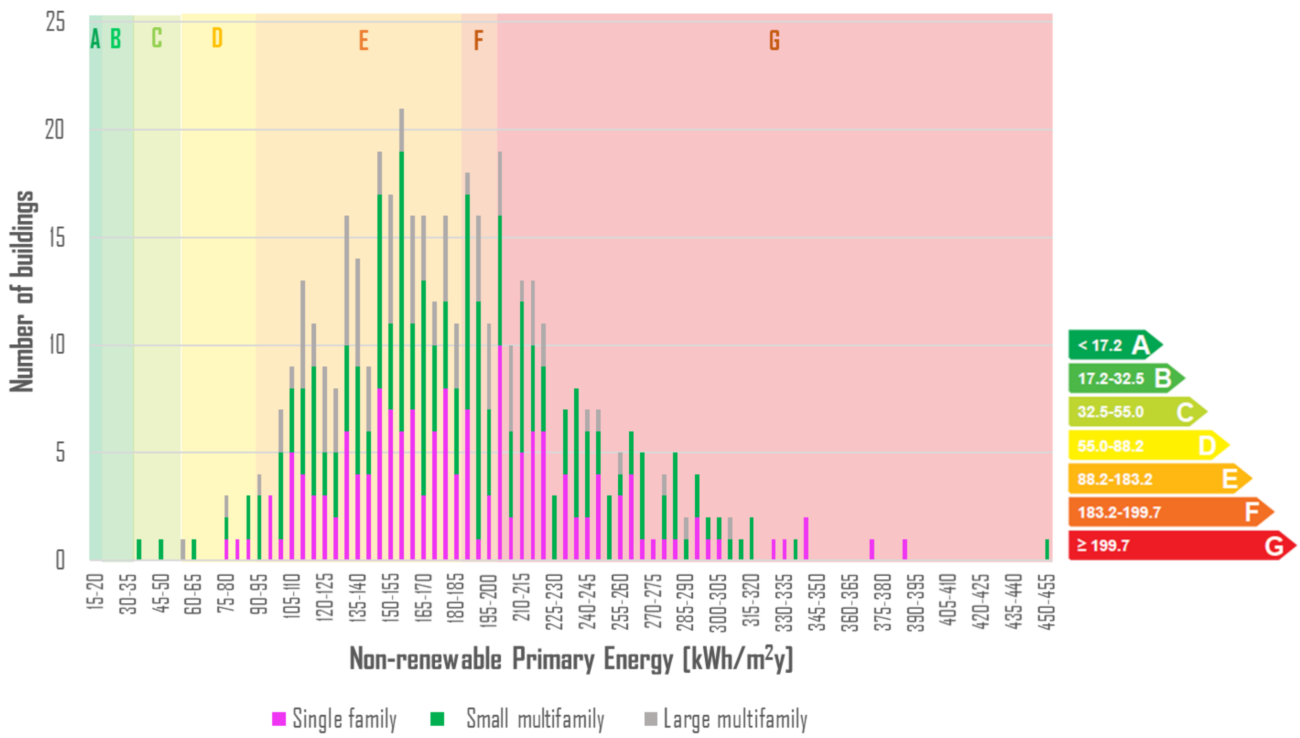


Figure 39. *Histogram with registered energy certificates in the ERRP area.*

The majority of energy certificates are between the letters E-F-G, therefore, the potential for energy efficiency improvement is significant in the area. Furthermore, in relation to the number of dwellings, large multi-family buildings are found in the medium letters (E-F), but the most energy-consuming buildings are single-family and small multi-family buildings.

According to the results obtained with the detailed simulations, the overall results could be C-D ratings with passive measures and B-C labelling with active measures. Only in cases where all active measures are applied, certificates with the maximum rating A can be achieved.

Appendix F – Energy simulations - Official EPC shows the energy certificates performed in the city council of Palma for the buildings most similar to the simulated archetypes and the retrofitting measures applied to obtain each level of subsidy.

4.4. SUMMARY

The decision-making process for large-scale retrofitting actions is an important aspect, as the impact of a good or bad decision can be considerable. Therefore, in order to support this decision-making phase in the context of a large-scale retrofitting, a detailed study of the possible actions and their impacts was prepared.

The main objective is to retrofit the dwellings in such a way that the investment is affordable for the owners. This means that the result achieved may not be optimal in terms of energy, but is optimal technically and economically. All this while taking into account the available public subsidies.

The following conclusions can be drawn:

- First, that the complete renovation of the building envelope and windows gives the best scenarios both in terms of initial investment and total costs over the life cycle of the building.
- Secondly, that retrofitting the installations as a whole is not the best solution in technical-economic terms.
- On the other hand, it has been shown that the use of PV in this type of retrofit can be very effective in terms of both energy consumption and total costs.

As far as comfort is concerned, it has been shown that in the Mediterranean climate, excessive insulation of a building leads to an increase in air conditioning needs in the summer that is not accompanied by a similar reduction of the energy in the winter. So, the thickness of the insulation to be installed or the thermal behaviour of the materials to be used are other important aspects to be analysed in this type of retrofitting of residential buildings.

Table 16. *Summary of objectives achieved.*

Assessment criteria	Objective for renovated buildings	Results of the analysis
Energy	**At least 50% reduction in energy needs** compared to pre-renovation levels. At least Nearly Zero Energy Building (**NZEB**) standard.	The maximum primary energy reduction applying all measures is **80%,** and in the techno-economical optimal case, it is **60%.**
Life Cycle Costs	**At least 20% reduction** for the community compared to local current practice.	Overall life cycle costs have been reduced by an average of **36%.**

Finally, in terms of the overall analysis, in both cases the higher initial investment costs of using materials with a lower carbon footprint are not particularly significant compared to the energy costs over the life cycle of the materials. Thus, the key to adopting more sustainable materials lies in the financing model and in addressing the change in the construction model at a societal level, with public institutions and private companies working together to change materials in the construction sector.

5. DESIGN IN NEW SOCIAL HOUSING BUILDING

5.1. DESCRIPTION OF THE BUILDING

The project proposes an organisation of the space which, combined with a constructive proposal, makes possible homes with very low energy consumption, a high-quality living experience, and a building that is integrated into the landscape in an environment with architectural value. The building, with 35 dwellings, is made up of two cores and is accessed via a walkway through the interior courtyard. In this way, all of the homes have vital cross ventilation that, together with the captivating use of the double thermal intermediate spaces acting as greenhouse (front and back), while solar control and thermal inertia allow for a very reduced energy demand whilst maintaining a very high level of comfort.

Figure 40. *Image of the façade.*

This construction strategy allows for an integration with the environment and historical background of the neighbourhood. The ground floor is raised above street level in order to improve the relationship between the houses on the ground floor and the pedestrians on the street while also allowing natural ventilation into the car park. The homes are distributed continuously along the access walkway, meaning that all the homes have two bays facing the walkway; the entrance and a room. Additionally, the proportions of the vertical solar protection elements help to properly protect the garden façade from the sun.

A low-technology construction is proposed, based on load-bearing walls, which helps to drastically reduce the environmental impact of the construction and improve the thermal inertia of the homes, while simultaneously establishing a tectonic dialogue with the surrounding buildings. Almost all of the load-bearing walls are oriented from east to west and are perpendicular with the longest side of the building in order to take advantage of solar gains homogeneously throughout almost the entire building. **Figure 41** demonstrates typological configuration strategy for the building.

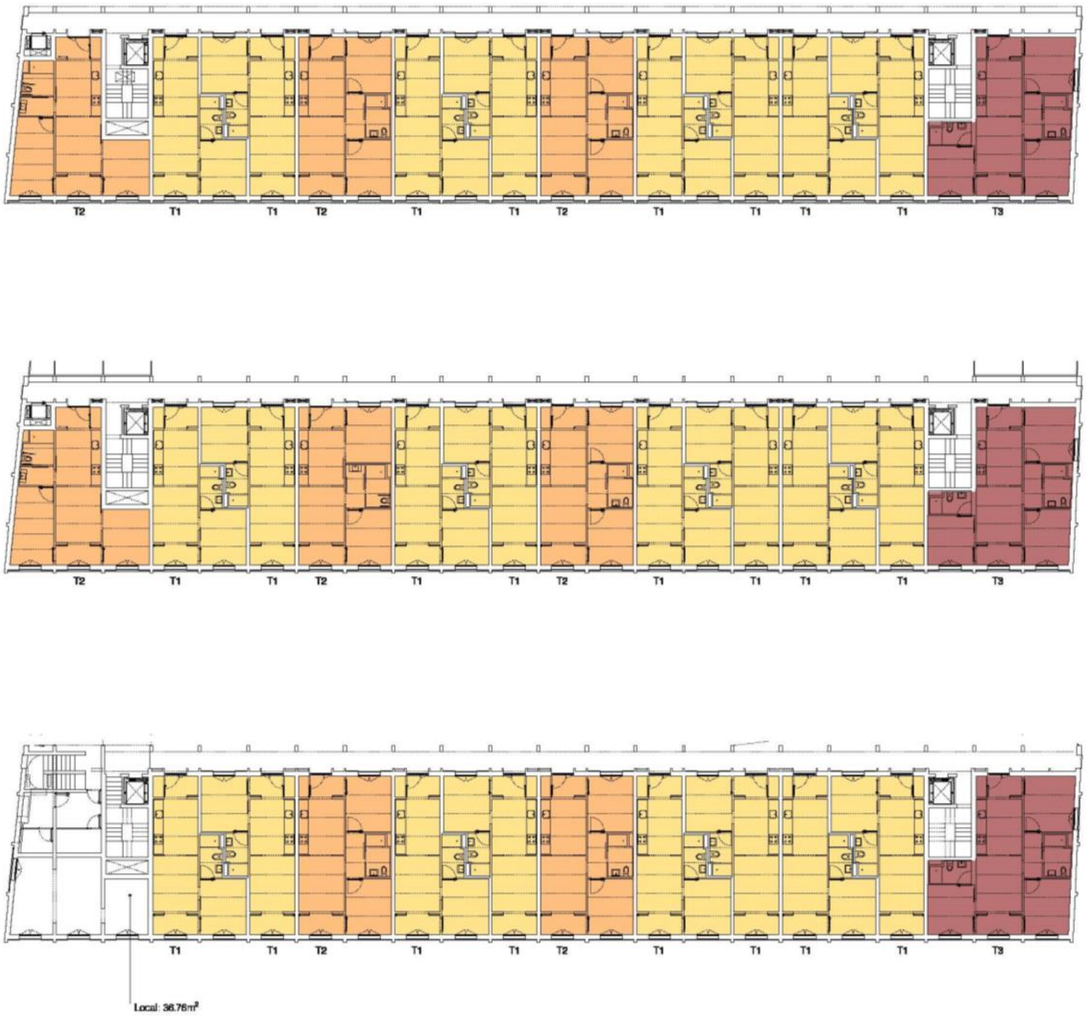


***Figure 41**. Typological configuration strategy for the building: second floor (top image), first floor (middle image) and ground floor (bottom image).*

5.2. CONCEPT DESIGN

A building project involves both the definition of constructive elements and the establishment of the physical conditions and resources to achieve maximum comfort and habitability. If before the objective was to guarantee the achievement of liveability and comfort, today's demand for sustainability now includes a consideration of the resources used in order to obtain it. Efficiency as well as effectiveness. It is for this reason that the project defines a strategy to obtain habitability and comfort at an environmentally reasonable cost of resources, looking to make the most of the opportunities offered by the site, the configuration of the building, the materials used and the different resources, techniques, and facilities available. This strategy seeks maximum environmental efficiency for each amenity obtained, aiming to reduce the number of resources required for the building to be constructed and operational.

To reach environmental efficiency we aim to reduce the amount of resources that affect our planet wherever possible (biotic, abiotic, water, erosion, etc.) and minimise environmental impacts by using renewables, recycling and reusable materials. To carry out energy simulations, the dynamic simulation software 'Design Builder' has been used, which uses Energy Plus as its calculation engine.

5.2.1. ENVIRONMENTAL OBJECTIVES AS ESTABLISHED IN THE ARCHITECT'S CONTEST

The homes must comply with the municipal regulations and those of HOP (Homes with Official Protection), as well as the introduction of measures to ensure compliance with the following quantifiable indicators defined by the IBAVI:

- Energy efficiency, Class A. As the primary line of action, passive measures must be implemented to reduce the energy demand to 17.20 <kW/m^2/year, as well as active measures to cover the demand through renewable energy.
- Water consumption, maximum 100l/person/day plus accumulation of rainwater.
- Reduction of waste by 50%.
- Reduction of CO_2 emissions from the materials by 25% (compared to a conventional solution.)

5.2.2. DESIGNED ENVIRONMENTAL STRATEGY

The proposal suggests passing typologies along the east and west axis. These orientations, forced by urban planning, do not have ideal sunlight in winter, nor in summer. The proposal compensates for these constraints by generating, in its volumetric definition, mobile sensing elements, thermal intermediate spaces which give the building a dynamic form (compact in winter and more dissipative in summer) and an effective façade plan to give more absorbing exterior in winter and a more protected interior in summer. Captured elements will generate hot air that will in turn be used through micro-ventilation to ventilate the main rooms in contact with them. In addition, as far as possible, the south facing orientation of the windows is maximized.

In terms of energy conservation, insulation is maximised in spaces that are in contact with the outside and windows that benefit from high thermal resistance are suggested in combination with high solar factors.

Regarding the demand for a reduction of cooling, exterior and interior openings are proposed in the house to guarantee cross ventilation, "Mallorca style" blinds to intercept solar radiation, which at the same time leave free passage for air and ventilation.

The vertical structure of the building is made with sandstone, which aside from the environmental benefits in terms of incorporated CO_2, provides important benefits in terms of interior comfort. The resulting thermal inertia, as well as the hygroscopic behaviour of the materials used, allows the building to regulate the temperature variations of day and night and deliver high levels of comfort to the users during most of the year.

The resulting yearly energy demand for heating and cooling is 4.90 kWh/m^2 without considering the effect on comfort of cross ventilation and fans. Throughout the project, work has been done to reduce energy use as much as possible, achieving a building that provides comfort to its users at minimal consumption. As for strategies to reduce water consumption, the installation of efficient devices and the reuse of rainwater is being considered. Through these strategies, it is estimated to reach a consumption of less than 65 l of water/person/day.

Strategies for ventilation in summer and for utilising solar radiation in winter are illustrated in **Figure 42**.

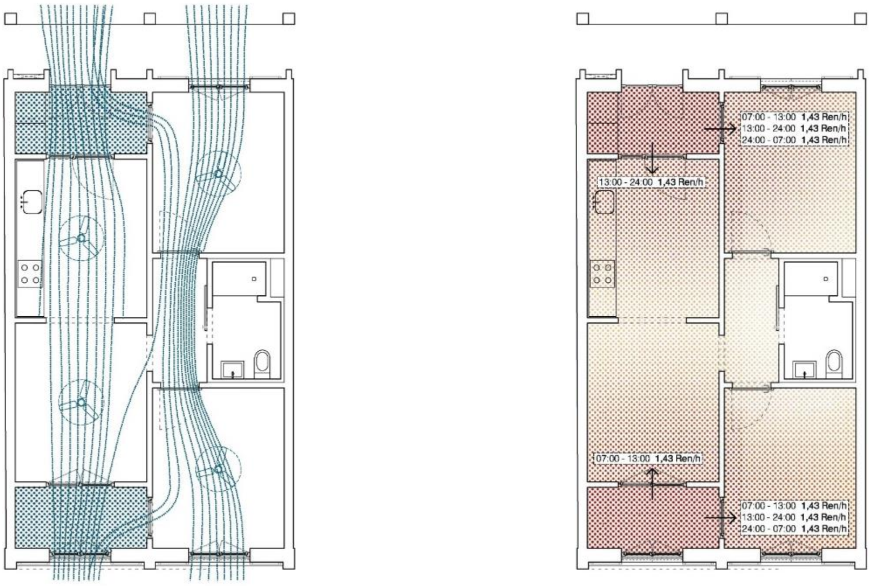


Figure 42. *Ventilation strategies in summer (left) and harvesting of solar gains in winter (right).*

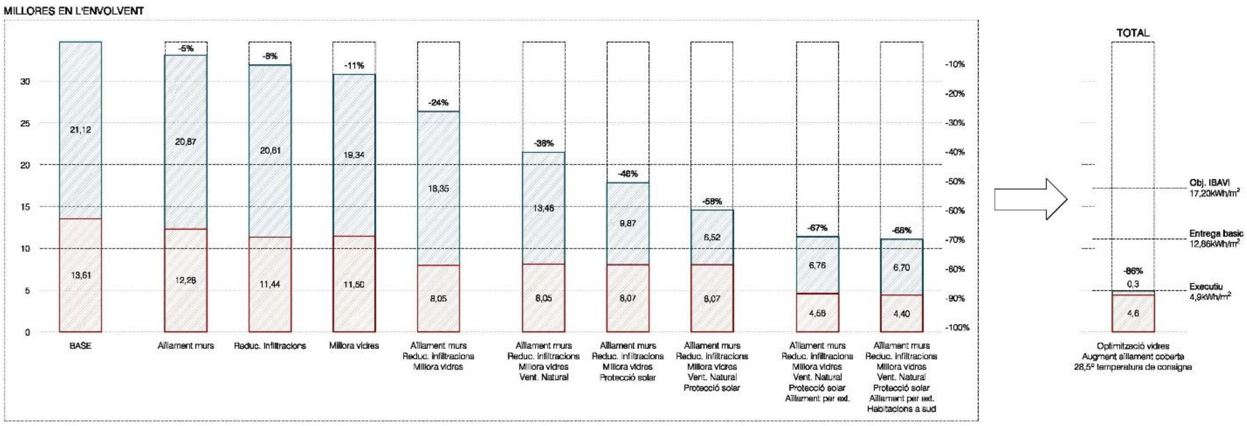


Figure 43. *Summary of passive and envelope improvement measures. Extracted from the project documentation (in Catalan language[3]).*

In terms of CO_2 emissions, the pre-fabrication of the horizontal wooden structures, the use of natural materials such as marés (Balearic sandstone) for the load-bearing walls, the pre-fabrication of all enclosures (carpentry and locksmithing), and the reduced presence of concrete and metal in the work all allow for a significant reduction of waste in terms of production. At the same time, in terms of CO_2 emissions, the vertical construction using marés (Balearic sandstone), the use of Forest Stewardship Council (FSC) wood for the prefabricated ceilings, as well as the use of sandstone on the exterior for durability ensures a significant reduction in CO_2 emissions from the materials compared to an equivalent conventional building.

Regarding solar control, two different strategies have been applied to the main façades:

- **Street façade:** Solar protection and shade are achieved with vernacular Mallorcan shutters that are mobile and give control to the user. At the same time, they provide the necessary privacy for the ground

[3] Will be updated and translated into English in the next version of the document.

floor, with the porticos on this floor divided into two sections to give different levels of privacy and adaptability.

- **Garden façade:** The rooms on the corridor also have a portico system. However, in the thermal intermediate spaces, in order to prioritise ventilation and natural lighting, there is no portico and we rely on the solar control exerted by the marés (Balearic sandstone) ribs on the outer walls of the corridor. As can be seen in the images below, the direct solar radiation on the interior façade of the garden is greatly reduced thanks to the shadow cast by the vertical ribs.

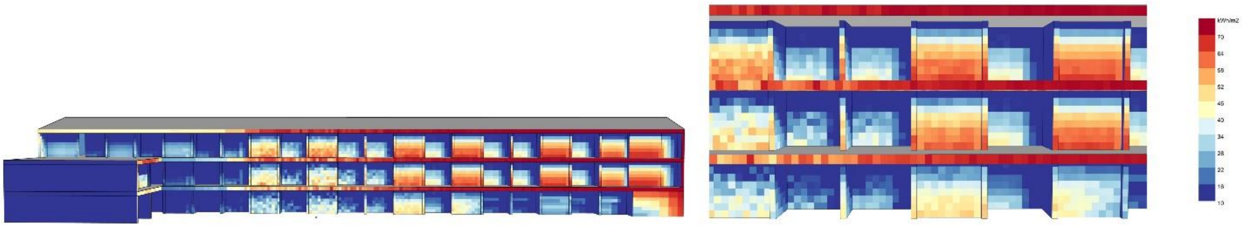


Figure 44. *Image of solar radiation without solar protection ribs in the garden façade.*

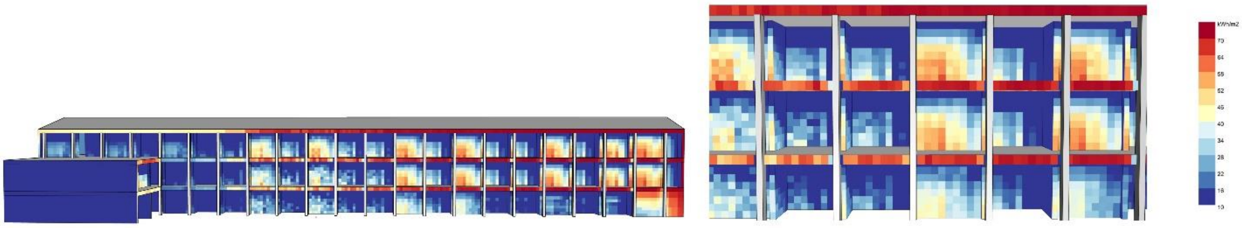


Figure 45. *Image of solar radiation with solar protection ribs in the garden façade.*

A project focused on sustainability, such as the one presented, must provide information on the resources necessary for obtaining the desired conditions of use and comfort. This is of great interest for an environmentally responsible project, which demands that the design of the building fulfils specific and verifiable requirements in its fulfilment, including the limited consumption of necessary resources.

In fact, the project has been designed on specific environmental objectives and decisions have been dependent on environmental concerns. For example, a limit has been set on energy and emission levels caused by the construction and specific designs such as a roof that captures rainwater and a façade that lowers energy demand have been introduced.

The response of the building to the physical demands of sustainability, or in other words, the environmental quality it will obtain throughout its life cycle, especially during the phases of extraction and the manufacturing of materials (which is where up to 90% of environmental impact is concentrated) can be summarised by four basic indicators:

- **Materials:** The consumption of materials is equivalent to the final weight of the different elements that make up the constructive matter for the building, including waste during construction.
- **Energy:** Consumption associated with all the processes throughout the life of the building, especially the extraction and manufacture of materials and the daily use of the building (mainly air conditioning, sanitary hot water and lighting).
- **Water:** Water consumption from sanitary services, cleaning, irrigation and air conditioning during use of the building.
- **Waste:** Generation and management of the waste produced during the construction of the building.

And a global indicator or indicator of indicators which is **CO_2 emissions:** Release of carbon dioxide related to the production of energy used throughout the life cycle of the building.

5.3. DETAILED DESIGN AND ENVIROMENTAL PERFORMANCE ANALYSIS

5.3.1. CLIMATE

The climate of Mallorca is a temperate one, located in climate zone B3 of the CTE DB-HE where the severity of the climate in winter is indicated by the letter (less severe to more severe α, A, B, C, D, E) and with the number referencing the heat of the summer (4 the hottest and 1 the coolest).

Although the official technical code document sets out climate standards that are used for certification, a more specific climate archive, extracted from the Meteonorm Climate Statistics Platform database [14], has been used in the energy simulation. Substantial differences are observed in the two climate models since, as proposed by the CTE, the maximum temperatures are higher, and the relative humidity lower, compared to the real data. This difference must be taken into account, especially when it comes to developing and calculating the effects of different bioclimatic strategies that affect air conditioning demand and comfort.

5.3.2. ORIENTATION AND PLOT LAYOUT

The proposal presents a plot, which supposes an elongated building presenting the two longitudinal façades oriented towards east and west. The north and south façades are smaller, giving little room for solar capture from the south and posing an important challenge in terms of solar protection from the east and west, especially in summer, while offering sufficient solar capture during the winter.

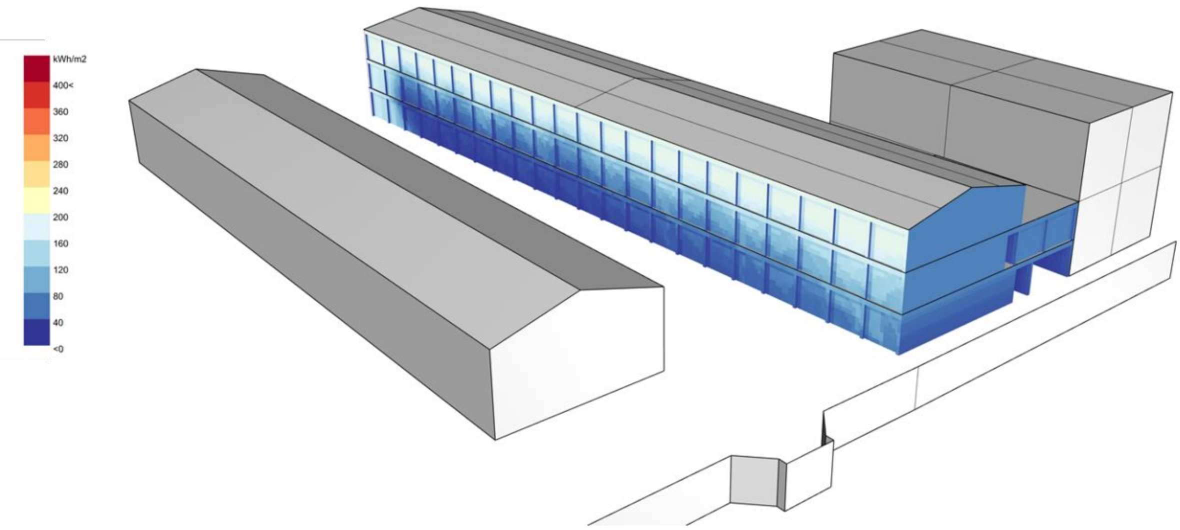


Figure 46. *Solar radiation gains during winter on the east façade.*

In winter, the east façade lacks sunlight on the lower floors due to the influence of the nearby buildings. The north façade, as can be expected, also has no capture and it will be necessary to reduce openings and insulate the walls well.

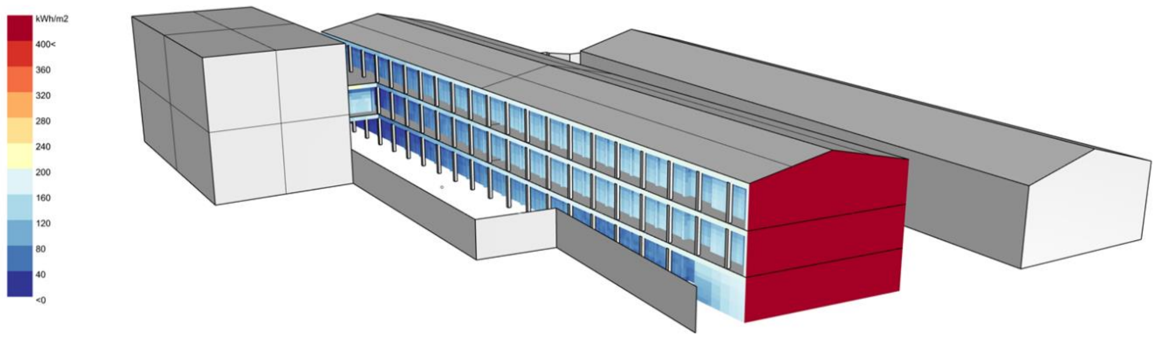


Figure 47. *Solar radiation gains in winter on the north façade.*

As with the east façade, there is limited capture. This is due to vegetation and other environmental factors. The overhangs of the walkways do not prevent the sun from reaching the façade.

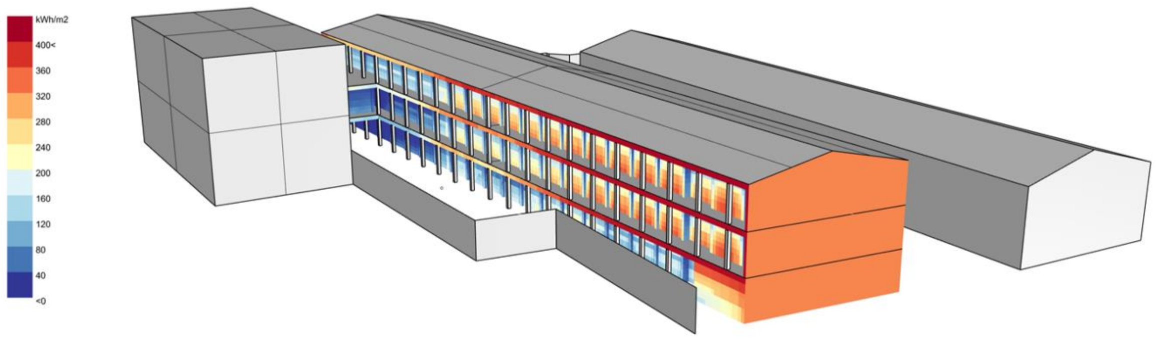


Figure 48. *Solar radiation gains in the afternoon during the summer on the west façade.*

In the summer, the west façade is rather punished by the afternoon solar incidence and sun protection is necessary.

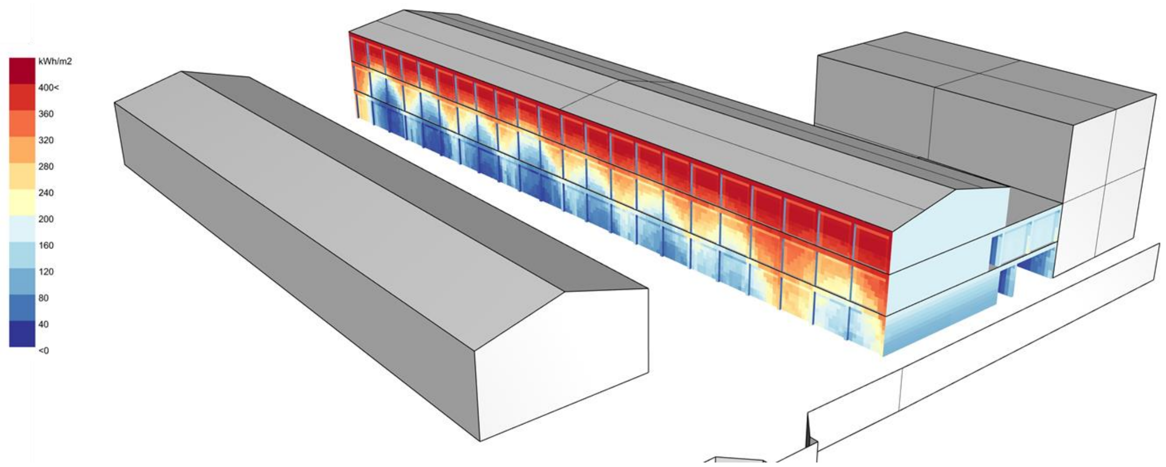


Figure 49. *Solar radiation gains in the morning during the summer on the east façade.*

On the east façade, it is necessary to protect the solar incidence because the morning sun is more intense than on the rest of the north and south façades.

5.3.3. ENVELOPE AND BIOCLIMATIC ELEMENTS

Envelope characteristics

A basic action in the design is to increase the insulation performance of the materials to a high level of demand, since the effort in terms of thermal loads will be optimised. It is, therefore, important not to waste the accumulated energy unnecessarily. To carry out the energy simulation, the levels of definition obtained from the construction details of the project report have been taken into account. The project requires transmittance of the enclosures in contact with the outside, based on the recommendations made by the document of the technical code on energy savings.

By way of summary, the following closures of the thermal envelope remain:

Table 17. *The description of the structural elements of the envelope.*

Element	U-value [W/m²K]	Total thickness [m]
External wall	0.35	0.3
Internal wall	1.09	0.22
Internal slab on a parking lot	0.3	0.355
Internal slab of the house (on slab P1)	0.26	0.4
Pitched roof	0.19	±0.4
Flat roof	0.25	±0.25

Once the conditions of the envelope have been determined, the model can be simulated using a dynamic balance calculation program that allows us to extract the demand of each space and read the elements that have the most influence on heat loss or gain. This also takes into account both the variability and the management of the elements.

A low-tech construction is proposed, based on load-bearing walls, which drastically reduce the environmental impact of the construction and improves the thermal inertia of the homes, while establishing a tectonic dialogue with the surrounding buildings. Almost all of the load-bearing walls are oriented from east to west, and are orthogonal to the longest side of the lot in order to take advantage of the solar gains homogeneously throughout almost the entire building. The walls are separated by approximately 3m and with the help of the timber walls, a network of undifferentiated rooms can be generated in order to make the homes more habitable. Thus, within the mesh, an arrangement is proposed which provides alternative and flexible typologies within different homes (1 or 2 rooms) that can coexist inside of the same structure and façade in order to respond to varied social and family needs. At the same time, it is proposed to reduce circulation spaces and have an arrangement of rooms that are always the same to facilitate the easy use of the interior spaces, even being possible to segregate a part of the house (the room in contact with the corridor, for example, which could end up having an independent entrance). The layout of the rooms allows for south-facing windows to be inserted which would favour the capture of light in the interior.

Bioclimatic elements

One of the key points of the project is to allow for an adaptability of the building based on the situation of each year. Through manually or automatically regulated bioclimatic elements, it is possible to ventilate in summer or capture and conserve heat in winter. These bioclimatic elements can be related to each flat individually. One of the most important problems associated with the loss of heating during the winter is linked to the minimum ventilation required by regulations. One of the strategies adopted to reduce losses is to use the variable flow ventilation method. This ventilation allows the air to be heated previously before introducing it into the home through bioclimatic capturing spaces that act as thermal intermediate spaces and reduce losses.

The management of both the thermal intermediate spaces and the atriums is very important as they allow systems to be optimised and construction materials to be saved. However, if the management of these spaces was not adequate, imbalances could occur in the interior, causing overheating in the summer - if there is no ventilation or sufficient protection - or cold temperatures in the winter - if the capturing potential is not taken advantage of.

A simulation of the building corresponding to the final executive version has been carried out without adequate management of this thermal cushion space in winter. An option has been simulated where the user does not ventilate using this space but directly from the outside – understanding that he is not correctly managing the thermal cushion as a collecting space but as a balcony. Even though in this case it partially accounts for a thermal cushion function, it penalizes at the same time solar capturing because the solar rays have to pass through two glasses instead of one.

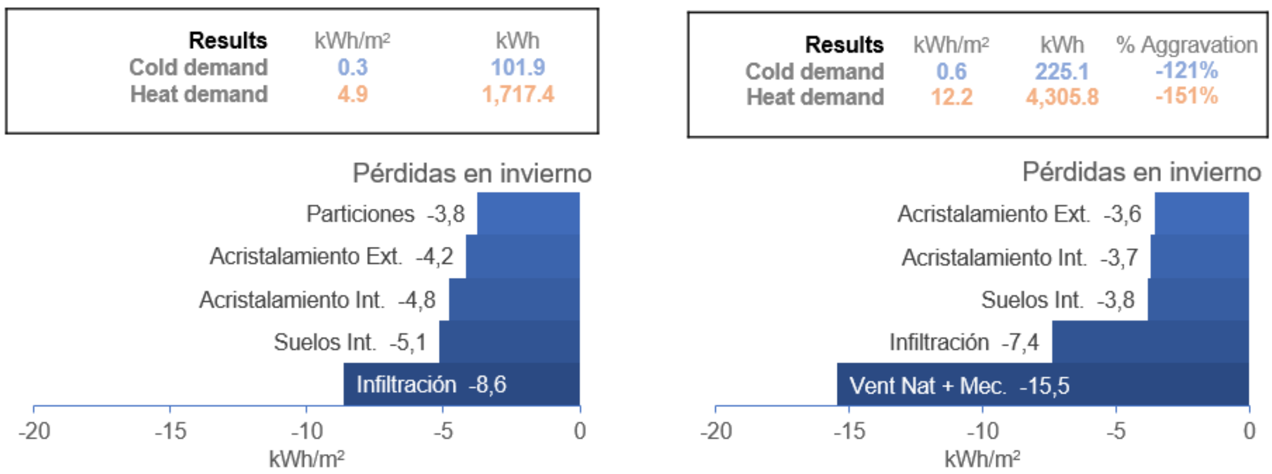


Figure 50. *Galleries with management (left) and galleries without management (right). Extracted from the project documentation (partly in Spanish language[4]). Pérdidas en invierno = losses in winter, particiones = partitions, aristalacimiento = glazing, suelos = floors, infiltración = infiltration.*

5.3.4. ENERGY PERFORMANCE

Methodology

Through an energy simulation, the most advantageous solutions are proposed which present a potentially optimal model within the technical and economic possibilities of the project. In the detailed design phase, therefore, improvements and limitations have been incorporated based on prices and constructive solutions in a realistic and economic model.

Based on the energy simulations, the weak points are detected and the insulation thicknesses, the finishing materials and the specific thermodynamic properties of the materials are checked. This analysis is reflected in the inner comfort of the homes, which is the final indicator of the home's solvency. The building-user relationship is the most important in terms of priorities and from where all construction and project solutions pivot, so the final comfort indicator is what will mark the quality of the home.

[4] Will be updated and translated into English in the next version of the document.

Energy demand analysis

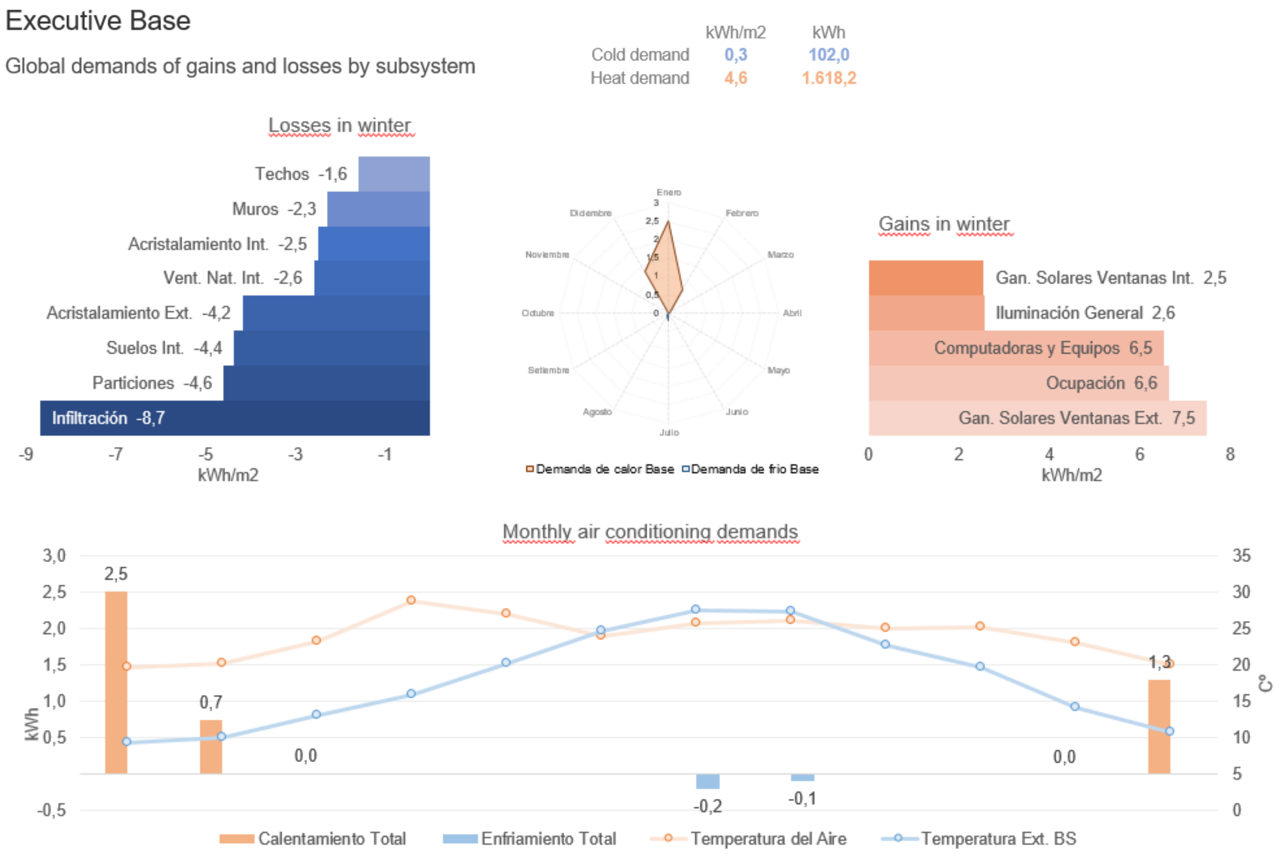


Figure 51. *Energy demand analysis. Extracted from the project documentation (partly in Spanish language[5]). Techos = roofs, muros = walls, gan. solares ventanas int. = internal solar gains from windows, iluminacion general = general lighting, computadoras y equipos = computers and equipment, ocupacion = occupation, demanda de calor base = base heating demand, demanda de frio base = base cooling demand, calentamiento total = total heating, enfrianmiento total = total cooling, temperatura del aire = air temperature, temperatura ext. = outdoor temperature.*

In this graph, it can be seen that the heat losses in winter due to the thermal envelope are well resolved and the capture from the east and west is well used, giving a sufficiently low energy demand, which puts the project within the limit of energy rating A.

The fields that correspond to the thermal envelope are reduced and the biggest losses remain infiltration, which depends a lot on the quality of the work's execution.

[5] Will be updated and translated into English in the next version of the document.

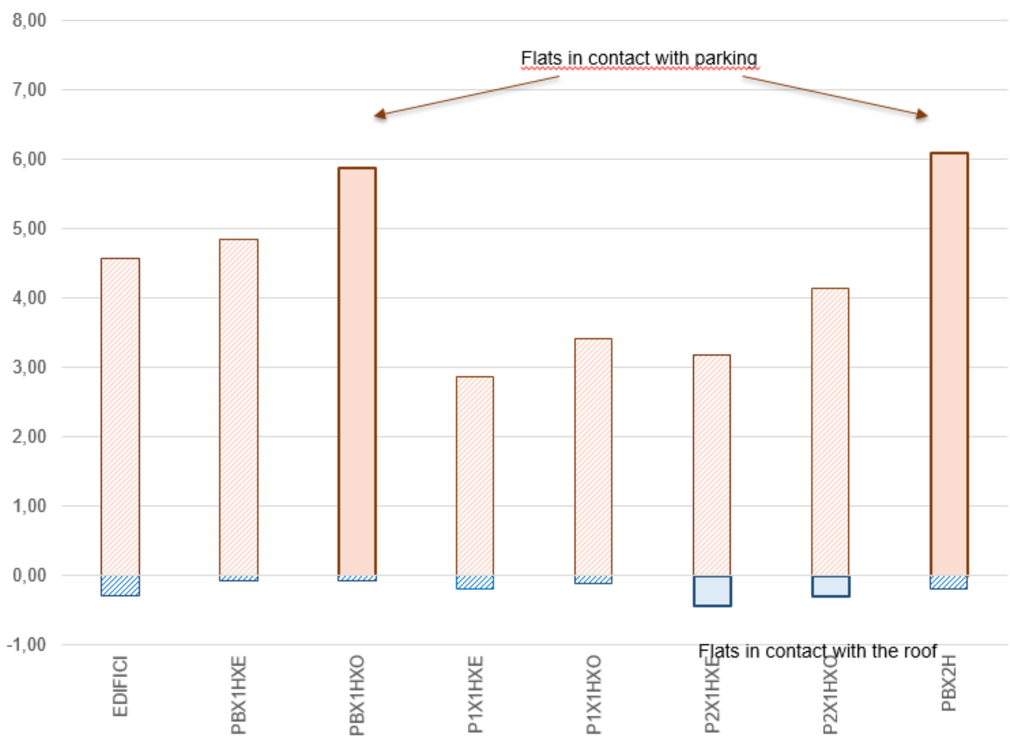


***Figure 52**. Distribution of building demands.*

In the attached graph we can see the distribution of the different demands for each part of the building. We are shown the differences between the flats in contact with the ground, where the demand for heating is higher, and the flats under the roof, where the cooling demand is increased compared to other parts. From here, the different solutions that optimise the economic and constructive aspects that give coherence to the proposal are checked.

The optimisation of insulation has been part of a process where the relationship of CO_2 emissions generated between the energy saving of the building and the impact associated with the production of the material is not linear. As centimetres of insulation are added, the impact on energy savings is reduced. Therefore, it is important not to "waste" material and find the optimal value of thickness.

Two thicknesses are tested to study the optimal insulation in the floor in contact with the parking. One of 15 cm (the base) and the other of 15 cm of recycled cotton with a thermal conductivity of 0.04 W/(m·K). The overall result for the building is extracted to see what level we are at with respect to the energy label.

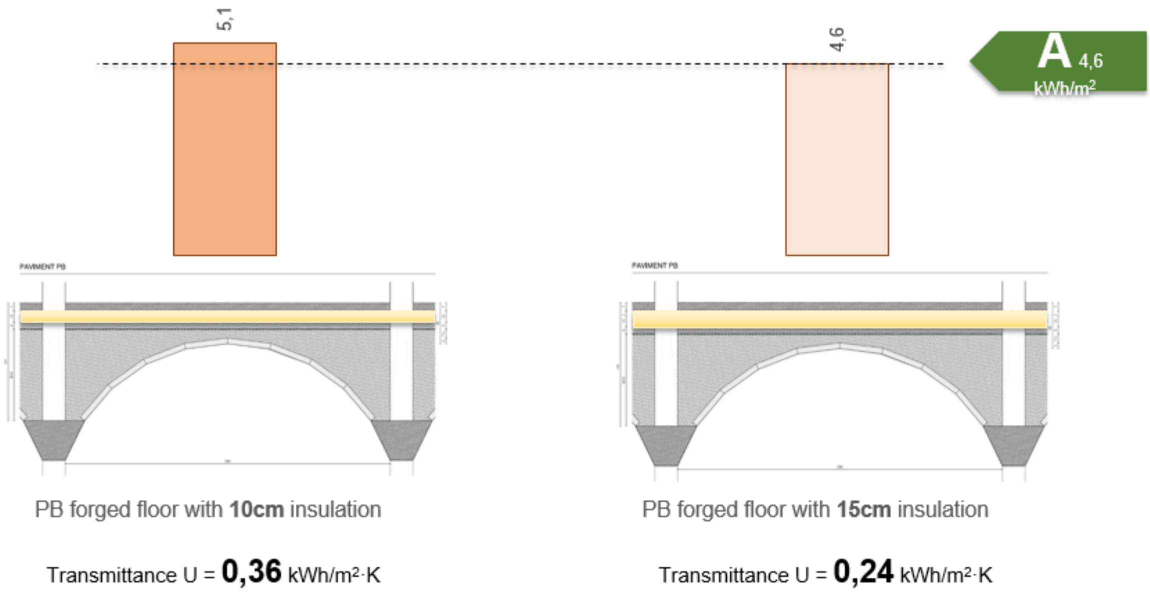


Figure 53. *Insulation tested for the partition between the car park and the ground floor of the dwellings.*

With respect to global demand, it can be seen how demand increases by 11% using a 10 cm thick insulation. However, on the flats in contact with the parking lot you can see how the drop is greater than 10% overall.

A possible alternative to the 10 cm insulation is to use an insulation with a lower thermal conductivity, to optimise the thickness without losing thermal performance but to the detriment of its ecological footprint. Finally, to opt for a 10 cm XPS insulation with a conductivity of 0.034 W/m/K. This signifies a change in transmittance of the closure from 0.24 kWh/(m^2·K) to 0.30 kWh/(m^2·K).

An optimisation is proposed in the transmittance of the interior glass in relation to the space that acts as a thermal cushion. In the base model, a good transmittance is proposed for the outer leaf of this space since, due to its orientation, its solar capture is secondary to the conservation of the accumulated energy. The interior glass becomes a thermal cushion and regulation of the entry of this air can be checked to determine what extent it can be favourable to have good transmittance in this interior section. It is proposed with respect to the base where a transmittance of 3.1 kWh/(m^2·K) is proposed, a simple glass of 5.7 kWh/(m^2·K) is used.

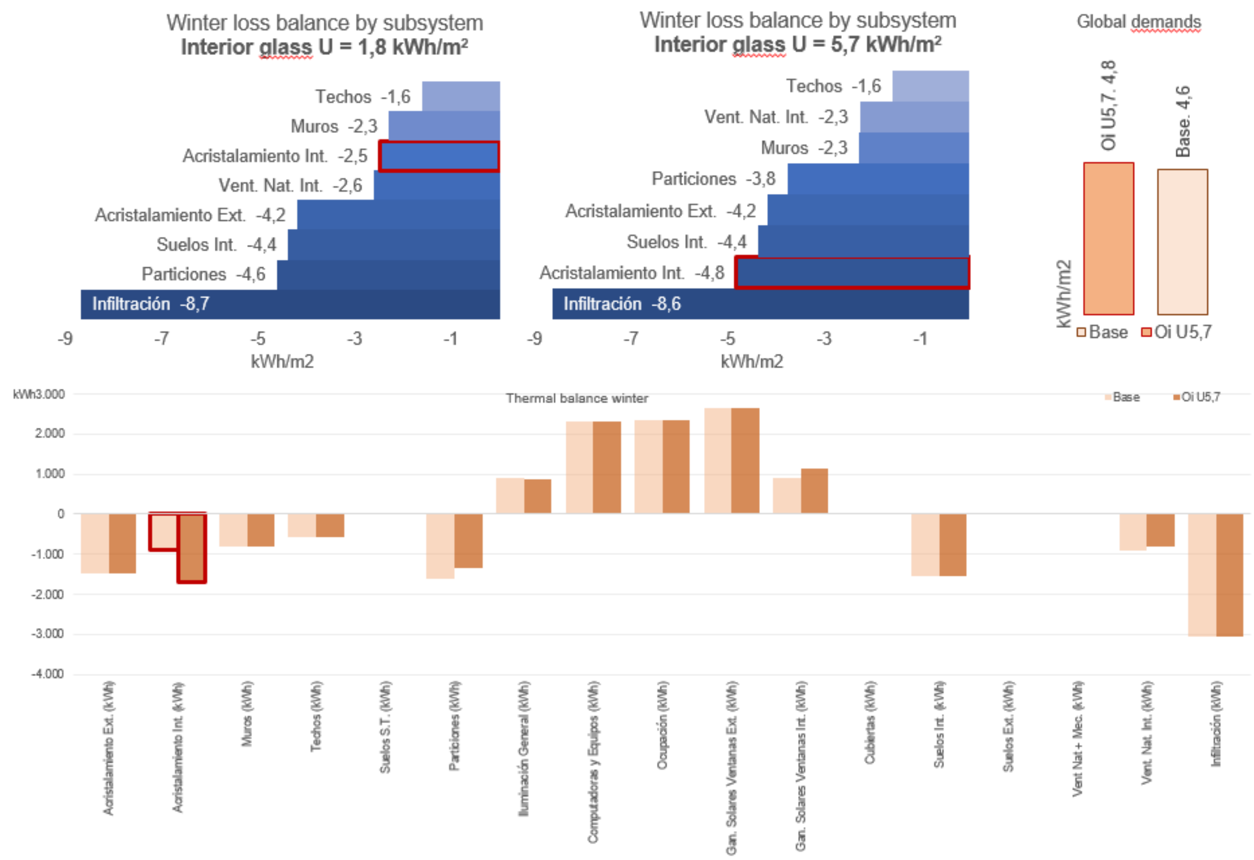


Figure 54. *Comparison of the internal loss balance depending on the performance of the glass. Extracted from the project documentation (partly in Spanish language[6]).*

5.3.5. COMFORT PERFORMANCE

Analysis of annual comfort serves to look globally at what the comfort situation is in the entire building. Since the values are taken globally, the average of the good and bad performances in reference to the different floors is obtained. But it also gives a very representative picture of which values we are between. To understand the overall situation, the most extreme periods are usually analysed since the intermediate periods require finely tuned management of the façade systems either automatically or manually, but still perfectly reflect the idiosyncrasy of a building in a Mediterranean climate where the spring and autumn seasons are very variable. In these situations, the management scheduled according to the calendar can generate great discomfort, whether due to heat in "colder" seasons or cold in "hotter" seasons. Since an automated control system for the elements of the envelope (sun protection, window opening) is not planned for, we consider that manual management is basic. And it will require user information and training to properly manage the home. So the periods to be studied are those most extreme in terms of external climate conditions, in the extreme weeks of winter and summer.

[6] Will be updated and translated into English in the next version of the document.

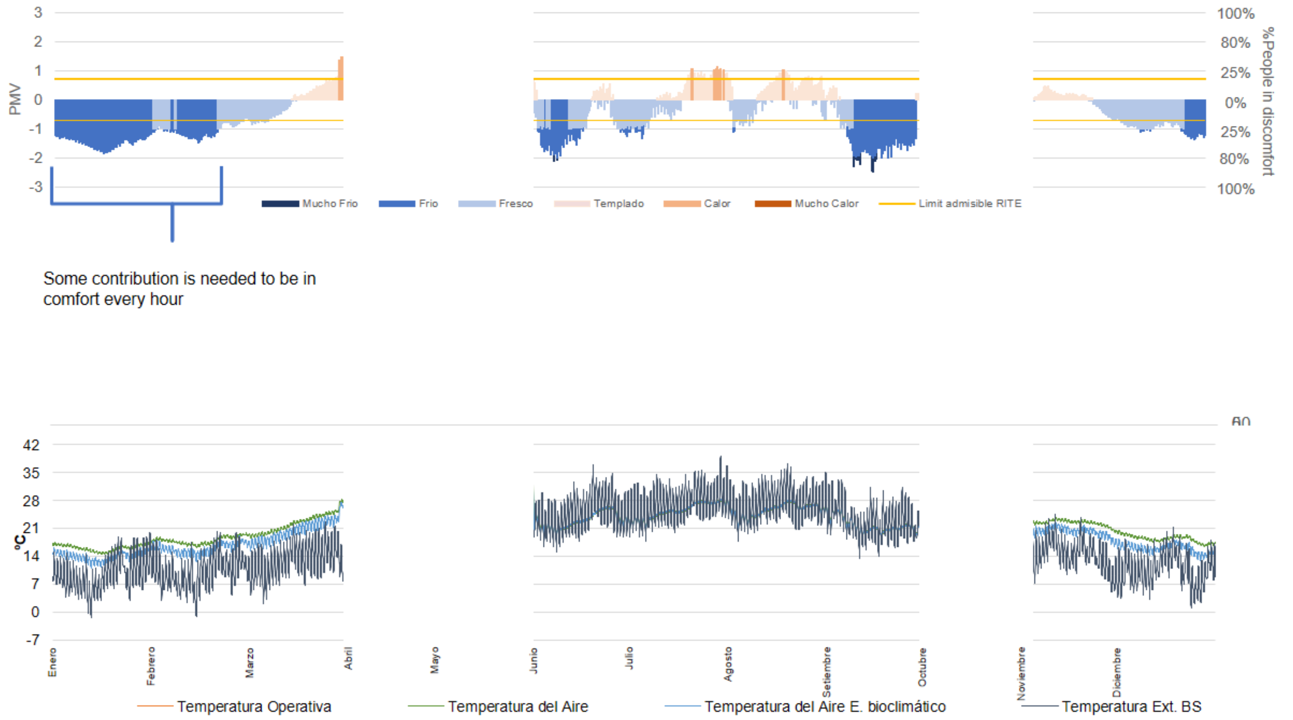


Figure 55. *Overview of the annual comfort analysis. Extracted from the project documentation (partly in Spanish language[7]).*

Winter comfort

The most unfavourable flats in the winter season are those that require a higher heating demand. In this case, they are the flats in contact with the parking lot. This is for two reasons:

- They are in contact with a non-habitable space and generate losses for the façade envelope and the entire surface.
- They are the ones that receive less solar radiation Take as an example Room 2 on the ground floor with a heating demand of 7.31 kWh/m².

In the most unfavourable flat, the total distribution of temperature and comfort during the winter hours are as follows:

[7] Will be updated and translated into English in the next version of the document.

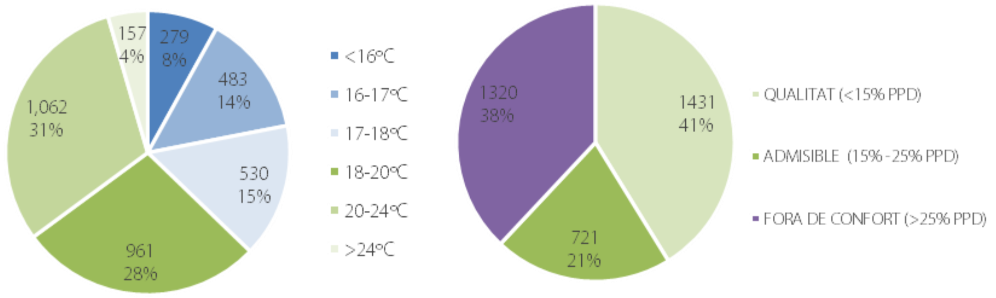


Figure 56. *Distribution of the number of hours in each temperature interval (left) and in each comfort range (right). Extracted from the project documentation (in Catalan language[8]). Qualitat = quality, admisible = admissible, fora de confort = comfort zone.*

We can observe that at a general level, 38% of the hours of comfort are below 18ºC, which generates discomfort due to the cold. If we go further into the study, we can conclude that we do not reach a temperature high enough to be within the comfort zone. Even so, it can be observed that the evolution of the temperature throughout the week remains extremely stable and barely fluctuates at all in the day/night interval.

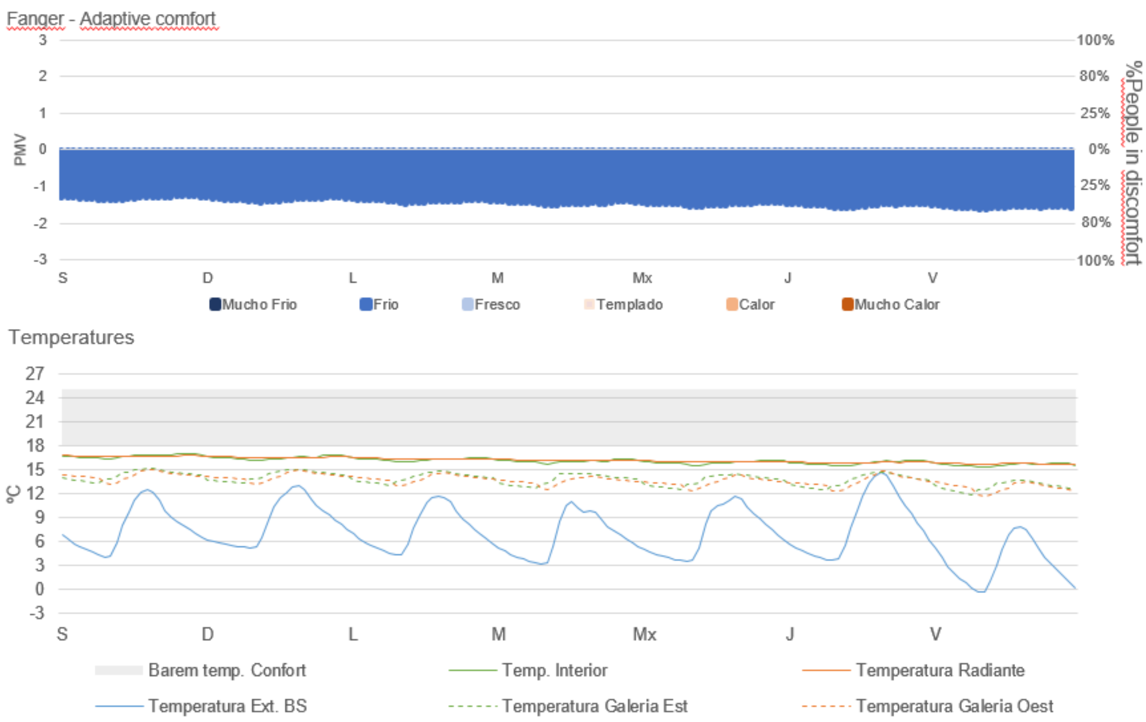


Figure 57. *Adaptive comfort model. Temperature fluctuations.*

The temperature itself remains almost constantly below the comfort range of 15ºC and 18ºC when peaks of 0ºC are reached outside during the night. Therefore, we can see that the building is able to store and sustain the little energy it contains, passively creating thermal differences of up to 15ºC .If we analyse in a more advanced study what the minimum needs would be to achieve comfort, it can be intuited from

[8] Will be updated and translated into English in the next version of the document.

the outset that from the little energy generated inside the home it would be possible to maintain this temperature within the comfort range.

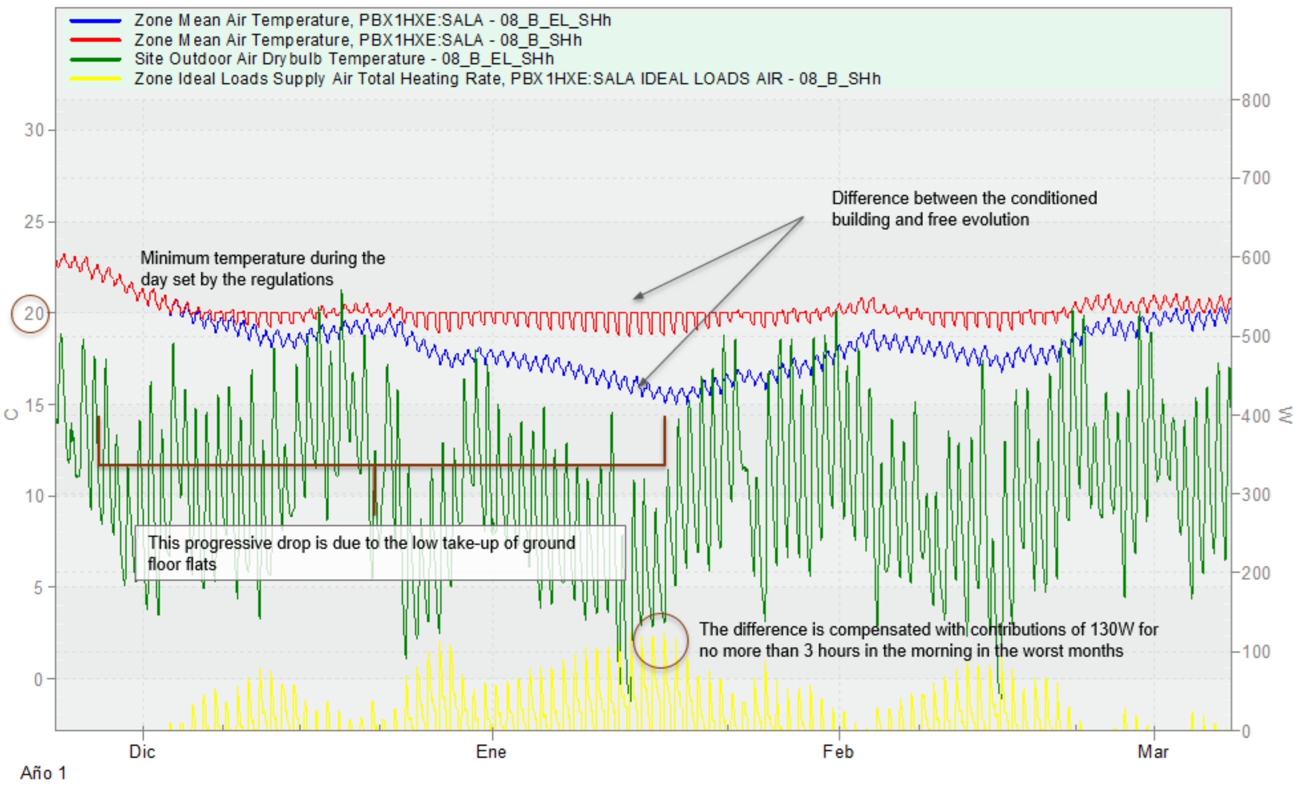


Figure 58. Analysis of heat demand in winter without air conditioning systems.

The previous graph shows that with a small daily contribution of less than 200 W you could keep the room comfortable. This 200 W of energy would be equivalent to 3 incandescent bulbs or a conventional desktop computer. It is such a small demand for a minimal space that it is not considered necessary to install any heating systems.

An additional option would be to install a small resistor to the ventilation fans in the rooms - if they were there - which would allow the air to be preheated when the fan was running. This is ideal for it would be at the exact moment you would need to ventilate and when the biggest losses occur. Therefore, the heating contribution need be synchronized with the heating needs and ventilation elements.

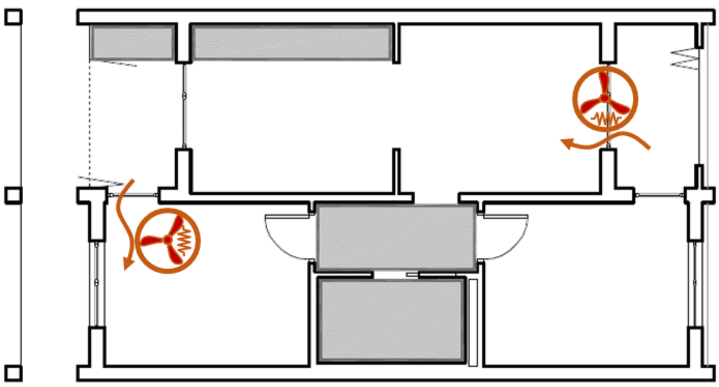


Figure 59. Proposal for electric heaters integrated into the fans to cover the heat demand in winter.

Summer comfort

Summer comfort, in the same way that winter comfort has been studied, tries to analyse the number of hours spent in a situation of discomfort and what the critical temperature ranges are. According to the results, the passive strategies that increase the range of comfort were sought out.

The flat chosen by the study was the flat with the worst cooling demand situation, located under cover.

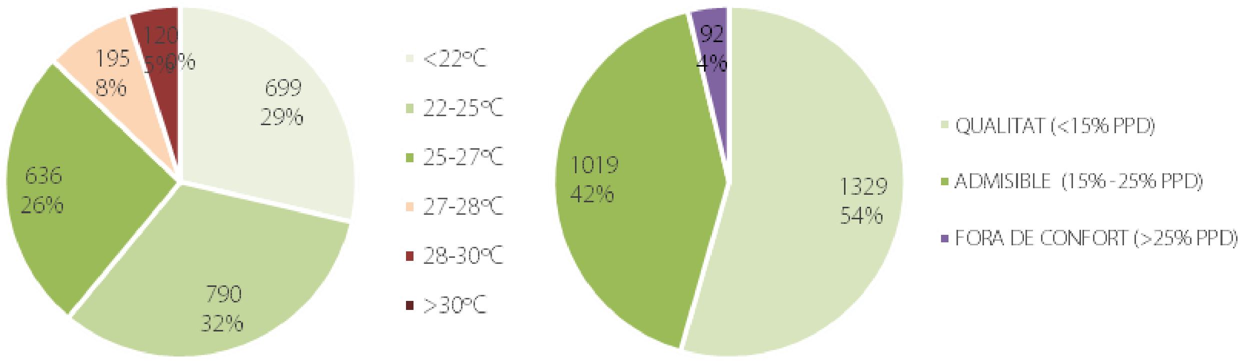


Figure 60. *Distribution of the number of hours in each temperature interval (left) and in each comfort range (right). Extracted from the project documentation (in Catalan language). Qualitat = quality, admisible = admissible, fora de confort = comfort zone.*

It can be concluded that 13% of the hours exceed a temperature of 27ºC inside and never exceed 30ºC on average throughout the flat. It should also be noted that 30% of the hours were below 22ºC. This behaviour is clearly created by the good inertia of the building and its ability to regulate humidity in the air in the interior space. This greatly reduces the sweltering sensation of a humid climate like that found in the coastal areas of Mallorca.

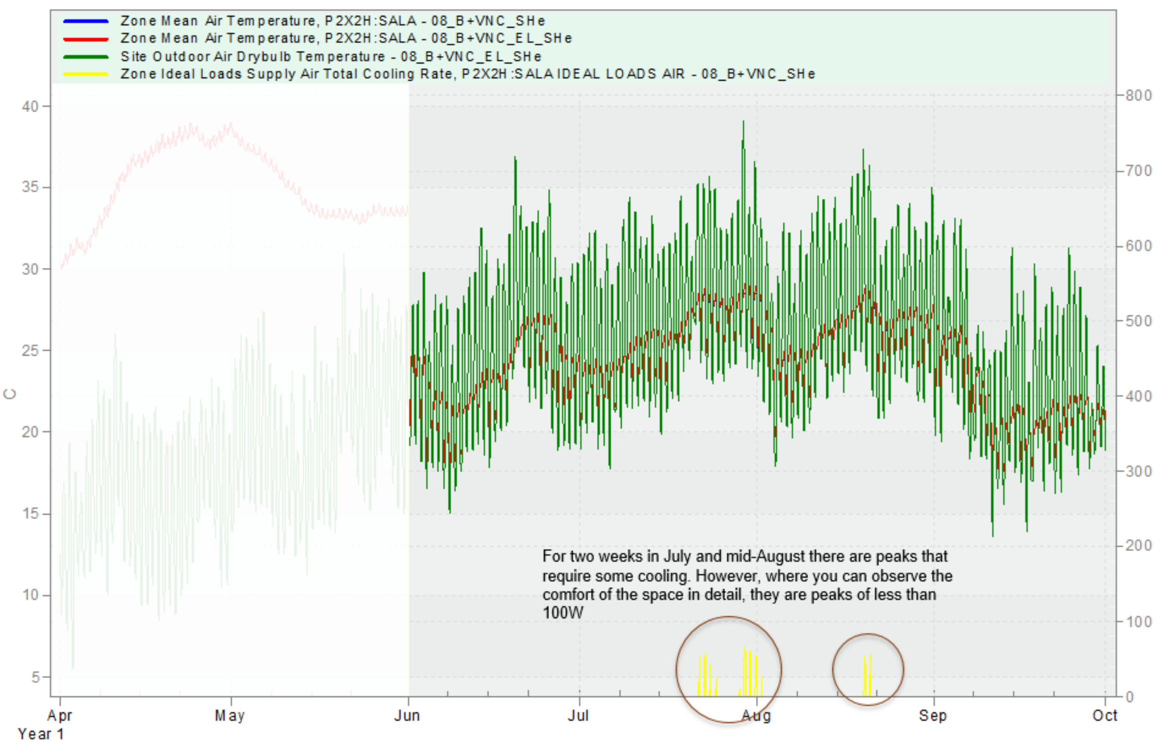


Figure 61. *Analysis of heat demand in summer without air conditioning systems.*

If the analysis is focused on the typical week, we can observe peaks in demand that could cause discomfort at certain times of the day. This situation must be analysed to ensure the viability of the proposed solutions.

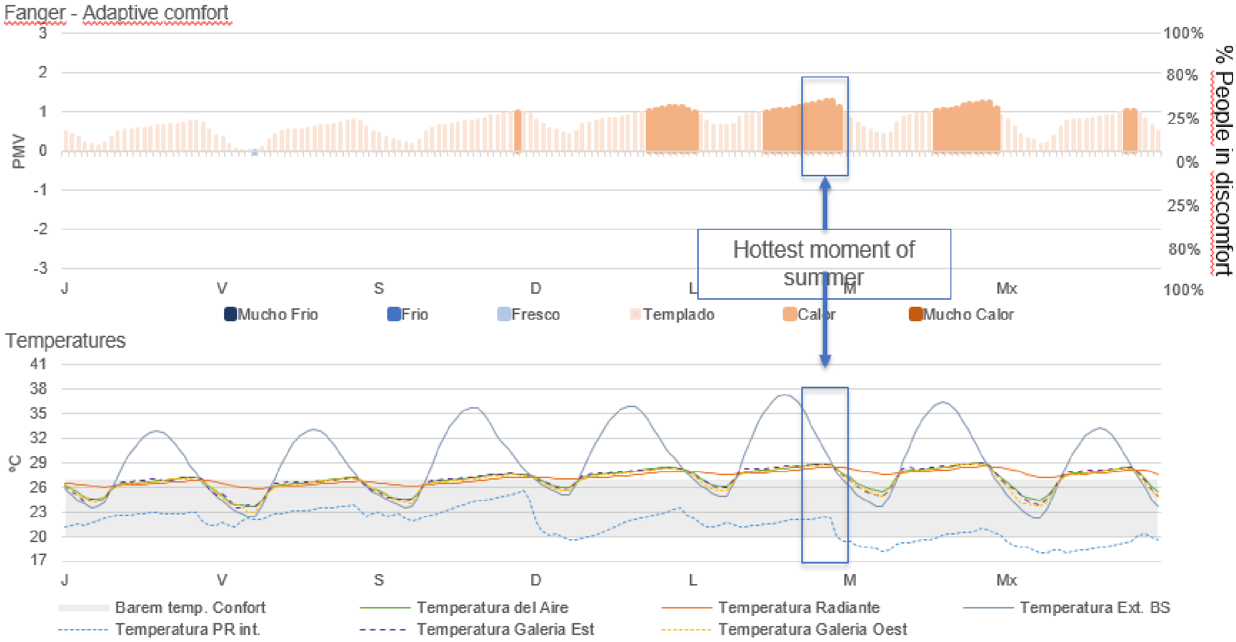


Figure 62. *Detailed analysis of peak demand during a typical week in summer.*

The simulation program optimises the management of façade elements by closing windows when the outside temperature exceeds 27ºC. Therefore, the temperature of the walls maintain the internal temperature of the air, reducing the sensation of heat. As can be seen in the graphs of the evolution of temperatures (**Figure 63**), if the external windows are closed when the outside temperature is very high, we can have up to 8ºC difference with the outside.

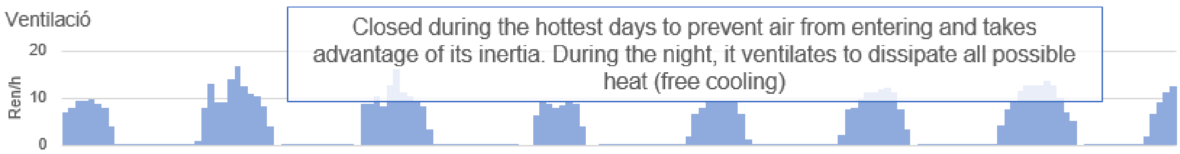


Figure 63. *Evolution of temperatures.*

In the hottest moments, comfort is achieved with passive strategies and the use of a ceiling fan to increase the air speed. The following graphs compares the thermal perception without and with celling fans.

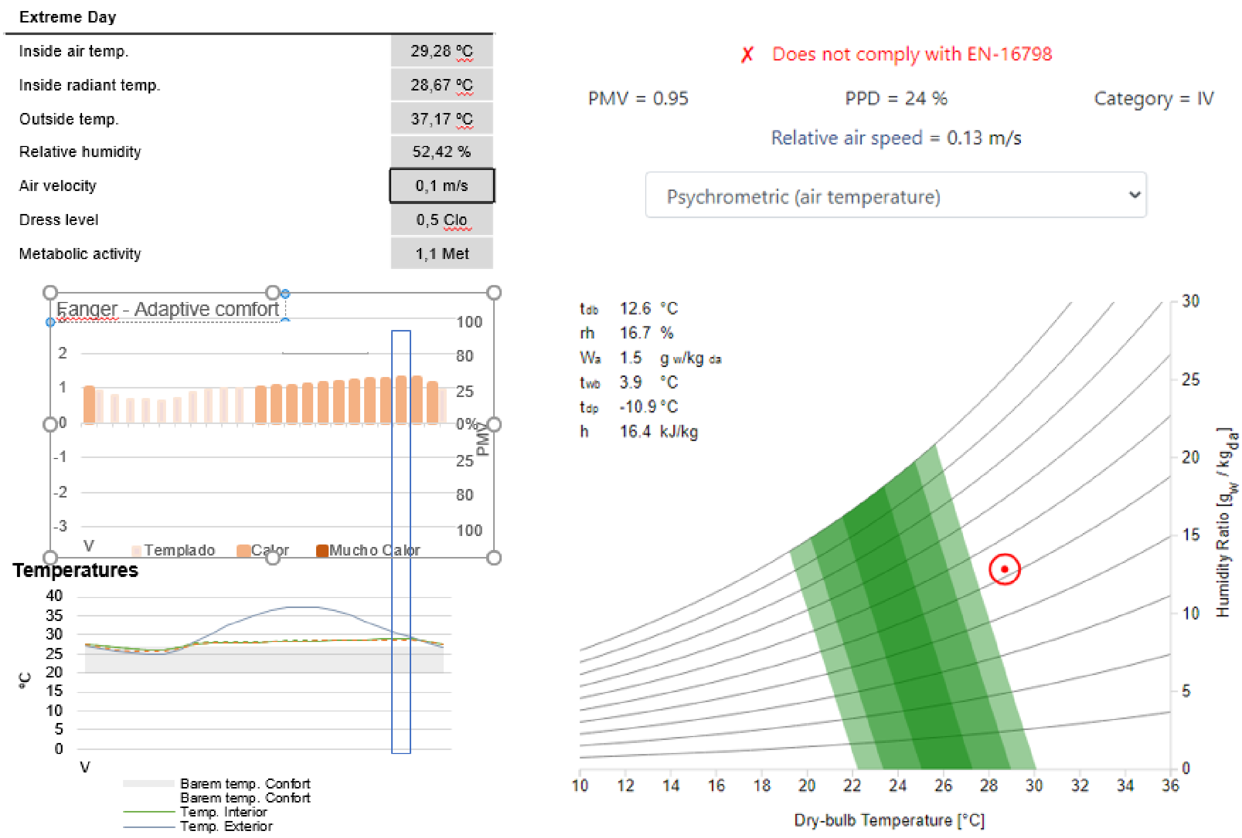


Figure 64. *Comfort analysis without ceiling fans. Templado = warm, calor = hot, mucho calor = very hot.*

It must be taken into account that the air speed should not exceed 1m/s as it could create discomfort for some users due to excess speed.

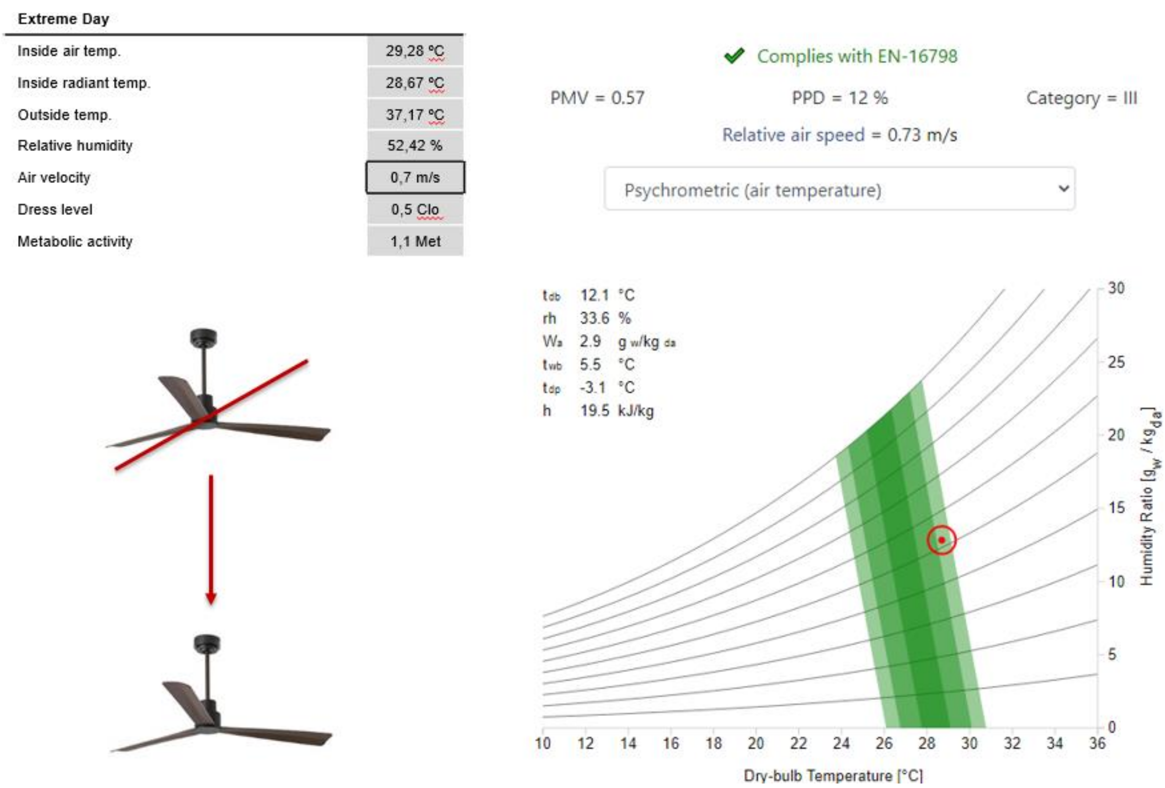


Figure 65. *Comfort analysis with ceiling fans.*

The conclusion is quite clear: the ceiling fan can prevent overall heat discomfort even in the most extreme moments. In any case, the average for the worst performing flat is not representative of the entire building and not all floors share the same conditions. To visually represent which is the worst time is another project tool that will reveal possible causes of heat discomfort.

Summer comfort in flats under roof

ACFD (Dynamic Calculation of Fluids) module tool is used to observe the distribution and behaviour of indoor air, especially in flats under the roof.

Detailed analysis allows to see that the building does not dissipate the heat to the interior and even when it is 37ºC outside the undercover is at a higher temperature. The radiant temperature of the slab under the roof, even though it is insulated, is in contact with a space that is hotter than the outside. The renovation analysis of this space will be key to knowing how much it will be necessary to ventilate it to dissipate the heat of the undercover. If this space is not ventilated, renovations charged every hour are exclusively those generated by infiltrations due to construction. When a pressure difference is generated due to temperature or wind, these infiltrations increase up to 0.2 Ren/h.

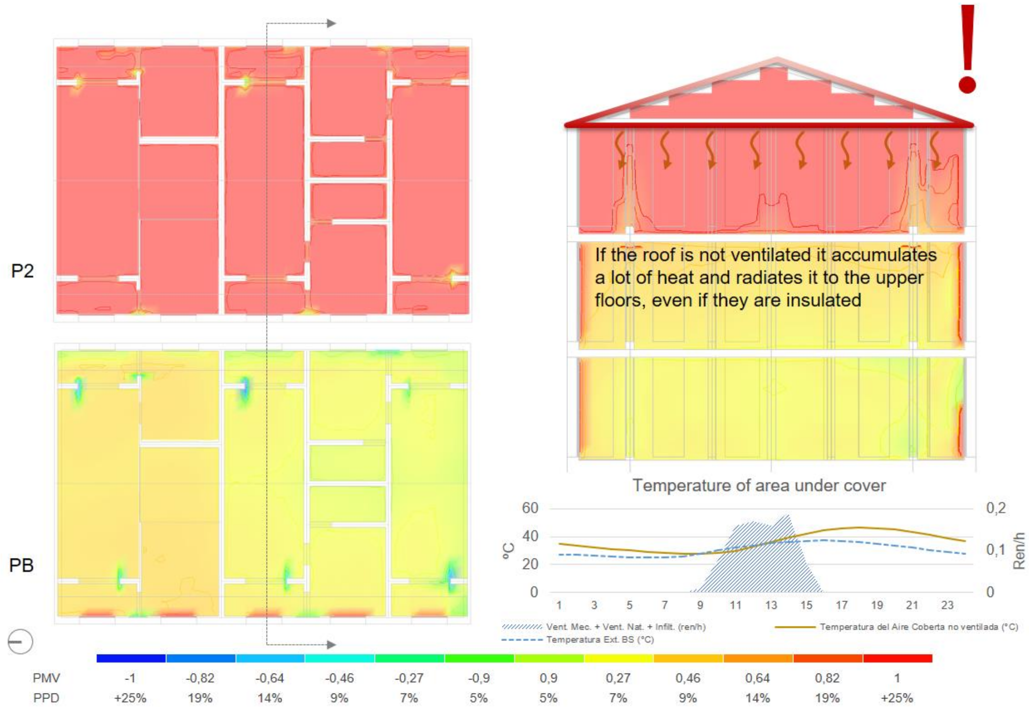


Figure 66. *CFD analysis of temperatures under the roof.*

In the comparison of the two sections of unventilated and ventilated roofs, the temperature is reduced by 8ºC since the latter is a shaded and ventilated space. Lateral openings in the gable roof of 0.5x0.5m every 4 m in length have been considered. This arrangement of openings has led to an increased air renewal of 0.2 Ren/h to 20 Ren/h.

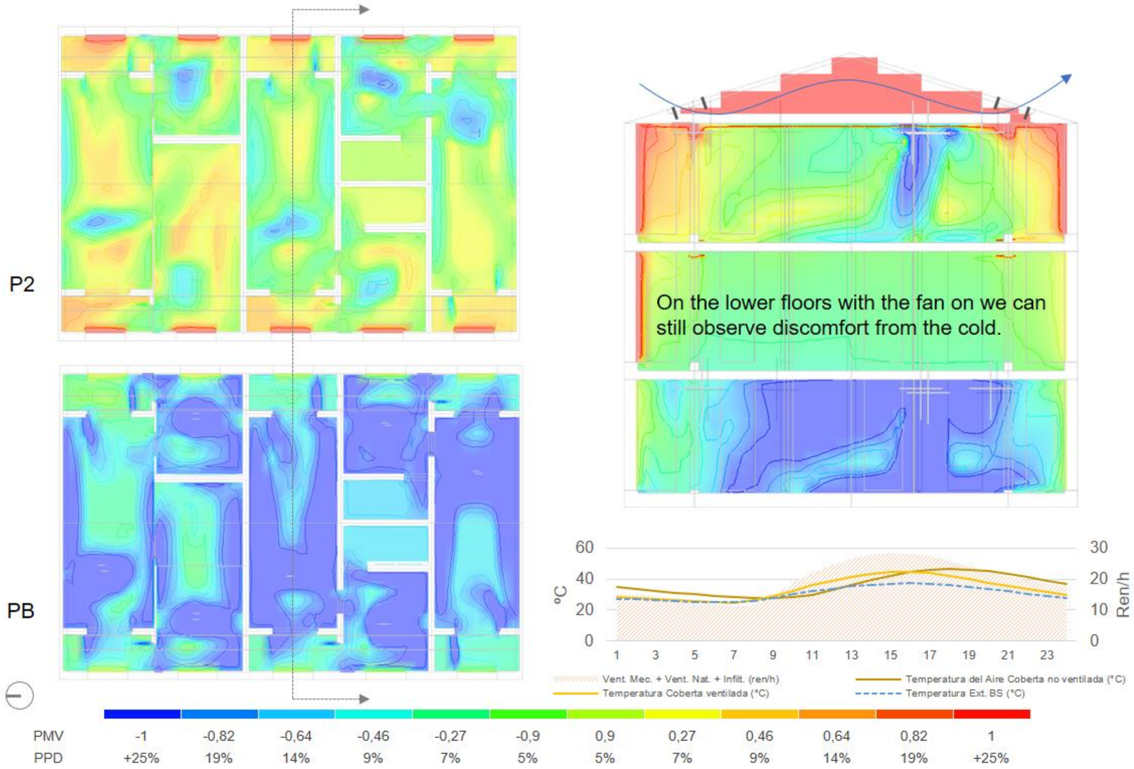


***Figure 67**. CFD analysis of temperatures.*

At the comfort levels of each floor in many cases the upper floor improves considerably, and the ceiling fans even generate a feeling of cold. In this way it can be concluded that theoretically, 100% of the summer hours are comfortable.

5.4. ENERGY LABEL

The CE3X tool was used to carry out the energy certification. In this tool, although it requires an energy simulation, the model conditions are different because the bioclimatic elements that help reduce demand are not represented. The systems used by CE3X are conventional systems with scheduled patterns and air conditioning agendas. While these are more unfavourable compared with the simulation using Design Builder, it is observed that the energy rating obtained is an A with a primary energy consumption of 10.7 kWh/m^2/year, with carbon dioxide emissions of 2.8 kgCO$_2$/m^2/year.

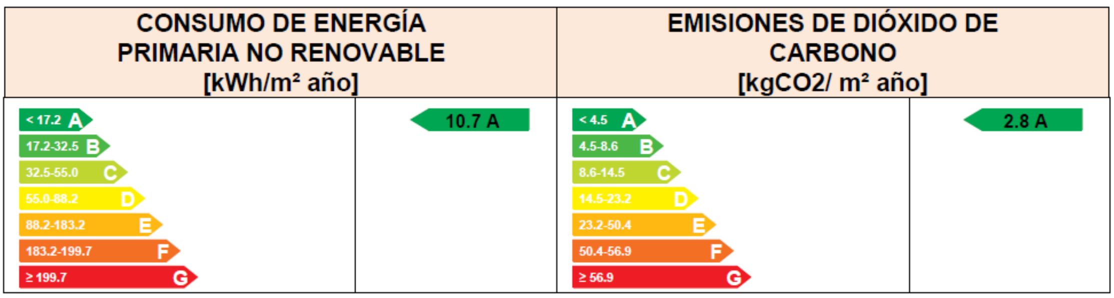


***Figure 68.** Energy labelling of the analysed building. Non-renewable primary energy consumption (left) and CO$_2$ emissions (right).*

For the energy certification, the following calculation parameters have been considered:

- Thermal bridges have been considered according to the Therm calculation program and have been entered into the calculation included in the wall closure solution.
- The natural ventilation flow of the building is 0.42 ren/h
- The thermal intermediate spaces have been considered as a unique envelope solution. Therefore, the capture has been generated on the outer plane which is where the insulation line is with a joint transmittance of all the elements.
- The seasonal shade defined in the openings apply from June to October.
- A daily hot water consumption of 2016 l/day.

5.5. SUMMARY

This chapter explain the main results of the design process of new social residential buildings in the Mediterranean climate. The project proposes an organisation of the space which, combined with a constructive proposal, that it makes possible homes with very low energy consumption, a quality living experience and a building that is integrated into the landscape in an environment with architectural value. The designed building in Palma de Mallorca, with 35 dwellings, is made up of two cores and is accessed via a walkway through the interior courtyard. In this way, all of the homes have vital cross ventilation that, together with the captivating use of the double thermal intermediate spaces acting as greenhouse (front and back), while solar control and thermal inertia allow for a very reduced energy demand whilst maintaining a very high level of comfort.

The process design and procedure are within the frame of public procurement procedures led by IBAVI, the public body in the Balearic Islands acting as promoter and owner of the building. IBAVI has introduced ambitious objectives relating energy and water consumption, reduction of construction waste and reduction of embodied emissions. In a constant dialogue with the promoter, the architects' team with the support of sustainability experts, have proposed a high architectural valued design while overcoming the initial ambitious targets (see **Table 18**).

***Table 18**. Summary of objectives achieved in the design of new social housing.*

Assessment criteria	Objective for new construction	Results of the design
Energy	**At least 50% reduction in energy needs** compared to current country building code. **Positive energy** level based on primary energy.	Heating and cooling demands are almost reduced to 0. The building is an **A class** (official energy label procedure in Spain). With planned PV system the building will reach a **Positive Energy** level.
IEQ	High levels of indoor environment quality according to EU norms.	High levels of IEQ are achieved by means of passive strategies and air circulation (fans)
Embodied emissions	**At least 50% reduction** compared to local current practice.	Ambitious targets established in the public procedure are achieved in the design phase.
Construction/retrofitting costs	**At least 30% reduction** compared to local current practice.	

6. DESIGN IN GESA BUILDING

6.1. DESCRIPTION OF THE BUILDING

The “GESA” building was the headquarters of the GESA company, a local power company that nowadays is part of ENDESA. The building was designed by the architect Josep Ferragut Pou at the 1963, which construction was carried out between the 1967 and the 1977.

The building was intended for administrative use, and it was designed with the rational style of the time. It introduced new construction technologies and a great concept of functionality. The central core of the building was provided with the main structure, elevators, stairs, and auxiliary services. Hence, the rest of the building was structure-free with big open spaces. The cubic shape of the building stands out with its four curtain glass façades.

This building was declared of heritage interest by the Consell de Mallorca in the 2007. The protection was granted due to the interest of the building as a testimony of the Modern Movement in Mallorca. In the past years it has been abandoned, which has led it to degradation. However, its structure is still in acceptable conditions.

Figure 69. *GESA building and surrounding areas. Adopted from* [15].

The ARV project intervention expected for the building consists of installing the latest generation photovoltaic panels into the façade for energy production. This intervention will be carried out by replacing the transparent and opaque façade modules with aesthetics and energy savings criteria in mind. The panels will be removed at the end of the project.

The refurbishment of old office buildings with BIPV in the Mediterranean region is a topic scarcely tackled in the literature [16]. The work takes as a reference the office buildings representative of the architectural trends of the 60s, following the international line of Modern architecture, some examples are shown in **Figure 70.**

The case study for this research is the GESA building, an emblematic office building in Palma de Mallorca (Spain). Despite of its iconic and protected status, the GESA building has been abandoned for several years, hence it requires a refurbishment that will also update its skin to the current energy efficiency standards.

a)  b)  c) 

Figure 70. *Some images of Modern architecture buildings of the 60s. a) Seagram building in New York* [17]*, picture by Steve Cadman licensed under CC BY-SA 2.0, b) SEAT building in Barcelona* [18]*, picture by Albert Esteves and published with the permission of the author and c) Athens Tower in Athens* [19]*, picture by Dimitris Kamaras licensed under CC BY-SA 2.0.*

The stakeholders that are part of the GESA building refurbishment project (**Figure 71**) and their key roles are summarised below:

- **Endesa/Enel:** Spanish multinational electric utility company. Owners and architects of the building and surrounding land.
- **Ajuntament de Palma (Palma City Council):** in order to preserve the front sea line of Palma de Mallorca, the City Council has reached an agreement with the owners to develop the area promoting sustainability and considering future generations.
- **Departament de Cultura, Patrimoni i Política Lingüística (Palma de Mallorca Regional Government):** as the GESA building was declared protected, the Regional Government provided approval of any modification of the existing building.
- **Aiguasol:** consultant in energy and sustainability. Early stage design for the refurbishment of the building.
- **IREC (the Catalonia Institute for Energy Research):** research and selection of BIPV design, monitoring of performance.
- **BIPV and façade solution providers.**

Endesa/Enel developed a proposal of planning (use classes) of the GESA building and the surrounding land. The GESA building will host exhibition and office areas that will be used by the City Council of Palma. The building will also incorporate more offices and two restaurant/store areas. **Figure 72** and **Figure 73** demonstrates the proposed project.

Figure 71. *GESA building stakeholders.*

Figure 72. *Planning "use classes" (part 1).*

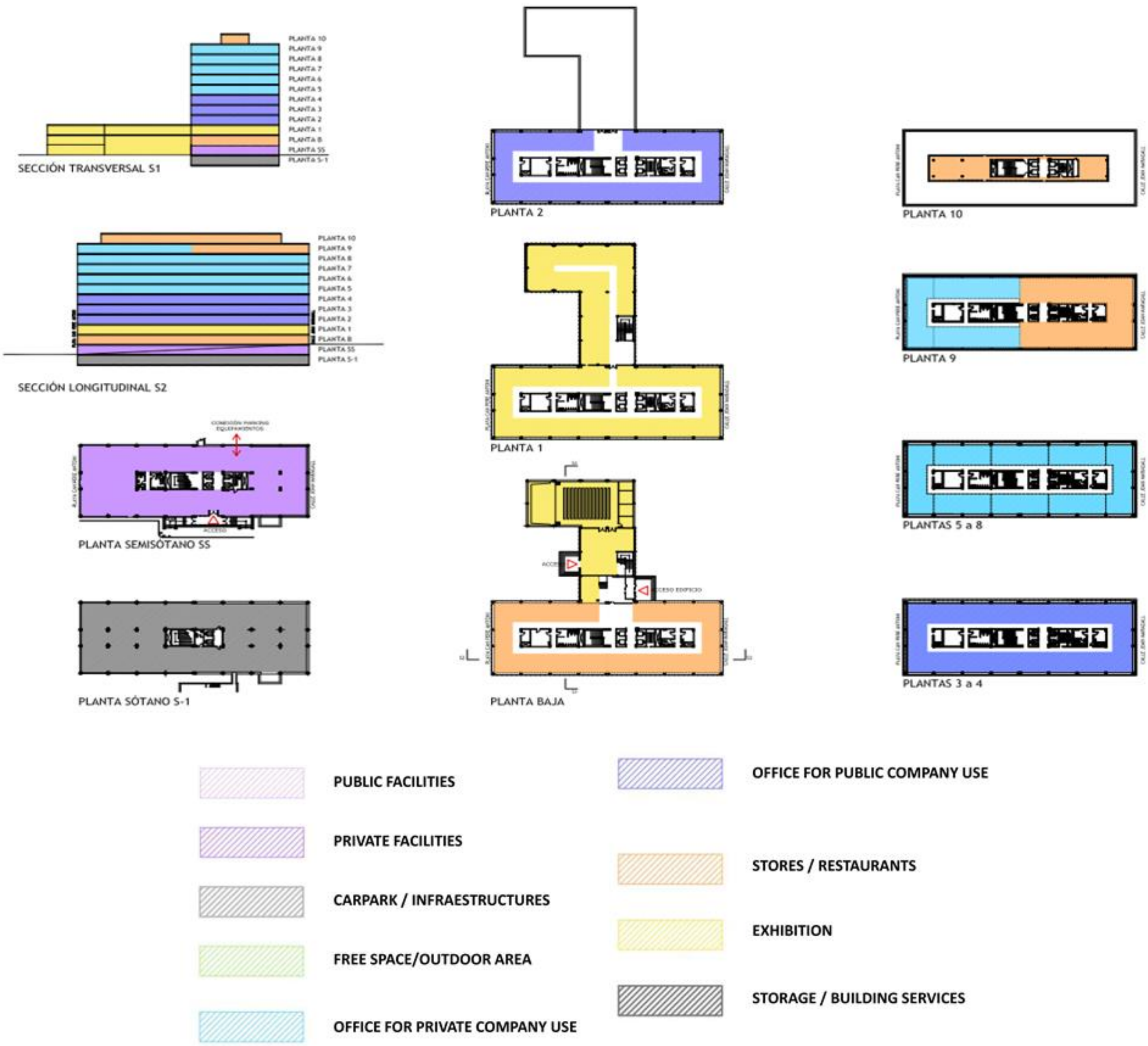


Figure 73. *Planning "use classes" (part 2).*

6.2. METHODOLOGY AND OBJECTIVES

6.2.1. METHODOLOGY

Nowadays the GESA building is in a dilapidated state and several measures of refurbishment are needed just to put it back to work. Between the building construction and the actuality, thermal regulations and the expected energy consumption in buildings have been improved hugely. A full refurbishment means to position the GESA building in terms comparable to a new office building. It is important to understand that the expected life of a building clearly surpass the duration of the construction regulations and future regulations, or trends have to be considered by the design team in order to avoid obsolete buildings in a short period of time. Obsolescence not only affects the energy performance of the building but also its value in the market and the owner's profit.

The process of optimizing a building follows the rules shown in the previous chapter (Action 1).

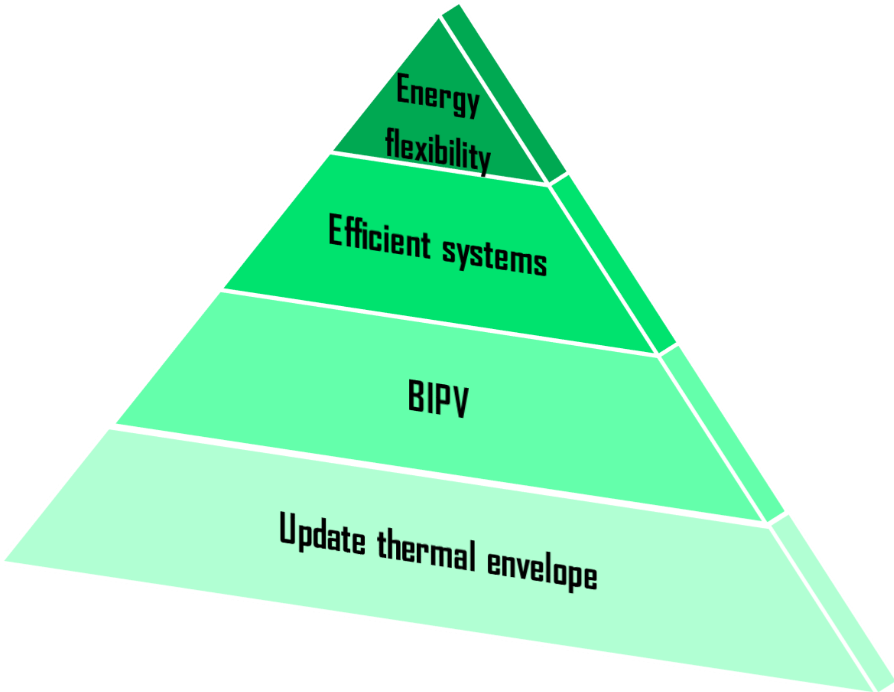


Figure 74. *The integrated energy design process strategy.*

Following these rules, in first instance, the building envelope will be optimized taking into account the use of the building, the weather, the volumetry and all the parameters that affects the energy consumption and the thermal and visual comfort. Once the thermal and electric demands are reduced at the minimum, several energy systems will be analysed in order to adapt the best energy system to the final optimized demands. Finally, the renewable energy production will be determined with the objective of a full renewable energy coverage.

For doing so, energy models of the building and the active systems will be used. TRNSYS18 is the software in which those studies will be carried out. It allows a transient dynamic simulation that incorporates all the phenomena that affects a building behaviour.

6.2.2. ENERGY AND ENVIROMENTAL PERFORMANCE OBJECTIVES FOR THE GESA REFURBISHMENT

The constant evolution of the European Energy Performance Directive [20], with a new version in revision (not yet approved) claims for a total primary energy consumption in tertiary buildings (offices) in the Mediterranean climate under the 70 kWh/m^2 year that should be full covered by renewable energy. This regulation is currently under revision, but points to an objective that ensures the durability of the refurbishment in terms of energy and environmental performance. From a passive point of view, it is possible to avoid prescriptive limitations for the envelope, with a thermal energy demand below 15 kWh/m^2 year for heating and/or cooling in the last update of the thermal energy demand regulation for Spain [14]. For these reasons, it will be considered that, from an energy performance point of view, the objectives of the GESA building refurbishment are:

- Heating thermal demand under 15 kWh/m^2 year.
- Cooling thermal demand under 15 kWh/m^2 year.
- Total primary energy under 70 kWh/m^2 year, including the consumption for heating, cooling, humidity treatment, ventilation, and lighting.

These general objectives do not exclude other exigencies that must be (not for regulation but for high quality building standards) achieved like the ones that follows:

- Thermal comfort during the 100% of the labour hours.
- Visual comfort based on Annual Sunlight Exposure (ASE) and spatial Daylight Autonomy (sDA) studies.

The calculations and analysis of these other aspects will be analysed in further stages in the design process.

6.3. ENERGY AND ENVIRONMENTAL PERFOMANCE OF THE ACTUAL BUILDING

In this chapter, the building in its actual configuration and different design options will be studied. The actual state of the building requires several operations of maintenance and refurbishment, with important leakages and holes in the envelope. For having a baseline reference, it will be assumed that the GESA building is restored to its initial state, with the actual design.

6.3.1. ACTUAL ENVELOPE DESIGN OF THE GESA BUILDING

The most iconic feature of the GESA building and probably the construction element that influences the most in the building energy performance, is the configuration of the façade.

Figure 75. *Pictures of the façade*

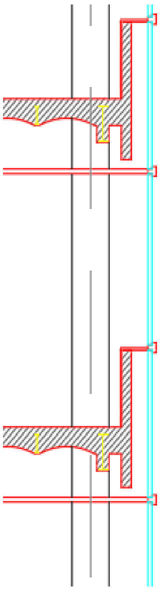


Figure 76. *Technical drawing – Detail of the façade section.*

In the drawings, it is possible to observe the single skin façade that closes the building, giving a homogeneous appearance from the outside. Problems attached to this design are:

- No option for openings that enhance the natural ventilation.
- Glass transmittance of 2.76 W/(m^{2}K) that nowadays is far from modern glass standards.
- Glass g-value of 0.491 without any exterior solar protection device.
- Absence of insulation layers.
- Very light façade without thermal capacity/inertia.
- Important thermal bridges.

6.3.2. CHARACTERISATION OF THE GESA BUILDING

The general parameters that affect the characterisation of a building are defined for the GESA building below:

- Occupancy defined from 8 am to 6 pm as a ramp in the occupant's entrance and exit of the building.
- Internal heat gains due to occupancy of 12 W/m^2.
- Heat gains due to equipment of 7.0 W/m^2.
- Heat gains due to lighting of 7.3 W/m^2.
- Ventilation air change ratio of 1.7 ach according with RITE minimum fresh air renovation.
- Variable from 0.30 to 1 ach depending on the internal and external temperature[9].
- Heating set point of 21ºC without set back.
- Cooling set point of 26ºC without set back.
- $U_{\text{windows value}}$ = 2.76 W/(m^{2}K).
- $g_{\text{glass value}}$ = 0.49.

As an early phase of re-design for optimization, an office use has been considered. The main objective in the passive optimization is to achieve the minimal thermal demands trough the façade optimization, and the area with an office use is the most dominant in the building. The optimal case has been applied to the whole building, using its real configuration and uses presented in the previous chapters.

Specific approaches to areas with other uses (as restauration or auditorium) will be studied in following versions of this deliverable.

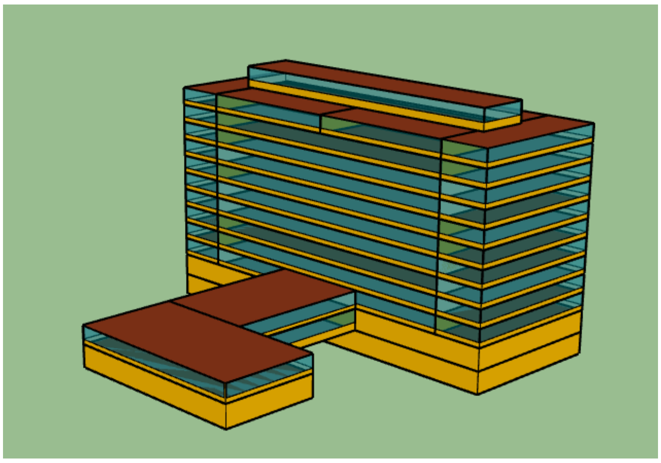


Figure 77. *3D model for the GESA building used in TRNSYS18.*

[9] ASHRAE semi empirical model named K1, K2, K3 for infiltration.

For the building optimization a thermal zone has been used instead the whole building in order to achieve a more detailed simulation. The dimensions of this thermal zone are: width 22.31 m, length 7.45 m and height 2.62 m.

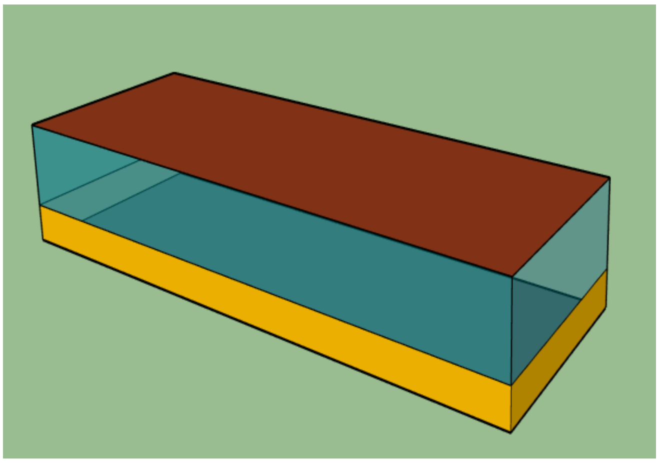


Figure 78. *3D model for the detailed zone used in TRNSYS18.*

6.3.3. ENERGY AND ENVIRONEMENTAL RESULTS FOR THE GESA BUILDING IN ITS ACTUAL STATE

The GESA Building has been modelled with TRNSYS18 in order to study the optimization of the façade. Simulations has an hourly time basis, but results have been aggregated monthly or yearly to enhance a better comprehension. The actual design presents the following thermal demand and energy consumptions:

Table 19. *Thermal demands for heating and cooling.*

Thermal energy demands for heating and cooling				
	Sensible loads		**Latent loads**	
	Heating	**Cooling**	**Humidification**	**Dehumidification**
	kWh/m²	*kWh/m²*	*kWh/m²*	*kWh/m²*
Annual	**3.9**	**31.8**	**0.0**	**2.1**

From these results, it is possible to conclude that:

- The behaviour of the building is so stational, with a low simultaneity between thermal demands (see monthly distribution for electricity consumption shown below).
- The main thermal demand of the building is the cooling demand, with a 91% over the whole thermal demand for climatization purposes.

Comparing the actual results with the objectives for a NZEB building:

Table 20. *Thermal demands for comparison between the actual building and the objectives.*

Thermal demand objectives NZEB		
	Limit	**GESA Building**
Heating (kWh/m2 year)	15	3.9
Cooling (kWh/m2 year)	15	31.8

The actual building is far over the cooling demand objective, by doubling the thermal needs (112%). In order to achieve an energy primary consumption, several hypotheses have been assumed:

- Efficiency of the thermal conversion for heating - 3.0.
- Efficiency of the thermal conversion for cooling - 2.5
- Conversion factor for CO_2 emissions - 0.932 $kgCO_2$/kWh – emission factor (EF) for Balearic Islands [21].
- Conversion factor for Primary Energy - 2.967 kWh_{EP}/ kWh EF.

In terms of electricity consumption, the monthly distribution is shown below:

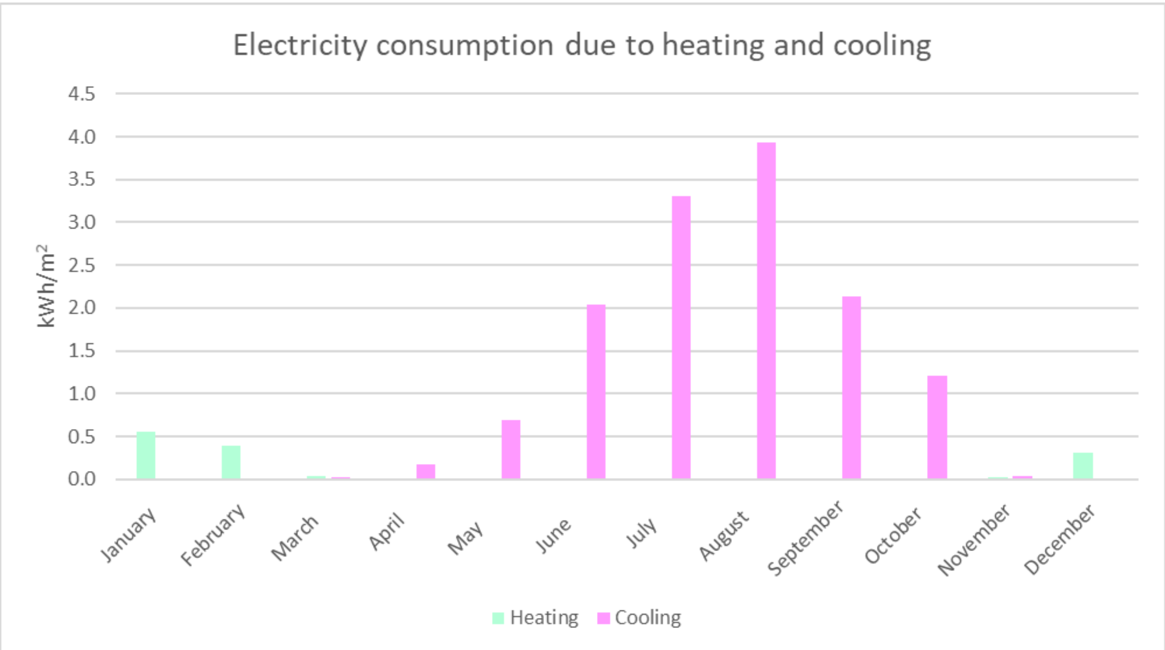


Figure 79. *Electricity consumption monthly distribution due to heating, cooling and humidity treatment.*

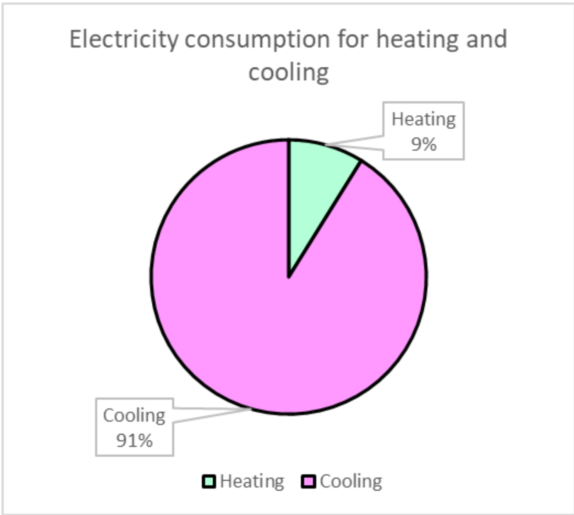


Figure 80. *Electricity consumption percentage due to heating, cooling and humidity treatment.*

Other consumptions have been included for a total primary energy consumption calculated according to the Energy Performance Building Directive. This means consumptions due to ventilation, DHW and lighting:

- Electricity consumption due to ventilation - 4.71 kWh/m^2 year.
- Electricity consumption due to lighting - 19.0 kWh/m^2 year.
- Electricity consumption due to DHW - 3.86 kWh/m^2 year.

When only heating and cooling are considered:

Table 21. *Consumption and emissions due to heating and cooling needs for offices in the GESA building.*

Consumption and emissions due to heating and cooling		
Final Energy consumption	14.9	*kWh/m^2 year*
Primary Energy consumption	44.1	*kWh/m^2 year*
CO_2 emissions	13.9	*kgCO$_2$/m^2 year*

Including the other services, the primary energy consumptions for GESA building are shown below:

Table 22. *Primary energy consumption by services.*

		Primary energy consumption				
		Heating & Cooling	**Ventilation**	**Lighting**	**DHW**	**Total**
		kWh/m^2 year	*kWh/m^2 year*	*kWh/m^2 year*	*kWh/m^2 year*	*kWh/m^2 year*
Offices in GESA Building		44.1	14.0	56.5	11.5	126.0

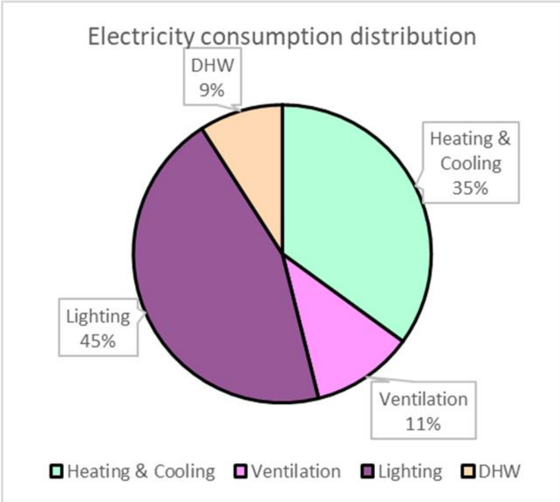


Figure 81. *Primary energy consumption for offices in the GESA Building.*

Results shows that total primary energy consumption is far from the NZEB objective. The actual consumption is about 126 kWh $_{EP}$/m^2 year and the future reference for new tertiary buildings is supposed to be 70 kWh $_{EP}$/m^2 year. It is important to remember as well as this target energy consumption should be covered fully by renewable energy.

With these results, the following actions will be pointed to reduce the cooling thermal demand, that is the most important of both thermal demands, trying to reduce at the minimum the consumptions due to heating and cooling purposes.

6.4. SOLUTIONS FOR FAÇADE REFURBISHMENT IN THE GESA BUILDING

From the results on the previous chapters, it is clear that one of the main potential thermal energy reductions is the façade of the building. Updating and improving the façade does not only have influence in the thermal demand (better U value, better air leakage, better solar protection) but also updates the building in its aesthetics, and it has a good impact in the asset value.

6.4.1. CONCEPT DESIGN FOR REFURBISHED FAÇADES

The actual façade of the GESA building is a single skin façade (**Figure 82**).

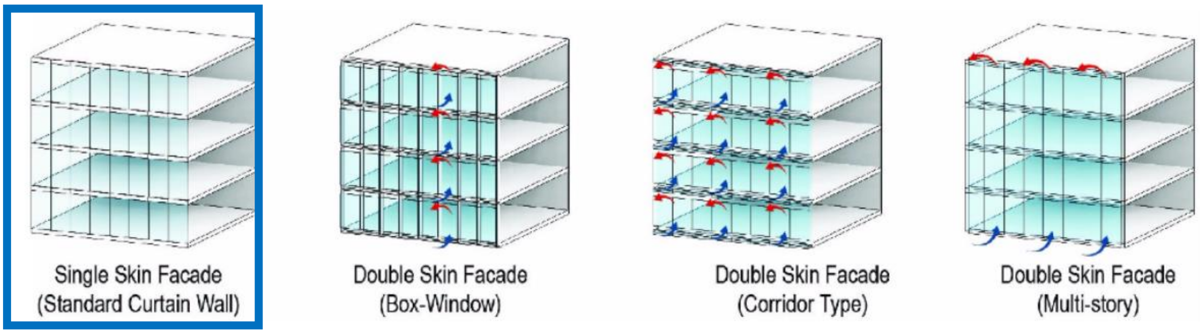


Figure 82. *Types of single and double skin façades for office buildings.*

Results show a dominance in the thermal cooling demand. The re-thinking of the façade should then, be oriented to the cooling reduction. This can be achieved by:

- Improving the solar protection → Improving the Solar Heat Gain Factor.

- Improving the possibilities of ventilation → Ventilated façades and operability.

While the improvement and reduction of the Solar Heat Gain Coefficient (SHGC) can be achieved with the properties of the glass, the ventilation needs a different approach from the actual design, updating a static façade and evolving it to a dynamic one.

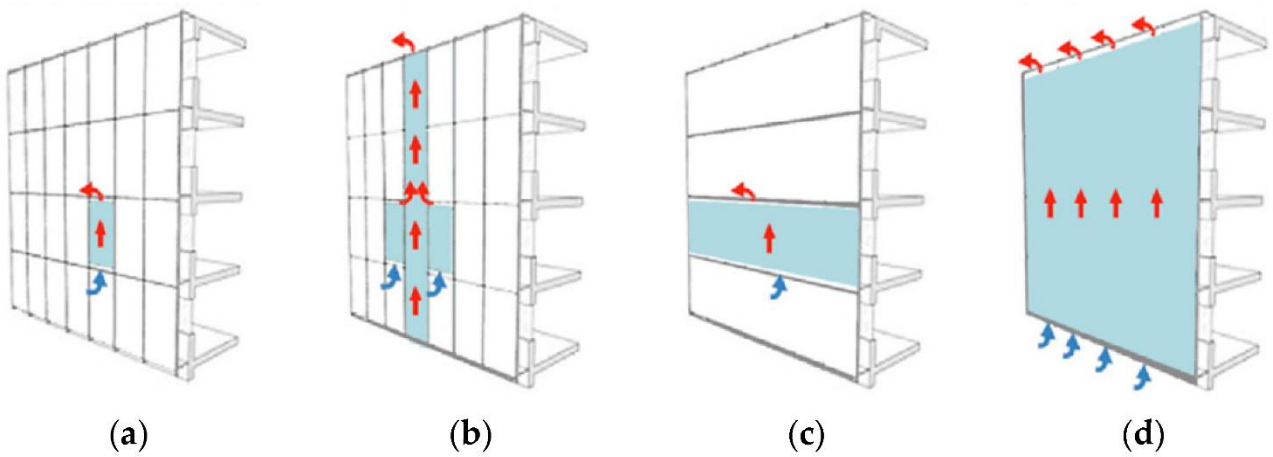
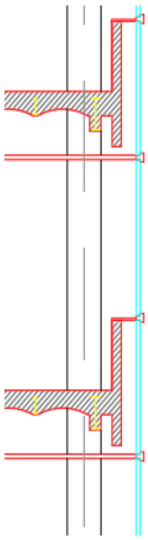
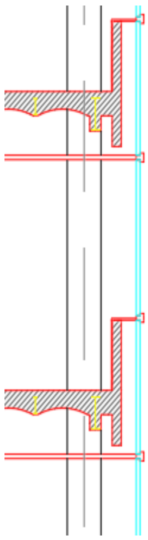
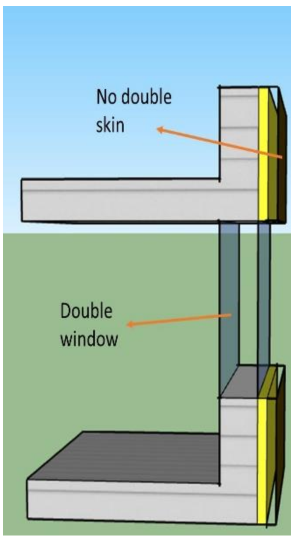
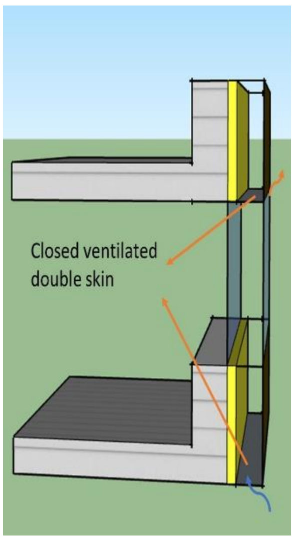
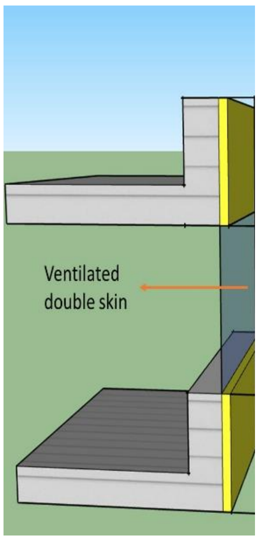
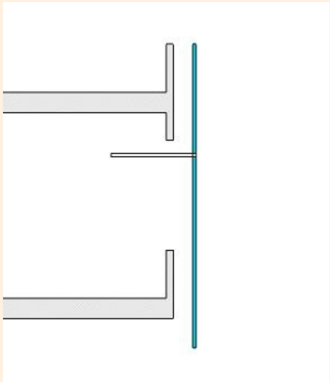
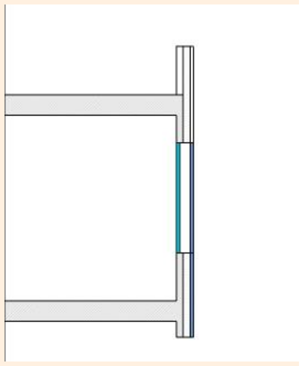
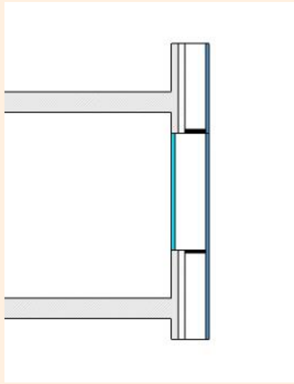
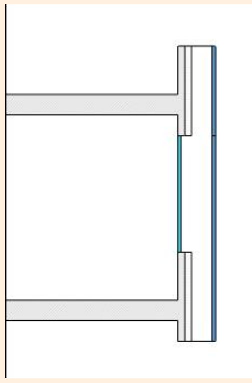


Figure 83. *Types of single and double skin façades for office buildings.*

There are also many other aspects to be considered. Overall, in a refurbishment project, as it could be the existing wall and claddings, the maintenance, the operability of the windows, etc. Following the schematic concepts shown in the previous chapter, several façade configurations have been modelled and parametrized in TRNSYS.

Table 23. *Façade models for TRNSYS18 and the GESA Building.*

Actual Model	Model 0	Model 1	Model 2	Model 3
Current façades properties	CTE 2022 Replaces current by PV panels	CTE 2022 Double window with external PV glass and PV on the opaque's façade	CTE 2022 Double ventilated skin (closed at slabs) with external PV glass and PV on the opaque's façade	CTE 2022 Double ventilated skin (continuous) with external PV glass and PV on the opaque's façade
				

Actual Model	Model 0	Model 1	Model 2	Model 3
				

Base Model: the named "Base Model" tries to reproduce the actual design and properties of the façade, but without the pathologies that can be present nowadays due to the lack of maintenance. It reproduces the building behaviour as it was in the first year of operation.

Model 0: it is the Base Model but with all the components updated and upgraded in order to achieve actual CTE standards. The window in this case has to achieve CTE standards and also produce electricity, with the BIPV.

Model 1: it is a new concept of façade, with a single skin. Both the opaque and transparent parts are photovoltaic in the outer layer. In the opaque section, an insulating layer has been added to reduce the thermal conductivity of the façade and also to break the thermal bridges due to the slab encounter. In the translucent section, an inner double glass has been considered. This inner layer has the required thermal properties of the CTE. The outer layer, the photovoltaic one is a simple single layer. This Model can ventilate through opening in lower and upper sections of the second layer (the Photovoltaic one), but this is not a ventilated façade in its usual understanding.

Model 2: it is a double ventilated skin. The ventilation occurs from slab to slab, as it is shown in the c) scheme shown above. Thermal properties and characteristic are similar to Model 1. The big difference between these models is that exist a ventilated air chamber between the second and the first layer.

Model 3: it is the same scheme than Model 2 but, in this case, the ventilation is done through all the façade height, with openings at the bottom of the façade and openings at the upper section (not from slab to slab).

The description of the parameters that rules the performance of the different façades are shown below (**Table 24**):

Table 24. *Types of single and double skin façades for office buildings modelled in TRNSYS.*

	Actual Model	Model 0	Model 1	Model 2	Model 3

Description	Current model	Refurnished façade PV glass improved solution PV panel on opaque façade Opaque façade insulated	Ventilated façade PV glass single solution Interior glass PV panel on opaque façade Opaque façade insulated	Ventilated double skin façade (slabs) PV glass single solution Interior glass PV panel on opaque façade Opaque façade insulated	Ventilated double skin façade (continuous) PV glass single solution Interior glass PV panel on opaque façade Opaque façade insulated
			Parameters		
U wall	Current	CTE	CTE: From 1 to 0.9	CTE: From 1 to 0.9	CTE: From 1 to 0.9
U roof	Current	CTE	CTE	CTE	CTE
U ground floor	Current	CTE	CTE	CTE	CTE
U PV glass	-	Improved	Single	Single	Single
U interior glass	Current	-	CTE and two additional cases	CTE and two additional cases	CTE and two additional cases
Ventilated chamber width	-	-	12 cm	30 cm	30 cm
Ventilated chamber air renovation	-	-	Sealed, convection, 10 ach	Sealed, convection, 10 ach	Sealed, convection, 20 ach

6.5. PERFORMANCE ANALYSIS

Recent tools and analysis techniques allow the parametrization of the designs. Following these tendencies, a parametric analysis has been conducted to ease the definition of the optimal values for the design parameters.

The parameters' values for the simulations are described below (**Table 25**):

Table 25. *Values for the design parameters.*

	Actual Model	**Model 0**	**Model 1**	**Model 2**	**Model 3**
	Current façades properties	CTE 2022 Replaces current by PV panels	CTE 2022 Double window with external PV glass and PV on the opaque's façade	CTE 2022 Double ventilated skin (closed at slabs) with external PV	CTE 2022 Double ventilated skin (continuous) with external PV glass and

				glass and PV on the opaque's façade	PV on the opaque's façade
U_{wall} (W/m²K)	1.25	0.56	0.56	0.56	0.56
U_{roof} (W/m²K)	1.14	0.44	0.44	0.44	0.44
U_{ground} (W/m²K)	3.00	0.75	0.75	0.75	0.75
U_{FV} (W/m²K)	-	1.27	5.35	5.35	5.35
$U_{interior\ glass}$ (W/m²K)	2.76	-	1.47	1.38	1.47
Ventilated chamber with (cm)	-	-	12	30	30
Ventilation air changes	-	-	Sealed / Convective / Forced	Sealed / Convective / Forced	Sealed / Convective / Forced

6.5.1. PARAMETRIC ANALYSIS AND RESULTS

Two types of simulations have been carried out:

- **Free evolution temperature**: without any temperature set point for climatization. The results of this simulation allow the assessment of the passive behaviour of the building,
- **With thermal energy systems**: With temperature setpoints for heating, cooling, and humidity setpoint for latent gains. This simulation allows the calculation of the amount of energy needed to maintain a certain degree of thermal comfort.

For the winter season, temperatures (at free evolution) are shown below for a winter week (**Figure 84** and **Figure 85**):

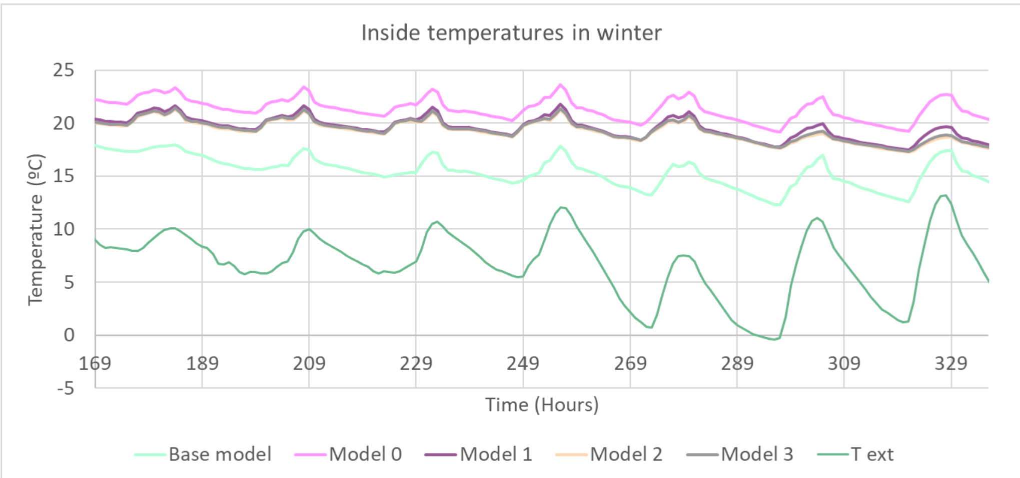


***Figure 84.** Inside temperatures for a winter week.*

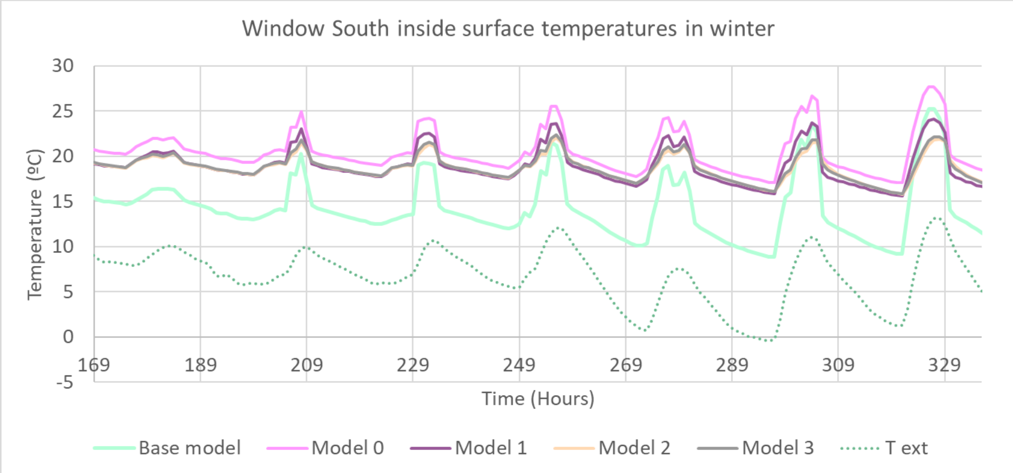


Figure 85. *Window inner surface temperatures for a winter week.*

For the summer season, temperatures (at free evolution) are shown below for a summer week:

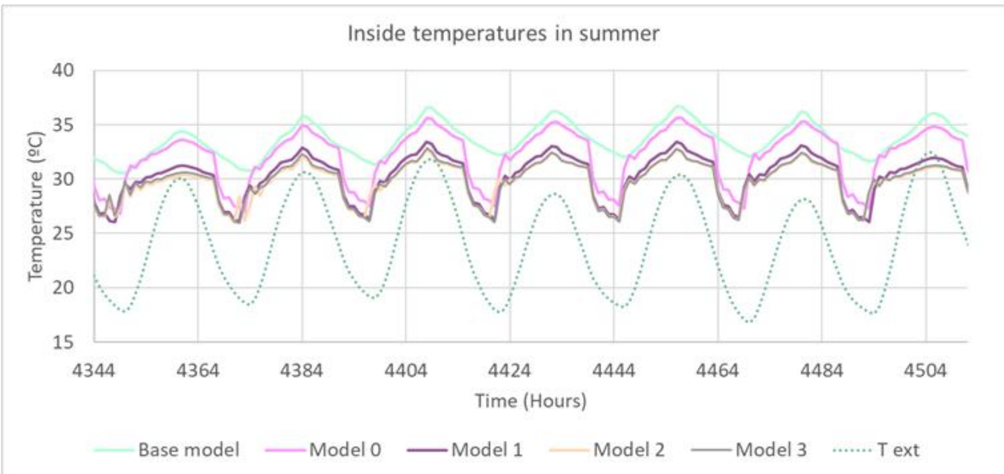


Figure 86. *Inside temperatures for a summer week.*

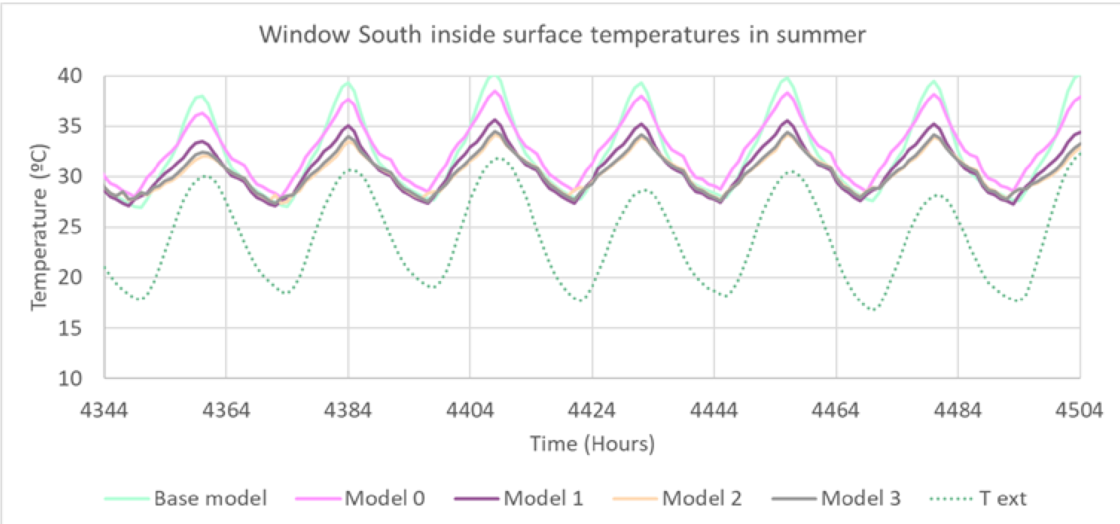


Figure 87. *Window inner surface temperatures for a summer week.*

These graphic shows the free evolution of the operational temperature inside the thermal zone. The model includes internal heat gains, infiltration, and ventilation.

In winter:

- The actual model presents a lower temperature than all other scenarios. Its thermal amplitude is higher than the refurbished scenarios, what means higher thermal demands and higher discomfort. In the refurbished scenarios, thermal amplitude is much lower, and it is similar between models.
- Model 0 presents the higher temperature due to the lack of façade ventilation. Model 1, 2, 3, all of them ventilated has similar floating temperature evolution, some degrees below Model 0 temperature.
- Model 1, 2, 3 presents free floating temperature around and above the 20 ºC during the office workday schedule.

In summer:

- The base model and Model 0 presents a free evolution temperature above the ventilated chamber's models (1, 2 and 3).
- These three models present similar temperatures between them.

So, it can be concluded that:

- In a Mediterranean climate and following the climate change previsions, the design criteria should be clearly focused on reducing the potential cooling load.
- The different models of ventilated chamber perform in a similar way in a free evolution scenario, and the three presents a clear difference with the actual model and model 0, both without ventilation.
- Due to the different façade configuration and the similar performance between ventilated chamber, other aspects could be more important than the energy performance differences. These aspects could be: a) industrialized solutions that could improve the embodied carbon on the Life Cycle phase A, b) maintenance possibilities and costs, c) investment, etc.

These same scenarios have been also studied, as it was said before, with ideal thermal energy systems, in order to get the energy consumptions. With a typical energy system, the façade solutions influence can be assessed comparing energy consumption values. For every scenario an ideal active energy system has been considered, with the following characteristics:

- Heating Coefficient of Performance (COP) = 3.0.
- Cooling European seasonal energy efficiency ratio (ESEER) = 2.5.

These performance coefficients are only used for comparing scenarios. They are not related with the active system optimization that will be studied further on.

Conversion factors for electricity have been also considered.

- 0.932 $kgCO_2$ / kWh_{FE}.
- 2.968 kWh_{PE} / kWh_{FE}.

The values for every scenario are defined in the following table:

Table 26. *Simulation parameters values.*

Simulation parameters values		
CTE standards	W/m^2K	0.56
90% $U_{wall\ CTE}$	W/m^2K	0.50
$U_{glass\ FV}$	W/m^2K	1.27 (Model 0) / 5.35 (Model 1, 2, 3)

$g_{glass\ FV}$	-	0.54 (Model 1,2,3)
$U_{glass\ CTE}$ Solar factor $_{CTE}$	W/m^2K	1.47 0.52
$U_{glass\ option\ 1}$ Solar factor $_{option\ 1}$	W/m^2K	1.10 0.42
$U_{glass\ option\ 2}$ Solar factor $_{option\ 2}$	W/m^2K	1.10 0.24
Air chamber width	*cm*	20, 40, 60
Air changes	*ACH*	Sealed, convective, forced

Results for all scenarios are summarized in the table below:

Table 27. *Electricity consumption for every scenario.*

Final energy consumption					
	Base Model	**Model 0**	**Model 1**	**Model 2**	**Model 3**
	kWh/m² year	*kWh/m² year*	*kWh/m² year*	*kWh/m² year*	*kWh/m² year*
Actual Model	14.9				
CTE standards		14.2	9.6	8.1	8.4
90% U wall CTE			9.6	8.1	8.4
U glass CTE			9.6	8.1	8.4
U gass option 1			9.1	8.1	8.4
U glass option 2			8.2	7.6	7.9
Sealed			9.6	8.1	8.4
Convection			9.6	8.1	8.4
Enhanced Ventilation			9.5	7.9	8.3
20 cm width				8.1	8.4
40 cm width				8.1	8.4
60 cm width				8.1	8.4
Ventilated chamber 20cm				7.9	8.3
Ventilated chamber 40cm				7.9	8.3
Ventilated chamber 60cm				7.9	8.3
Optimal	**14.9**	**14.2**	**8.1**	**7.4**	**7.8**

For every model, some of the measures have been applied together to define an optimal scenario for every façade design. The selected measures are:

- Reduce 10% the CTE thermal transmittance for the opaque areas.

- Select the option 2 for the glazing.
- Select the forced ventilation.

Table 28. *Electricity consumption for the optimal scenarios.*

Final energy consumption							
	Heating	Cooling	Humidification	Dehumidification	Total Heating	Total Cooling	Total consumption
	kWh/m²	*kWh/m²*	*kWh/m²*	*kWh/m²*	*kWh/m²*	*kWh/m²*	*kWh/m²*
Base Model	1.3	12.7	0.0	0.8	1.3	13.5	14.9
Model 0	0.0	13.4	0.0	0.8	0.0	14.2	14.2
Model 1	0.1	7.2	0.0	0.9	0.1	8.0	8.1
Model 2	0.1	6.4	0.0	0.9	0.1	7.3	7.4
Model 3	0.1	6.8	0.0	0.9	0.1	7.7	7.8

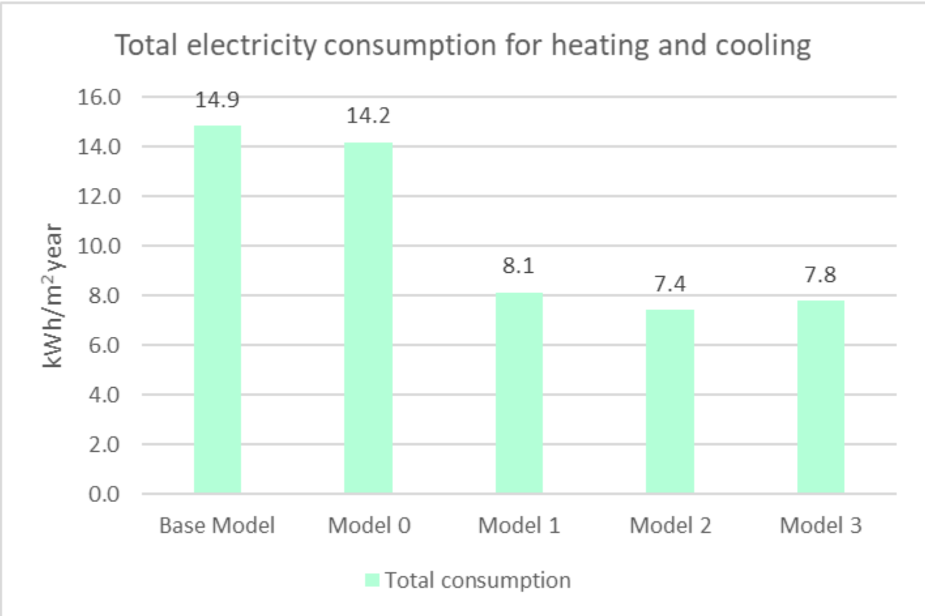


Figure 88. *Electricity consumption for the optimal scenarios.*

Looking at these results, it can be concluded that:

- Models with ventilated chambers presents a lower electricity consumption due to the reduction in the cooling loads.
- A low SHGC is very relevant to reduce the cooling loads but it should be balanced with visual comfort because the solar factor is really low when photovoltaic glass is incorporated to the glass system.
- With low SHGC + ventilated façade the key vector to decide could be others like: embodied carbon, ease of installation, better maintenance, etc.

6.5.2. WHOLE GESA BUILDING MODEL AND COMPARISON BETWEEN BASE CASE AND OPTIMAL CASE

With all the lessons learned in the previous chapter, that were the result of stressing a thermal model based in one thermal zone with office use, the whole GESA building has been modelled and two scenarios have been considered:

1. **The actual scenario:** with the known characteristics of the building. This model is based on the so-called "Actual Model" of the previous chapters.

2. **The refurbished scenario.** This model incorporates:

- It is based in the Model 3 with a full ventilated façade. According with the results of the previous chapters, without important differences between the two ventilated chamber configurations, it has been considered that a homogeneous façade would be more feasible from a technical point of view. This assumption will be revised once the real façade systems will be definitive.
- U – values with a reduction of the CTE standards.
- Option 2 for the glass properties.
- Ventilation in the chamber has been defined as natural ventilation, following the convective phenomena, to avoid mechanical ventilation devices.

Other uses apart from an office use are intended to be developed in the final configuration of the GESA Building. These uses are (**Table 29**):

Table 29*. Area of different uses in GESA building.*

	Area
	m^2
Office	5 852
Public Office	3 901
Restaurant	2 304
Exhibition	2 705
GESA Building	**14 763**

Results for final optimized model are shown below:

Table 30*. Final energy consumption for the optimized GESA Building.*

	Office	Public office	Restaurant	Exhibition	Total consumption
	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	**kWh/m^2**
Heating	0.1	0.1	0.5	1.4	**0.4**
Cooling	5.6	6.7	13.0	0.3	**6.1**
Humidification	0.0	0.0	1.9	0.0	**0.3**
Dehumidification	0.7	0.8	0.1	0.5	**0.6**
Total consumption	**6.5**	**7.7**	**15.5**	**2.2**	**7.4**

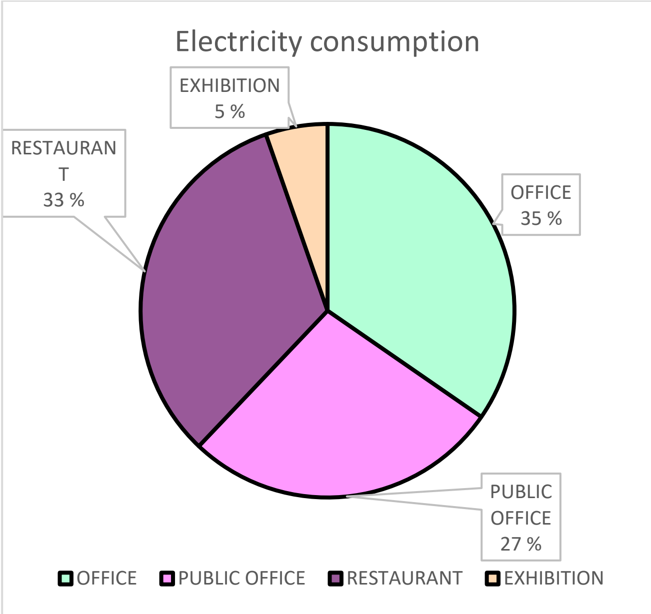


Figure 89. *Final energy consumption distribution for uses.*

The difference between office and public office is mainly the density occupancy. While the office uses has an occupancy density of 10 m²/person, the public office increases the occupation with a density of 6 m²/person. Results reflects this, with a slight increase in the cooling consumption.
It is important to understand that the focus in this version of the deliverable has been the façade refurbishment, that pretends to optimize the energy consumption for an office use. Other uses, such as the restaurant one, will need specific measures to reduce its energy consumption due to the special parameters of operation.

Differences between the actual model and the refurbished one are shown below:

Table 31. *Savings in the final energy consumption due to the façade optimization*.

	Office	**Public office**	**Restaurant**	**Exibition**	**Total consumption**
	kWh/m²	***kWh/m²***	***kWh/m²***	***kWh/m²***	***kWh/m²***
Base Model	11.3	12.9	21.6	3.1	11.9
Optimized Gesa Building	6.5	7.7	15.5	2.2	7.4
Savings	43%	41%	28%	29%	37%

6.6. ACTIVE SYSTEMS ANALYSIS AND PERFORMANCE

The following section discusses the potential implementation of a range of Low or Zero Carbon technologies for the proposed GESA Building in Palma de Mallorca. At the end of this design guide, in the **Appendix B – Systems description**, you can find an overview of each technology proposed. This section focuses on advantages, disadvantages, and a site-specific design consideration for each technology.

6.6.1. AIR SOURCE HEAT PUMP (ASHP)

Advantages

- Cost effective renewable for heat dominant buildings.
- Can be used, without any risk, within a heating or cooling only application.
- Reduced running costs.
- Tried and tested technology.
- Easy to maintain.

Disadvantages

- COP/EER (Energy Efficiency Ratio)/TER (Total Efficiency Ratio) is dependent on-air temperature.
- Lower efficiency than ground source heat pumps.
- Temperature above 50 degrees, the efficiency drops significantly, therefore usually cannot be considered renewable. This is considered renewable when SPF is above 2.5.

Site specific design considerations

Thermal model results shows that air source heat pumps/chillers could provide a proportion of onsite renewable contribution. An evaporative cooling tower is discarded due risks of Legionella, as location would be close to outdoor public areas.

For this particular building, air source heat pumps, capable of producing instantaneous heat and cooling, will be sized to provide the heating and hot water needs of the building. These will also provide cooling and hot water during the summer. As the cooling needs of the building are higher than heating, 3 times higher, the remaining power required would be provided via water-cooled chillers with dry coolers or packaged chiller units.

6.6.2 GROUND SOURCE HEAT PUMP (GSHP)

Advantages

- Can provide significant carbon savings in the correct application, e.g. mixed use schemes with significant heating and cooling loads.
- Reduced running costs.

Disadvantages

- Large area of land required for horizontal loops.
- Can be expensive (capital cost) in horizontal and vertical collectors.
- Not generally recommended for heating only (or cooling only) systems. The ground heat extraction has to be the same or less than the earth can provide, if this is not accomplished in long-term means a lower efficiency of the system. A site-specific study is required by a borehole specialist to determine whether soil conditions are favourable for the needs of the building. In heating mode, we are discharging the heat ground, when cooling or stopped system it is charging. This is not the case in open loop systems.

Site specific design considerations

GSHP seems to be one of the viable options to provide onsite renewable contribution. In Palma de Mallorca the following restrictions applies to geothermal systems:

- From 0-200 meters of coastline open geothermal energy to capture water with the same salinity as the sea.
- From 200-800 meters of coastline only closed geothermal, prohibited open geothermal, for both seawater and freshwater collection.
- At more than 800 meters of coastline allowed open geothermal energy with freshwater intake.
- Closed geothermal energy is always allowed.

In this case, an open loop working against the sea, it should be possible, depending on administrative authorities permits. This technology could be the best cost-effective solution for the building, as the number of boreholes can be reduced considerably compared to a vertical closed loop system. Seawater temperatures are not as stable as ground temperatures, decreasing its efficiency. Depending on orography and level of the capture of the seawater is key to make this option viable.

At this stage of the project, both options are still being considered as both could be interesting for the project. In this early phase of re-design, only vertical ground source heat pumps are calculated. In the next version, other ground (and sea) sources will be considered.

It would be necessary heat pumps in both cases. Ground source heat pumps, capable of producing instantaneous heating and cooling, would be sized to provide the minimum power required to provide the heating and hot water needs of the building. These will also provide cooling and hot water during the summer. As the cooling needs of the building are higher than heating, 3 time higher, the remaining power required would be provided via water-cooled chillers with dry coolers or packaged chiller units, depending on external plant available.

At this point, it is known the minimum ground source power required, but this could be increased as ground source heat pumps are more efficient than chillers. In order to provide data for decision-making, parametric scenarios are provided, increasing that power and comparing them from a cost-optimal perspective and in CO_2 emissions terms.

Appendix D – GSHP calculations for GESA building presents preliminary calculations at 33% GSHP option.

6.6.3 PHOTOVOLTAICS (PV & BIPV)

Advantages

- Electricity generating renewable.
- Zero carbon technology (in operational phase).
- Visual statement of sustainability.
- Electricity is generated during daylight hours.
- Electricity can be stored in batteries during the day for use in the evenings.

Disadvantages

- Obstructions will have a dramatic effect on the productivity of the panels.
- Best results produced when there is a clear sky and direct sunlight.
- Expensive technology, requiring large areas for significant production.
- Cleaning and maintenance issues, especially in areas with surrounding trees.
- Carbon footprint of the product stage.

Site specific design considerations

The main idea is to accommodate solar photovoltaic panels in the façade of the building, also called BIPV solutions. This façade will not only provide electricity but also will help to keep an improved air tightness, reduce the solar heat gains, reduce thermal bridges effects, and lower thermal conductivity. Please refer to **Appendix C – BIPV commercial solutions for GESA building** for further details of BIPV systems.

For windows (transparent) it is considered the following solar panel characteristics:

- Nominal power 57 Wp.
- Dimensions 1170 x 1730.
- Photovoltaic cell: thin film.

For opaque areas it is considering the following solar panel characteristics:

- Nominal power 137 Wp.
- Dimensions 1480 x 1170.
- Photovoltaic cell: monocrystalline.

The following areas are used in all the calculations for both opaque and transparent areas:

- main south façade;
- secondary south façade;
- west and east façade.

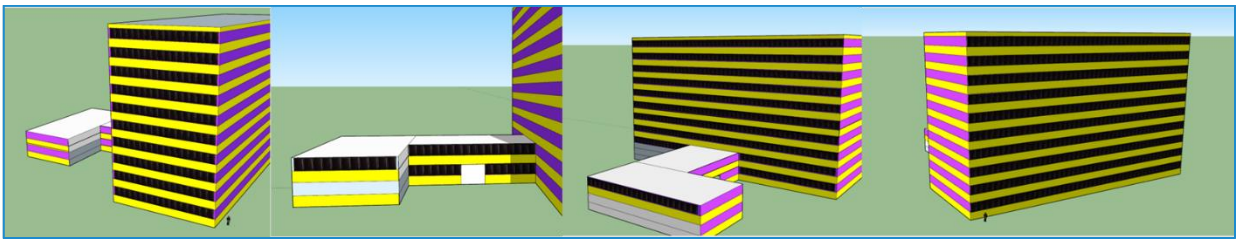


Figure 90. *Façades panels are placed: main south façade, secondary south façade, west and east façade.*

Roof areas are suitable to be used for other purposes. For this reason, two scenarios have been calculated:

- A first scenario in which the roof area is not available to place a photovoltaic field and will be used for other purposes
- A second scenario in which the roof area is available to place a photovoltaic field.

For the first scenario it is possible to achieve a production of 211.34 MWh/year.

Table 32. *PV annual production.*

Annual Production	211 344	kWh/year
Average Daily Production	579.03	kWh/day
Power	254.62	kWp
N. Panels	2 227	n. panels
Opaque Panels	1 136	n. panels
Transparent Panels	1 091	n. panels

The second scenario states that the roof could be used for electricity production due to panel placement. The 3D images below show the possible locations:

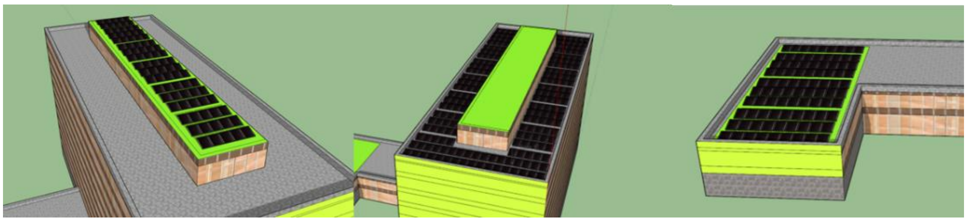


Figure 91. *Additional areas taken into consideration for location of PV panels.*

For the second scenario it is possible to achieve a production of 297.6 MWh/year.

6.6.4 SOLAR THERMAL

Advantages

- Hot water is produced during daylight hours.
- Water can be stored during the day for use in the evenings and following morning.

Disadvantages

- Obstructions will have a dramatic effect on the productivity of the panels.
- Best results produced when there is a clear sky and direct sunlight.
- A high efficiency panel comes at a high cost.

Site specific design considerations

Solar thermal panels could provide significant carbon savings due to the significant water load of the building. As we need another cooling/heat source for the building and we are proposing heat pumps, those will provide heat waste when producing cooling during the year. Cooling demands are high, therefore heat waste will be interesting to be used for hot water production. Additionally, as we are introducing a huge number of PV panels that will produce electricity, it is also interesting to use as much in-site electricity during the day, therefore solar thermal is discarded.

4 pipe or 2 pipe system

In the building itself it is difficult that we will have simultaneous demand of cooling and heating, the main reason for this is because each floor is not divided in different sections, having an open plan office, as Consell de Patrimoni requirements. This makes difficult to sectorize each façade and therefore having only one thermal zone in each floor. In this manner is difficult that would have cooling and heating at the same time, even having different needs it is difficult to sectorize. If this is the case, it is recommended to use a 2-pipe system for pipe distribution. Only hot water would provide a simultaneity during cooling demand, and this would have its own pipe system allowing heat rejection to be used.

6.6.5 COMPARATIVE RESULTS BETWEEN ACTIVE TECHNOLOGIES STUDIED

Table 33 shows the different parametric options we considered for the study.

Table 33*. Variables considered for each scenario.*

GSHP	ASHP	GSHP cooling		GSHP heating		Boreholes		ASHP cooling		ASHP heating		Temperature ASHP	
		Power	EER	Power	COP	Num	Depth	Power	EER	Power	COP	T_{heat}	T_{cool}
%	%	kW		kW		u	m	kW		kW		ºC	ºC
75	25	164.7	4.27	203.3	4.3	19	130	523.6	3	698	2.8	45	7
50	50	72.4	4.27	89.3	4.3	10	130	615.9	3	821	2.8	45	7

33	67	41.3	4.27	51	4.3	5	130	646.9	3	863	2.8	45	7
25	75	30.1	4.27	37.1	4.3	3	130	658.	3	878	2.8	45	7
0	100	0		0		0	0	688.3	3	918	2.8	45	7

Results for each option are shown below:

Table 34. *Results for each scenario.*

		GSHP heating			**GSHP cooling**			**ASHP heating**			**ASHP cooling**			**OPEX**
GSHP	**ASHP**	**C**[10]	**COP**	**W**[11]	**C**	**EER**	**W**	**C**	**COP**	**W**	**C**	**EER**	**W**	**Year**
		MWh		**hours**	**MWh**		**hours**	**MWh**		**hours**	**MWh**		**hours**	**euros**
%	**%**													
75	25	32.7	4.3	5 110	30.4	6.3	2 987	0	3.2	1	18.2	3.1	424	23.9
50	50	31.7	4.4	5 110	23	6	2 987	538	3.2	114	34.4	3.1	877	26.3
33	67	28.2	4.3	5 110	14.1	6	2 987	5.9	2.9	923	47.5	3.2	1 532	28
25	75	24.7	4.3	5 110	8.5	7.2	2 987	12	2.7	1 435	58.1	3.2	1 709	30.3
0	100							54.2	2.6	5 110	76.6	3.2	2 987	38.3

Results for each scenario are shown below, classified by percentage of demand covered by a geothermal system GSHP. The rest would be covered via air source heat pumps.

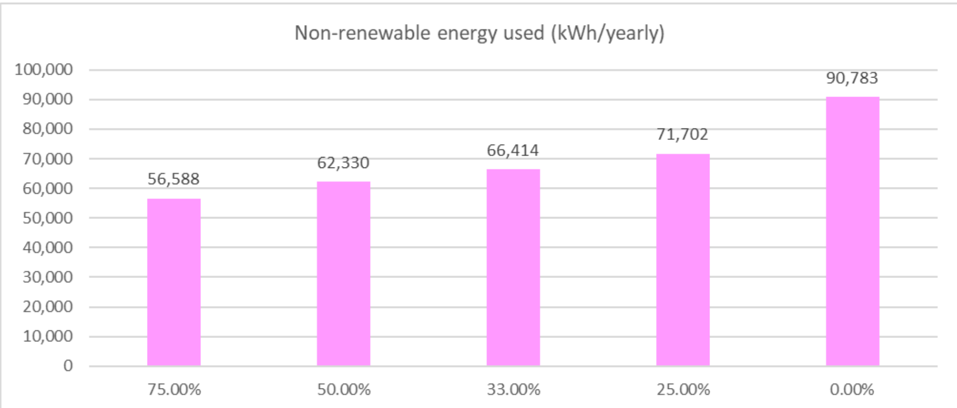


Figure 92. *Non-renewable energy used, and percentage of demand satisfied for each option.*

[10] C for Energy Consumption

[11] W for working hours during a year

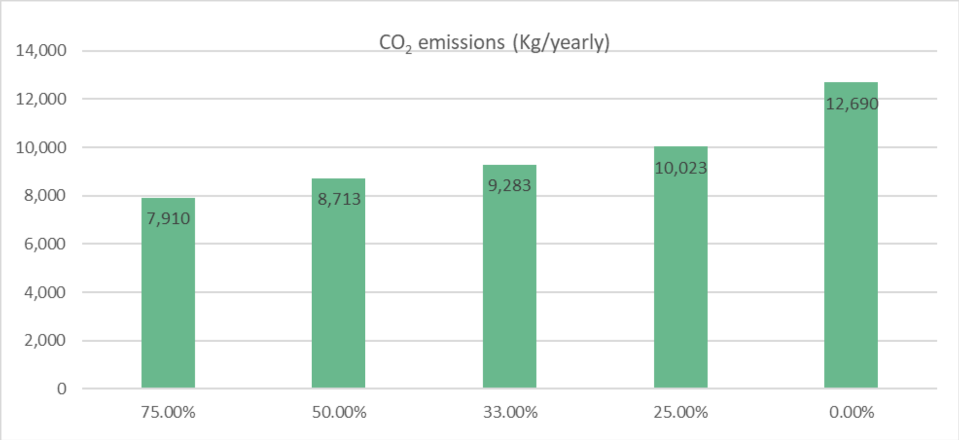


Figure 93. *CO_2 emissions and percentage of demand satisfied for each option.*

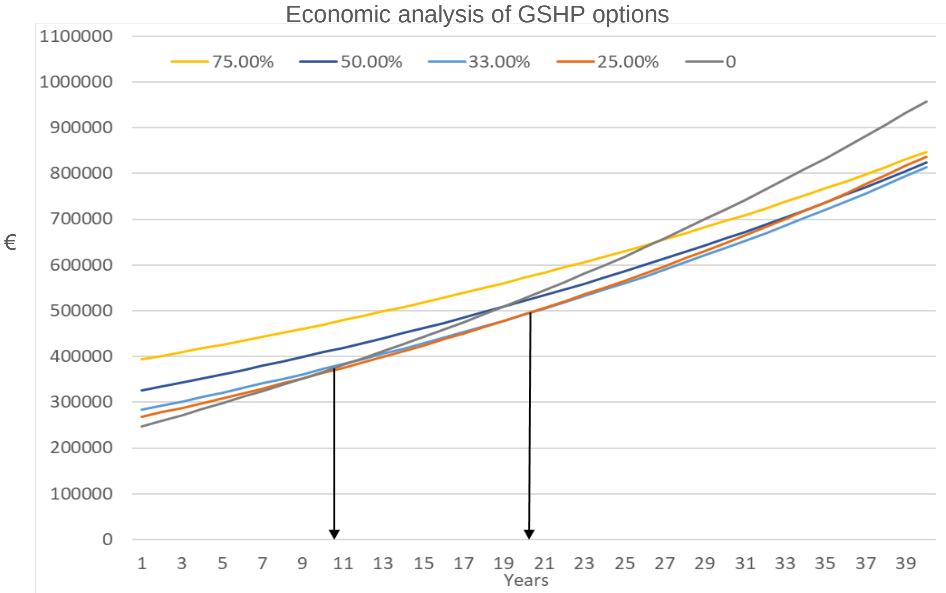


Figure 94. *Economic comparison of the different scenarios over the years.*

6.6.6 CONCLUSIONS OF THE ACTIVE THERMAL SYSTEM ANALYSIS

For this analysis we are taking into account the following hypothesis:

- 0.293 euro/kWh.
- 5 euro/kW/year for electric power contracted.
- 2% inflation rate.

This analysis just takes into account the energy needed for heating, cooling and DHW purposes. It means that not all the electricity consumption is taken into account. Furthermore, the electricity produced by the photovoltaic field is not yet included. The different amount of final energy supply can affect the final choice.

For this reason, although conclusions for the best energy system can be achieved, the integration of these parallel effects should be taken into consideration in the next version of the deliverable.

If it only the heating, cooling and DHW demands are considered, it can be concluded that:

- After 9 years a 25% GSHP option would be better than an 100% ASHP option.

- After 19 years a 33% GSPH option would be more beneficial approach than a 25% GSHP option.

Depending on the financial parameters of the investors, cost optimal best scenario can differ from the 25% GSHP option to a 33% GSPH option. This last, will be also closer than the best option for a climate positive evaluation point of view, in which it is assumed that environmental parameters are far more relevant than economical ones.

6.6.7 OVERALL PERFORMANCE

Currently, the electricity generation and consumption of the building in terms of heating, cooling, hot water, and lighting are not coupled in a single model. At this stage, this is not yet achieved, but it will be in the following deliverables. In order to maximise usage and production of electricity, batteries or buffer vessels will be calculated if required to allow the building to be as much independent from the network, reducing CO_2 emissions and electricity bills. A complete energy balance of the building, considering all electricity used during the day, which is possible being an office building, that main working hours are during daylight.

Table 35. *A complete energy balance for the GESA building.*

Usage	*kWh/m²/yearly*	*kWh yearly*
Heating, Cooling and Hot Water (33% ASHP and 66% ASHP)	7.51	95 721
Ventilation only	4.71	60 060
Dehumidification	0.9	11 476
Lighting	19	242 282
TOTAL	**32.11**	**409 540**
Electricity produced (only façade)	**-16.57**	**-211 344**
Net Energy Balance	**15.52**	**186 719**

More than 50% of the final energy consumption is covered by the electricity produced just in the façade areas. The possibility of increasing these areas to the roof should be taken into account in order to achieve a real positive building in a yearly net energy balance.

6.7. SUMMARY

The preliminary design of the retrofitting solutions for an iconic building as the GESA building have been analysed in that chapter. The solutions mainly act on:

- The integral configuration of the glass-curtain wall.
- Integration of BIPV, both in the opaque and transparent portions of the facades.
- A cost-optimal solution for active systems combining GSHP and ASHP.

Preliminary design phase involves constant dialogue between the owner of the building, the city council, the sustainability consultant firm, the research centre working on innovative solutions as well of specialized product providers and firms. Other important stakeholder in this process is the Heritage Comission of the Consell de Mallorca which has been established some protection rules in the building that should be taken in consideration. As the design process progress, more detailed calculations and concepts will be part of the analysis, looking for the integration of innovative solutions and the achievement of ambitious objectives.

Table 36. Summary of objectives achieved.

Assessment criteria	Objective for renovated buildings	Results of the analysis
Energy	**At least 50% reduction in energy needs** compared to pre-renovation levels. At least Nearly Zero Energy Building (**NZEB**) standard.	The primary energy results in a value of **45 kWh/m²** which is by far less than 126 kWh/m² (current status) and 70 kWh/m² (objective for new office buildings)
IEQ	**At least 30% improvement** compared to pre-retrofitting levels according to EN 16798-1:2019.	The building is currently not used. So, making it occupied and used again is the primary objective. IEQ values will always fulfil standards for new buildings.

7. INNOVATIONS IN THE PALMA DEMO

The innovations in the Palma demo for three actions can be summarised as follows.

Testing and monitoring BIPV solutions in terms of aesthetic aspects and energy production

In order to realise the architectural vision of the project, the design concept of GESA building includes a pre-test of several latest generation BIPV solutions, which are described in detail in **Appendix C – BIPV commercial solutions for GESA building.** Designing an optimal solution for highly glazed office buildings has implications not only for aesthetics, but also for heating and cooling loads and energy generation. Different HVAC solutions and strategies are analysed and adapted to the local climate through integrated design in conjunction with the envelope solutions in the façades.

Solutions based on eco-materials for new and retrofitting buildings

Solutions based on the restoration of eco-friendly local materials such as expanded cork and pinewood are tested for the residential retrofitting. Based on passive design measures, different design parameters for the insulation of different parts of the building envelope were tested for the selected dwellings, depending on the building type. The preference for local materials is expected to reduce GHG emissions and non-renewable primary energy consumption of the building during its life cycle. Also, different solutions have been designed for the new social housing elements.

Combined approach for facilities improvement

From active design measures, the chosen dwellings have undergone a process of testing different facilities improvement scenarios such as HVAC design options (installation of HPs both for DHW and for heating and cooling) and renewable energy integration (PV installation).

Economic cost – environmental optimal analysis

Processes that aim to accelerate the rate of retrofitting of the building stock and/or increase the number of high quality / high efficient social housing should consider the economic constraints. By one hand, economic contributions of the private owners can be highly limited due to their socio-economic conditions being one of the reasons of low retrofitting rates. Budget rates investments for new social housing are also limited to certain values. So, economic aspects should be considered from the first stages of the design processes and should consider the impact of some new business models. In the case of large-scale retrofitting under innovative Public Private Mechanisms, impact on the investment quotes is a key aspect that have been considered on the analysis.

8. BEST DESIGN PRACTICES AND CHALLENGES

DESIGN PRACTICES

The design of a building is always challenging, no matter the size of the project. During this process, designers analyse the different strategies that can be incorporated and be beneficial to improve comfort and sustainability. Each option implies a different carbon footprint and costs. Inherent limitations of the existing buildings require a deeper analysis, as some strategies may not be feasible.

Detailed analysis of all possible strategies is highly time-consuming. Furthermore, the information required for the analysis needs to be modified and updated continuously due to the existence of unknown parameters or requirements of the project. As a consequence, decisions are regularly made based on previous experience of the designer and many strategies are not considered or they are discarded at the initial stages. Therefore, the automatization of the design process is highly beneficial not only for a fast implementation of changes in the design, but also to improve productivity of the whole process and get accurate results. Furthermore, it is also key to minimize uncertainty of design criteria to achieve the desired output.

At early stages of the design, some assumptions are taken in order to be able to carry out analyses, which is key to evaluating the different options and provide guidance for the decision-making. However, it is important to validate these assumptions at later stages for the final design.

CHALLENGES

Challenges for three actions of the Palma are summarised below:

Design in the large-scale retrofitting process

A large-scale retrofitting process requires, among other things, strong cooperation, and acceptance from the local community. Compared to the other two actions, the social situation of the neighbourhood therefore plays an important role for large-scale retrofitting. Similar to the second action, the solutions offered should be affordable for the owners. However, the main challenge in this action is to find an optimal balance between reducing the energy demand to obtain the housing grant and providing cost-effective solutions so that the price of the retrofit remains affordable for the owners.

Design in new social housing

With the aim of building social housing with Positive Energy Buildings target and therefore effective energy efficiency strategies, the main challenge in this action is to find optimal solutions considering budget constraints. The energy efficiency measures should not only meet the energy target for the buildings, but also maintain an affordable price for the owners, which is one of the main requirements for social housing. Another challenge is to find appropriate local products and construction processes that minimizes the embodied emissions of the building.

Design in the GESA building

The main challenge in the sustainable design of the building GESA, a flagship building in Palma, was to propose innovative design solutions to meet current energy and environmental regulations, but at the same time maintain the high aesthetic quality of this local heritage building.

FUTURE UPDATES

This deliverable will be updated in Month 24 (December 2023, second version), Month 36 (December 2024, third version) and in Month 48 (December 2025, final version) of the ARV project.

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ACKNOWLEDGEMENTS AND DISCLAIMER

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APPENDIX A – GLOSSARY OF TERMS

Table A.1 *Abbreviations used in the report.*

Abbreviation	Description
AC	Alternating Current
ACFD	Dynamic Calculation of Fluids
ASE	Annual Sunlight Exposure
ASHP	Air Source Heat Pump
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAPV	Building Applied Photovoltaics
BIPV	Building-Integrated Photovoltaics
CID	Council Implementing Decision
CIGS	Copper Indium Gallium and Selenide
COP	Coefficient of Performance
CPCC	Climate Positive Circular Communities
DC	Direct Current
DHW	Domestic Hot Water
DILL	The Llevant Innovation District
DSWC	Direct Surface Water Cooling
EER	Energy Efficiency Ratio
EF	Emission Factor
EICs	The Expected Impacts of the Call
EPC	the Energy Performance Certificate
EPS	Expanded Polystyrene
ERRP	Residential Environments of Programmed Rehabilitation
ESEER	European seasonal energy efficiency ratio
FSC	Forest Stewardship Council
GA	Grant Agreement
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump

HOP	Homes with Official Protection
HP	Heat Pump
HSWHP	Hybrid Surface Water Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
KPIs	The Key Performance Indicators
LCA	Life Cycle Assessment
NZEB	Nearly Zero Energy Building
PPP	Public Private Partnership
PV	Photovoltaic
PVC	Polyvinyl Chloride
RES	Renewable Energy Systems
sDA	spatial Daylight Autonomy
SEER	The Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
Si	Silicon
SPF	Seasonal Performance Factor
SWHP	Surface Water Heat Pump
TER	Total Efficiency Ratio
TRNSYS	Transient System Simulation Tool
WP	Work Package
XPS	Extruded Polystyrene

APPENDIX B – SYSTEMS DESCRIPTION

ASHP overview

An ASHP is regarded as a renewable technology in the European Commission guidance. An ASHP works by converting energy from the outside air into heat. This can be used for heating in the winter, but can be reversed for cooling in the summer. It can also produce heating and cooling at the same time, increasing significantly its overall efficiency as one of them is product of producing the other. ASHPs work by extracting heat from the outside air and passing it through a refrigeration compressor cycle, which increases its temperature. The heat is then distributed to the rooms. In cooling mode, the cycle is reversed.

An ASHP will typically have a lower COP, EER or TER (system efficiency) than a GSHP due to the variability of the outside air temperature when compared to the earth. However, the capital cost of an ASHP is much lower, is easier to maintain than ground source, a tried and tested technology and there is no need for any extensive ground works.

The Coefficient of Performance (COP) is a measure of the instantaneous efficiency of a heat pump. The heat energy produced by an ASHP is deemed renewable if it meets a specified sustained COP over a period of time, e.g., a seasonal performance factor (SPF or SCOP). Typical values of COP are 2.8-3.5.

The Energy Efficiency Ratio (EER) is defined the ratio of cooling capacity provided to electricity consumed same rating system is used for air conditioners or AHSP, allowing for straightforward comparisons of different units. The Seasonal Energy Efficiency Ratio (SEER) value in cooling is the equivalent of SCOP or SFP in heating. Typical values of EER are 2.8-3.2.

The Total Efficiency Ratio (TER) of the device in simultaneous operation can be extremely high in ASHP at up to 8.7. Unfortunately, simultaneous demand is not achieved regularly.

Efficiencies values will vary depending on external temperatures, refrigerants used, secondary system temperatures and overall performance of the equipment used.

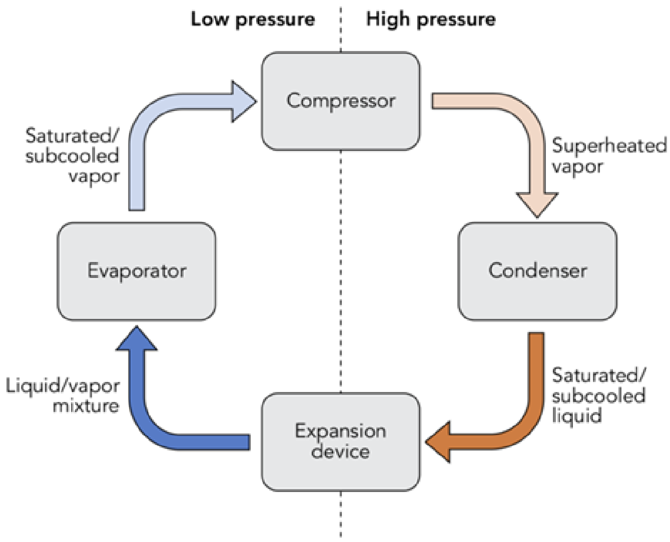


***Figure 95.** Heat pumps under Creative Commons Licence* [22].

Evaporative Cooling Towers overview

Many air-conditioning systems rely on a chiller to produce chilled water, which is distributed around the building by pumps and pipework. Chilled water systems are hydronic systems, with many of the same technical considerations as hydronic heating systems. The way in which the chilled water is used depends on the type of air-conditioning system the chiller serves. A chiller itself it is the same as an ASHP working to produce cooling only.

In order for a chiller to cool the water used in the air-conditioning system it must first extract heat from the water and then get rid of it. Heat rejection from chillers can be achieved in several ways. The simplest approach is to combine the heat rejection system and chiller into a single unit called a packaged chiller, also known as an air-cooled chiller. This incorporates one or more fans which draw fresh air through the unit to carry away the heat. It must be located outdoors.

Large chillers often have a separate heat rejection system linked to the chiller by condenser water pipework, enabling the chiller to be located in a plant room. This is known as a water-cooled chiller. The heat rejection system can take several forms. The most efficient is the evaporative cooling tower which uses the cooling effect of evaporating water to boost the cooling provided by fresh air. Water treatment is required for the condenser water in systems using evaporative cooling towers. This approach has become less popular during the last 20 to 25 years as a result of the risk of Legionnaires' disease associated with poor maintenance. However, for some building applications, cooling towers remain the favoured method of heat rejection due to their high efficiency which enables a small footprint.

A more widely used system for providing separate heat rejection is the dry cooler. This consists of a low profile unit containing one or more fans which drive fresh air across a serpentine coil. The coil contains condenser water from the chiller which is cooled and pumped back to the chiller. Alternatively, the coil can contain hot refrigerant directly from the refrigeration process, which is cooled in the same way and then travels back to the chiller. In this case it would be known as a remote condenser, and the chiller would be known as condenserless.

Outbreaks of Legionnaires' disease have been linked to bacteria in cooling tower drift droplets being drawn into the building through air intakes [23].The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 12 gives advice on cooling tower maintenance for minimizing the risk of Legionnaires' disease, and suggests keeping cooling towers as far away as possible from intakes, operable windows, and outdoor public areas. No specific minimum separation distance is provided or available. Prevailing wind directions should also be considered to minimize risk. Evaporative cooling towers can have several other effects: water vapor can increase air conditioning loads, condensing and freezing water vapor can damage equipment, and ice can block intake grilles and filters. Chemicals added to retard scaling and biological contamination may be emitted from the cooling tower, creating odours or health effects, as discussed by Vanderheyden and Schuyler [24].

GSHP overview

GSHP transfer heat from the ground into a building to provide space heating, cooling and/or pre-heat hot water. In this case we are using very low enthalpy geothermal system that would need a water-water heat pump in order to produce heating or cooling. As an air source heat pump, it can provide simultaneous cooling and heating. Therefore, we have the same efficiency indicators as explained before, COP, SCOP or SFP, EER, SEER and TER.

Closed Loop GSHP

Closed loop GSHP are the more common systems with the technology being more readily available (for example does not need an extraction license from the Environmental Agency).

A closed loop installation consists of plastic piping which is buried in the ground and connected to a pump. A mixture of water and antifreeze is passed through the looped pipes where it absorbs heat from the ground. This fluid then flows in to an electrically powered heat pump before discharging back to the ground.

There are two main types of closed loop ground source heat pumps: horizontal and vertical.

Vertical loops require bore holes to be drilled deep into the ground (typically around 120 m in depth) but are more reliable than horizontal systems due to the constant temperature obtained in all seasons. GSHPs require extensive ground works which incur high capital costs. Piles foundations of the building can be used as energy piles as well, incorporating pipes in them and therefore exchanging heat from the ground.

Open Loop GSHP

Open loop GSHP systems work in a very similar manner to closed loop GSHPs, with the difference being that aquifer water or sea water is used as a cooling and/or heating medium. Bore holes are drilled down into the aquifer or sea level where ground water is pumped to a heat exchanger and the energy is extracted from the water. In sea water, this must be from the same salinity as the sea, equivalent to 50,000mS/cm and seal the interface zone.
The water is then passed back down (re-injected) to the aquifer/sea. The direct contact of the source water through the heat exchanger makes it more efficient and the number of boreholes on an open system can be much smaller than a closed loop system for the same output capacity. Due to extracting water from the aquifer/sea, a license is required from the administrative authorities.

There are three different uses of Open GSHP Loops:

- Direct surface water cooling (DSWC) systems: systems that use seawater or lake water to provide cooling without the use of heat pumps or chillers. There may, of course, be intermediate heat exchangers to isolate fouling-prone seawater or lake water from the building system.
- Surface water heat pump (SWHP) systems: systems that use heat pumps or chillers to provide heating and/or cooling, with their heat source or sink, surface water. Depending on location and application, the systems may provide heating only, cooling only, or heating and cooling.
- Hybrid surface water heat pump (HSWHP) systems: systems that use heat pumps or chillers to provide heating and/or cooling; however, they can also use seawater or lake water directly to provide cooling when water temperatures allow this to be done.

Solar thermal overview

Solar thermal technologies generate hot water from the sun's energy through the use of solar collectors. The sun's heat energy is accumulated by the solar cells and then water is pumped through these thus heating the water. The heated water is then stored or distributed for use. These systems tend to be incorporated on to roof space so that they are clear of obstacles (obstructions on the roof can have an effect on the solar cell array). As with photovoltaic panels, the solar collectors are more effective if they are in a South-facing position.

There are two main types of Solar Thermal system; flat panel and thermal vacuum tubes. Flat panels consist of a flat "radiator" absorber, covered by glass and insulated. Their efficiency depends on the insulation properties and type of construction. More expensive double-glazed units have a better efficiency, so that a smaller area of solar thermal panels is required – a compromise would need to be made between efficiency and cost. Solar thermal panels are especially worth considering for new buildings, since they can be effectively built into roof structures at the construction stage.

Thermal vacuum tubes are a more recently developed technology designed for obtaining heat from the sun. These have been developed over the last thirty years into units that are now up to 90% efficient. Water is passed through an evacuated tube, which contains a black absorber plate. Vacuum tubes are more efficient and therefore a smaller area of collector is required. Solar vacuum tubes are capable of operating at higher working temperatures than flat plate collectors. Thermal losses for vacuum tubes also tend to be lower than those of flat plate collectors due to improved heat insulation. The vacuum provides insulation, and this allows the water to be heated to higher temperatures, and remain very effective even on cloudy days. The optimum generation tends to occur during the summer months.

Photovoltaics overview

PV or solar cells, as they are often referred to, are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays which can be used to charge batteries, operate motors and power any number of electrical loads.
With the appropriate power conversion equipment (inverters) PV systems can produce alternating current (AC) compatible with any conventional appliances and operate in parallel with the utility grid.

PV systems require only daylight to generate electricity (although more is produced with more sunlight). Therefore, energy can still be produced in overcast or cloudy conditions and used successfully in all parts of the UK. Ideally, PV panels should face between South- East and South-West, at an elevation of about 30-40º. However, in the UK, even flat roofs receive 90% of the energy of an optimum system. They are particularly suited to buildings that use electricity during the day and that are occupied during the summer.

Building Integrated Photovoltaics (BIPV) is the integration of PV into the building envelope. Please refer to **Appendix C – BIPV commercial solutions for GESA building** for further explanation.

APPENDIX C – BIPV COMMERCIAL SOLUTIONS FOR GESA BUILDING

INTRODUCTION - REQUIREMENTS

As mentioned in chapter 6, the GESA building has curtain wall façades made of glass with golden-orange hue. Two different areas can be clearly differentiated, one being transparent and the other one being opaque. In the framework of its rehabilitation, one of the proposed innovations consists in improving the energy efficiency with the replacement of the current façade with BIPV products. To do so, a screening of the different BIPV solutions available for both the opaque and transparent parts has to be performed. Some requirements have to be taken into account, among which (1) the specific dimensions of the opaque and transparent glasses (which is not a standard dimension of BIPV modules and thus implies customisation), (2) the current aesthetic aspect and colour, which should be preserved or maintained (some colour variation could be possible, especially if energy production could be improved), (3) the weight of the BIPV solutions which often include a frame and its fitting into the enclose (which could need reinforcement), (4) the power production capability of the BIPV products, (5) the degree of transparency for the transparent BIPV solutions and (6) the cost (panel and installation cost) and availability of the BIPV modules in case of a future rehabilitation of the whole building. The BIPV solutions thermal transmittance and solar factor will strongly influence the thermal performance of the building. Therefore, these parameters are of key importance and they will be also taken into account. However, in the first step of potential BIPV products screening these parameters aren't yet considered.

In the following, a state of the art of potential BIPV products for such rehabilitation is presented based on the considerations above mentioned.

STATE OF THE ART

As previously introduced, the rehabilitation of the building requires BIPV solutions for both the opaque and transparent part.

For the opaque part, several commercial products can already be found as standard, especially using silicon (Si) technology, and meet the requirements on the aesthetic aspect (especially the colour) and the module performance. Manufacturers propose such standard products and some detailed specifications are even available online. Other products made from thin film PV technologies could also be interesting, such as CIGS (Copper Indium Gallium and Selenide) or organics which offer the advantage of having a more homogeneous aesthetic aspect than Si. In addition, they are normally easily tuneable in size and they can be made on low-weight substrates, such as stainless steel. However, less information is found for such products. Several examples of these BIPV products using the different cited technologies are found in recent construction and/or rehabilitation. **Table 37** summarizes the main identified products from several manufacturers. However, despite standard products are available, they often do not fit the dimension requirement and no other dimensions are proposed rendering customization almost mandatory. To date, LOFSolar, MetSolar and Onyx are the most reliable manufacturers to provide customized BIPV products fitting most of the requirements. In **Figure 96** some examples of BIPV products are shown.

Table 37. *Opaque BIPV solutions found in the market.*

Provider	Ref. Product	Colour/s	PV Technology	Efficiency [%] / (Power)	Reference
Solarday	Coloured 290-350W	Red, Green, Yellow	Si	17.6-17.9 (290-350 Wp)	[25]
VGS	60 Cells - VE160PVMR	5BB Polycrystalline - Red	Si	15.2-15.85 (power 250-260 Wp)	[26]
LOF	Classic Series Polycrystalline Colour PV Modules / 270-265Wp	tile red, forest green, true steel, golden brown, lavender, terractotta, turkish bluide	Si	14.44-16.60 (235-270 Wp)	[27]
LOF	LOF Mono PERC Series Mono crystalline Colour PV Modules / 320-300 Wp	tile red, forest green, true steel	Si	(300-320 Wp)	Information requested
LOF	LOF Marble Series Poly crystalline Colour PV Modules / 280 -265Wp	Marble series / several colours possible	Si	16.2-17.2 (265-280 Wp)	Information requested
LOF	6x6 BIPV module	All classic, marble, and custom series	Si	10.3-11.5% (120-135W)	[28]
LOF	6x10 Multi Solar Panel in Modern bronze/Terracotta colour	Modern bronze/Terracotta	Si	240-275W	Information requested
REC	N-PEAK 2 SERIES	Black	Si	19.7-20.5 (360-375 Wp)	[29]
REC	N-PEAK 2 BLACK SERIES	Black	Si	19.1-20.3 (350-370 Wp)	[30]
METSOLAR	CUSTOM	Wide range of colours	Si	Range of efficiencies and power	[31]
MIASOLE	FLEX SERIES-02WS	Blue/Black	CIGS	14-17 (210-250 Wp)	[32]
MIASOLE	FLEX SERIES-03W 1 METER	Blue/Black	CIGS	14-18 (160-200 Wp)	[32]
FLISOM	eFLEX	Black	CIGS	(55 Wp)	[33]

FLISOM	eMETAL	Black	CIGS	(50-60 Wp)	[34]
MIDSUMMER	SLIM SERIES	Solar film with opaque solar area and black coloured edge	CIGS	(65-160 Wp)	[35]
HELIATEK	HELIASOL	blueish	Organics	(50-55 Wp)	[36]
HELIATEK	HELIAFILM	blueish	Organics	No details	[37]
ANTECSOLAR	CUSTOM	Range of colours	CIGS-custom	Various efficiencies and power	[38]
AVANCIS	SKALA	Range of colours	CIGS	11.4-13.3 (120-140 Wp)	[39]
ONYX	CUSTOM	Wide range of homogeneous colours	Si	(80-140 Wp/m^2)	[40]

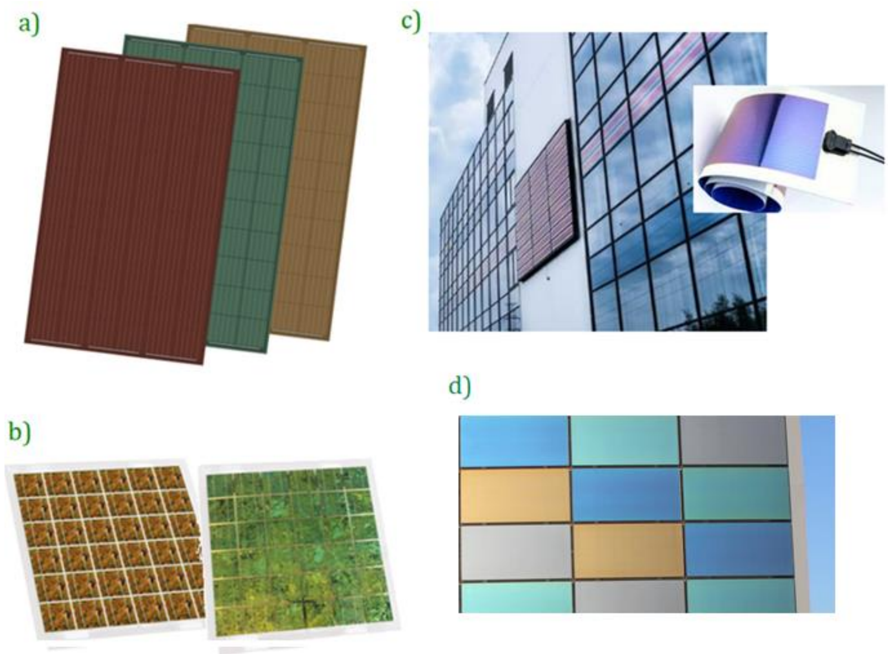


Figure 96. *Examples of opaque BIPV solutions: a) Solarday – coloured monocrystalline Si [11], b) coloured LOF – polycrystalline Si (information requested), c) Heliatek – coloured organics on flexible substrate [19] and d) Antec Solar – CIGS [21].*

For the transparent part, the offer is more limited, and very few commercial products can be found as standard. Available products generally consist on cell-cladding solutions. Cell cladding systems are glazing systems with inhomogeneous transparency, where the percentage of light that passes through is due to a separation space between opaque PV cells (mainly Si cells). Despite this solution is the most encountered one, it is compromised by the lack of uniformity in its visual aspect. Uniform semi-transparent products are much more attractive, and some solutions exist and are based on amorphous Si or organics. **Table 38** summarizes the main identified manufacturers of such solutions. However, since these solutions are typically customized, details are only available upon request. In **Figure 97** some examples of semi-transparent BIPV products are presented.

Table 38. Semi-transparent BIPV solutions found in the market.

Provider	Ref. Product	Colour/s	PV Technology	Efficiency [%] / (Power)	Reference
Onyx	CUSTOM	Wide range of homogeneous colours	a-Si	57.6 Wp/m^2	[40]
Kaneka	CUSTOM	Range of colours	a-Si	No details	[41]
Armor Asca	CUSTOM	Range of colours	Organics	40 Wp/m^2	[42]
METSOLAR	CUSTOM	Wide range, cell cladding	Si	different Si technologies possible	[31]
ANTECSOLAR	CUSTOM	Wide range of colours	Several	No details	[38]

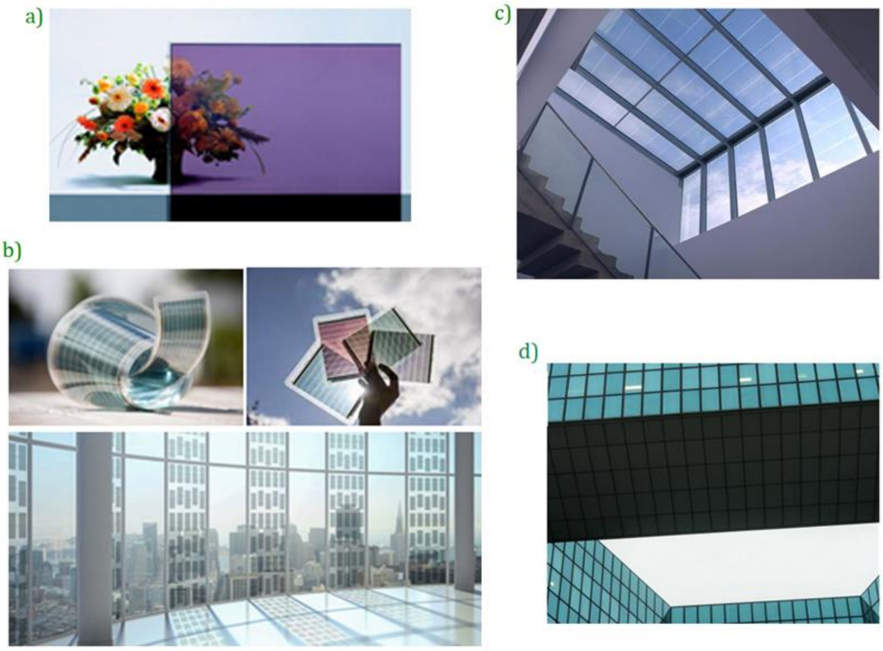


***Figure 97.** Examples of semi-transparent BIPV solutions: a) Onyx – coloured amorphous Si* [40]*, b) Kaneka - coloured amorphous Si on flexible substrate* [41]*, c) Armor Asca – coloured organics* [42] *and Antec Solar – CIGS* [38].

APPENDIX D – GSHP CALCULATIONS FOR GESA BUILDING

HEATING AND COOLING LOADS

In the following graphs, heating and cooling load data is shown. This data comes from the modelled GESA building resulting from the process of passive optimization. The thermal model used to reproduce the thermal energy systems is coupled with the building thermal model. This allows to take into account effects like different energy performance depending on the exterior and interior conditions.

Heating energy loads are shown below:

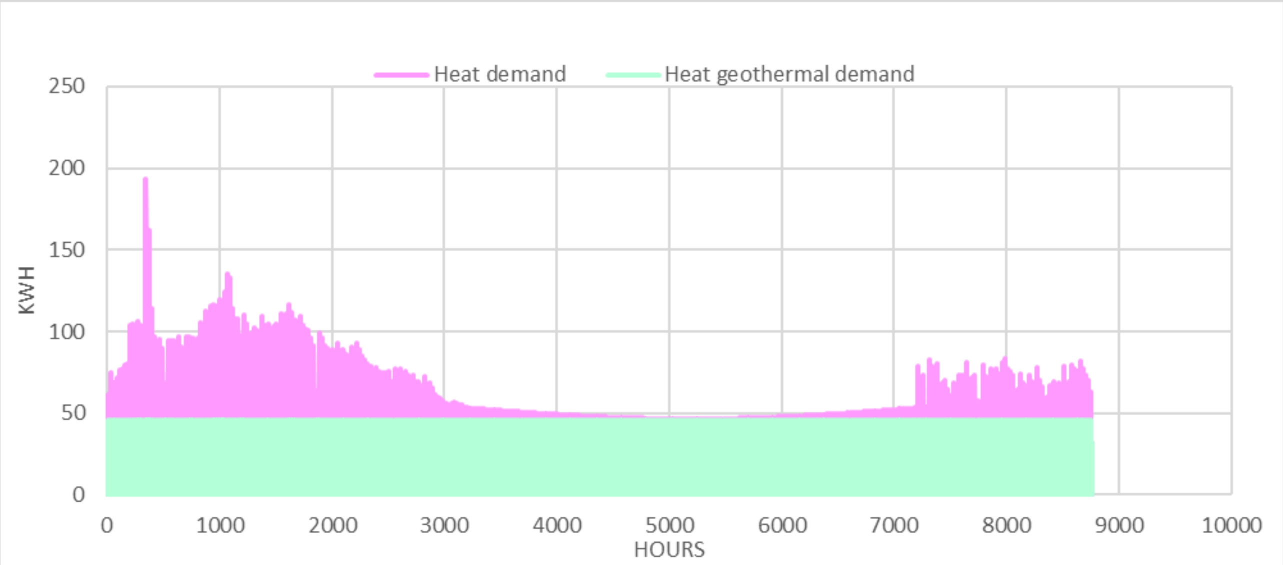


Figure 98. *Heating loads.*

Cooling energy loads are shown below:

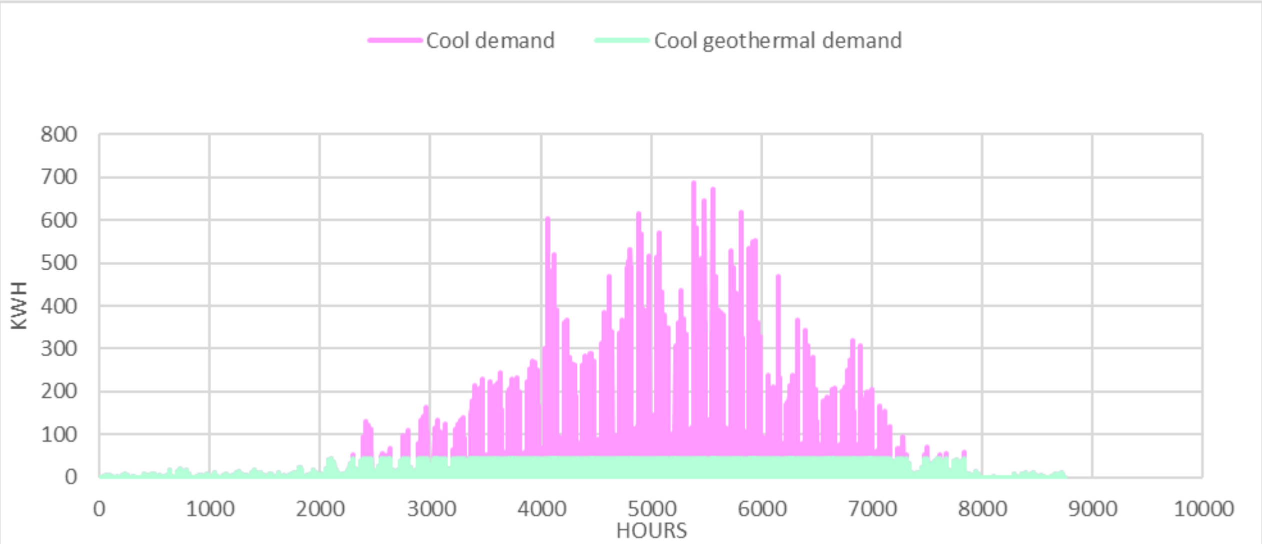


Figure 99. *Cooling loads.*

GSHP DATA

Table 39. GSHP Data.

Heating		
Thermal power	44.8	kW
COP	4.6	
Temperature range	7- 17	º C
Cooling		
Thermal power	44.6	kW
EER	4.4	
Temperature range	35-25	º C

CONFIGURATION OF THE BOREHOLES FIELD

Table 40. Boreholes configuration.

Geothermal boreholes field		
Line length	48	m
Number of boreholes	5	
Distance between boreholes	8	m
Boreholes depth	135	m

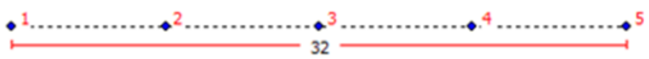


Figure 100. Boreholes configuration

Exact placement of the boreholes is not yet determined, but the available area is wide enough to place the required field.

TEMPERATURES IN THE GEOTHERMAL BOREHOLES OVER A PERIOD OF 25 YEARS ANALYSIS

The aim of this study is to determine the variation of the temperature in the ground due to the thermal exchange with the geothermal boreholes. The analysis of the average temperatures of the fluid inside the boreholes shows stability over 25 years staying within the range of working temperatures of the heat pump.

The demands of the building that are intended to be covered with geothermal energy are well balanced between heating and cooling and thus maintain the ground temperatures over a period of 25 years. This ensures the maintenance of the efficiency of the geothermal system over time.

Several time periods will be used to assess the geothermal system behaviour:

- 25 years period.
- Last year of the 25 years period.

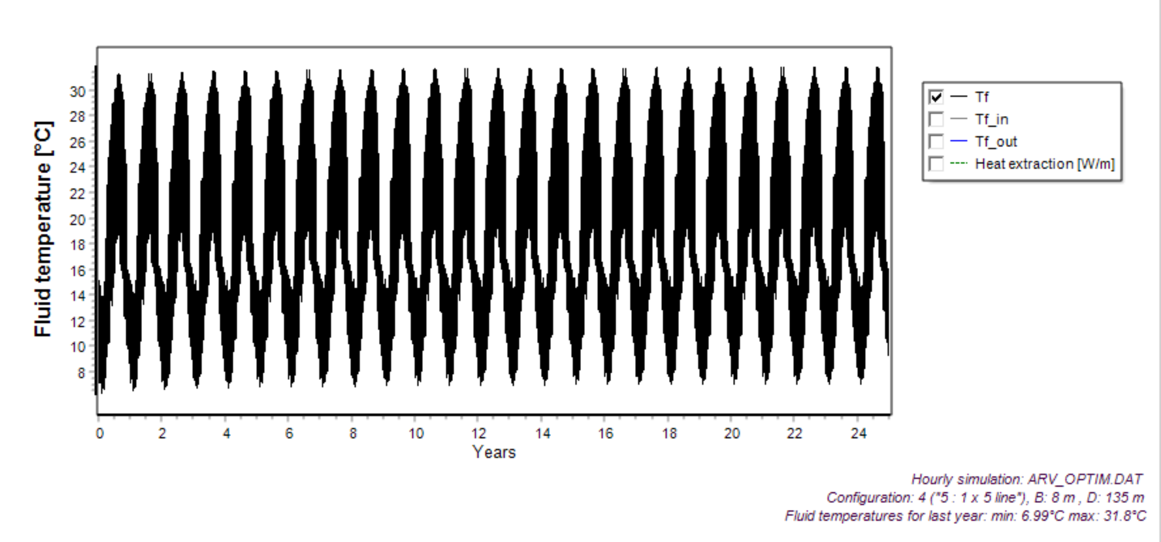


Figure 101. *25 years temperature fluid analysis extracted from the ground.*

In the graphic above, the fluid temperature is presented for a 25 years' time period. Fluctuations are due to year evolution temperatures. Taking into account the low resolution of the graphic for this time period, it is possible to sense that maximal and minimal temperatures do not differ much from year 1 to 25. This is telling that the thermal exchange does not affect the terrain enough and it can recover from the absorbed energy. If the terrain is stable, fluid temperature will change very little.

The graphic shown below presents the fluid temperature of the last year of the 25 years' time period.

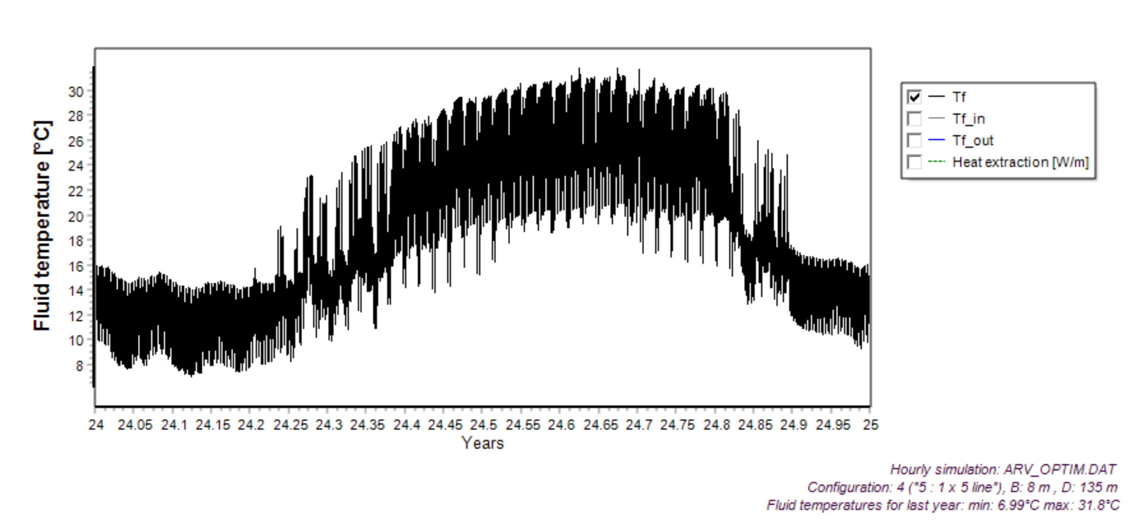


Figure 102. *One year temperature fluid analysis extracted from the ground (25 years).*

It can be seen how the temperature remains within the previously specified pump temperature range: 7-17ºC in heat generation and 35-25ºC in cold generation.

BOREHOLES HEAT EXTRACTION ANALYSIS

The heat extraction power of the geothermal boreholes ranges between 55 W/m for heating and 65 W/m for cooling. These values, which result from the requirement of stability of the soil temperature, remain in the range of "acceptable" values, considered between 20 and 80 W/m² depending on the conductivity of the ground.

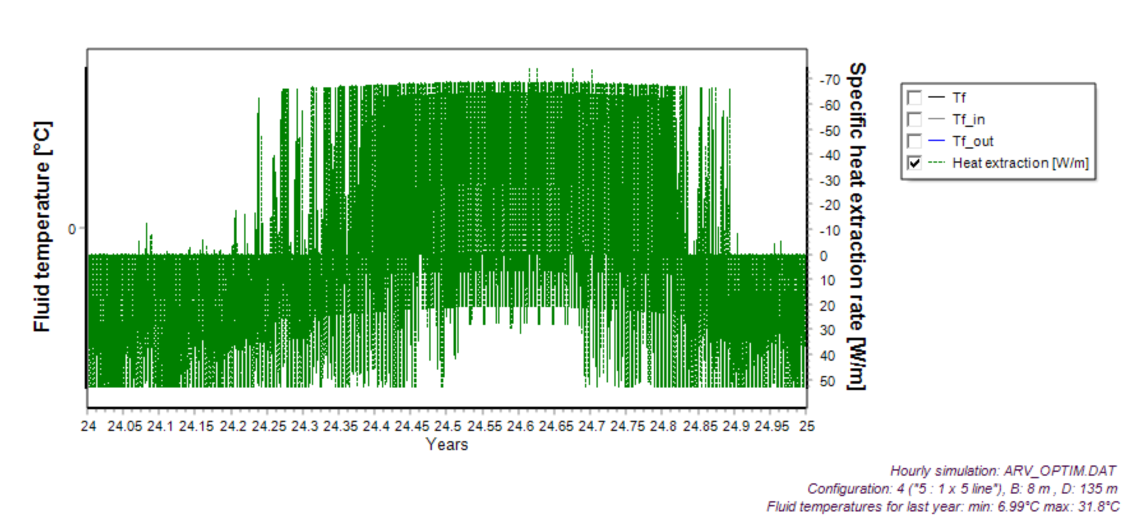
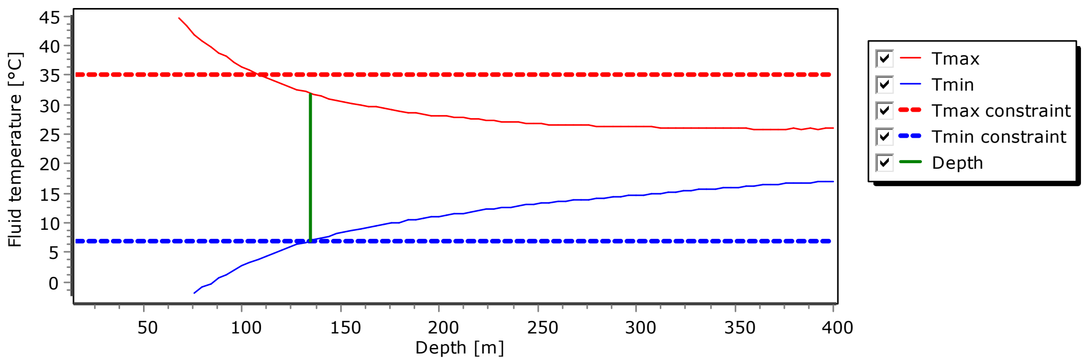


Figure 103. *Heat extraction analysis for 25 years in W/m.*

BOREHOLES DEPTH CALCULATION

In this chapter, an evolution of fluid temperature is represented as a function of the borehole's depth. It is possible to check that the thermal behaviour of the fluid is asymptotic. The minimum recommended depth is about 135m.



Hourly simulation: ARV_OPTIM.DAT
Year: 25
Configuration: 4 ("5 : 1 x 5 line")
Spacing B: 8 m
Calculated depth D: 135 m
Tf min: 7°C max: 31.8°C

Figure 104. *Depth analysis for geothermal boreholes.*

APPENDIX E – DETAILED DATA FOR ECONOMIC CALCULATIONS

Table 41. *Costs with material execution budget + general costs + industrial benefit*

Package & Surface	Material	Insulation Thickness (mm)	Global cost (€/m²) [9]
P1.1 & P2.1 Wall Conventional	EPS insulation (expanded polystyrene insulation)	60	79.57
		80	83.31
		100	87.55
		120	91.01
		140	93.42
P1.2 & P2.2 Wall Ecological	Graphite EPS (expanded polystyrene insulation)	60	81.98
		80	86.06
		100	90.06
		120	94.03
		140	103
P1.1 & P2.1 Roof Conventional	XPS (Extruded Polystyrene)	60	142.35
		80	145.68
		100	148.81
		120	151.95
		140	155.13
P1.2 & P2.2 Roof Ecological	Natural cork	60	166.9
		80	177.76
		100	189.49
		120	201.24
		140	212.95
P1.1 & P2.1 Floor (archetype 1) Conventional	Rock wool + plasterboard	60	82.18
		80	94.4
P1.2 & P2.2 Floor (archetype 1) Ecological	Cork + plasterboard	60	81.05
		80	92.09
P1.1 & P2.1 Conventional	PVC window frame + glass 4-14-6 LE	1 unit	676.97
P1.2 & P2.2 Ecological	Pinewood window frame + glass 4-14-6 LE	1 unit	1272.35

Table 42. Global retrofitting cost per dwelling without grants (Archetype 1).

Package	Insulation Thickness (mm)	Total cost (€)	Wall cost (€)	Floor cost (€)	Roof cost (€)	Windows (€)	Electrical renovation (€)
P1.1	60	15 361	8 613	2 363	4 214	0	170
P1.1	80	15 765	9 018	2 363	4 214	0	170
P1.1	100	16 224	9 477	2 363	4 214	0	170
P1.1	120	16 599	9 852	2 363	4 214	0	170
P1.1	140	16 860	10 113	2 363	4 214	0	170
P1.2	60	16 517	8 874	2 331	5 142	0	170
P1.2	80	16 959	9 316	2 331	5 142	0	170
P1.2	100	17 392	9 749	2 331	5 142	0	170
P1.2	120	17 821	10 179	2 331	5 142	0	170
P1.2	140	18 792	11 150	2 331	5 142	0	170
P2.1	60	19 788	8 613	2 363	4 214	4 428	170
P2.1	80	20 193	9 018	2 363	4 214	4 428	170
P2.1	100	20 652	9 477	2 363	4 214	4 428	170
P2.1	120	21 026	9 852	2 363	4 214	4 428	170
P2.1	140	21 287	10 113	2 363	4 214	4 428	170
P2.2	60	24 838	8 874	2 331	5 142	8 322	170
P2.2	80	25 280	9 316	2 331	5 142	8 322	170
P2.2	100	25 713	9 749	2 331	5 142	8 322	170
P2.2	120	26 143	10 179	2 331	5 142	8 322	170
P2.2	140	27 114	11 150	2 331	5 142	8 322	170

Table 43. Retrofitting cost per dwelling without grants (Archetype 2).

Package	Insulation Thickness (mm)	Total cost (€)	Wall cost (€)	Roof cost (€)	Windows (€)	Electrical renovation (€)
P1.1	60	25 984	15 582	10 002	0	400
P1.1	80	26 716	16 314	10 002	0	400
P1.1	100	27 547	17 144	10 002	0	400
P1.1	120	28 224	17 822	10 002	0	400
P1.1	140	28 696	18 294	10 002	0	400
P1.2	60	28 659	16 054	12 205	0	400
P1.2	80	29 458	16 853	12 205	0	400
P1.2	100	30 241	17 636	12 205	0	400
P1.2	120	31 018	18 413	12 205	0	400
P1.2	140	32 775	20 170	12 205	0	400
P2.1	60	25 984	15 582	10 002	3 599	400
P2.1	80	26 716	16 314	10 002	3 599	400
P2.1	100	27 547	17 144	10 002	3 599	400
P2.1	120	28 224	17 822	10 002	3 599	400
P2.1	140	28 696	18 294	10 002	3 599	400
P2.2	60	28 659	16 054	12 205	6 764	400
P2.2	80	29 458	16 853	12 205	6 764	400
P2.2	100	30 241	17 636	12 205	6 764	400
P2.2	120	31 018	18 413	12 205	6 764	400
P2.2	140	32 775	20 170	12 205	6 764	400

APPENDIX F – ENERGY SIMULATIONS - OFFICIAL EPC

Reduction of consumption between 30% and 45%

REHABILITACIÓ ENERGÈTICA D'EDIFICI RESIDENCIAL PLURIFAMILIAR

DADES DE L'EDIFICI

Ús principal	RESIDENCIAL PLURIFAMILIAR
Superficie habitable	676,35 m2
Núm. Habitatges	8
Ubicació	NOU LLEVANT
Situació	AÏLLAT
Any de construcció	1977

ASPECTES ECONÒMICS

Reducció del consum d'EPNR >30%

Cost de les actuacions	€	78.170,34
Percentatge màxim ajuda		40%
Quantia aplicant % màxim	€	31.268,14
Subvenció màxima per habitatge	€	8.100,00
Quantia aplicant màxims per habitatge	€	64.800,00
Subvenció (Mínim entre % i quantia habitatges)	€	31.268,14
Import a cobrir amb fons propis	€	46.902,20
Import fons propis per habitatge	€	5.862,78

COMPORTAMENT ENERGÈTIC

Qualificació energètica inicial	G
Consum EPNR inicial	206,2 kWh/m2 i any
Consum EPNR inicial	139463 kWh/any
Qualificació energ. rehabilitat	E
Consum EPNR rehabilitat	129,27 kWh/m2 i any
Consum EPNR rehabilitat	87432 kWh/any
Estalvi energètic anual	76,93 kWh/m2 i any
	52032 kWh/any
	37,31%

CARACTERÍSTIQUES DE L'INTERVENCIÓ

PROPIETATS DE L'ENVOLUPANT

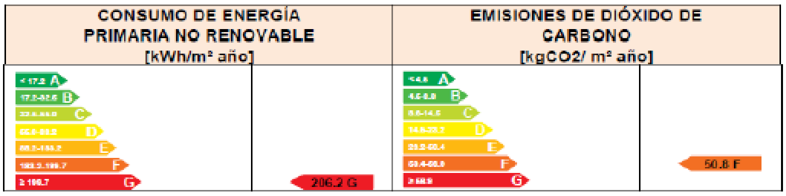
	Estat inicial	Estat rehabilitat millores >30%
Umurs exteriors / Umurs	2,38 W/m2*K	0,34 W/m2*K
Uparticióinterior	W/m2*K	W/m2*K
Usòl	2,5 W/m2*K	2,17 W/m2*K
Ucoberta	2,17 W/m2*K	0,34 W/m2*K
Ubuits	3,78 W/m2*K	3,78 W/m2*K
Buits		
Tipus vidre	Simple	Simple
Tipus marc	Alumini sense RPT / Fusta	Alumini sense RPT / Fusta

DESCRIPCIÓ DE LES ACTUACIONS

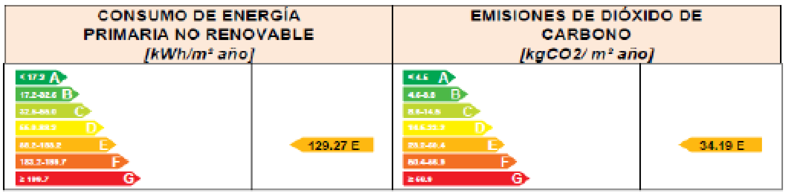
Les obres consisteixen en l'aïllament tèrmic dels murs de façana principal, posterior i dels patis interiors, amb una aïllament amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,34 W/m2*K. Demolició i execució de nova coberta, amb impermeabilització i aïllament tèrmic amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,34 W/m2*K.

RESULTATS ENERGÈTICS OBTINGUTS

Estat inicial

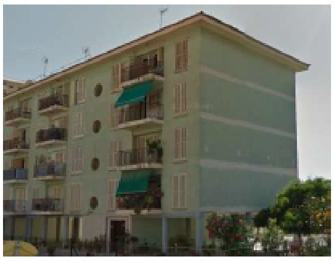


Estat rehabilitat



Reduction of consumption between 45% and 60%

REHABILITACIÓ ENERGÈTICA D'EDIFICI RESIDENCIAL PLURIFAMILIAR



DADES DE L'EDIFICI

Ús principal	RESIDENCIAL PLURIFAMILIAR
Superfície habitable	676,35 m2
Núm. Habitatges	8
Ubicació	NOU LLEVANT
Situació	AÏLLAT
Any de construcció	1977

COMPORTAMENT ENERGÈTIC

Qualificació energètica inicial	G
Consum EPNR inicial	206,2 kWh/m2 i any
Consum EPNR inicial	139463 kWh/any
Qualificació energ. rehabilitat	E
Consum EPNR rehabilitat	106,45 kWh/m2 i any
Consum EPNR rehabilitat	71997 kWh/any
Estalvi energètic anual	99,75 kWh/m2 i any
	67466 kWh/any
	48,38%

ASPECTES ECONÒMICS

Reducció del consum d'EPNR >45%

Cost de les actuacions	€	85.962,74
Percentatge màxim ajuda		65%
Quantia aplicant % màxim	€	55.875,78
Subvenció màxima per habitatge	€	14.500,00
Quantia aplicant màxims per habitatge	€	116.000,00
Subvenció (Mínim entre % i quantia habitatges)	€	55.875,78
Import a cobrir amb fons propis	€	30.086,96
Import fons propis per habitatge	€	3.760,87

CARACTERÍSTIQUES DE L'INTERVENCIÓ

PROPIETATS DE L'ENVOLUPANT

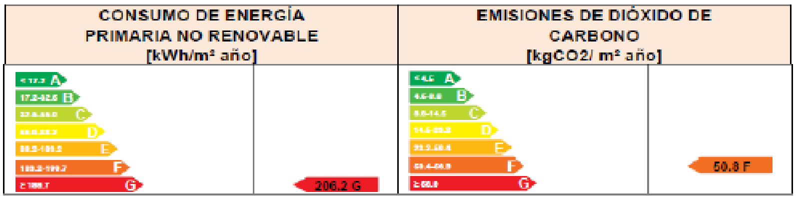
Estat inicial		Estat rehabilitat millores >45%	
Umurs exteriors	2,38 W/m2*K	Umurs	0,34 W/m2*K
Uparticióinterior	W/m2*K	Uparticióinterior	W/m2*K
Usòl	2,5 W/m2*K	Usòl	2,17 W/m2*K
Ucoberta	2,17 W/m2*K	Ucoberta	0,34 W/m2*K
Ubuits	3,78 W/m2*K	Ubuits	3,78 W/m2*K
Buits		Buits	
Tipus vidre	Simple	Tipus vidre	Simple
Tipus marc	Alumini sense RPT / Fusta	Tipus marc	Alumini sense RPT / Fusta

DESCRIPCIÓ DE LES ACTUACIONS

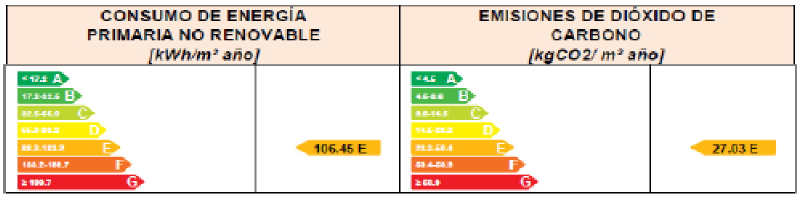
Les obres consisteixen en l'aïllament tèrmic dels murs de façana principal, posterior i dels patis interiors, amb una aïllament ambλ = 0,04 W/m*K i gruix de 12 cm, amb transmitància final de 0,29 W/m2*K. Demolició i execució de nova coberta, amb impermeabilització i aïllament tèrmic ambλ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,34 W/m2*K. I també una contribució d'energies renovables mitjançant una instal·lació fotovoltaica d'autoconsum compartit sobre coberta amb una potència instal·lada de 4 kWp i producció anual estimada de 5200 kWh (1300 kWh per cada kWp).

RESULTATS ENERGÈTICS OBTINGUTS

Estat inicial



Estat rehabilitat



Reduction of consumption of more than 60%

REHABILITACIÓ ENERGÈTICA D'EDIFICI RESIDENCIAL PLURIFAMILIAR

DADES DE L'EDIFICI

Ús principal	RESIDENCIAL PLURIFAMILIAR
Superficie habitable	676,35 m2
Núm. Habitatges	8
Ubicació	NOU LLEVANT
Situació	AÏLLAT
Any de construcció	1977

COMPORTAMENT ENERGÈTIC

Qualificació energètica inicial	G
Consum EPNR inicial	209,1 kWh/m2 i any
Consum EPNR inicial	141425 kWh/any
Qualificació energ. rehabilitat	D
Consum EPNR rehabilitat	80,78 kWh/m2 i any
Consum EPNR rehabilitat	54636 kWh/any
Estalvi energètic anual	128,32 kWh/m2 i any
	86789 kWh/any
	61,37%

ASPECTES ECONÒMICS

Reducció del consum d'EPNR >60%

Cost de les actuacions	€	94.729,19
Percentatge màxim ajuda		80%
Quantia aplicant % màxim	€	75.783,35
Subvenció màxima per habitatge	€	21.400,00
Quantia aplicant màxims per habitatge	€	171.200,00
Subvenció (Mínim entre % i quantia habitatges)	€	75.783,35
Import a cobrir amb fons propis	€	18.945,84
Import fons propis per habitatge	€	2.368,23

CARACTERÍSTIQUES DE L'INTERVENCIÓ

PROPIETATS DE L'ENVOLUPANT

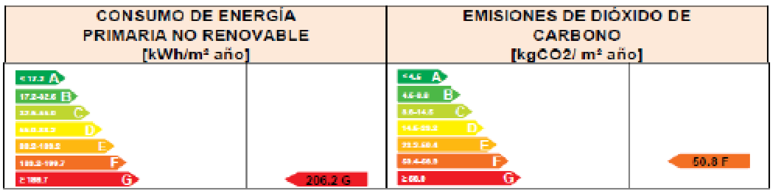
Estat inicial		Estat rehabilitat millores >45%	
Umurs exteriors	2,38 W/m2*K	Umurs	0,34 W/m2*K
Upartícióinterior	W/m2*K	Upartícióinterior	W/m2*K
Usòl	2,5 W/m2*K	Usòl	2,17 W/m2*K
Ucoberta	2,17 W/m2*K	Ucoberta	0,34 W/m2*K
Ubuits	3,78 W/m2*K	Ubuits	3,78 W/m2*K
Buits		Buits	
Tipus vidre	Simple	Tipus vidre	Simple
Tipus marc	Alumini sense RPT / Fusta	Tipus marc	Alumini sense RPT / Fusta

DESCRIPCIÓ DE LES ACTUACIONS

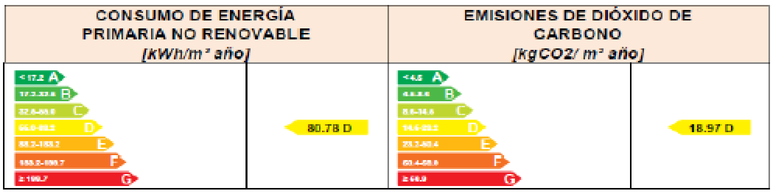
Les obres consisteixen en l'aïllament tèrmic dels murs de façana principal, posterior i dels patis interiors, amb una aïllament ambλ = 0,04 W/m*K i gruix de 12 cm, amb transmitància final de 0,29 W/m2*K. Demolició i execució de nova coberta, amb impermeabilització i aïllament tèrmic ambλ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,34 W/m2*K. I també una contribució d'energies renovables mitjançant una instal·lació fotovoltaica d'autoconsum compartit sobre coberta amb una potència instal·lada de 8,5 kWp i producció anual estimada de 11050 kWh (1300 kWh per cada kWp).

RESULTATS ENERGÈTICS OBTINGUTS

Estat inicial



Estat rehabilitat



Reduction of consumption between 30% and 45%

REHABILITACIÓ ENERGÈTICA D'EDIFICI RESIDENCIAL PLURIFAMILIAR PETIT

DADES DE L'EDIFICI

Ús principal	RESIDENCIAL
Superficie habitable	201,4 m2
Núm. Habitatges	3
Ubicació	LA SOLEDAT SUD
Situació	Aïllat*
Any de construcció	1968

ASPECTES ECONÒMICS

Reducció del consum d'EPNR >30%

Cost de les actuacions	€	42.968,71
Percentatge màxim ajuda		40%
Quantia aplicant % màxim	€	17.187,48
Subvenció màxima per habitatge	€	8.100,00
Quantia aplicant màxims per habitatge	€	24.300,00
Subvenció (Mínim entre % i quantia habitatges)	€	17.187,48
Import a cobrir amb fons propis	€	25.781,23
Import fons propis per habitatge	€	8.593,74

COMPORTAMENT ENERGÈTIC

Qualificació energètica inicial	F	
Consum EPNR inicial	313,1	kWh/m2 i any
Consum EPNR inicial	63058,3	kWh/any
Qualificació energètica rehabilitat		
Consum EPNR rehabilitat	185,06	kWh/m2 i any
Consum EPNR rehabilitat	37271,1	kWh/any
Estalvi energètic anual	128,04	kWh/m2 i any
	25787,3	kWh/any
	40,89%	

CARACTERÍSTIQUES DE L'INTERVENCIÓ

PROPIETATS DE L'ENVOLUPANT

Estat inicial

Umurs exteriors	2,56	W/m2*K
Uparticioinferior	2,17	W/m2*K
Ucoberta	2,17	W/m2*K
Ubuits	3,8	W/m2*K

Buits
Tipus vidre Doble
Tipus marc Alumini

Estat rehabilitat millores >30%

Umurs	0,35	W/m2*K
Uparticioinferior	2,17	W/m2*K
Ucoberta	2,17	W/m2*K
Ubuits	3,8	W/m2*K

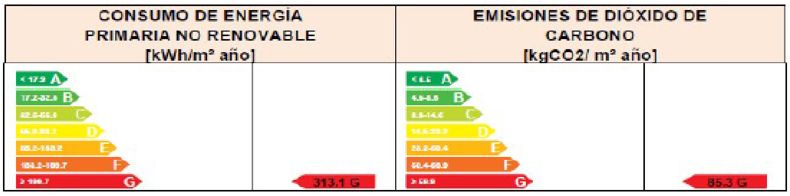
Buits
Tipus vidre Doble
Tipus marc Alumini

DESCRIPCIÓ DE LES ACTUACIONS

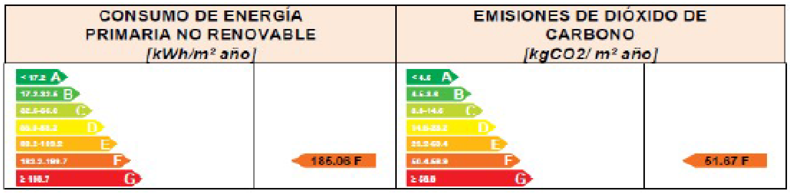
Les obres consisteixen en l'aïllament tèrmic dels murs de façana principal, posterior, laterals i del pati de ventilació, amb una aïllament amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,35 W/m2*K.

RESULTATS ENERGÈTICS OBTINGUTS

Estat inicial



Estat rehabilitat



Reduction of consumption between 45% and 60%

REHABILITACIÓ ENERGÈTICA D'EDIFICI RESIDENCIAL PLURIFAMILIAR PETIT

DADES DE L'EDIFICI

Ús principal	RESIDENCIAL
Superficie habitable	201,4 m2
Núm. Habitatges	3
Ubicació	LA SOLEDAT SUD
Situació	AÏLLAT
Any de construcció	1968

ASPECTES ECONÒMICS

Reducció del consum d'EPNR >45%

Cost de les actuacions	€	71.737,80
Percentatge màxim ajuda		65%
Quantia aplicant % màxim	€	46.629,57
Subvenció màxima per habitatge	€	14.500,00
Quantia aplicant màxims per habitatge	€	43.500,00
Subvenció (Mínim entre % i quantia habitatges)	€	43.500,00
Import a cobrir amb fons propis	€	28.237,80
Import fons propis per habitatge	€	9.412,60

COMPORTAMENT ENERGÈTIC

Qualificació energètica inicial	E	
Consum EPNR inicial	313,1	kWh/m2 i any
Consum EPNR inicial	63058	kWh/any
Qualificació energètica rehabilitat		
Consum EPNR rehabilitat	164,59	kWh/m2 i any
Consum EPNR rehabilitat	33148	kWh/any
Estalvi energètic anual	148,51	kWh/m2 i any
	29910	kWh/any
	47,43%	

CARACTERÍSTIQUES DE L'INTERVENCIÓ

PROPIETATS DE L'ENVOLUPANT

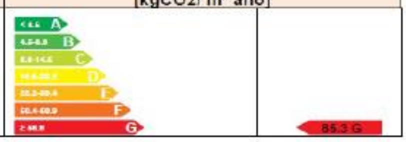
Estat inicial		Estat rehabilitat millores >45%	
Umurs exteriors	2,56 W/m2*K	Umurs	0,35 W/m2*K
Uparticioinferior	2,17 W/m2*K	Uparticioinferior	2,17 W/m2*K
Ucoberta	2,17 W/m2*K	Ucoberta	0,34 W/m2*K
Ubuits	3,8 W/m2*K	Ubuits	1,74 W/m2*K
Buits		Buits	
Tipus vidre	Doble	Tipus vidre	Doble baix emissiu
Tipus marc	Alumini	Tipus marc	PVC

DESCRIPCIÓ DE LES ACTUACIONS

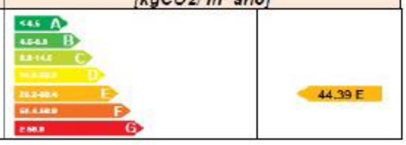
Les obres consisteixen en l'aïllament tèrmic dels murs de façana principal, posterior i dels patis interiors, amb una aïllament amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,35 W/m2*K. Demolició i execució de nova coberta, amb impermeabilització i aïllament tèrmic amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,34 W/m2*K. Adiccionalment es canvien les fusteries exteriors per altres tipus PVC i vidres, amb transmitància post millora de 1,74 W/m2*K.

RESULTATS ENERGÈTICS OBTINGUTS

Estat inicial

CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE [kWh/m² año]	EMISIONES DE DIÓXIDO DE CARBONO [kgCO2/ m² año]
	

Estat rehabilitat

CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE [kWh/m² año]	EMISIONES DE DIÓXIDO DE CARBONO [kgCO2/ m² año]
	

Reduction of consumption of more than 60%

REHABILITACIÓ ENERGÈTICA D'EDIFICI RESIDENCIAL PLURIFAMILIAR PETIT

DADES DE L'EDIFICI

Ús principal	RESIDENCIAL
Superfície habitable	201,4 m2
Núm. Habitatges	3
Ubicació	LA SOLEDAT SUD
Situació	AÏLLAT
Any de construcció	1968

COMPORTAMENT ENERGÈTIC

Qualificació energètica inicial	E
Consum EPNR inicial	313,8 kWh/m2 i any
Consum EPNR inicial	63199 kWh/any
Qualificació energètica rehabilitat	
Consum EPNR rehabilitat	119,08 kWh/m2 i any
Consum EPNR rehabilitat	23983 kWh/any
Estalvi energètic anual	194,72 kWh/m2 i any
	39217 kWh/any
	62,05%

ASPECTES ECONÒMICS

Reducció del consum d'EPNR >60%

Cost de les actuacions	€	76.121,02
Percentatge màxim ajuda		80%
Quantia aplicant % màxim	€	60.896,82
Subvenció màxima per habitatge	€	21.400,00
Quantia aplicant màxims per habitatge	€	64.200,00
Subvenció (Mínim entre % i quantia habitatges)	€	60.896,82
Import a cobrir amb fons propis	€	15.224,20
Import fons propis per habitatge	€	5.074,73

CARACTERÍSTIQUES DE L'INTERVENCIÓ

PROPIETATS DE L'ENVOLUPANT

Estat inicial		**Estat rehabilitat millores >60%**	
Umurs exteriors	2,56 W/m2*K	Umurs	0,35 W/m2*K
Uparticioinferior	2,17 W/m2*K	Uparticioinferior	2,17 W/m2*K
Ucoberta	2,17 W/m2*K	Ucoberta	0,34 W/m2*K
Ubuits	3,8 W/m2*K	Ubuits	1,74 W/m2*K
Buits		Buits	
Tipus vidre	Doble	Tipus vidre	Doble baix emissiu
Tipus marc	Alumini	Tipus marc	PVC

DESCRIPCIÓ DE LES ACTUACIONS

Les obres consisteixen en l'aïllament tèrmic dels murs de façana principal, posterior i dels patis interiors, amb una aïllament amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,35 W/m2*K. Demolició i execució de nova coberta, amb impermeabilització i aïllament tèrmic amb λ = 0,04 W/m*K i gruix de 10 cm, amb transmitància final de 0,35 W/m2*K. Adiccionalment es canvien les fusteries exteriors per altres tipus PVC i vidres, amb transmitància post millora de 1,74 W/m2*K. I també una contribució d'energies renovables mitjançant una instal·lació fotovoltaica d'autoconsum compartit sobre coberta amb una potència instal·lada de 2 kWp i producció anual estimada de 2600 kWh (1300 kWh per cada kWp).

RESULTATS ENERGÈTICS OBTINGUTS

Estat inicial

Estat rehabilitat

PARTNER LOGOS

WWW.GREENDEAL-ARV.EU