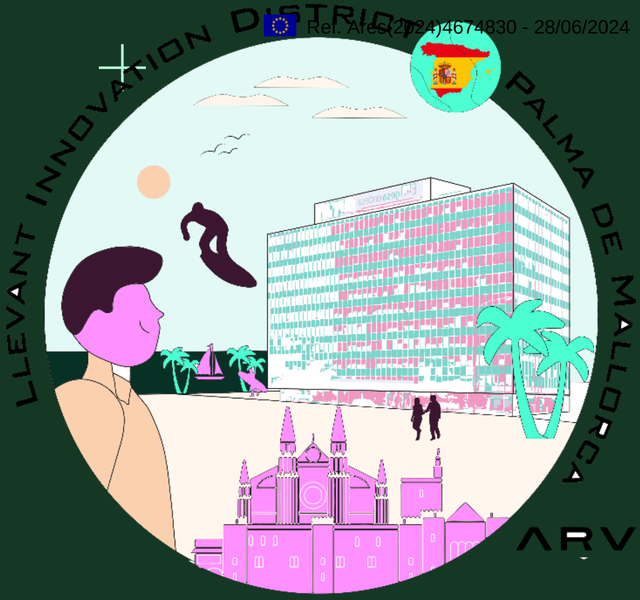
ARV

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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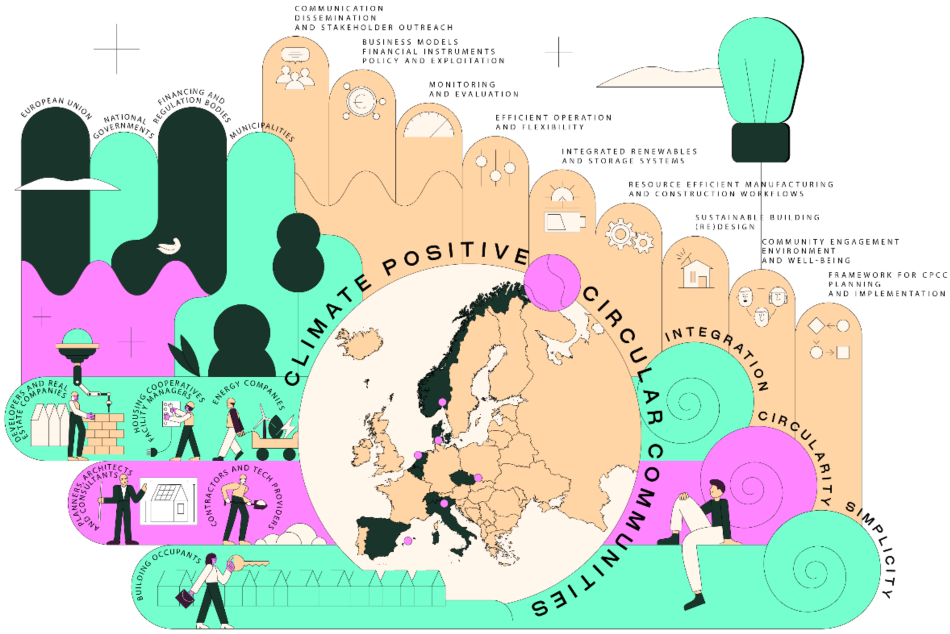
ABOUT THE ARV PROJECT

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.

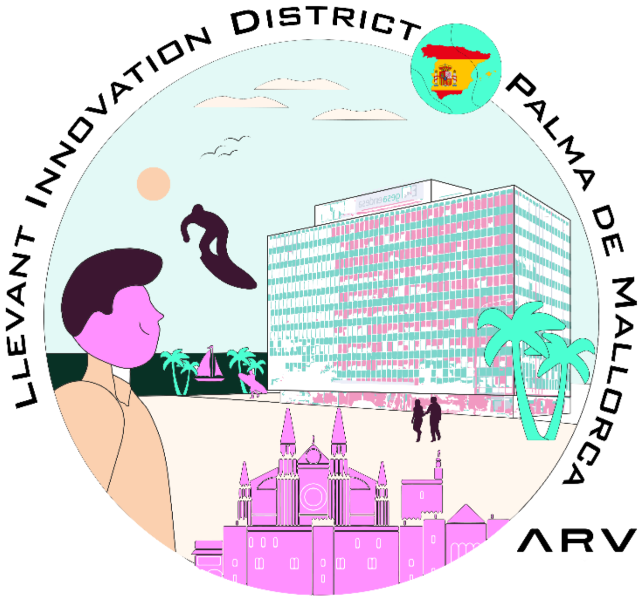
EXECUTIVE SUMMARY

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 considering 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 dwellings by means of a novel Public-Private-Partnership.
- New positive energy social housing building with 35 apartments.
- Energy Renovation of a flagship heritage protected building from the 70's modern movement.



Design and evaluation process is 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.

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 35 apartments.
- Energy Renovation of a flagship heritage protected building from the 70's modern movement (GESA Building)

This report is dedicated to documenting the planning and design 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, energy and economical calculations and reporting. First version of this report was released in December 2022. A final revision (December 2024) will describe and report further indicators and complete the analysis. The current version updates the first version of the report. Main changes can be summarized as follows:

- For the retrofitting analysis, the economic and energy performance analysis has been extended to two new archetypes buildings in the district. A Life-Cycle Analysis (LCA) has been introduced to compare low-carbon footprint constructive solutions against conventional ones
- Design description of the new social housing by IBAVI has been updated and a LCA is described
- A complete analysis of design options for active systems, including economic impact has been added to the analysis of the renovation of the GESA Building.

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

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 35 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 or GESA Building) 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, in 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 ceilings and tile 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.

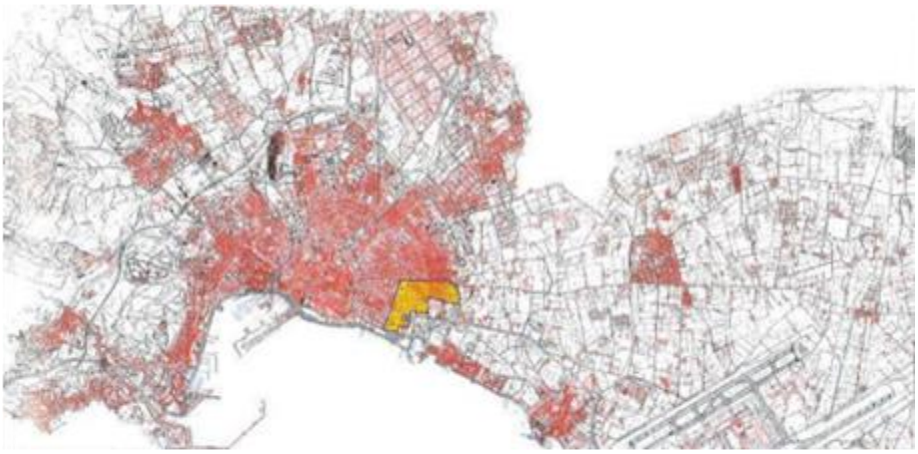


Figure 5. *"La Soledat" and "Polígono de Levante" in the city. Adopted from [3].*

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 "**Consell 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 Llevant Inovation District.

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

Medium term (2022-26)

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"

"Es Laboratori" Living Lab 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 (2026-34)

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 audiovisual sector, cultural creation and dissemination. In this sense, the attraction of talent related to audiovisual 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 re-parcelling 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.**

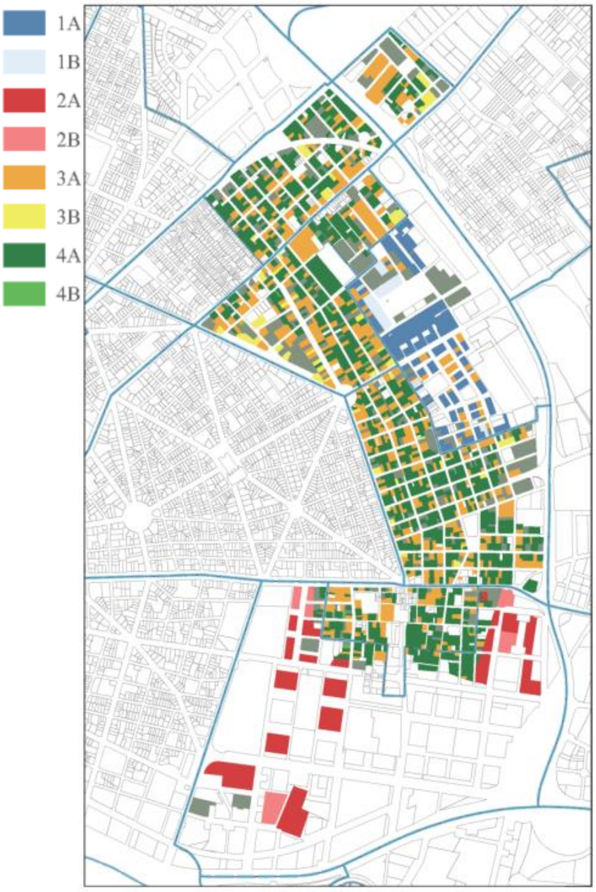
Therefore, the main objective in the large-scale renovation of existing buildings is to reduce the energy consumption of houses to at least 30% of non-renewable primary energy consumption, referring to the Energy Performance Certificate (EPC). For residential buildings, this goal can be achieved by improving 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**.

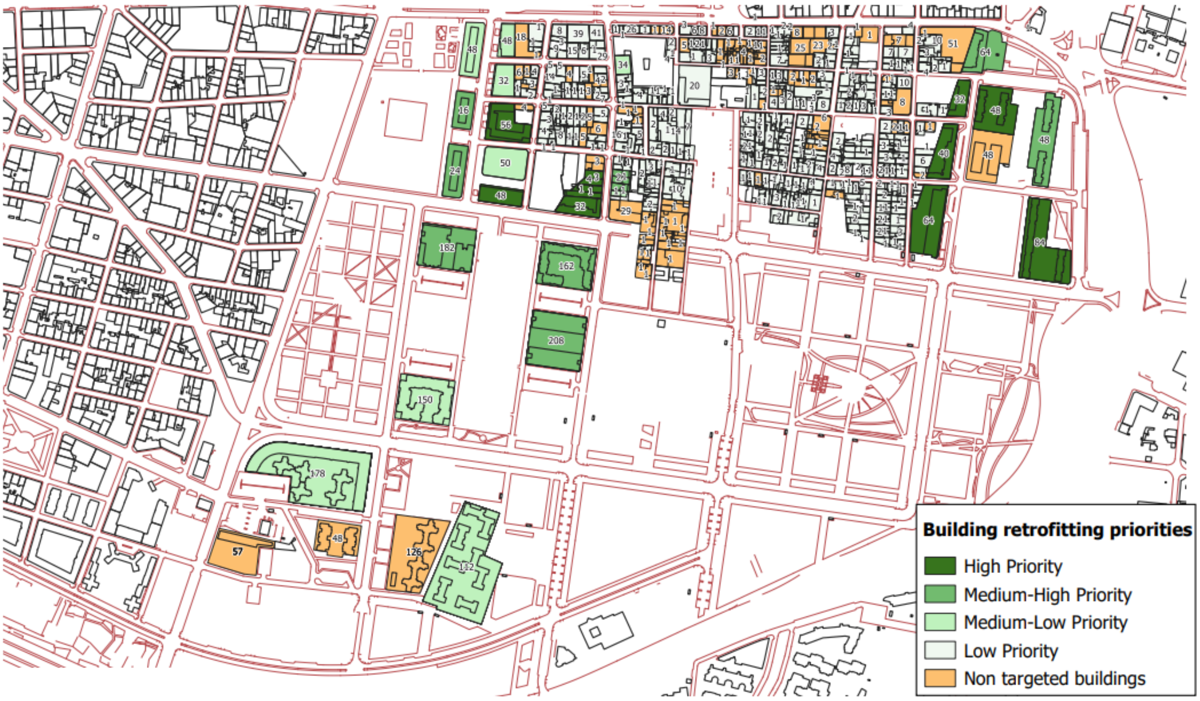
Figure 12. *Building codes according to assignment in ERRP document.*

Two areas can be clearly identified: one centered on "La 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 "La Soledad" 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 *rehabilitation agent* through a public-private cooperation model based on a single public tender where a private company is selected to promote and support citizens in the retrofitting journey of their buildings. Preliminary concept of the PPP mechanism is depicted in **Figure 14**.

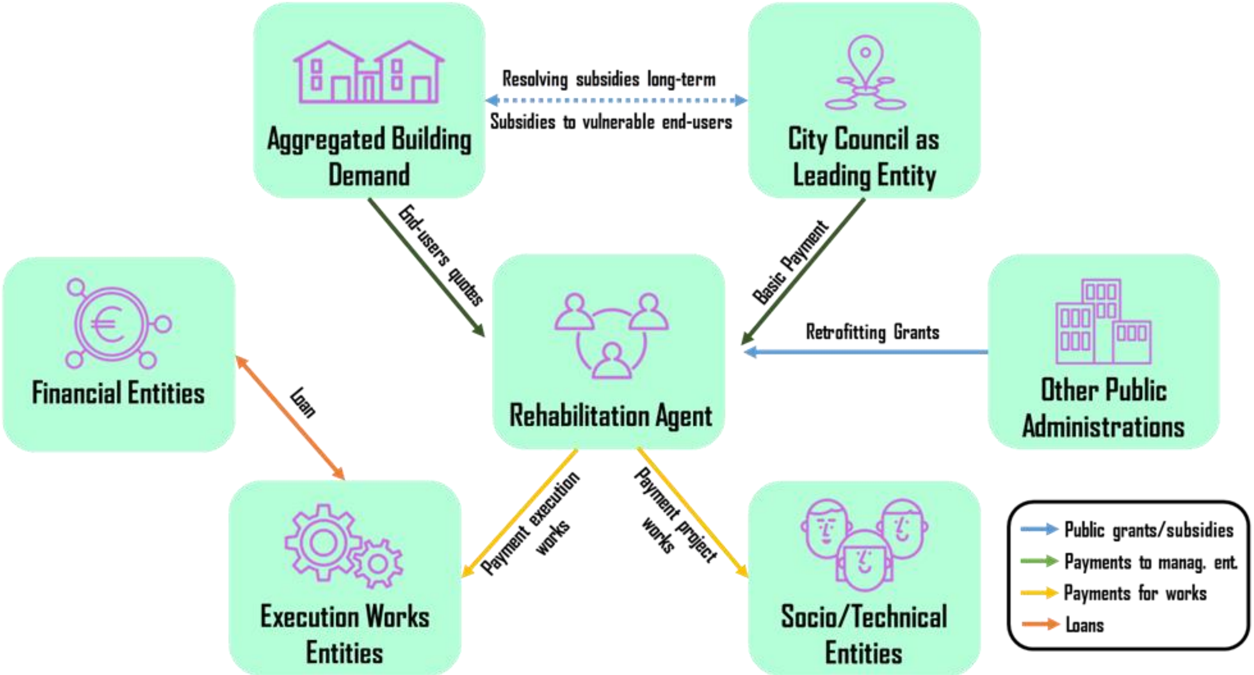


Figure 14. *Monetary and financial fluxes for the PPP model. Adopted from [5].*

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.

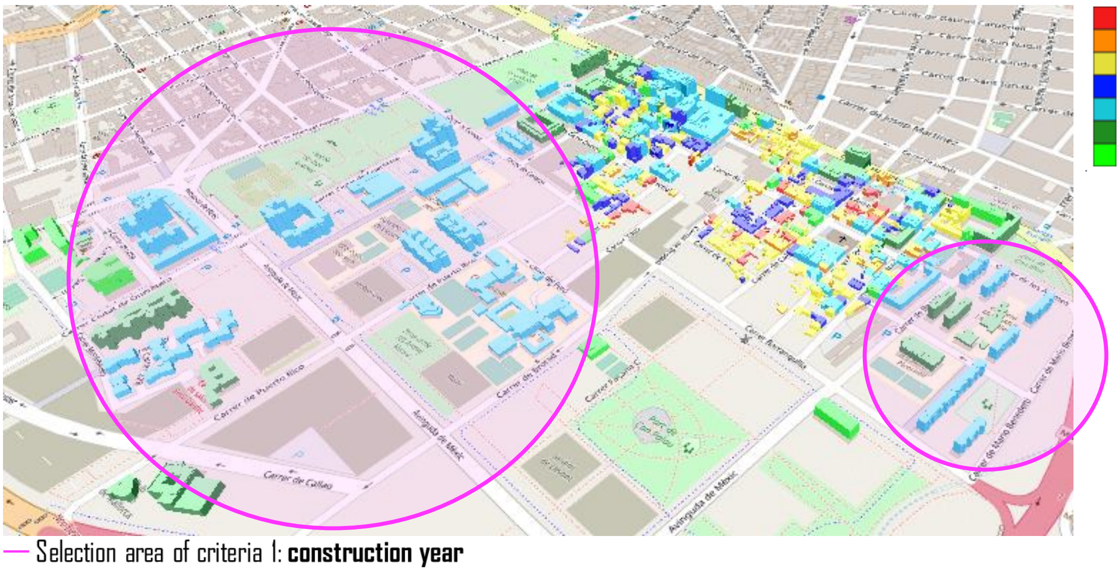


Figure 15. *A map of the selected area with different colour codes for the buildings based on the construction year.*

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

The second criteria 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
Medium 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.

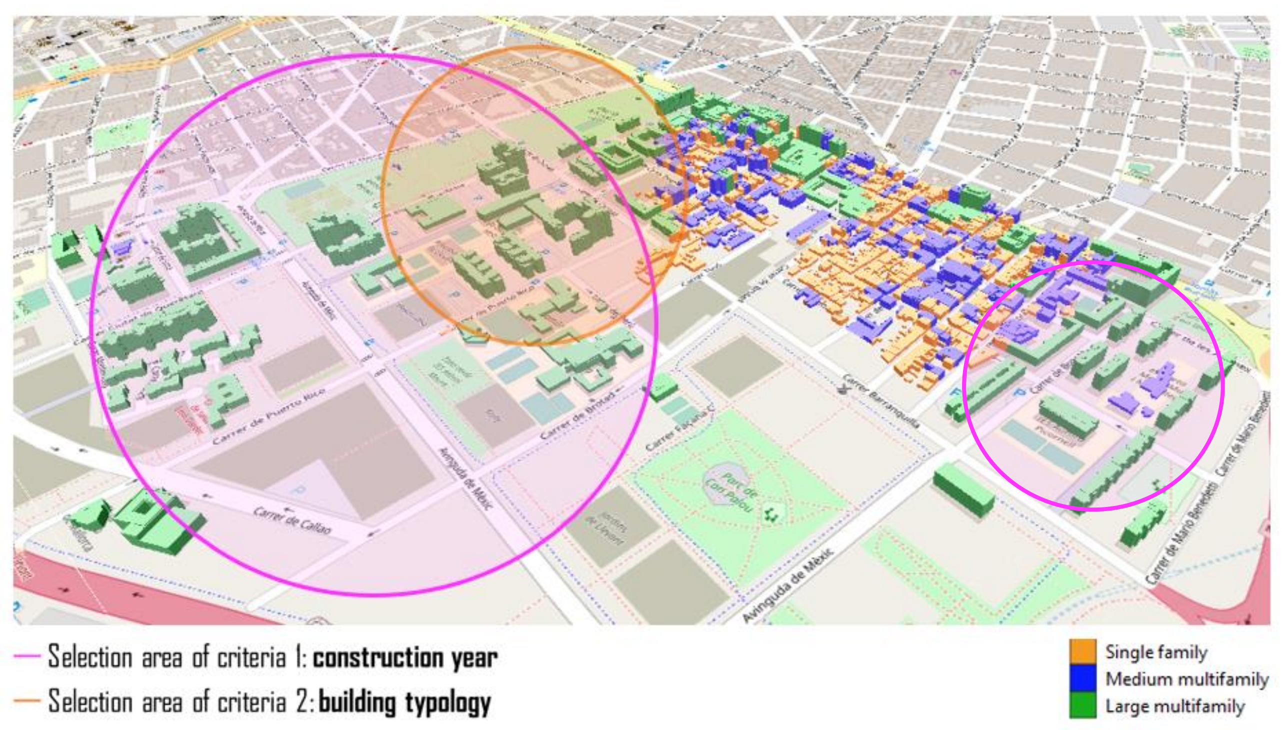


Figure 16. *A map of the selected area with different colour codes for the buildings based on the construction year (criteria 1) and building typology (criteria 2).*

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

As a result, the selected building archetypes 1 and 2 are located in the intersection of the areas with the following criteria: construction years in the period of 1961-1980 and to be representative typologies in the priority area, which are defined as: a large multifamily and a medium multifamily buildings**. Figure 17** and **Figure 18** show two first building archetypes that were chosen for the detailed analysis:

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

The two selected archetypes have a high building retrofitting priority, based on the priority area defined by the Palma City Council (**Figure 13**). At the same time, retrofitting multifamily dwellings will facilitate the achievement of large-scale retrofitting of 250 dwellings, which is a goal of the Action 1. However, in order to get a complete picture of the neighbourhood, two other archetypes typical of the area were also selected for analysis.

Archetype 3 and Archetype 4 are very small multifamily building (two dwellings) or single family housed constructed typically before 1940 and can be described as the traditional building types of the neighbourhood. These buildings has a low retrofitting priority according to **Figure 13**.

- **Archetype 3:** Small multifamily building – code 4A (**Figure 19**).
- **Archetype 4:** Single-family building – code 4A (**Figure 20**).

Figure 19. *Selected building archetype: small multifamily building 4A (Carrer de Siquier, 20).*

Figure 20. *Selected building archetype: single-family building 4A (Carrer de la Fe, 35).*

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 21**), obtaining the resident owners, the non-resident owners and the legal entities of priority areas according to **Figure 13**.

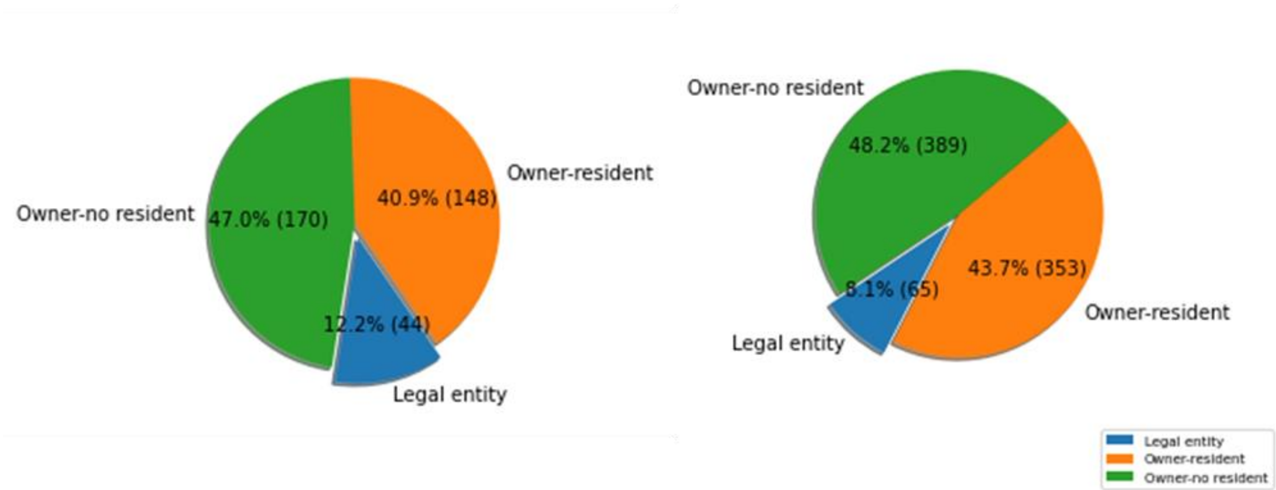


Figure 21. *Pie chart with the distribution of high priority (left) and medium-high priority area (right) of the typology of owners.*

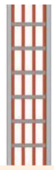
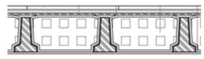
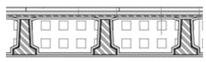
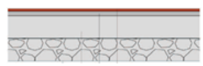
It is expected that the legal entities are open to the retrofitting process because the value of the houses would increase, together with the owners that are living within the buildings. Therefore, in the case of high priority area we obtain 53.1% of owners who could be more open for retrofitting and 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 (Archetype 1).

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 22**).

Figure 22. *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 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 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.

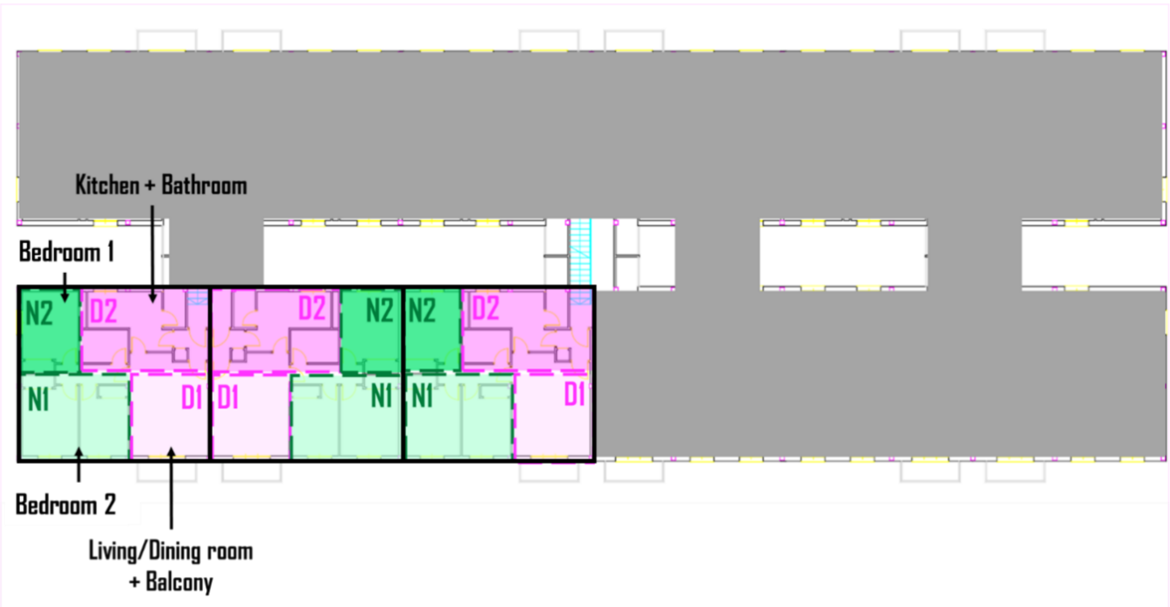


Figure 23. *The internal distribution of the floor with thermal zones proposal (Archetype 1).*

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 representative building type in the area of La Soledat Sud. 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 24**.

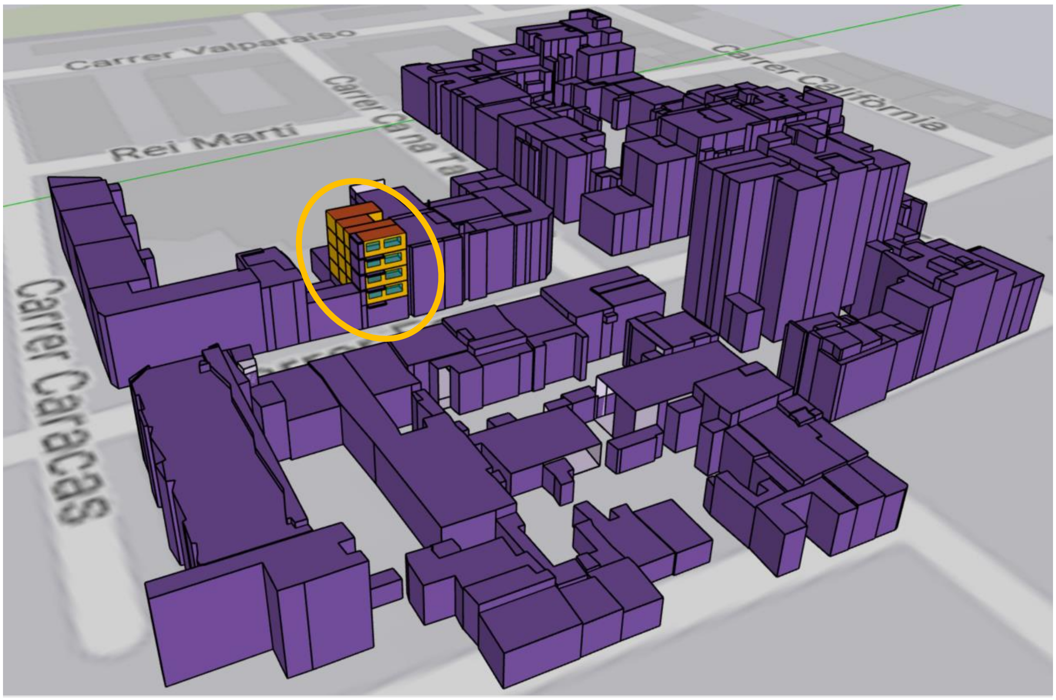


Figure 24. *The building model with nearby buildings (Archetype 2).*

The internal distribution of the floor is presented in **Figure 25**. 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.

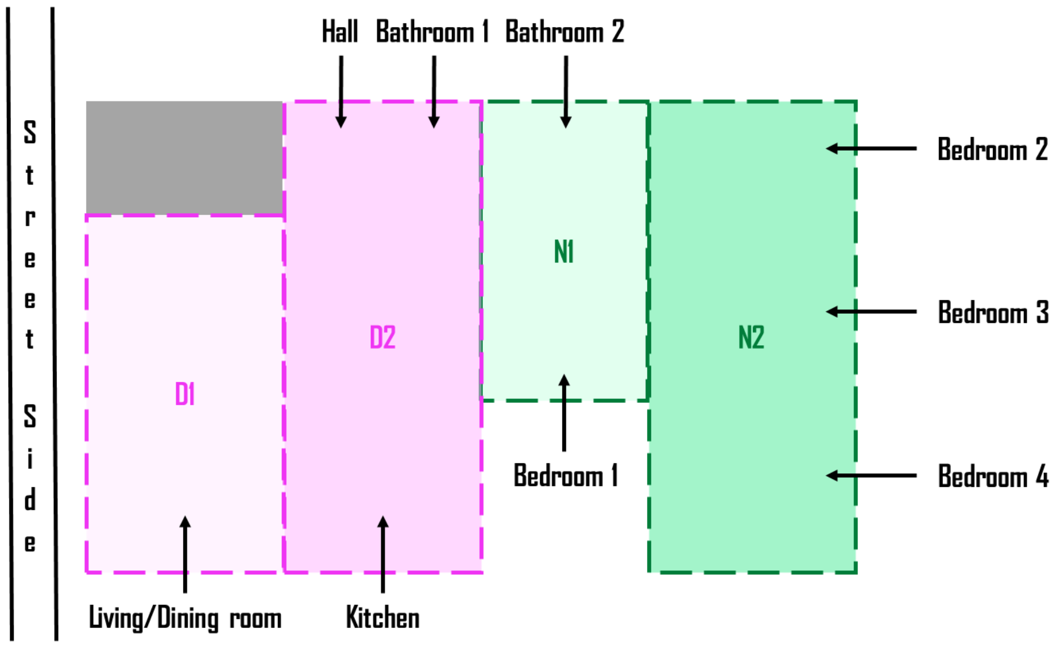


Figure 25. *The internal distribution of the floor with thermal zones proposal (Archetype 2).*

4.1.3. DESCRIPTION OF SMALL MULTIFAMILY BUILDING ARCHETYPE

The third typology selected for sustainable design is a small multifamily building at Carrer de Siquier, 20 (**Figure 19**), which is another representative building type in the area of La Soledat Sud. It is a two-storey building, where each floor consists of a one apartment. The apartment on the first floor consists of two bedrooms, a hall, a garage, two living rooms, a dining room, a kitchen, a bathroom and a laundry room. The apartment on the second floor consists of two bedrooms, a bathroom, a living room, a hall, a dining room, a kitchen and a laundry room. 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.

The building was constructed before 1980 (the national cadastre records it by 1940), when energy regulations for buildings were absent. Therefore, buildings from this construction period can be characterised by minimal thermal performance requirements for the building envelope, non-efficient cooling and heating systems, old windows and other high-consuming energy features. The description of the structural elements of the building such as walls, floors, windows and ceilings are summarised in **Table 5**.

Table 5. *The description of the structural elements of the building (Archetype 3).*

Element	Layers	Thickness [m]	U-value [W/m²K]
External walls - Façade	Exterior coating	0.02	2.545
	Marés stone wall	0.25	
	Interior coating	0.01	
Ceiling Slab	Terrazzo pavement	0.03	1.591
	Cement mortar	0.02	
	Unidirectional slab	0.2	

	Interior coating	0.02	
External walls – Party wall	Marés stone wall	0.25	2.703
	Interior coating	0.01	
Internal walls	Interior coating	0.01	2.052
	Ceramic masonry brick wall	0.14	
	Interior coating	0.01	
Roof	Ceramic roof tile	0.06	1.227
	Unidirectional slab with ceramic vault (Volta catalana)	0.2	
	Air chamber	0.5	
	Plaster ceiling	0.02	
Ground floor	Ceramic floor	0.01	1.142
	Cement mortar	0.01	
	Compacted backfill	0.4	
Windows (back and front facade)	Glass: single glass (6 mm)	0.006	5.73
	Frame: wood no thermal break	-	

The energy simulations of the building with impacts of shading effects from nearby buildings is presented in **Figure 26**.

Figure 26. *The building model with a shading effect from nearby buildings (Archetype 3).*

The internal distribution of the ground and the first flour are presented in **Figure 27** and **Figure 28** respectively. Each dwelling has one day and one night zone, which consists of different rooms for each of the flours.

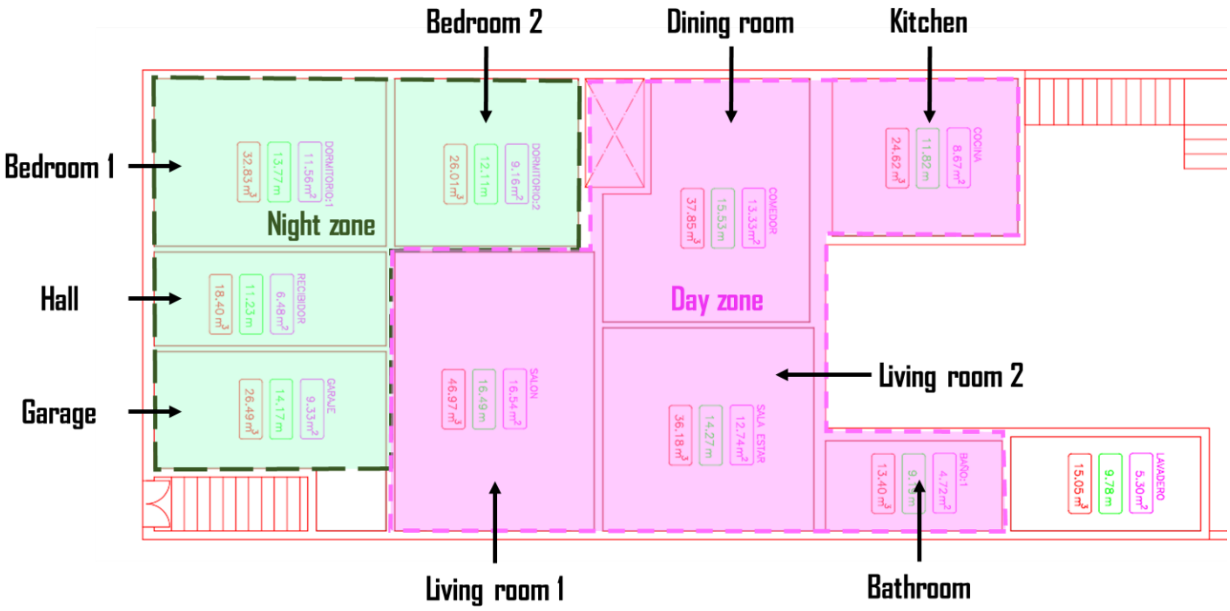


__Figure 27.__ The internal distribution of the ground floor with thermal zones proposal (Archetype 3).

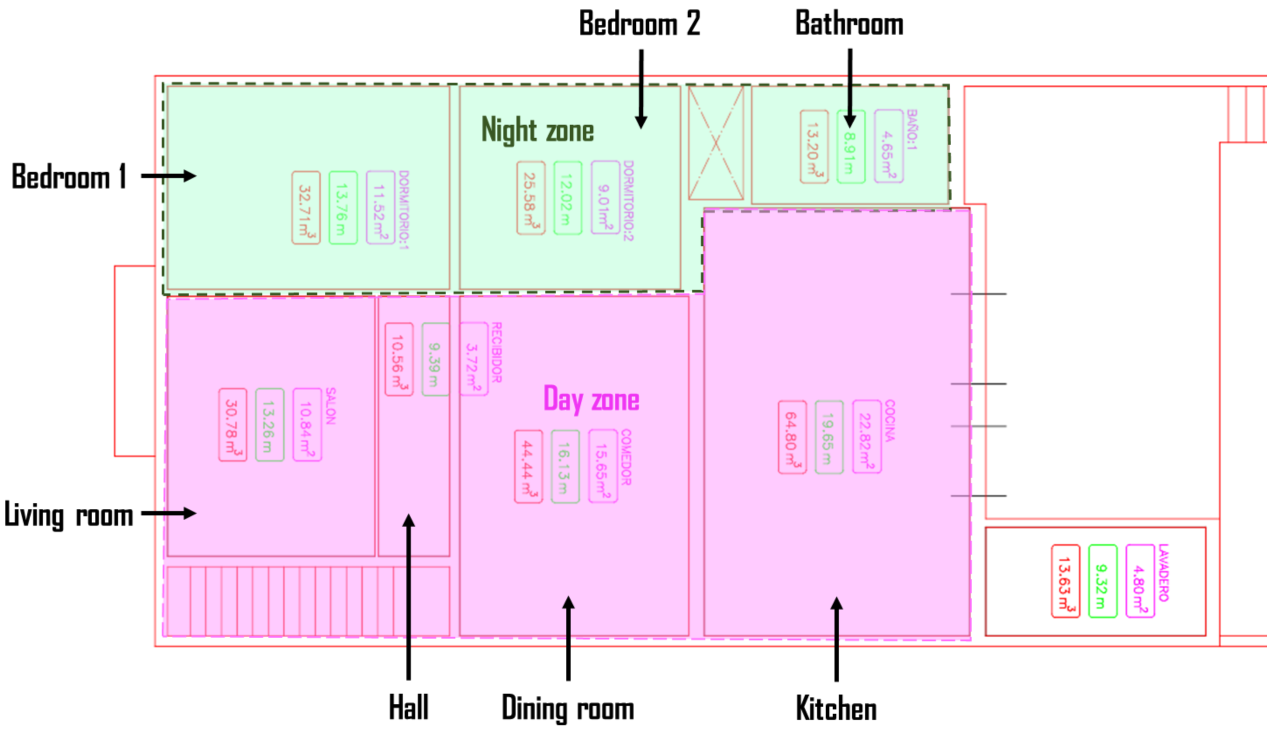


__Figure 28.__ The internal distribution of the first floor with thermal zones proposal (Archetype 3).

4.1.4. DESCRIPTION OF SINGLE-FAMILY BUILDING ARCHETYPE

The fourth typology selected for sustainable design is a a single-family building at Carrer de la Fe, 35 (**Figure 20**), which is another representative building type in the area of La Soledat Sud. It is a one-storey building, where the complete floor surface is a single-family house. The single-family house consists of two bedrooms, two bathrooms, a hall, a dining room, a storage room, and a kitchen with a living room. The main façade connecting the building to the street faces northwest and another main façade faces other buildings to the southeast. The side façades face southwest and northeast respectively.

Similar to Archetype 3 typology, the building was constructed before 1980 (the national cadastre records it by 1910) and is characterized with the similar materials presented in **Table 5**,which are the ones used in traditional architecture in Mallorca The energy simulations of the building with impacts of shading effects from nearby buildings is presented in **Figure 29**.

Figure 29. *The building model with a shading effect from nearby buildings (Archetype 4).*

The internal distribution of the floor is presented in **Figure 30**. Distribution of day and night zones is proposed as following: the single-family house has one night zone with two bedrooms and a hall, and one day zone, which consists of a dining room, a storage room, two bathrooms and a kitchen with a living room.

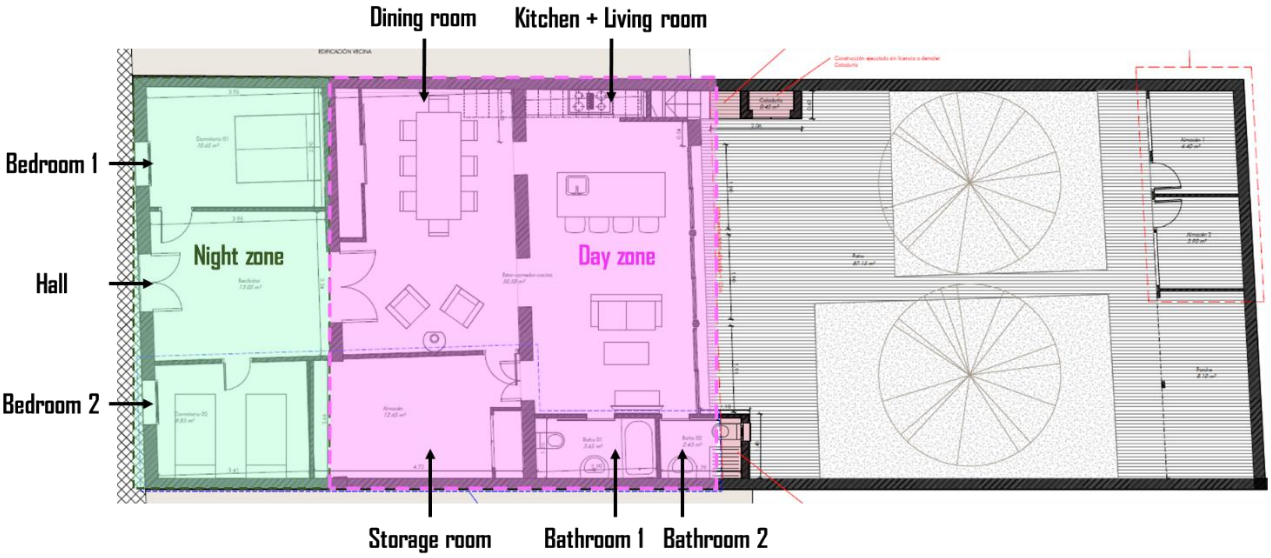


__Figure 30.__ The internal distribution of the floor with thermal zones proposal (Archetype 4).

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 31**), starting from acting in the design phase by integrating passive measures to implementing Renewable Energy Systems (RES).

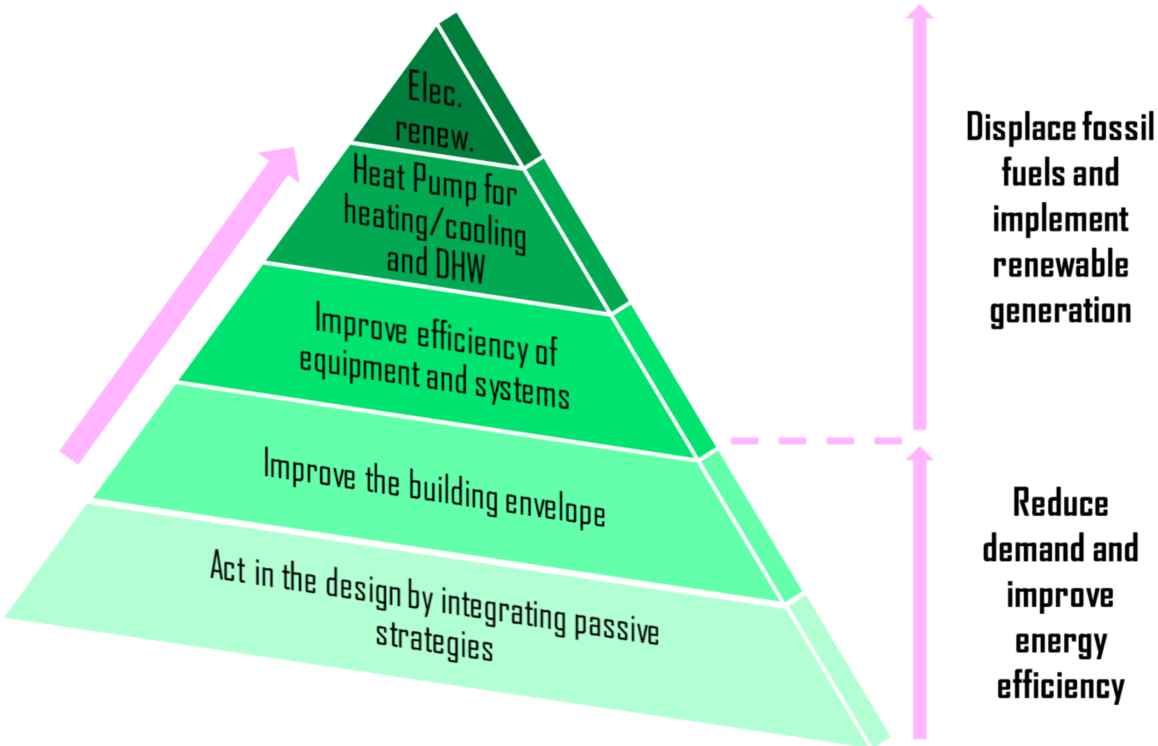


__Figure 31.__ The integrated energy design process strategy.

Therefore, the integrated energy design process of the buildings 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 for archetypes 1 and 2 and the whole building simulation for archetypes 3 and 4, 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, although only selected results are reported here.

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. More energy aware occupant behaviour, also incorporating vernacular attitudes, could lead to reduced energy consumption and/or better indoor thermal conditions, particularly in summer.

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), Polyvinyl Chloride (PVC) and rock wool.
- The low environmental impact solution based on the use of the local eco materials such as expanded cork, pinewood, Graphite EPS, lime insulating mortar, and recycled insulating mortar.

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 highly efficient solutions and displacing the use of fuel-fossil based solutions using natural gas or butane.

The conceptual scheme of applied packages of passive measures for archetypes 1 and 2 is demonstrated in **Figure 32** and for archetypes 3 and 4 in **Figure 33**.

For some of the building elements, several options for conventional and/or ecological retrofitting materials were tested. In this case, the following code was used for these options: PX.X.X, where:

- The first number indicates whether the windows are changed (1 is not changed and 2 is changed).
- The second number indicates whether the option is conventional (1) or ecological (2).
- The third number indicates the material option according to the internal list of materials.

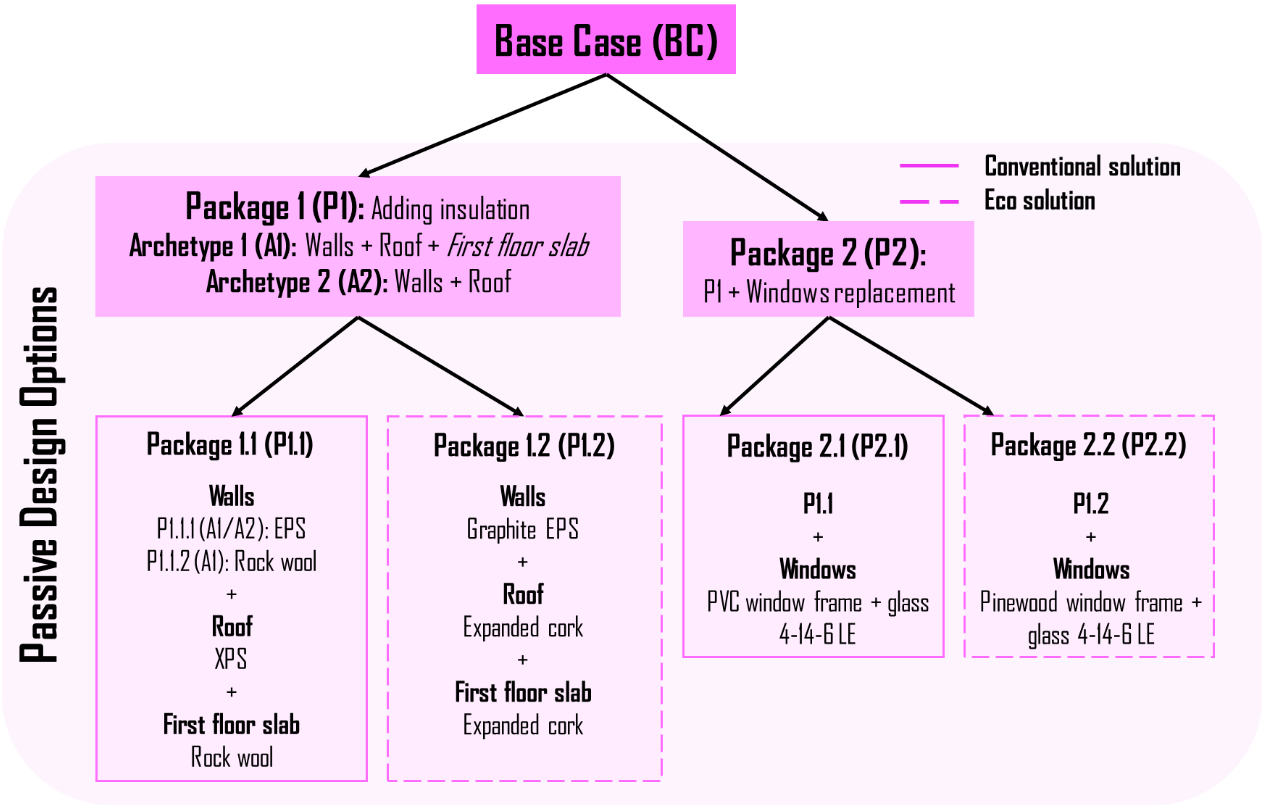


Figure 32. *Passive measures packages for Archetypes 1 and 2.*

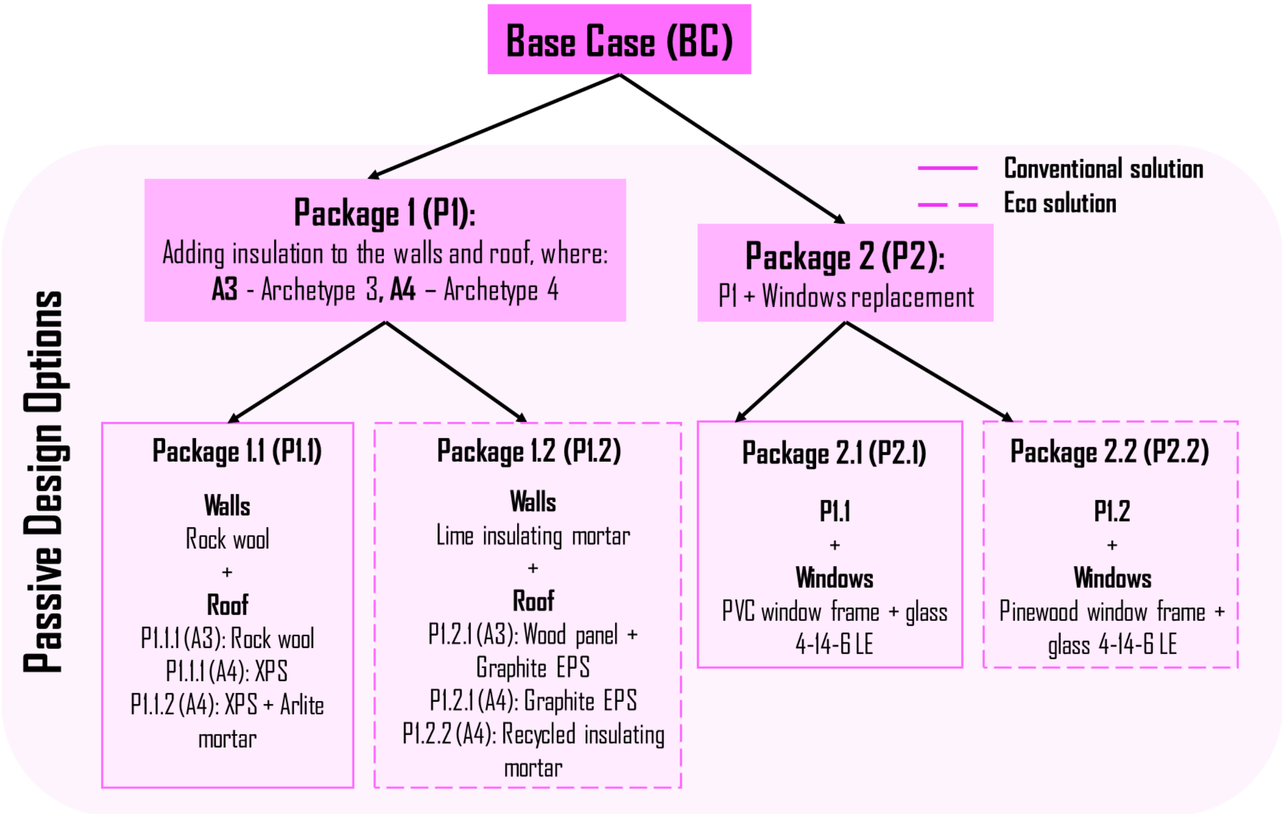


Figure 33. *Passive measures packages for Archetypes 3 and 4.*

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
	Walls - Rock wool	0.08
	Roof - XPS	0.06 / 0.08 / 0.1 / 0.12 / 0.14
	Roof – Rock wool	0.08
	First floor slab – Rock wool	0.06 / 0.08
Eco	Walls – EPS local	0.06 / 0.08 / 0.1 / 0.12 / 0.14
	Walls – Lime insulating mortar	0.06 / 0.08
	Roof – Natural expanded cork	0.06 / 0.08 / 0.1 / 0.12 / 0.14
	Roof - Graphite EPS	0.1
	Roof - Recycled insulating mortar	0.1
	Roof - Wood panel + Graphite EPS	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/m²)	Glass configuration	U_value (W/m²)
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, some of the simulations will be chosen 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 and heating systems of the houses/dwellings for high efficiency 3x1 multi-splits.

2. Implementation of PV systems in building roofs.
3. Change of the DHW equipment, typically gas or butane boilers or electrical DHW tanks, for heat pumps.

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 **Energy Performance Analysis** section (4.3.1) with the results of the analysis.

4.3. PERFORMANCE ANALYSIS

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. The conceptual scheme of the performance analysis is illustrated in **Figure 34.**

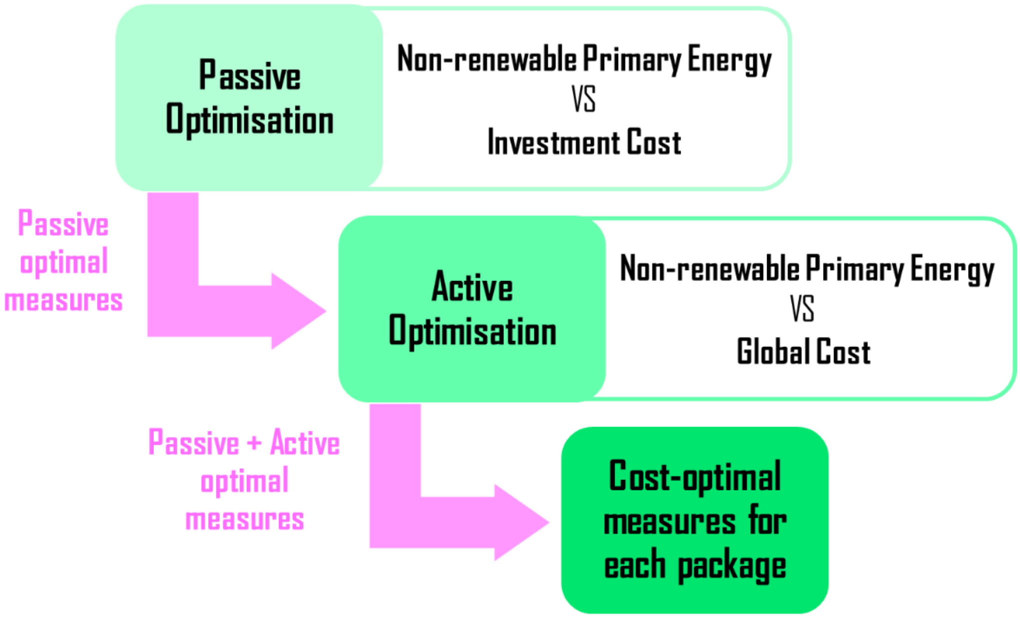


Figure 34. *The conceptual scheme adopted for the integrated energy design.*

4.3.1. ENERGY PERFORMANCE ANALYSIS

The main objective of this part 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 additional reduction of non-renewable primary energy.

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**. It should be noted that, for the calculation purposes and according to the Spanish building technical code, when no system is present equivalent performance of gas boilers and air conditioning split are considered for heating/DHW and cooling, respectively.

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	35%	1
	Heat pump	28%	2 [7]
	Natural gas boiler	15%	0.7 [8]
	Butane	15%	0.7
	No system	7%	0.7 [7]
Cooling	Heat pump	26.5%	2 [7]
	Split	6%	2 [7]
	Multi-split	2.5%	2 [7]
	No system	65%	2 [7]
DHW	Natural gas boiler	64%	0.7
	Butane	10%	0.7
	Joule	26%	1

Figure 35, **Figure 36**, **Figure 37** and **Figure 38** show the heating and cooling demands (left y-axe) and the non-renewable primary energy (including heating, cooling, DHW – right y-axe) for the actual orientation of the building and selected specific scenarios based on TRNSYS calculations. The results represent weighted average values for all the dwellings in the buildings. The specific insulation thicknesses for each archetype are:

- Archetype 1 and 2 (Caracas 1 and Fe 36): Wall insulation thickness 6cm and roof insulation thickness 8 cm (W6-R8).
- Archetype 3 (Siquier 20): Wall insulation thickness 8 cm and roof insulation thickness 8 cm (W8-R8).
- Archetype 4 (Fe 35): Wall insulation thickness 8 cm and roof insulation thickness 10 cm (W8-R10).

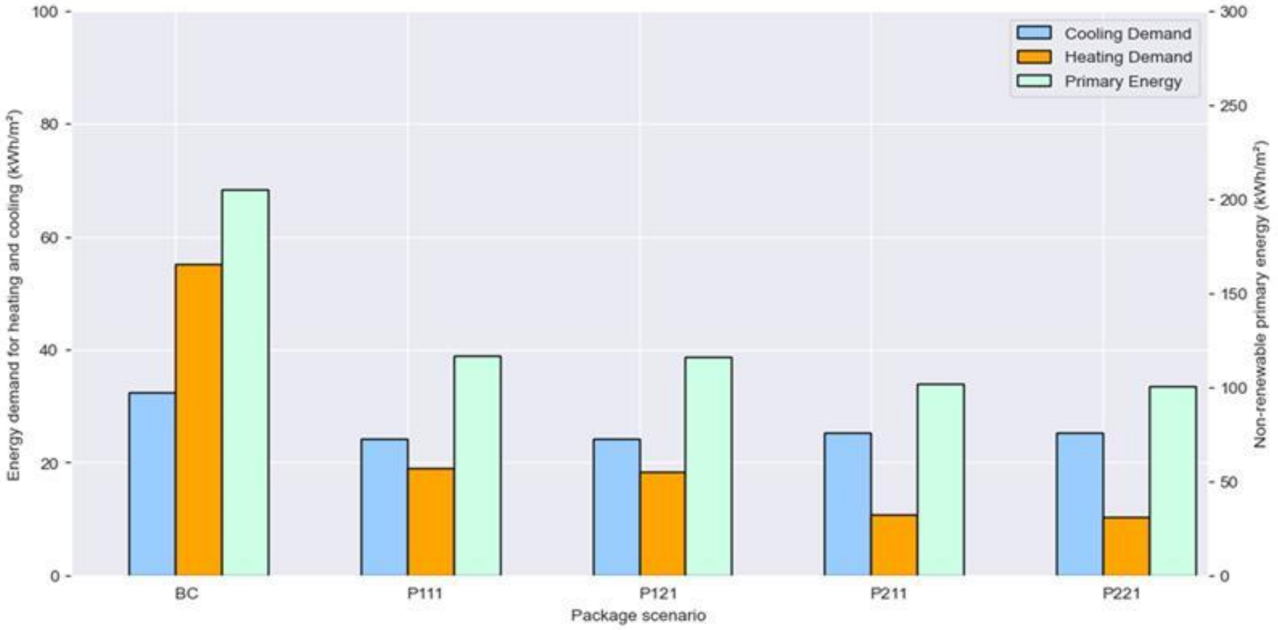


Figure 35*. Heating and cooling energy demands and non-renewable primary energy in the analysed scenarios (W6-R8) (Archetype 1).*

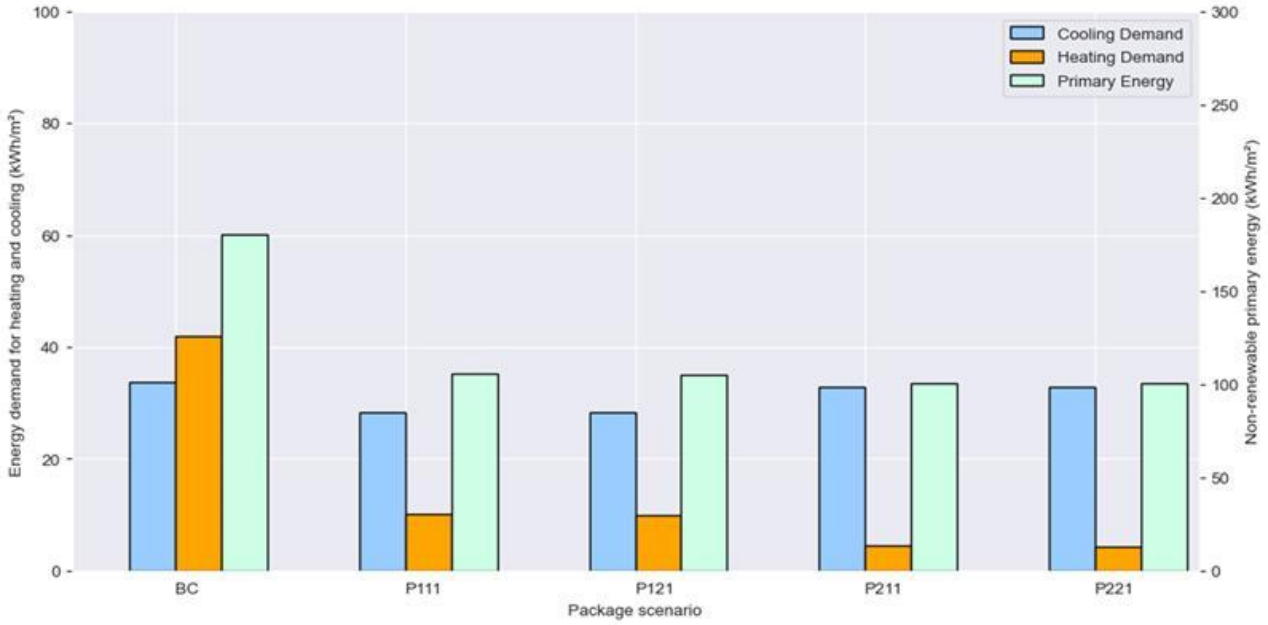


Figure 36*. Heating and cooling energy demand and non-renewable primary energy in the analysed scenarios (W6-R8) (Archetype 2).*

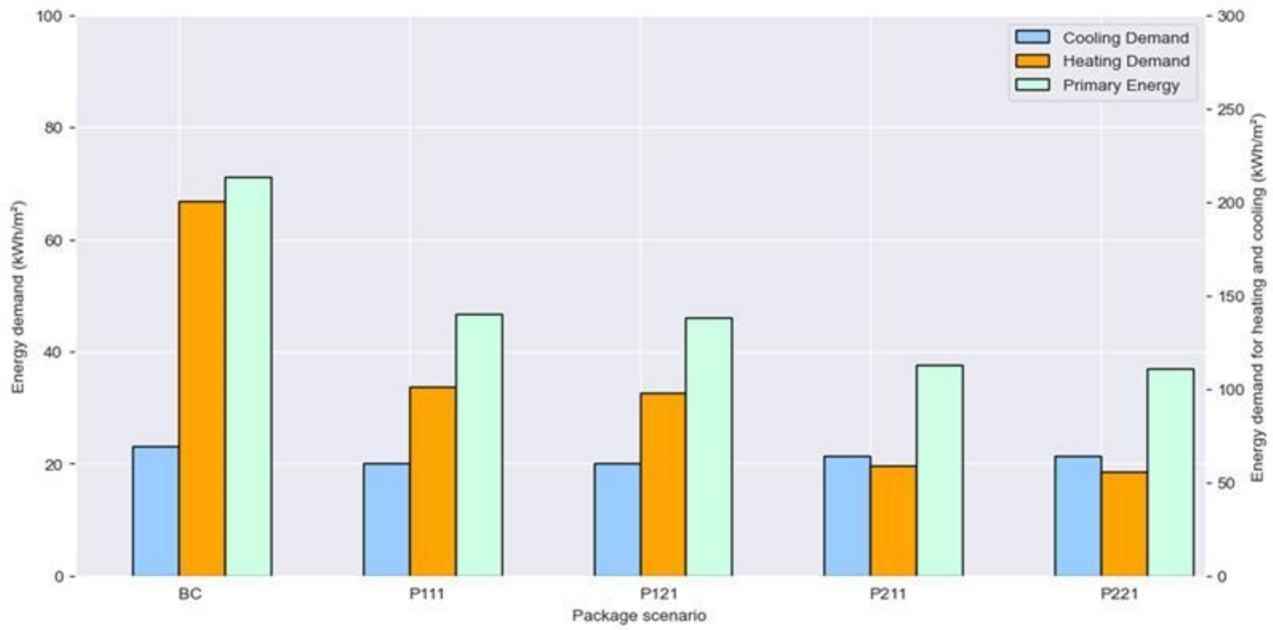


Figure 37. *Heating and cooling energy demands and non-renewable primary energy in the scenarios analysed (W8-R8) (Archetype 3).*

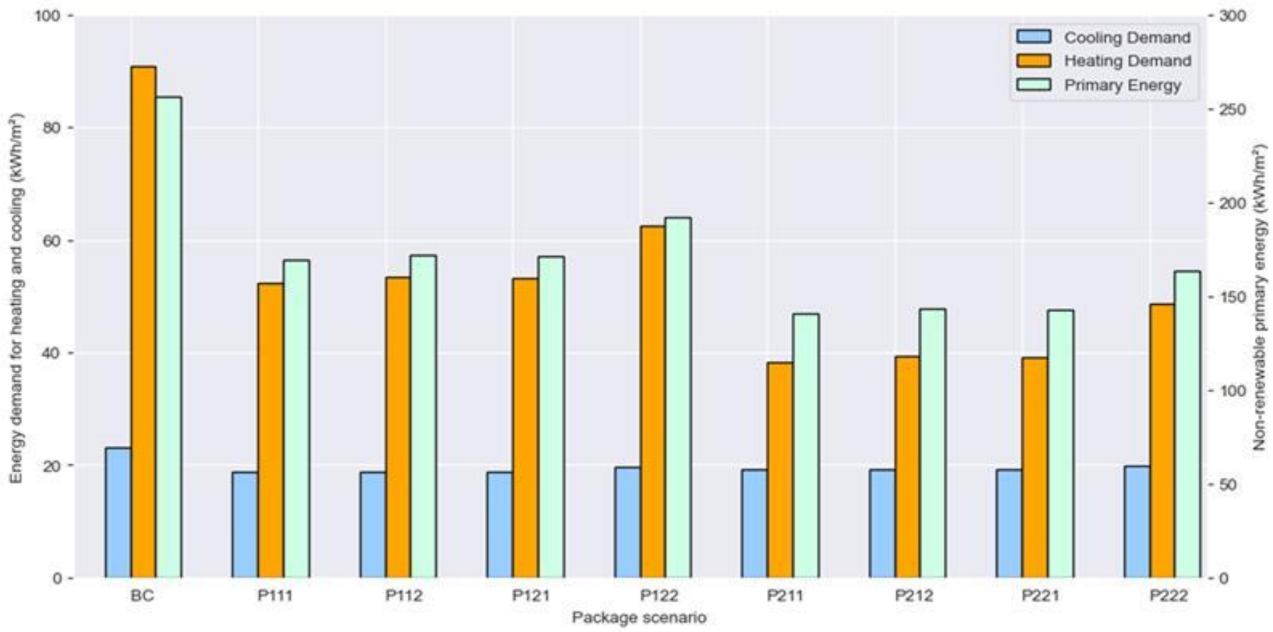


Figure 38. *Heating and cooling energy demand and non-renewable primary energy in the scenarios analysed (W8-R10) (Archetype 4).*

The heating demand in non-renovated scenarios for all the archetypes range from 42 to 91 kWh/m^2, these demands are, in some cases, not covered by the tenants of the dwellings, thus affecting the decrease in comfort. When renovating the building envelope the heating demands decreases significantly, reaching values below 20 kWh/m^2, for Archetypes 1, 2 and 3, and below 40 kWh/m^2 for Archetype 4 when windows are also renovated. Range for the reduction of heating demands is between 42 and 85%. More reduction can be achieved with package 2, where the windows are renewed, making the building more airtight, so reducing infiltration. However, there is not a significant change when comparing the demands of conventional and ecological packages, as the physical characteristics of that solutions are quite similar independently of the origin of the materials.

On the other hand, cooling demand behaves differently. The retrofitting packages are designed to decrease the heating demand, but no additional measures are considered in order to decrease the cooling demand besides night cooling and basic use of solar protections in summer. So an excessive insulation can cause overheating in the cooling seasons in the Mediterranean climates, as can be observed for package 2 (windows renewal). As a consideration, natural ventilation is a common practice in the dwellings at night, therefore, a better building envelope or more airtight windows might not cause a significant effective decrease in demand as the dwellings are ventilated almost every night, as a common users' behaviour 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.

The overall primary energy does not reduce at the same pace as heating/cooling demands due to the fact that domestic hot water remains constant for all the passive measures. The reduction of non-renewable primary energy of the different analysed retrofitted packages for the selected scenarios ranges from 34-53%. All demands and non-renewable primary energy can be found in **Appendix H – Detailed data for energy calculations for energy retrofitting packages.**

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 a crucial aspect become important. The final payments to the owners must be reasonable in order to be able to carry out the refurbishment. This should consider the construction costs (PEM – from the Spanish *"Presupuesto de Ejecución Material"*) plus additional costs, project and management fees and taxes.

Investment calculation

For the calculation of the total investment, the parameters in **Table 8** and

Table 9 have been considered. The detailed prices for all materials can be found in **Appendix E – Detailed data for economical calculations for Large Scale Retrofitting actions .**

Table 8. *Economic parameters for calculating total investment*

Concept	Value over PEM without VAT (%)
Material execution budget (PEM without VAT)	-
General costs	9%
Industrial profit	6%
Project fees	2%
Technical direction fees	4%

Table 9. Taxes applied to the different parts of the project

Concept	Value (%)
VA Tax over PEM+ General costs + Industrial profit	10%
VA Tax over Project fees + Technical direction fees + Project management	21%

Project management costs are incorporated into economic calculations as a fixed cost of €400 per dwelling, augmented by a factor of 1.4 to account for overhead costs and the industrial benefit associated with the operational expenses of the project management entity.

For the calculation of the surface areas, the generated 3D models (**Figure 22** and **Figure 24**) have been used together with the information from the cadastre. To obtain the value of PEM the quotation by multiplying the unit costs by the surface areas. For every building, the floor, roof and wall area are selected to determine the specific surface to be retrofitted and multiplied by every scenario cost per sqm. The results of the operation can be seen in detail in Appendix E – Detailed data for economical calculations for Large Scale Retrofitting actions, the global cost accounts for the corresponding taxes.

Table 10, **Table 11**, **Table 12** and **Table 13** 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 10.** Extraction of global retrofitting cost per dwelling without grants (Archetype 1).*

Package	Insulation Thickness (mm)	Wall cost (€)	Roof cost (€)	Windows (€)	Floor cost (€)	Total cost (€)
P111	W6-R8	3 192	3 329	0	1 568	8 089
P121	W6-R8	3 289	4 062	0	1 547	8 897
P211	W6-R8	3 192	3 329	8 403	1 568	16 492
P221	W6-R8	3 289	4 062	15 794	1 547	24 691

Comparing some results obtained, in the case of the package P1.1.1, the costs are distributed between walls, roof and floor for a facade insulation thickness of 6 cm, which represent the 39%, 41% and 19% respectively; while in the case of package P2.1.1 the specific weight of costs is affected by the change of windows obtaining a distribution of 19%, 20% and 10% respectively and 51% for the windows. Even increasing up to 64% in the case of applying an ecological window's frame solution with pinewood (P2.2.1).

Table 11. Extract of global retrofitting cost per dwelling without grants (Archetype 2).

Package	Insulation Thickness (mm)	Wall cost (€)	Roof cost (€)	Windows (€)	Total cost (€)
P111	W6-R8	7 242	5 630	0	12 872
P121	W6-R8	7 462	6 870	0	14 332
P211	W6-R8	7 242	5 630	10 247	23 119
P221	W6-R8	7 462	6 870	19 259	33 590

Table 12. Extract of global retrofitting cost per dwelling without grants (Archetype 3).

Package	Insulation Thickness (mm)	Wall cost (€)	Roof cost (€)	Windows (€)	Total cost (€)
P111	W8-R8	3 194	9 354	0	12 548
P121	W8-R8	5 325	11 446	0	16 772
P211	W8-R8	3 194	9 354	3 877	16 425
P221	W8-R8	5 325	11 446	7 287	24 059

Table 13. Extract of global retrofitting cost per dwelling without grants (Archetype 4).

Package	Insulation Thickness (mm)	Wall cost (€)	Roof cost (€)	Windows (€)	Total cost (€)
P111	W8-R10	1 903	16 246	0	18 149
P121	W8-R10	3 173	18 558	0	21 731
P211	W8-R10	1 903	16 246	7 939	26 088
P221	W8-R10	3 173	18 558	14 921	36 652

The main differences between the Archetypes 1 and 2 are the proportion of windows, the existence of uncovered party walls and the absence of a slab in contact with the exterior. It can be noted that single-family buildings have higher roof costs per dwelling than the multi-family buildings. Dividing the global cost between less household increases the cost of all retrofitting measures for this building typology.

To calculate the investment related to active measures, the market prices of different equipment have been obtained. These prices are summarised in **Table 14**, taking into account the total cost.

Table 14. Active measures costs.

Active measure	Model	Budget
Multisplit for heating and cooling	DAIKIN 3MXM52N R32 (3x1)	5 070.86 € [10]
PV field	PV module Sunrise SR-725MHLPro Huawei SUN2000L-33KTL (archetype 1) Huawei SUN2000-8KTL M1(archetype 2)	426.19 €/m²
Heat pump for DHW	BAXI BC 200 IN	3 531.65 €

The cost of 1 m² of PV is determined by the gross roof surface, that can be effectively dedicated to PV installations. The PV panels selected have 2.5 m² each, and an original price of 426 €/m². For each archetype a specific ratio has been specified in order to adapt PV installation to the building size. This ratio is reducing the effective roof surface, to a range between 10 to 25%, which determines the space of PV panels. The effective roof surface is determined as of 80% of roof surface, as approximately 20% of real surface is covered by construction elements non suitable for PV installation.

- Archetype 1: 25% of effective roof surface.
- Archetype 2: 15% of effective roof surface.
- Archteype3 and 4: 10% of effective roof surface.

Life cycle 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 consider the revisions that the installations need, repairs to be carried out and replacement of parts throughout the life of the equipment. Values are shown in **Table 15**. In relation to replacement costs, the lifetime of each piece of equipment is accounted, and at the end of this life, the investment will have to be made again according to **Table 15**. The formula used to calculate the replacement cost is the following:

Replacement = Investment * (Economic period/Lifetime –1)

Table 15. Replacement and maintenance costs of active measures.

Active measure	Lifetime (years)	Maintenance per dwelling [10]
PV System	25 (1 replacements)	38.95 € - Archetype 1 69.74 € - Archetype 2 70.25 € - Archetype 3 93.04 € - Archetype 4
Multisplit for heating and cooling	20-25 (1 replacement)	152.13 €
Heatpump for DHW	20-25 (1 replacement)	105.95 €

The energy costs are the billing price that the owner will have to pay for the energy used. This price gets reduced by the retrofitting measures, so it is a saving the owner will benefit in the next years. In addition to the costs related to the entire life cycle, the factors of facility degradation and electricity price inflation have also been considered.

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 (degradation). 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 initial energy vectors prices for the calculations can be seen in **Table *16***, including also the price that electricity from PV surpluses is economically compensated**.**

Table 16. *Initial prices chosen for each energy vector.*

Demand type	Cost per €/kWh
Purchased Electricity (from the grid)	0.23 [11]
Sold electricity (to the grid)	0.08
Natural Gas	0.10 [12]
Butane	0.13

Regarding the grant applied in relation to energy saving results for every scenario, specific thresholds are defined in Next Generation Programme-3. Hence, the total investment considers the grant calculation by subtracting it for retrofitting costs. In addition, monthly payments are considered with the discount on grants; except for the cost of replacement and maintenance which does not consider grants, as they are future investments based on the **Table 2** that shows the correlation between energy savings achieved with the action and the percentage of the subsidy.

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 by the private agent or banks 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 accounted when calculating the monthly instalments to be paid by the owners to the retrofitting agent or a financial entity. Two main types of financing scheme are considered (UT2, UT3), as following:

- UT2: Private financing with 5% interest rate for 10 years.
- UT3: Private financing with 5% interest rate for 15 years.

The financing costs and quotations for profiles UT2 and UT3 are computed, tailoring interest rates to the duration over which the loan is slated for repayment.

4.3.3. PASSIVE MEASURES ANALYSIS

As part of the analysis of the various sets of passive measures accounted for the retrofitting of the building archetypes, the actual orientations for each Archetype are the following (referring to the main façade):

- Archetype 1: South/ North (symmetrical isolated building).
- Archetype 2 and 3: East.
- Archetype 4: West.

Archetype 1

The results of applying the package scenarios to the demand shown in Figure 35 can be seen in Figure 39, which shows the relation between the investment including grants and the non-renewable primary energy used (including heating, cooling, DHW) for the actual orientation of the building. All passive packages are represented for this orientation. Archetype 1 is a special case because only 3 dwellings are simulated for all the building. This can cause an underrepresentation of dwellings that are facing the back façade. A real approach is the mean between the real orientation and 180º rotation from the real one as it's a detached multi-storey building.

Figure 39 shows the correlation between heating and cooling demand. All packages, thicknesses and orientations are included. Each point colour corresponds to the implementation of a building envelope improvement package. Each point corresponds to an insulation thickness according to each archetype and the options proposed in **Table 5**. The background colours correspond to the Energy Performance Certificate (EPC) set by the Spanish energy legislation in relation to the energy labelling.

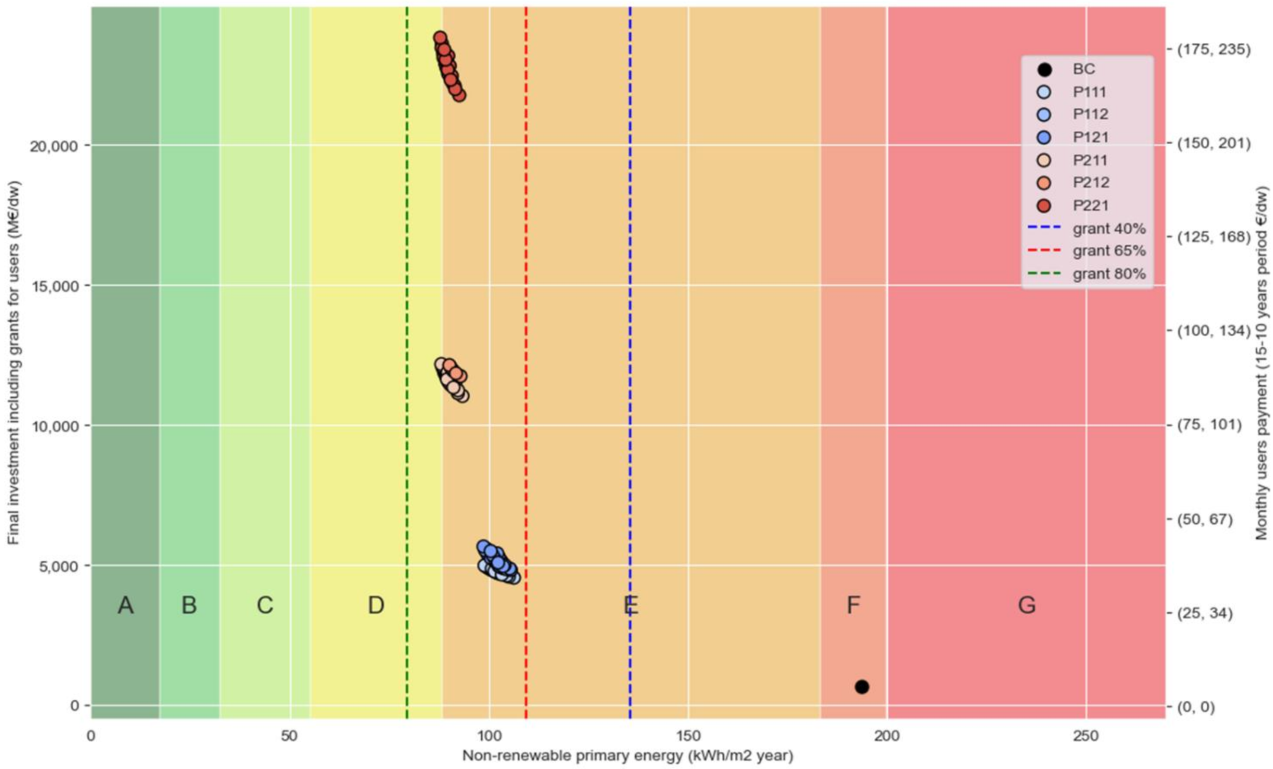


Figure 39. *Investment per dwelling vs Non-renewable primary energy (Archetype 1).*

The first relevant result of the study is that the second segment of subsidies (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 not enough to pass to the final segment.

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. Furthermore, the ecological windows double the price of the conventional ones

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.

Monthly quotes are about 50-65 €/month, that increase up to 100 €/month (aprox.) when renovating windows (in the range of 150 – 175 €/month). Relating the results in terms of the energy labelling bands all points are in the range of a low-E and/or D labelling

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 remarkably 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 40**). However, the orientation of the building is indeed a determinant factor to quantify the energy demand.

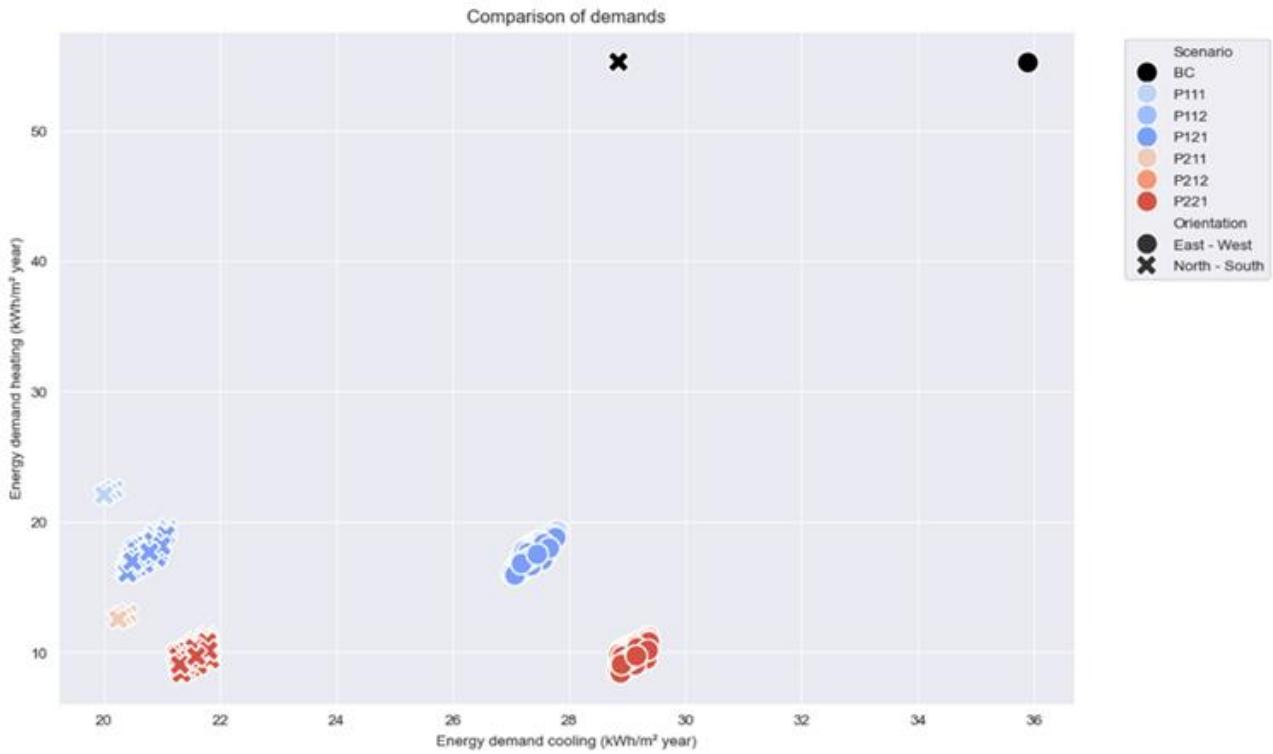


Figure 40. *Comparison between cooling and heating energy demand (Archetype 1); Real orientation: North-South.*

Archetype 2

The same analysis was carried out for the second archetype, for which some intermediate solutions with roof or wall thickness 14 cm and10 cm are discarded in order to see clearer the results.

Similarly, in **Figure 41** the points representing various packages are very close to each other as for the previous Archetype 1, but in Archetype 2 there is little improvement of energy efficiency compared to the increase of investment cost. Archetype 2 is a semi-detached multi-storey building with little surface of wall facing to the street. The party walls exposed to ambient temperatures are always insulated with a constant thickness of 6cm. Thus, there is a negligible efficiency difference between thicknesses insulations within the same package. However, some packages have distinct levels of investment.

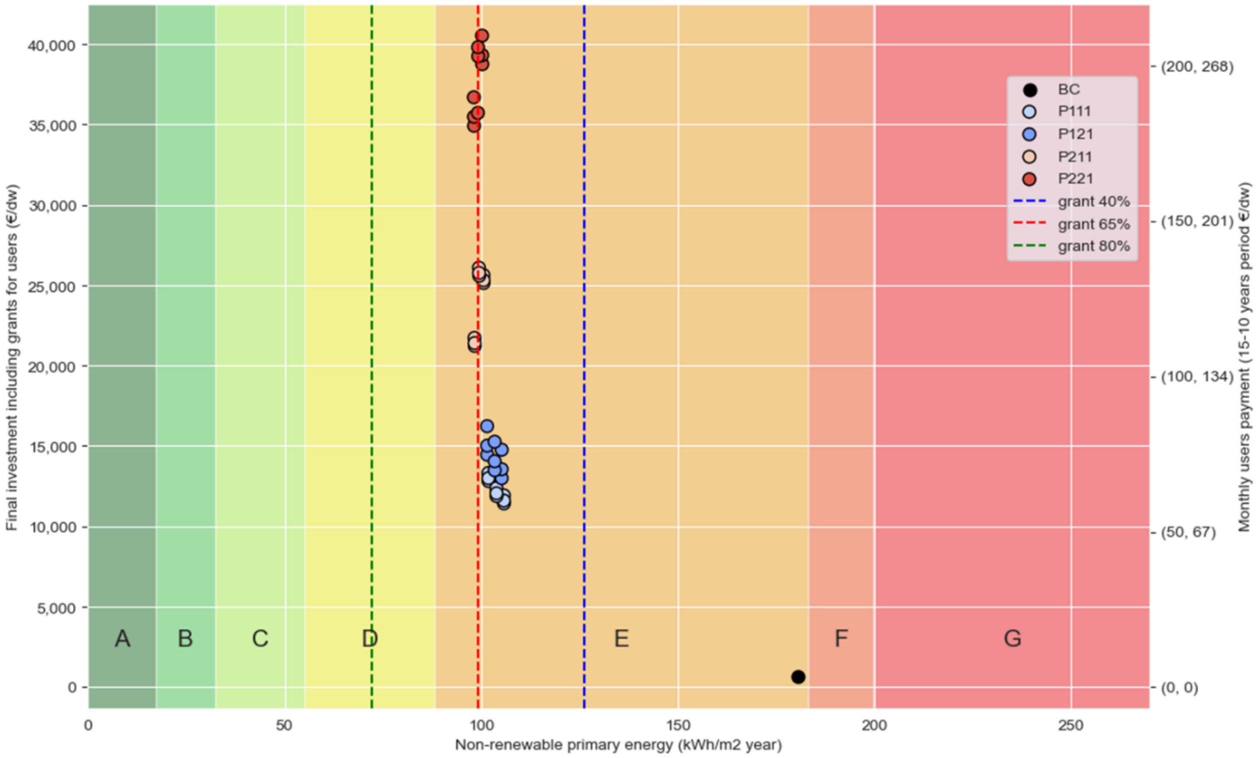


Figure 41. *Investment per dwelling vs Non-renewable primary energy (Archetype 2).*

Dislike the previous case, changing the windows does allow to reach the second segment of subsidy, which makes that the investment for some packages with higher thickness becomes more economical, as well as the packages without windows that also remain cheaper despite being in the first grants level. As in the former archetype, conventional packages are less expensive than ecological ones and do not improve the energy efficiency. Solution with windows represents a total investment, including grants, above 20 000 €/dwelling.

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 always remain in range E. By comparing results with the previous archetype, the **Figure 42** shows how the cooling and the heating demands are distributed differently, depending on the building orientation.

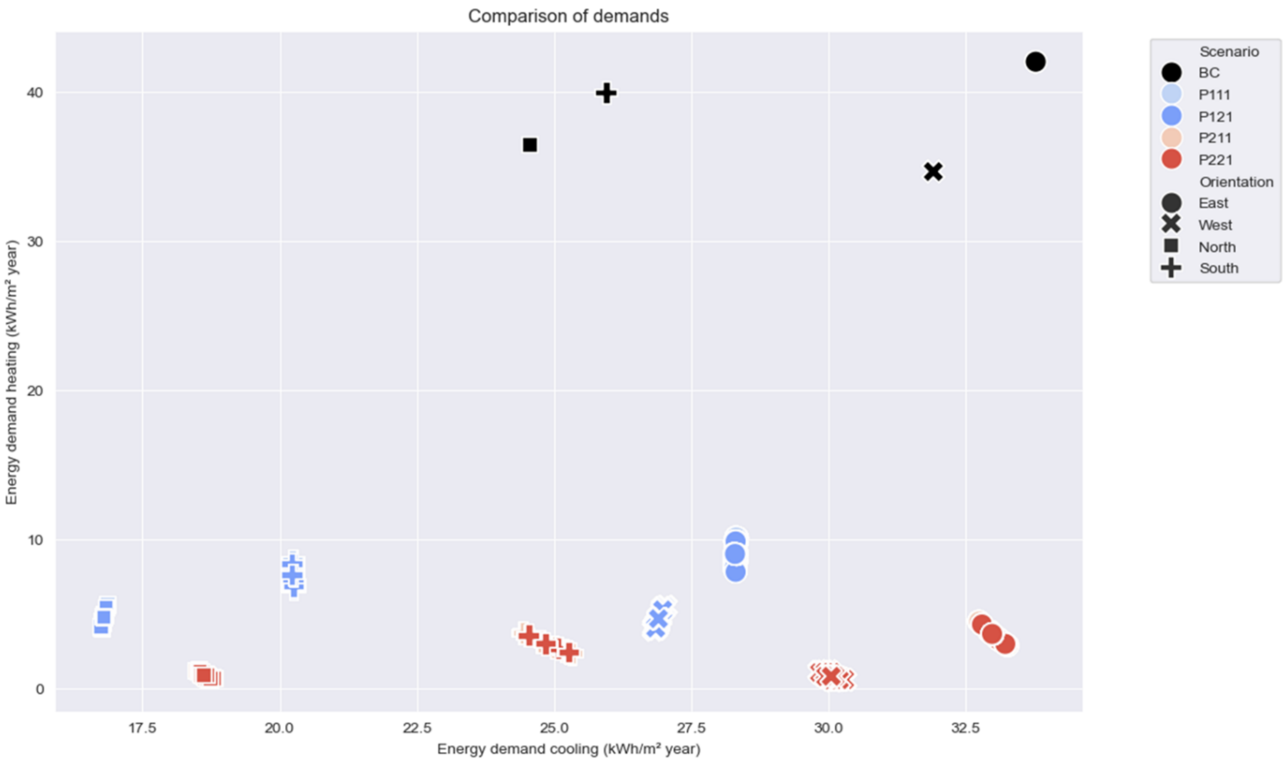


Figure 42. *Comparison between cooling and heating energy demand (Archetype 2); Real orientation: East.*

Archetype 3

The measures chosen for this archetype are less numerous, as can be appreciated in **Figure 43**. As in archetype 2, the window packages surpass one subsidy level and in the case of P211 also makes decrease the price respect P111. The energy labelling goes from a G and remains in E for all packages. Minimum investment quotes for loans (15 years) are about 80 €/month.

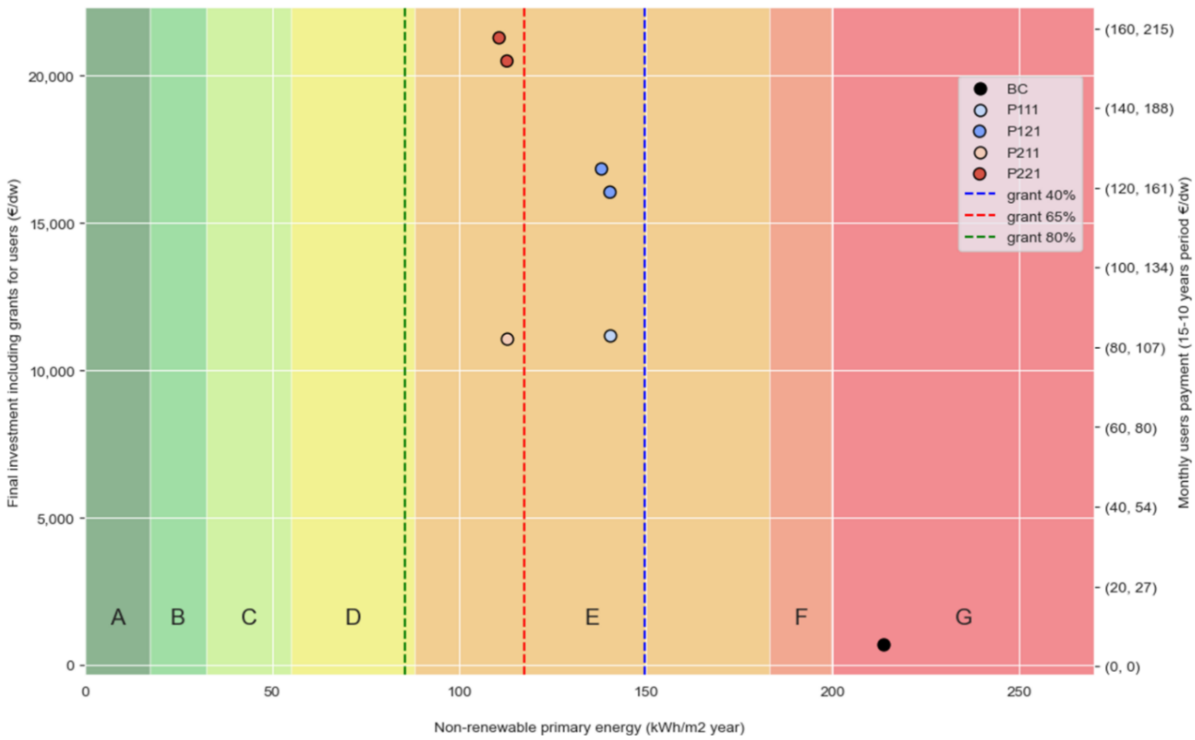


Figure 43. *Investment per dwelling vs Non-renewable primary energy (Archetype 3).*

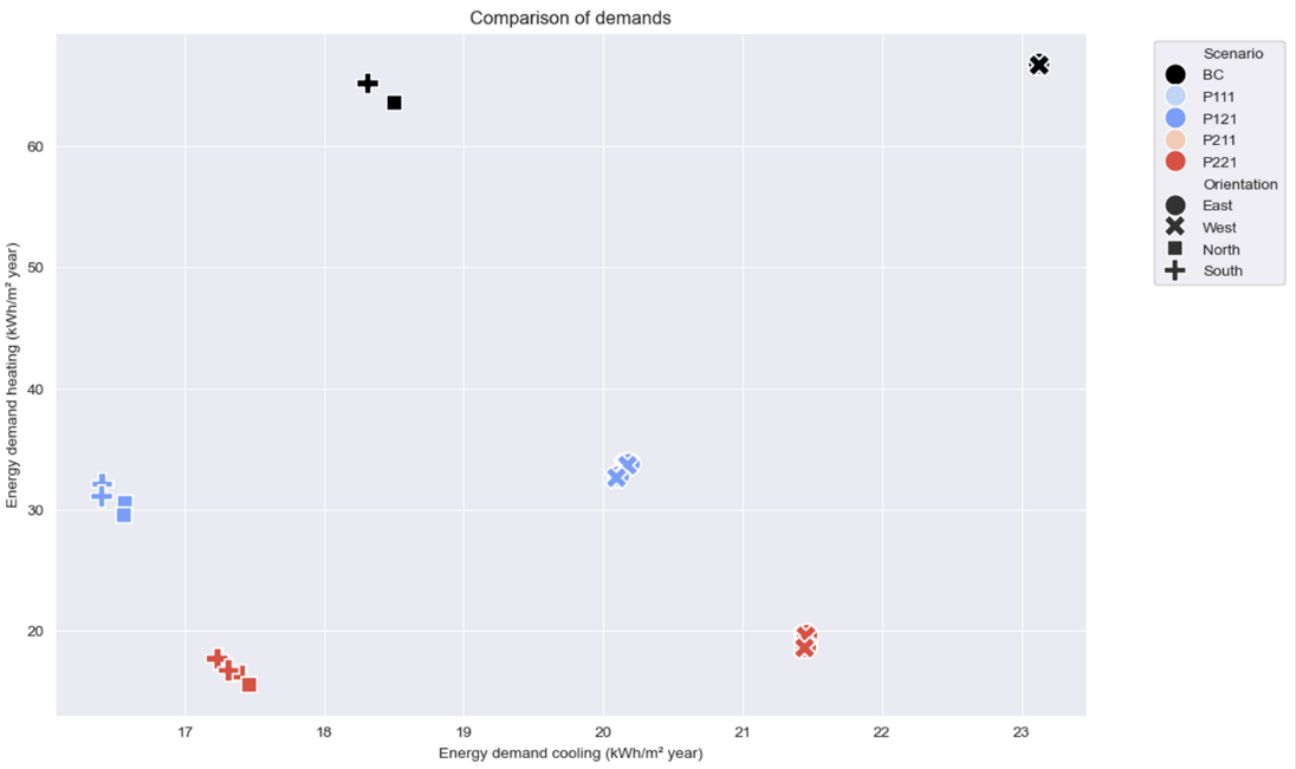


Figure 44. *Comparison between cooling and heating energy demand (Archetype 3); Actual orientation: East.*

Archetype 3 is practically symmetrical and has little shadowing from surroundings. **Figure 44** represents the similarity between South and North (with minor demands) main façade building orientated, East, and West (greater demands). As seen in other archetypes, the packages that renovate windows decrease more than half the original heating demands and also decreases the cooling demands compared to the reference cases.

Archetype 4

For this archetype, not all passive measures reach the minimum subsidy level, for instance, package P1.2.2 only arrives to an F labelling. Furthermore, only package P2.1.1 arrives to the second granting level. Unlike Archetypes 1 and 2, the roof thickness increase does have an influence on the energy performance.

The investment level of non-renovated windows packages in Archetype 3 is around 10.000 € which is similar to the levels in Archetype 2, but it is twice the price of Archetype 1 and half the price of archetype 4. This is a common behaviour for the large-scale renovation: a higher rate of dwellings renovated with the same solution can lower the global cost of the intervention. Quotes for archetype 4 are above 130 €/month.

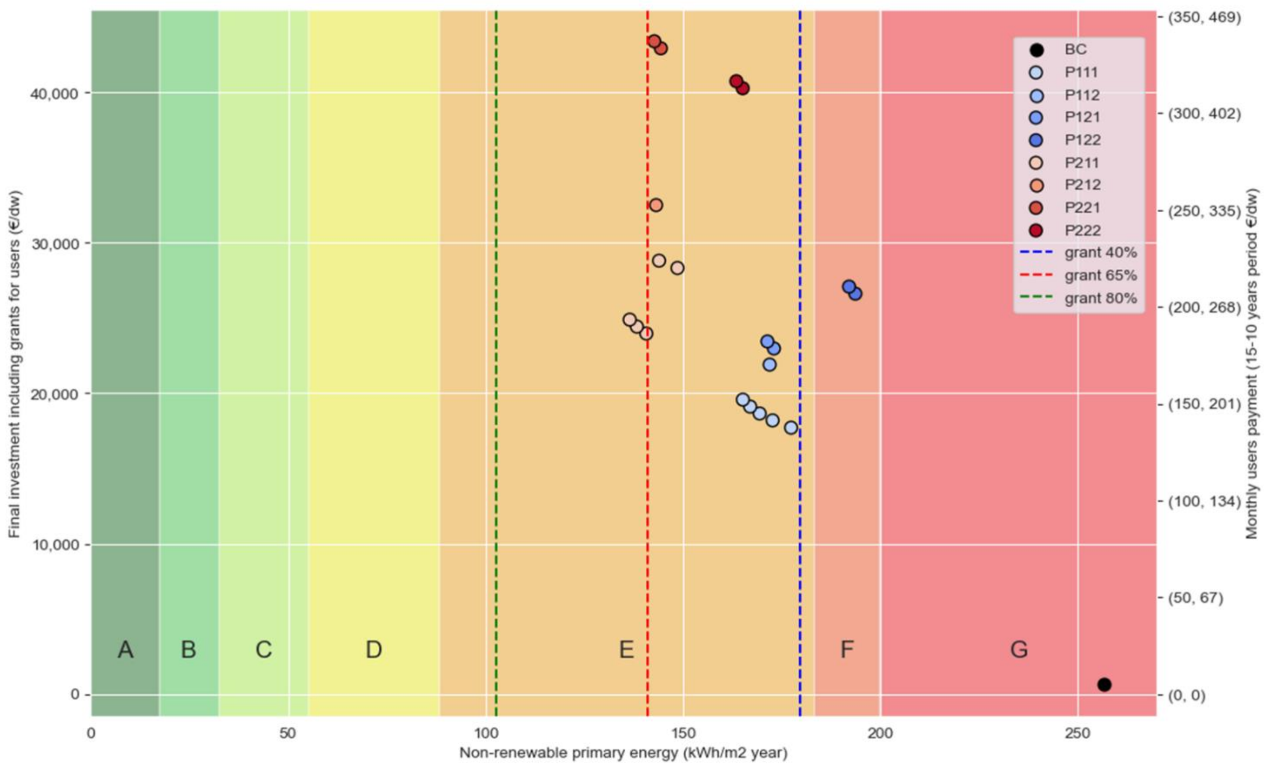


Figure 45. *Investment per dwelling vs Non-renewable primary energy (Archetype 4).*

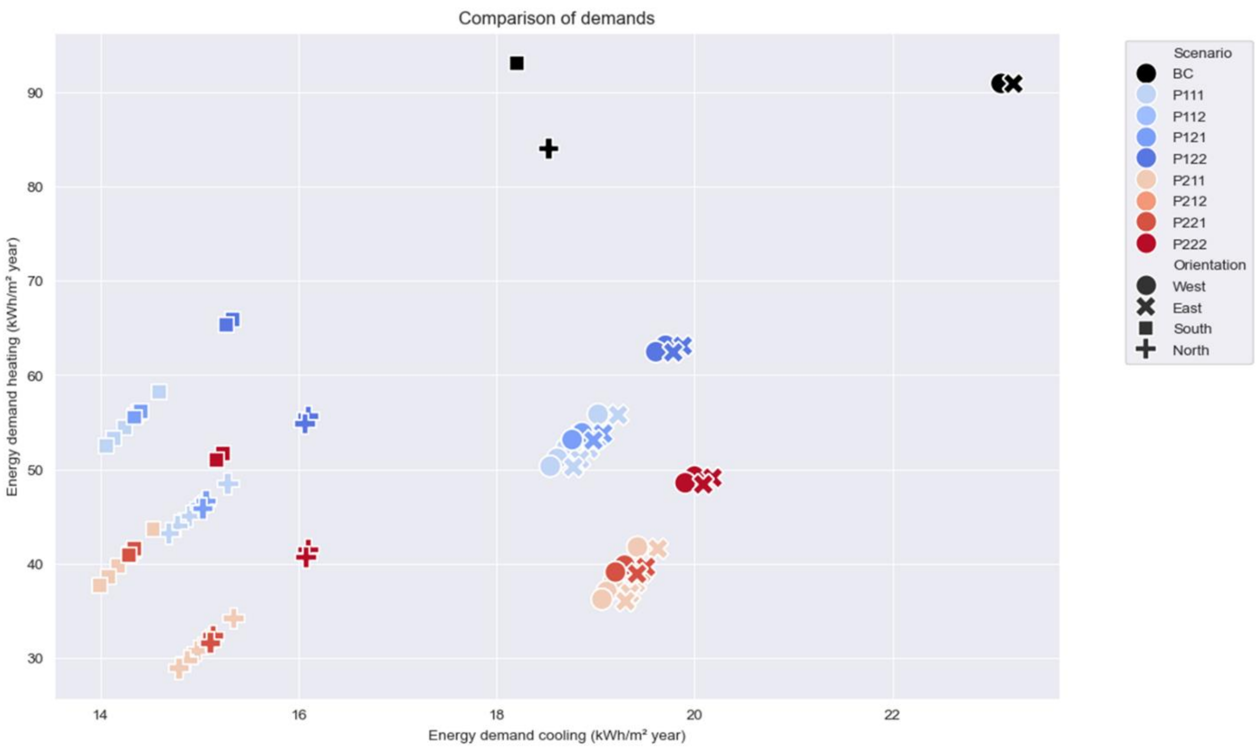


Figure 46. *Comparison between cooling and heating energy demand (Archetype 4); Real orientation: West.*

The building orientated both West and East (main façade) are similar, however, South and North differ significantly as packages with and without windows refurbishment have similar energy results respectively.

4.3.4. ACTIVE MEASURES ANALYSIS

Some hypothesis and considerations have been set regarding the active systems analysis when they are added to the retrofitting packages.

- Maximum heating and cooling demand is limited to 60 W/m^2, and active systems are sized to cover this power needs
- The seasonal performance of the active systems considered are:
    - 4.6 for heating based on heat pump / split technologies
    - 5 for cooling for multi-split air conditioning system
    - 3.12 for domestic hot water system heat pump
- The size of the photovoltaic installation differs within archetypes depending on the roof space and number of dwellings. The specific values are indicated in each archetype section

Archetype 1

In the **Figure 47**, the relation between the investment including grants and the non-renewable primary energy used (including heating, cooling, DHW) is represented for the actual orientation of the building. Specific wall and roof thicknesses are chosen for each archetype and package typology, so as all 7 combinations of active packages are represented, except for the base case that has no active but passive measures applied.

For all the selected scenarios of the Archetype 1, there is always a 6cm insulation in the first floor slab. In addition, other elements' thicknesses chosen are the following:

- P1.1.1 features 12cm insulation for its walls (external facades) and 12cm insulation for the roof, with consideration for the actual orientation of the structure.
- P1.2.1 features 12cm insulation for its walls (external facades), and 14cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.1.1 features 8cm insulation for its walls (external facades), and 8cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.2.1 features 8cm insulation for its walls (external facades), and 6cm insulation for the roof, with consideration for the actual orientation of the structure.

Figure 48 shows the result of a 50-year economic analysis, stacking the energy cost, the investment, the maintenance, and replacement costs. Non-renewable primary energy (including heating, cooling, DHW) is also illustrated. It allows to compare both passive and active measures in terms of economic feasibility. The PV field installation has a peak power of 46.7 kWp (974 Wp per dwelling).

All possible combinations between the different facilities options have been realised, which results in 7 analysed cases for each basic passive measures' package. The results of applying the active measures to the chosen scenarios are shown in **Figure 47.**

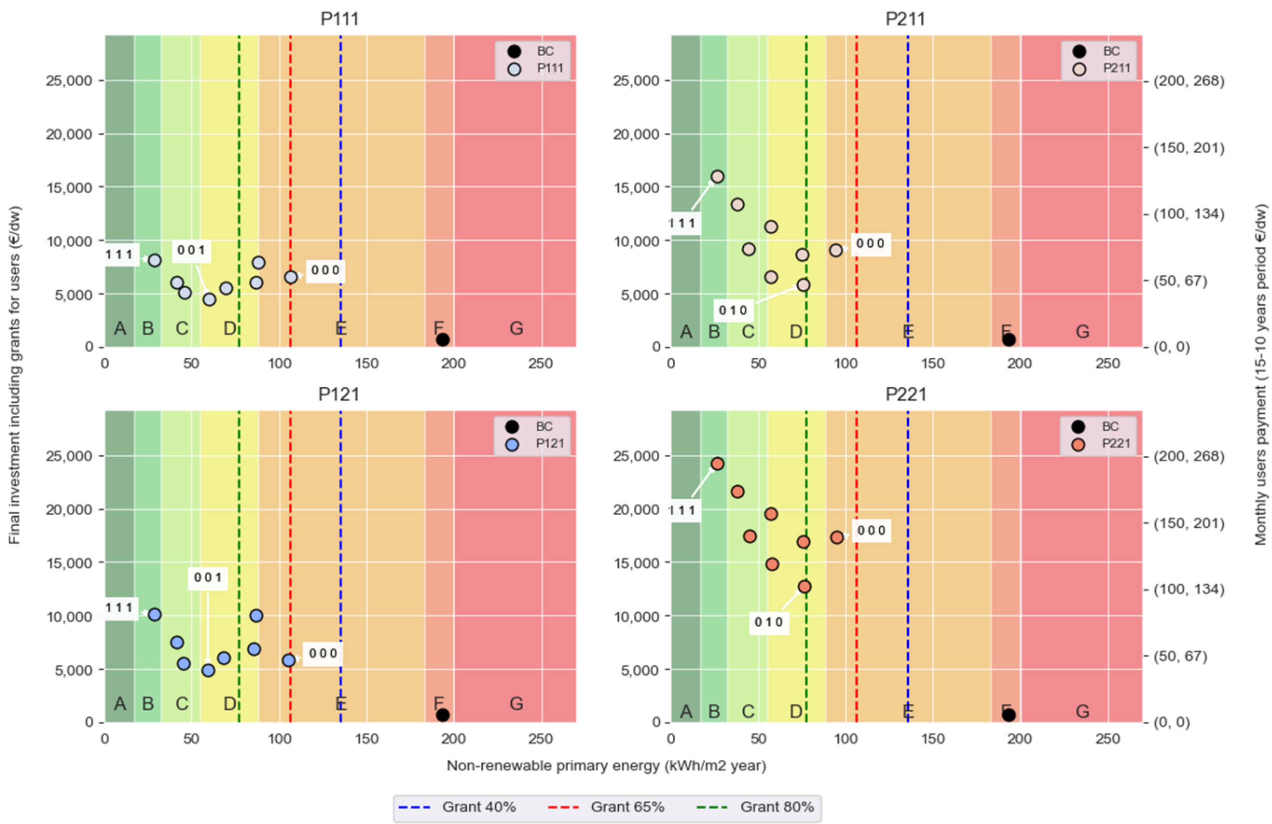


Figure 47. *Investment per dwelling vs Non-renewable primary energy (Archetype 1). Minimum investment points are indicated in the graph.*

In the **Figure 47**, it can be seen that the dots have moved to the left due to the decrease in primary energy consumption. In addition, there are five cases where it is possible even to reach the highest level of grants (80%) without retrofitting the windows, reaching B labelling.

A coding of zeros (0) and ones (1) of active measures allows to identify the solution from the base case (000) and the ones with all the active measures in place (111). Also, a label identified the one is more cost optimal in terms of investment required vs. reduction of primary energy. 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 and heating.

In terms of energy labelling there is a variety of results, such as obtaining a B 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. Those solutions packages are the ones replacing the DHW and heating systems by heat pumps (001) or adding PV systems (010).

The monthly quote for each neighbour is around 200 €/month in the most expensive packages and below 50 €/month in the most economic ones. However, to define the most favourable scenario, it is also representative to analyse a dynamic rather than 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 considered, 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 48** 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 (P2.1.1-111) stands for the following: P2.1.1. (number of the package applied) – 1 (change of air conditioning system) 1 (installation of PV) 1 (change of domestic hot water).

- Figure 52. Global cost vs Passive + Active measures and Non-renewable primary energy consumption (Archetype 1). – UPDATES CARACAS1

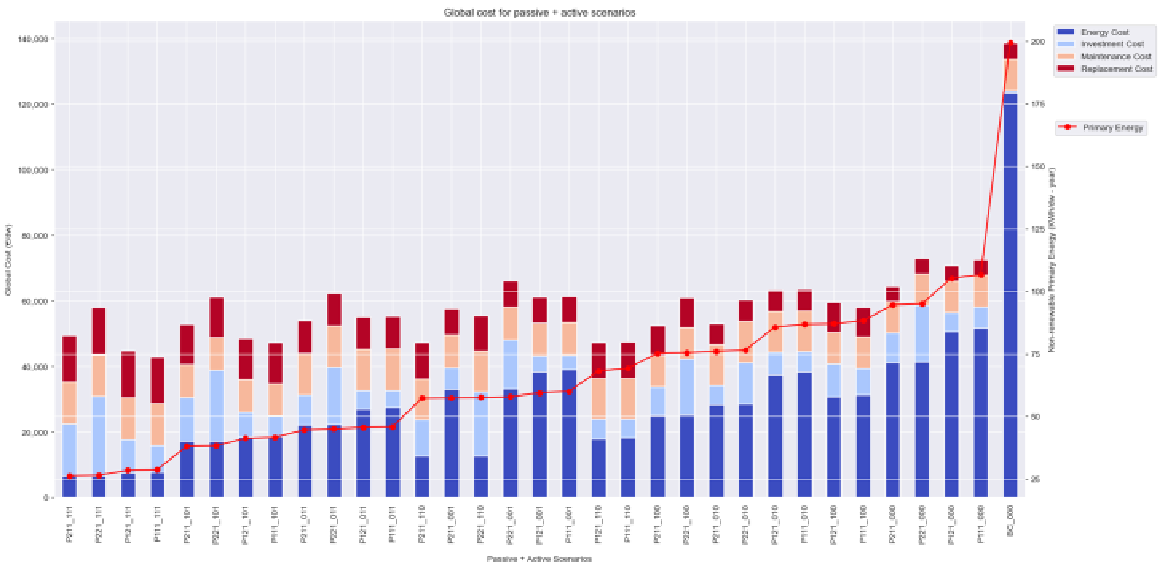


Figure 48. *Global cost vs Passive + Active measures and Non-renewable primary energy consumption (Archetype 1).*

Based on the results obtained from the study of the optimization of the passive and active measures scenarios, there are differences comparing initial investment or global costs. For example, in the case of package P2.1.1, where only the initial investment was accounted, the price with all the active measures implemented is not the most cost-effective. However, taking into account the global costs, the most cost-effective cases resulting are the implementation of all active measures (111) or installing a Multisplit for heating and cooling, and installing PV system (110).

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, considering 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, although investments are higher.

Finally, a complete refurbishment scenario would consume the least energy and, therefore, results in the lowest energy cost. Maintenance costs are more or less constant in all scenarios (refurbished and non-refurbished) but replacement costs are generally higher for new equipment.

Archetype 2

The scenarios chosen for Archetype 2 are:

- P1.1.1 features 8cm insulation for its walls (including facades), 6cm insulation for party facades, and 6cm insulation for the roof, with consideration for the actual orientation of the structure.
- P1.2.1 features 6cm insulation for its walls (all facades), and 8cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.1.1 features 8cm insulation for its walls (including facades), 6cm insulation for party facades, and 6cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.2.1 features 10cm insulation for its walls (including facades), 6cm insulation for party facades, and 6cm insulation for the roof, with consideration for the actual orientation of the structure.

In this case, the simulation takes into account the whole building. The PV field installation has a peak power of 7.5 kWp (1.87 Wp per dwelling).

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 49**.

Figure 49. *Investment per dwelling vs Non-renewable primary energy (Archetype 2). Minimum investment points are indicated in the graph.*

There is a difference around 15.000 € between cheapest and the most expensive scenario, while installing a heat pump for DHW can reach similar primary energy saving with the minimal investment costs.

In the case where only the initial investment is considered, the installing a heat pump for DHW and heating system is the most cost-effective measure for all the scenarios studied. In addition, only by applying the previous measure, the last segment of subsidy is reached. Further analysis, taking into account the overall cost, is demonstrated in **Figure 50.**

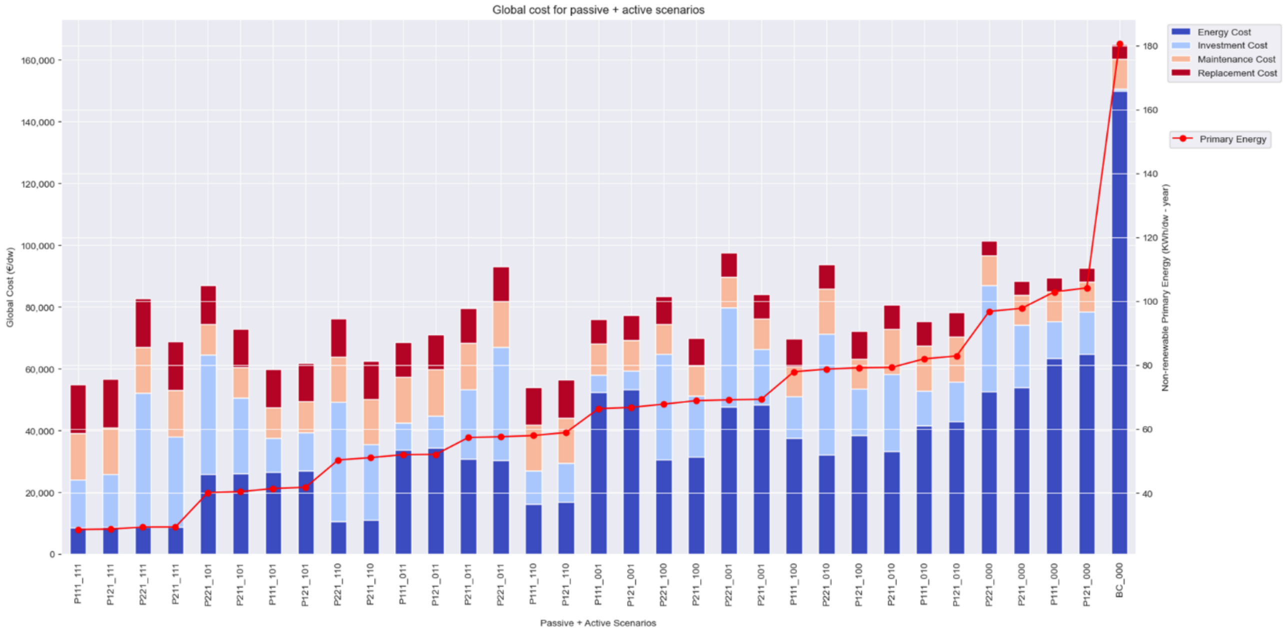


Figure 50. *Global cost vs Passive + Active measures and non-renewable primary energy consumption (Archetype 2).*

In contrast to the previous case, there is a combination of passive and active measures which is more favourable such as the modification of the air conditioning and heating system, and a photovoltaic installation. The decision of integrating specific measures will depend on the economic capacity of the community which will enable upgrading the energy performance of the building.

Archetype 3

As part of 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 3, the following scenarios have been selected:

- P1.1.1 features 8cm insulation for its walls (including facades), and 8cm insulation for the roof, with consideration for the actual orientation of the structure.
- P1.2.1 features 6cm insulation for its walls (all facades), and 8cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.1.1 features 8cm insulation for its walls (including facades) and 6cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.2.1 features 6cm insulation for its walls (including facades), and 8cm insulation for the roof, with consideration for the actual orientation of the structure.

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 51.** The PV field installation has a peak power of 4.4 kWp (2.2 Wp per dwelling).

As in the previous archetype, only by including the refurbishment of the DHW and heating heat pump helps to reach the highest level of subsidy and the range between solutions is also 15.000€. In addition, the photovoltaic installation combined with DHW heat pump changes the label from a D to a C, however, it increases the investment cost.

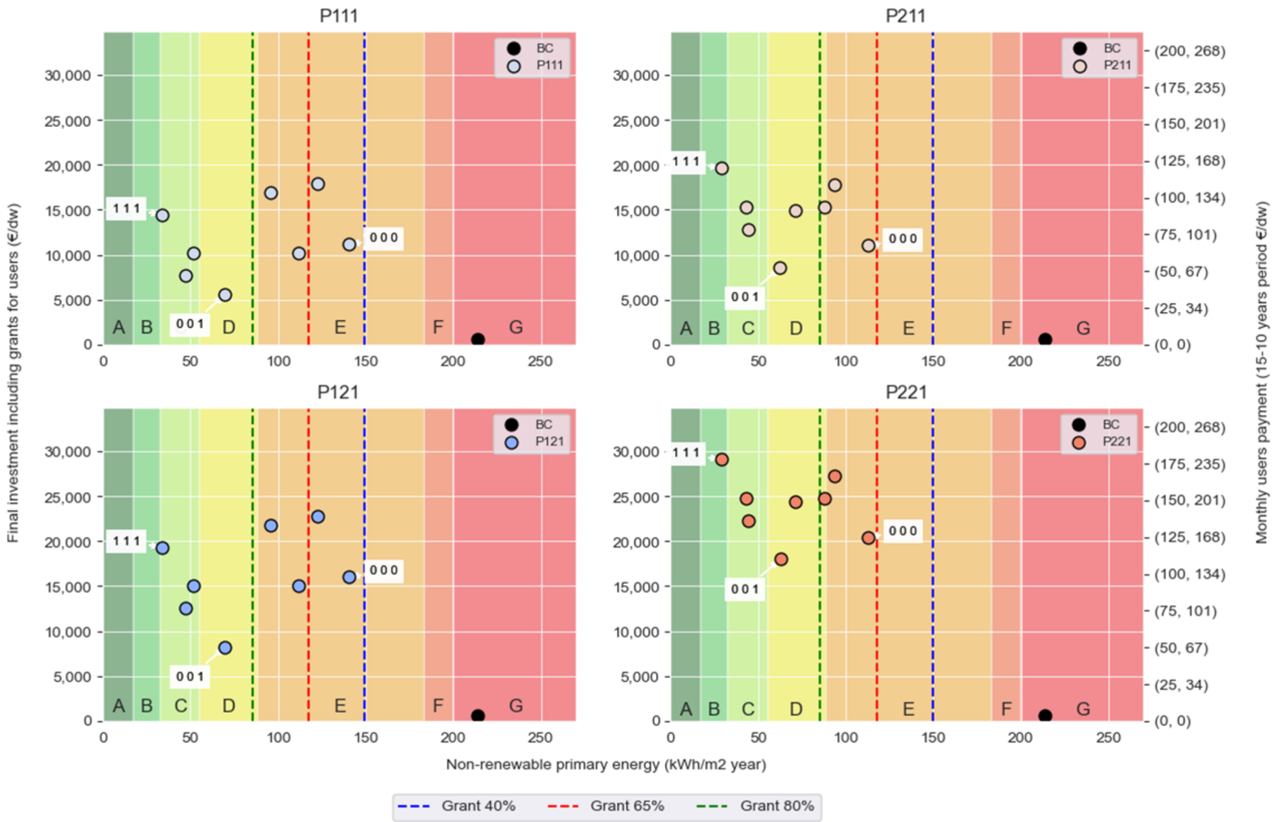


Figure 51. Investment per dwelling vs Non-renewable primary energy (Archetype 3). Minimum investment points are indicated int the graph.

Further analysis, taking into account overall costs, is shown in **Figure 52**.

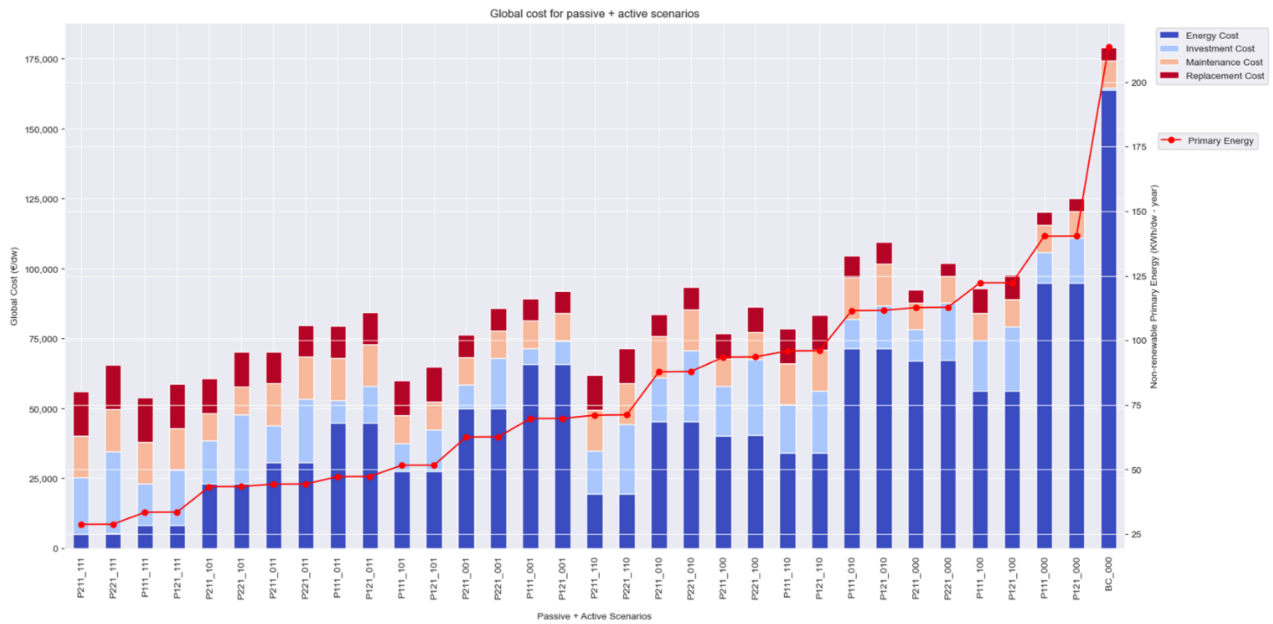


Figure 52. Global cost vs Passive + Active measures and Non-renewable primary energy consumption (Archetype 3).

In the case of Archetype 3, the most cost-effective measures in the long-term are applying all or the active ones and have similar results to applying the DHW heat pump and the heating and cooling multi-split and the case with PV plus heat pump for DHW and windows replacement (P211_110).

Archetype 4

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 4, the following scenarios have been chosen:

- P1.1.1 features 8cm insulation for its walls (including facades) and 8cm insulation for the roof, with consideration for the actual orientation of the structure.
- P1.2.1 features 6cm insulation for its walls (all facades) and 8cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.1.1 features 8cm insulation for its walls (including facades) and 10cm insulation for the roof, with consideration for the actual orientation of the structure.
- P2.2.2 features 6cm insulation for its walls (including facades), and 10cm insulation for the roof, with consideration for the actual orientation of the structure.

The PV field installation has a peak power of 3.1 kWp (3.1 Wp per dwelling). All combinations between the different facilities options have been realised, which results in 8 cases to be analysed. The results of applying the active measures to the chosen scenarios are shown in **Figure 53**.

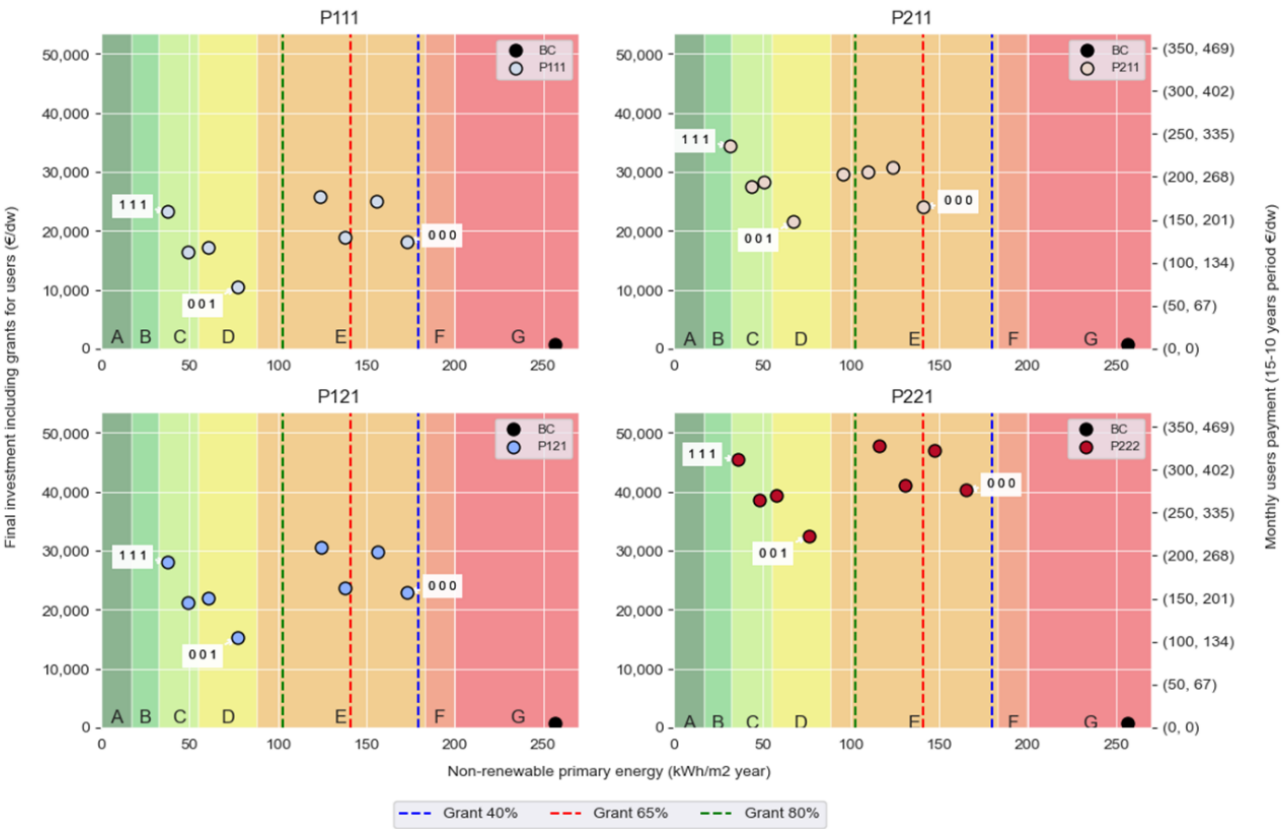


Figure 53. *Investment per dwelling vs Non-renewable primary energy (Archetype 4). Minimum investment points are indicated int the graph.*

In Archetype 4, there is a higher impact on the energy performance for the scenarios with active measures than in former archetypes (points are horizontally more distributed). This is due to the low efficiency of the base case, which accounts for a higher range of potential improvement. However, the best solutions in terms of energy performance remain a B labelling, which is similar for all the previous archetypes analysed. The domestic hot water and heating heat pump reaches the last level of subsidy as happens in previous archetypes. In addition, monthly quotes are, in general, higher than previous archetypes, between 70 €/month and almost 350 €/month.

Further analysis, taking into account overall costs, is depicted in **Figure 54**.

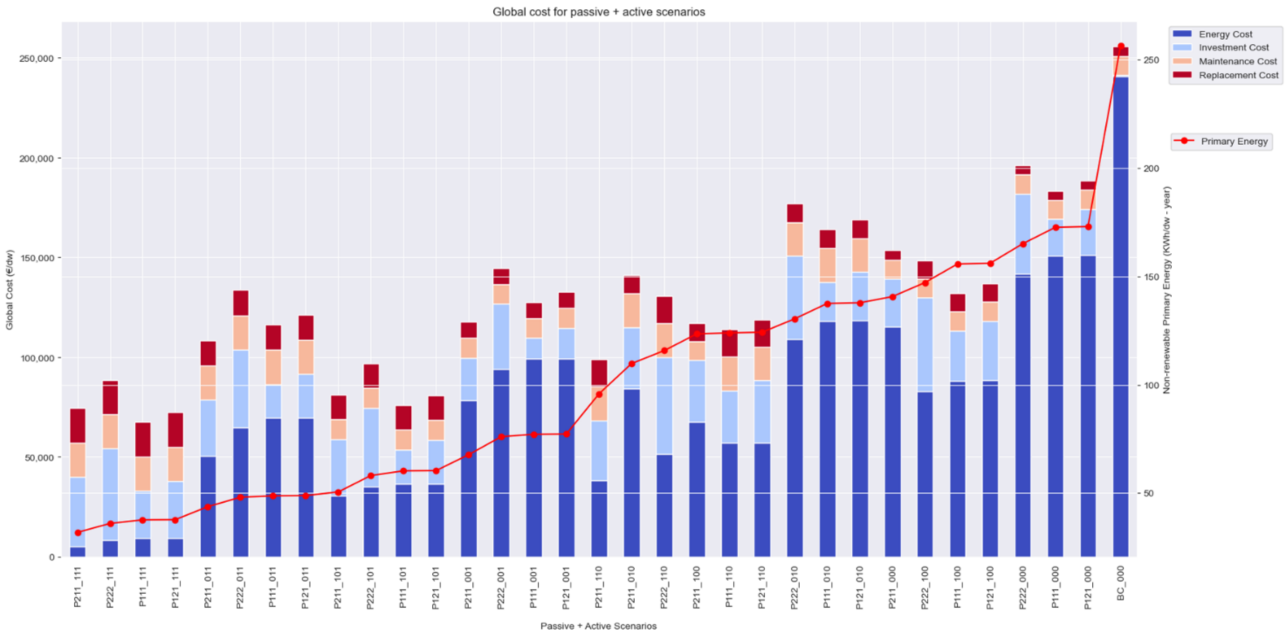


Figure 54. *Global cost vs Passive + Active measures and Non-renewable primary energy consumption (Archetype 4).*

Again, the combination of all measures or the combination of heating and cooling multi-split and the DHW heat pump appears to be the best solution in a long-term economic analysis, and there is no relevant difference between the ecological and conventional packages, as differences in investment are highly compensated with the reduction of the energy costs. Options with out PV system (101) have also similar global costs despite the higher primary energy consumption.

4.4. ENERGY LABELLING

Throughout the previous section the results of a detailed energy simulation of four 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 programmes 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 55** shows a histogram plotting the results of the analysis of the energy auditors who have performed it in the physical limits of the ERRP.

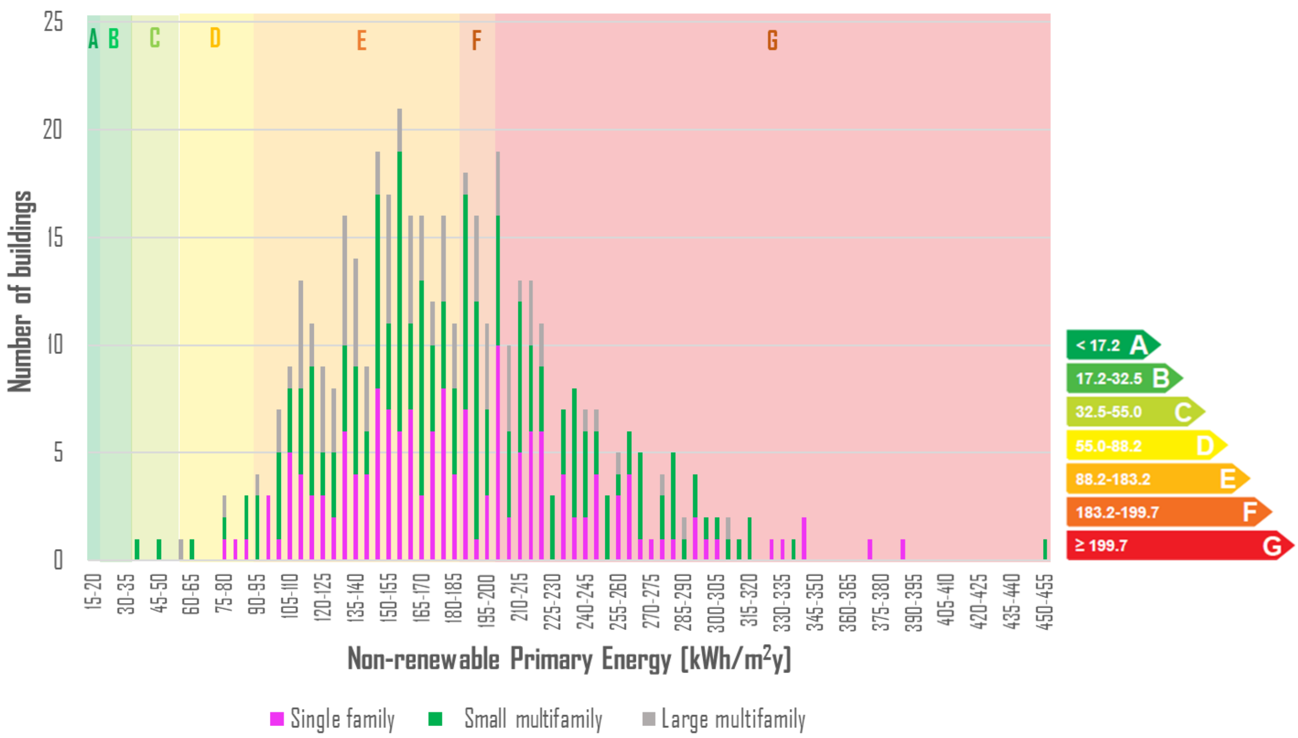


Figure 55. *Histogram with registered energy certificates in the ERRP area.*

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 D-E ratings with passive measures and B-C-D labelling with active measures. Only in cases where all active measures are applied, certificates rating B can be achieved.

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

4.5. ENVIRONMENTAL PERFORMANCE

The scope of this section is to calculate an environmental footprint of different design alternatives and to analyse how it can impact the decision-making process.

For this analysis, the most ambitious designs in terms of the energy performance, e.g. retrofitting packages P221_111 and P211_111, have been chosen for a considered building of Archetype 1, as one of the most representative building types in the neighbourhood.

4.5.1. METHODOLOGY

The calculations for LCA are done in One Click LCA [13] software, following the EN15804+A1 [14] standard, with the following methodological aspects considered:

- The assessment considers a 50-year life span following the ARV assessment framework based on Level(s) methodology [15].
- The possible benefits achievable through the exportation of renewable energy have not been considered for stage D.
- A burden-free approach has been considered for the retrofitting scenario. The materials inherited from the existing building does not account for any maintenance or waste produced at the end of their life cycle.

The boundaries of the analysis include the production stage (modules A1-A3), construction process (A4-A5), replacement and refurbishment (stage B4-B5), operational energy use (stage B6) and end-of-life stages, in particular, transport, waste processing and disposal (stages C2-C4). Benefits beyond the system boundaries (stage D) have been considered separately.

Calculation process for stage A

In order to model the environmental impacts of stages A1 to A3, private datasets for the retrofitting solutions have been created in One Click LCA based on the environmental profiles of the complete solutions obtained from CYPE database. BREEAM Spain, the entity in charge of evaluating and certifying sustainability in buildings, has validated the CYPE "Environmental Impact module. Life cycle analysis" [16], the tool that calculates the environmental impact generated by the construction of a building. To carry out this calculation, CYPE uses as environmental indicators the emissions of carbon dioxide (CO_2) and the embodied energy during the product manufacturing stages, its transportation to the site entrance and the product installation and construction process.

For the active measures, EPDs with the most similar characteristics to the considered energy systems have been obtained from One Click database.

The considered areas/units for the retrofitting elements/systems defined for the calculation are summarised in **Table 17**.

Table 17*. Considered areas/units for the LCA of retrofitting elements/systems.*

Construction element/ Energy system	Value	Unit
Wall	2712	m^2
Roof	1096.84	m^2
First floor slab	1090.45	m^2
Gross floor area	4362	m^2
Windows (1.2 m x 1.1 m)	96	unit
Windows (1.2 m x 2.1 m)	96	unit
Windows (1.85 m x 2.1 m)	48	unit
Multisplit for heating and cooling	48	unit
PV modules	232.29	m^2
Inverter	2	unit
Heat pump for DHW	48	unit

In order to model the module A4 the following assumptions were considered for the preliminary distances for the retrofitting solutions/active systems:

- The transportation distance has been always considered from the production site of the predominant materials. Thus, in cases where a complete solution was compounded by different types of materials and delivered from a unified storehouse such as, for example, ETICS (External Thermal Insulation Composite Systems), the distance considered has been the distance of the EPS panel, since it is the predominant material for the whole solution.
- Truck transportation until Valencia or Barcelona Port plus ship to Palma (Mallorca) has been considered for goods produced in Europe.
- For materials with production site in China, typically for electronical goods, the transportation considered has been a plane to Madrid and a plane from Madrid to Palma.

A summary of the transportation distances considered in presented in **Appendix I – Life cycle analysis data.**

Calculation process for stage B

In order to model the module B4 the following service lives were considered: 50 years for the insulation materials, 35 years for the windows, 20 years for heat pumps, 25 years for PV installations and 10 years for the inverters.

Module B6 accounts for the impacts linked to the operational energy use and derived from preliminary energy simulations performed using TRNSYS (**Table 18**) with the following emission factors for the Balearic Islands [17]: electricity – 0.932 $kgCO_2/kWh$, natural gas – 0.252 $kgCO_2/kWh$ and butane – 0.254 $kgCO_2/kWh$.

Table 18. *Electricity consumption and fuels demand in kWh/m^2y for existing building (base case), scenario with the conventional materials (scenario 1) and scenario with eco-materials (scenario 2).*

Case	Natural gas	Electricity	Butane	Active measures (MS+PV+BC)
Base case BC0_0	35.13	43.21	14.14	000
Scenario 1: Coventional P211_0_W6_R8	0	8.89	0	111
Scenario 2: Eco P221_0_W6_R8	0	8.85	0	111

Calculation process for stage C

Market scenarios for the end-of-life stages for the retrofitting solutions/active systems have been defined based on the standard practice on the market and proposed by One Click based on the type of the material added to the private database/EPDs for the active systems. Benefits of recycling and reuse of the materials have been considered in stage D.

4.5.2. SUMMARY OF THE RESULTS

In this section, the comparison of the environmental impact of the existing building (base case), scenario with the conventional materials (scenario 1) and scenario with eco-materials (scenario 2) is presented.

In general, the considered scenarios have demonstrated the following global-warming potential (GWP) performance normalized by the gross floor area and the calculation period (**Table 19**):

Table 19. *Summary of the GWP for the considered scenarios.*

	Base Case	Scenario 1 (Conventional)	Scenario 2 (Eco)

GWP [$kgCO_2/m^2y$]	52.72	13.58	11.59
Comments	Only use stage B6	Production stage (modules A1-A3), construction process (A4-A5), replacement and refurbishment (stage B4-B5), operational energy use (stage B6) and end-of-life stages: transport, waste processing and disposal (stages C2-C4)	

Therefore, the environmental impact of the considered archetype has decreased by 74% and 78% compare to the use stage of the existing building by applying a package with conventional and eco materials respectively.

Application of eco materials compare to the conventional materials gave a GWP reduction of 15%. One of the reasons for this difference is considering eco materials as retrofitting solutions, which have lower or even negative environmental footprint. The negative values for GWP-biogenic can be attributed to the production of the paper and/or wood products. Another reason is a reduced distance for eco materials transportation. Preference of the km0 materials has been one of the main motivations to consider eco materials for the renovation.

A comparison of how each of the phases contributes to the overall GWP of conventional and eco retrofitting solutions is demonstrated in **Figure 56**.

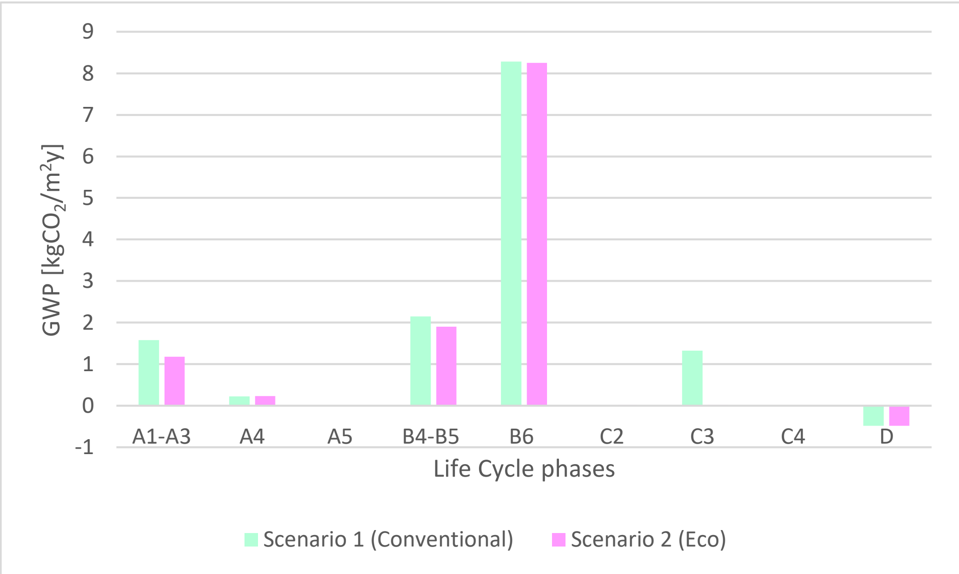


Figure 56. *Comparison of GWP for each of the life cycle phases for scenario 1 and 2.*

For the further comparison between the considered retrofitting scenarios, the Sankey diagrams (**Figure 57** and **Figure 58**) below show the flow of materials for the scenario 1 and 2 respectively. The flow goes from the life-cycle stage to the classifications into the resource types.

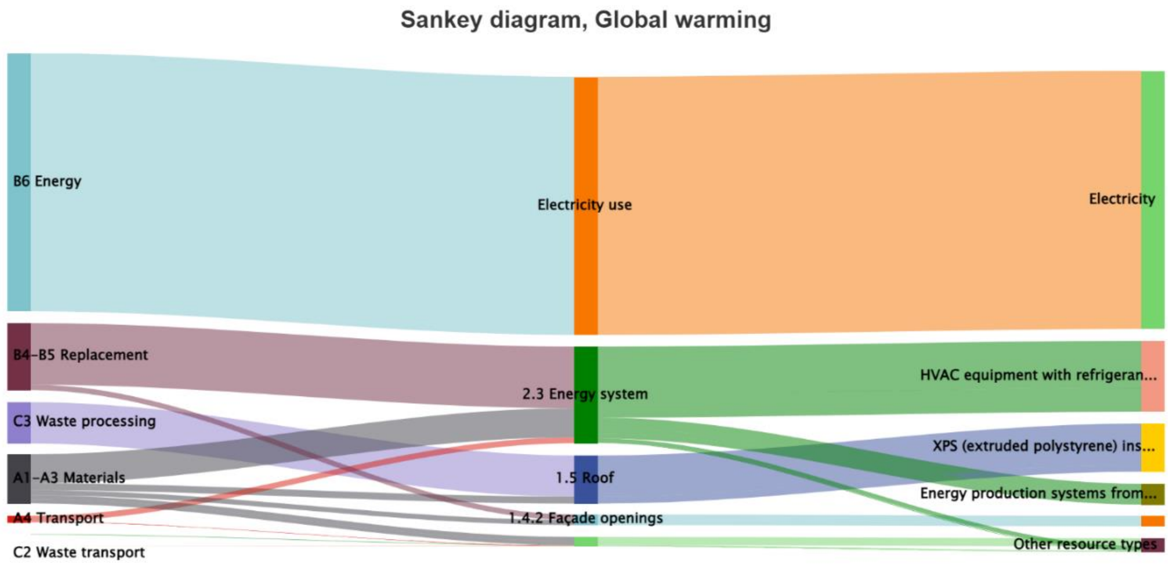


Figure 57. *Sankey diagram of scenario 1 (Conventional).*

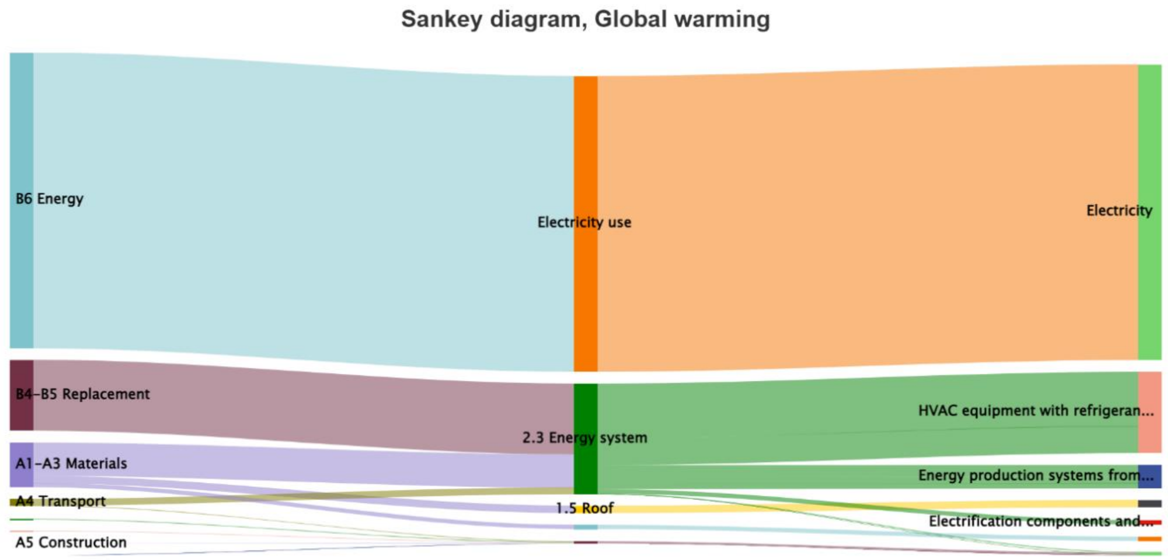


Figure 58. *Sankey diagram of scenario 2 (Eco).*

Based on the results obtained, it can be concluded that the top-3 GWP contributors in both packages belongs to the use phase (B6), following by the material replacement and refurbishment (B4-B5) and finally the construction materials (A1-A3).

In general, both packages of the retrofitting solutions have demonstrated quite similar environmental impact with an overall difference of 15% reduction towards the eco-solutions. However, it´s worth to mention that even though the environmental benefit might be one of the drivers towards the selection of the eco scenarios over the conventional material, it´s important to consider the economic feasibility of the solution. As one of the goals of the large scale retrofitting is to make the retrofitting affordable for the end-users. Based on **Figure 48**, the investment cost for the eco package is 36% higher compared to the conventional solution, therefore, will affect the final users' payments.

Thus, a final decision towards the retrofitting package should be based on the equilibrium between the energy and environmental performance versus the economical affordability of the retrofitting for the final user.

4.6. 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:

- Complete renovation of the building envelope and windows gives the best scenarios in terms of energy performance, but not always in terms of investment or long-term analysis.
- There is no substantial difference between the conventional and ecological solutions in terms of primary energy, and, although there is an increase of the investment in the latter, there is no significant difference in terms of costs over the life cycle of the building.
- In general, the DHW heat pump refurbishment solution is a good option to achieve a greater level of granting also combined with PV systems in some cases.
- In some cases, the increase of insulation thickness significantly increases investment cost without improving the energy performance outcomes. It has been shown how in the Mediterranean climate an excessive insulation of building envelopes leads to an increase in air conditioning needs in summer, which it is neither accompanied by a reduction of the energy in the winter. Hence, 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 for this typology of residential buildings retrofitting.
- It has also been shown that the solutions in this type of retrofitting can be very efficient both in terms of energy consumption and total costs i.e.:
    - the combination of all active measures for Archetypes 1 (large building), 3 and 4 (small buildings)
    - the combination of PV and multi-split for Archetype 2 (medium-size building)
    - Also combinations of heat pumps/multi-split for DHW, heating and cooling without PV for archetype 4
- The adoption of the most ambitious retrofit packages, including window replacement and all active measures and/or ecological options is limited by the investment effort that families can afford. The lowest monthly quotes (considering a basic financial scheme that includes all costs) are in the range of 50-70 €/month which are below 100-120 €, considered acceptable limits for dwellings. Inclusion of window replacement increases the initial investment, leading to values higher than 100 €/month, except for the case of archetype 1, where values can be kept in the order of 50-70 €/month when PV systems are considered together.

Table 20. 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 can be reduced by an average of **36%.**
Embodied Emissions	**At least 50% reduction** compared to local current practice.	GWP of archetype 1 can be decreased by **74%** and **78%** compared to the use stage of the existing building by applying a retrofitting package with conventional and eco materials respectively. When comparing difference between conventional retrofitting solutions with ecological ones, reduction is **15%.**

Finally, in terms of the overall analysis, in all 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

The main objective of this chapter is to define general parameters for the design of new social housing buildings in Southern Europe. This study is based on the experience of the Balearic Housing Institute (IBAVI), illustrated by construction of the building of 35 dwellings in Fornaris street within the ARV project.

This design guide is structured in a sequential manner, starting with the preliminary considerations to be taken into account in the formulation of the architectural brief, and going through all design stages of the building prototype.

This chapter explains the main results of the design process for new social housing in the Mediterranean climate. The project proposes a spatial organization that, combined with a constructive approach, allows for the dwellings with very low energy consumption, a quality living experience and a building integrated into a landscape with architectural value.

The building design process takes place through a public procurement procedure led by IBAVI. IBAVI is the public body in the Balearic Islands acting as developer and owner of the building, who during the last years has already set ambitious targets in terms of energy and water consumption, and reduction of construction waste and embodied CO_2 emissions. In a constant dialogue with the developer, the architects' team, with the support of sustainability experts, proposed a high-quality architectonic design, which allows achieving the original ambitious goals.

5.1. ANALYSIS OF THE CONTEXT

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 conditions. Whereas in the past it was a matter of ensuring the achievement both above-mentioned aspects, today's demand for sustainability also includes a consideration of the resources used.

The project in Fornaris defines a strategy to obtain habitability and comfort at an environmentally reasonable cost of resources by making the most of the opportunities offered by the site, using available resources, techniques and facilities. This strategy seeks to maximise environmental efficiency for each amenity obtained and aims to reduce the number of resources required for the building.

5.1.1. JUSTIFICATION OF CONSTRUCTION

The most sustainable way to build is to build less or not to build at all. Therefore, the first step before proceeding with the design of a new building should be to justify the need for its construction. A needs' assessment is essential to justify both the economic cost of the building and the environmental footprint its construction will create.

In the case of Fornaris building, the justification is given by the housing emergency on the island and the low percentage of public social housing.

The stock of protected rental housing in Spain accounted for 2.5% of the total stock in 2020, which is far from the European average of 9.3% [18]. Therefore, it remains a priority to promote social housing at national level, and especially in areas where the real estate market is under severe pressure

In terms of rental and sales prices, the Balearic Islands reached record levels in 2022. This region had the third highest rent in collective housing in Spain, surpassed only by the Community of Madrid and Catalonia [19]. On the other hand, the price per square metre of real-estate market sales increased by

10,5 % compared to the previous year [20], which was the largest increase in history. These figures have a direct impact on the number of applications for social housing. In 2019, the year of the Fornaris competition, the number of applications was 5 896, 40% more than the previous year. The housing shortage particularly affects vulnerable groups such as dependent persons, victims of gender-based violence and pensioners.

5.1.2. GEOGRAPHIC CONDITIONS

One of the major constraints in a building design is its geographical location. The site access determines the size of the building components, while the distance to the point of extraction and production of the materials has an impact on the CO_2 emissions related to their transport.

In the case study, the fact that the building is located on an island was critical to the design approach and the choice of materials. Concepts such as prefabrication need to be replaced by standardisation due to the scarcity of materials and construction technologies available in Mallorca.

Use of local materials

One of the most important tasks that should be carried out prior to the construction of a building is the preparation of a catalogue of local materials. In this context, IBAVI has carried out research into new sustainable materials combined with the adoption of traditional resource-efficient solutions that are no longer used. By observing and analysing the traditional methods of a region, its map of available resources can be recognised.

"A change in the production and consumption model is needed. If there are more than 7,000 languages spoken on Earth, given the globalised homogeneity of the 20th century, 7 000 languages of reduction need to appear, each adapted to its own territory."[3]

CO_2 emissions from building materials are mainly generated during manufacturing and transport. Therefore, it is essential to rethink these manufacturing processes to reduce emissions. In 2018, IBAVI created a catalogue of sustainable materials in the Balearic Islands, which served as the basis for all IBAVI's new buildings produced to date. The materials were classified from the lowest to the highest energy incorporated. The criteria were ranging from recovered and/or reused raw materials that do not involve an industrial process, to recycled materials or materials from waste or with an optimised industrial process compared to conventional materials that use fossil fuels (oil, diesel, fuel oil, gas, etc.).

A new website with sustainable constructive solutions is currently being developed as part of the ARV project. This catalogue will be a useful tool for designers, construction companies, developers, and other stakeholders to compare different materials and their environmental impacts.

5.1.3. CLIMATIC CONDITIONS

A thorough study of the climatic conditions of the site allows for a design that is better adapted to its location. The introduction of passive measures (insulation of the building envelope, protection from direct solar radiation in summer, bioclimatic galleries, etc.) are not only key to control indoor comfort during the different seasons, but also to reduce the energy demand of the building.

The climate in Mallorca is a temperate and it is located in climate zone B3 of the CTE DB-HE [21], where the severity of the climate in winter is indicated with a letter code (less severe to more severe: α, A, B, C, D, E) and with a number pattern for the heat in summer (4 is the hottest and 1 is the coolest).

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[3] A conversation with Cris Ballester Parets and Carles Oliver Barceló. Liliana Obal. El Croquis.

5.2. DESCRIPTION OF THE BUILDING

Fornaris is a 35-unit residential building in Palma. All the apartments have natural cross-ventilation, which together with the captivating use of the double thermal intermediate spaces acting as greenhouses (front and back), solar control and thermal inertia allows for very low energy demand while maintaining a high level of comfort.

Figure 59. *Image of the façade.*

This design strategy allows for integration with the surrounded built environment and historical background of the neighbourhood . The ground floor is raised above street level in order to improve the relationship between the ground floor apartments and pedestrians on the street, while allowing natural ventilation of the car park. The dwellings are distributed along the access walkway so that all of them have two structural bays - the entrance and a room. Additionally, the vertical columns help to adequately protect the west façade from the sun.

A low-tech design based on load-bearing walls is proposed, which helps to drastically reduce the environmental impact of the construction and improve the thermal inertia of the dwellings, while establishing a tectonic dialogue with the surrounding buildings. Almost all load-bearing walls are oriented from east to west and are perpendicular to the longest side of the building to take advantage of solar radiation evenly over the entire building.

The project areas are summarised in **Table 21**.

Table 21. Summary of project areas.

	Units	Net Areas (m²)	Gross Areas (m²)
Dwellings	35	1 692.87	1 972.87
Technical rooms	-	-	120.32
Access walkway to the dwellings	-	-	186.56
Stairs, lifts and lobbies	-	-	104.20
Carpark	35	-	868.41
Commercial/office unit	1		44.95
Total			**3 297.31**

5.2.1. STAKEHOLDERS

The stakeholders that are part of the new social housing building and their key roles are summarised in **Table 22** and **Figure 60.**

Table 22. List of stakeholders.

Stakeholder	
Landowner& Developer	IBAVI (Balearic Housing Institute)
Funding	Government of the Balearic Islands, EU Next Generation Funds
Lead Architect	DataAE (Claudi Aguiló, Albert Domingo)
Structure Consultant	MVA despatx d'arquitectura
MEP Consultant	Eletresjota tècnics associats
Acoustic Consultant	Àurea Acústica
Environmental Consultant	Societat Orgànica
Cost Consultant	Brufau Cusó Estudi d'arquitectura SLP
Construction Company	Construcciones Alea / Construcciones SILES

***Figure 60**. New social housing building stakeholders.*

5.2.2. TIMELINE

Due to the delay in the construction process, the initial timeline of the project has been updated and is illustrated in **Figure 61**.

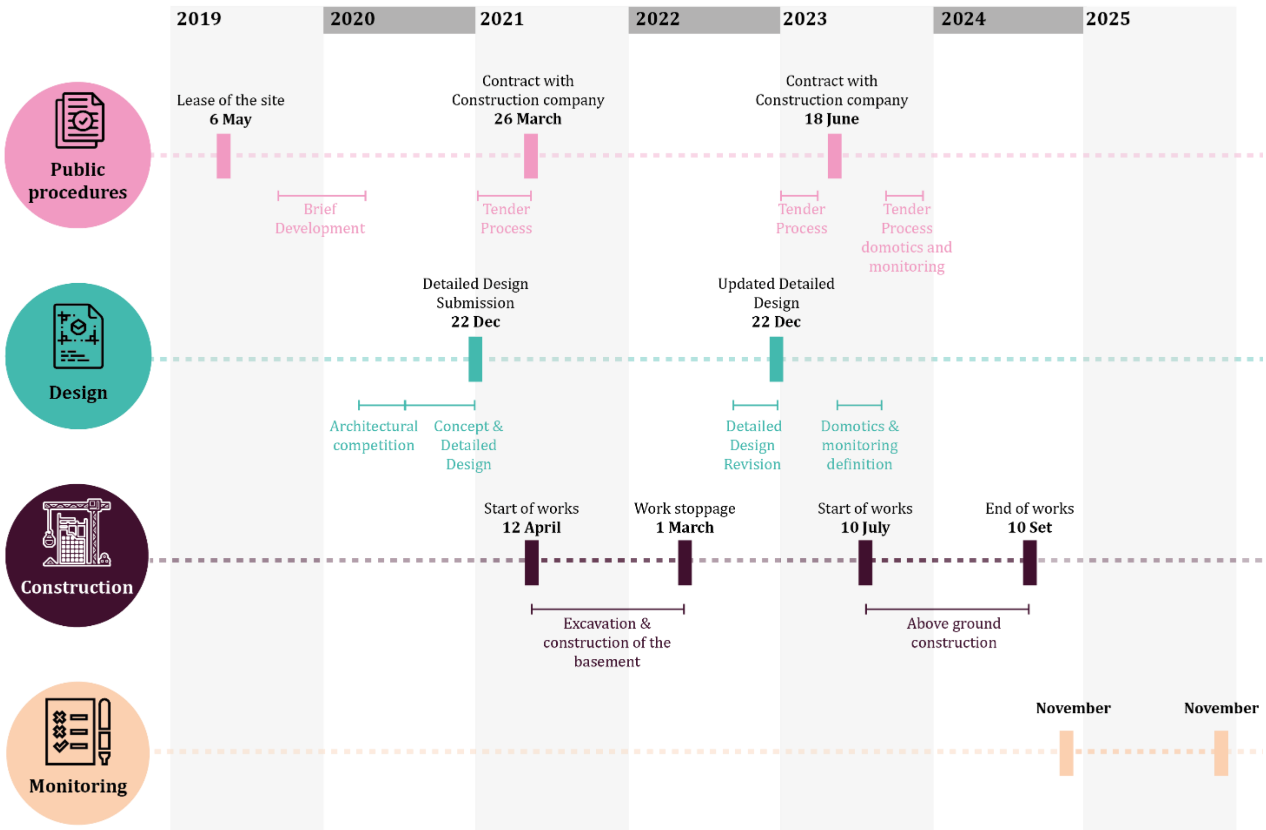

***Figure 61.** Timeline of the project.*

Architectural Competition

In April 2020, the IBAVI published a project tender with jury participation for the construction of five public housing units in Palma and Marratxí, including the plot in Fornaris Street.

For this project, 173 proposals were received, of which 170 were accepted as they were submitted within the deadline and in an appropriate manner. Among all the proposals, a professional jury that met on July 13, 2020, selected the work with the slogan "LITHICA" by DATAAE SLP (Claudi Aguiló and Aran, in collaboration with Albert Domingo i Ollé) as the best work and awarded it first prize.

In the competition requirements, IBAVI defined a number of measures to ensure compliance with the following quantifiable indicators:

- The minimum number of dwellings was set at 30, with proposals exceeding this number being positively evaluated.
- The size of the dwellings was set according to **Table 23.** These percentages are based on the applications received by IBAVI during the year of the 2019 (**Table 24**).

Table 23. *Indicative distribution of the dwelling in the brief of the public competition.*

Number of bedrooms	Max surface per dwelling (m^2)	Percentage of the total
1 bedroom	-	**40%**
2 bedrooms	70	**50%**
3 bedrooms	90	**10%**

Table 24. *Applicants for public housing in Palma in August 2019.*

Number of people per dwelling	Number of applications	Percentage of applications (%)
1	1 473	32.63
2	1 217	26.96
3	804	17.81
4	522	11.56
5	339	7.51
6	126	2.79
More than 6	31	0.69
To be determined	2	0.04
Total	**4 514**	**100**

- The number of carpark units follows the Palma General Urban Development Plan (PGOU) [22], which establishes the need for one parking space per dwelling. No more than one basement is accepted to avoid excessive excavation.

- The building must blend into the landscape of the Can Ribas industrial complex, using local sandstone (mares) as the main material for the façade.
- Implementation of passive measures to ensure indoor comfort in all dwellings such as cross-ventilation features, maximum daylight targets, solar protections for summer, adequate insulation, etc. is required.
- A set of minimum environmental parameters were established following this table:

Table 25. *Environmental parameters required in the competition.*

Parameters	Objective
Energy consumption	<17.20 $kW/m^2/day$
Water consumption	Max 100 l/person/day
Waste during construction	>50 % reduction[4]
CO_2 emissions from materials	>25 % reduction[5]

Design Development

From May to September 2020, the architectural team and IBAVI worked together to develop the project from the competition stage to Concept Design. During this process, the massing, envelope system and solar shading devices were defined to integrate the project as much as possible into the Can Ribas complex. This document was used to apply for the urban planning licence from the Palma City Council, which was finally granted in January 2021.

From September to December 2020, the Detailed Design was developed by the architectural team, by specifying all the construction details of the building. This document was used for the construction company´s tender, which was published in December 2020.

Construction

In March 2021, Construcciones Alea SL was selected as the best bid in the tender process and construction began in April 2021.

Although work progressed rapidly during the earthworks, the construction slowed down considerably with the foundation works. During construction, the project underwent the following changes:

- One-sided continuous retaining walls around the entire perimeter were modified.
- The beams of the car park were modified by a rectangular edge section.
- Stone columns in the car park were substituted by concrete columns. Steel reinforcement above stone vaults was added.

As the masonry work began with stone blocks, the delay increased, and finally the construction site came to a halt in April 2022.

Once the legal procedures were settled, the second call for tenders to continue the work was published in February 2023. During these months, the project has been revised to incorporate the changes made during construction and to simplify some constructive solutions to make construction easier and more economical. At this stage, it is decided to recalculate the solar panels project to make the building an NZEB.

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[4] Percentage of waste reduction compared to theoretical production calculation.
[5] Reduction compared to an average value of CO_2 emissions for all building types: 750 $kg/CO_2 \times m^2$.

Construction works resumed on July 20th 2023, by Construcciones Siles, with an estimated duration of 14 months. As of the date of this report (December 2023), ground floor walls are being erected (**Figure 62**), accumulating a delay of approximately 1.5 months since the works restarted.

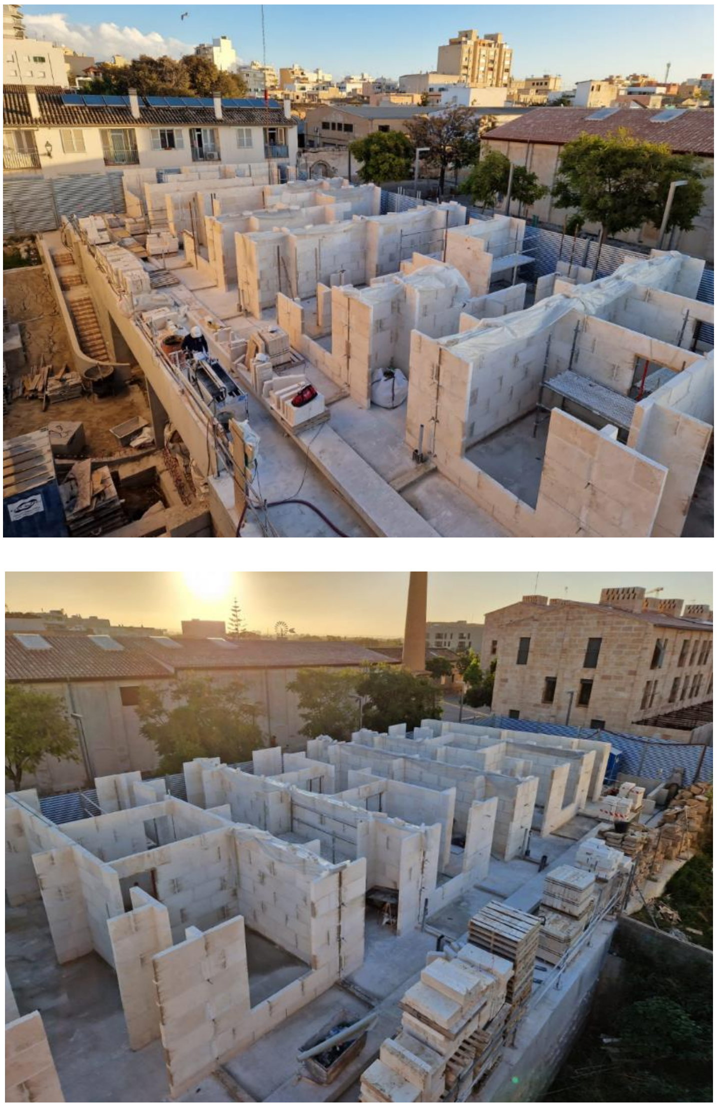


Figure 62. *Current state of the construction site (November 2023).*

5.2.3. ARCHITECTURAL QUALITIES

Aesthetics and visual qualities

The external appearance of the building relates to the Can Ribas' façade and a historic industrial building on the street side. In terms of massing, a single-long compact volume is proposed, following the urban planning and recalling old industrial typologies. At both ends, a porch space on the ground floor separates it from the neighbours and gives access for residents.

On the street façade, the pilasters give the building a constant rhythm and at the same time form the openings to the dwellings.

The entire façade and internal partitions are made of local sandstone (mares), the main material that can be extracted from the island itself and which characterises the traditional local constructions.

On the façade facing the interior garden, the composition follows the same order, but in this case, the rhythm is marked by the thick vertical solar protection elements.

Figure 63*. Integration of the building with Can Ribas.*

Flexibility and adaptability

The parallel load-bearing walls are separated by a distance of about 3 m, creating a network of undifferentiated rooms (**Figure 64**). Within the mesh, an arrangement is proposed that provides alternative and flexible typologies that can coexist as part of the same structure and facade, in order to respond to various social and family needs.

At the same time, this arrangement reduces circulation areas that facilitates an easy use of the interior spaces and even makes it possible to separate part of the house (e.g. the room in contact with the corridor, which could have an independent entrance).

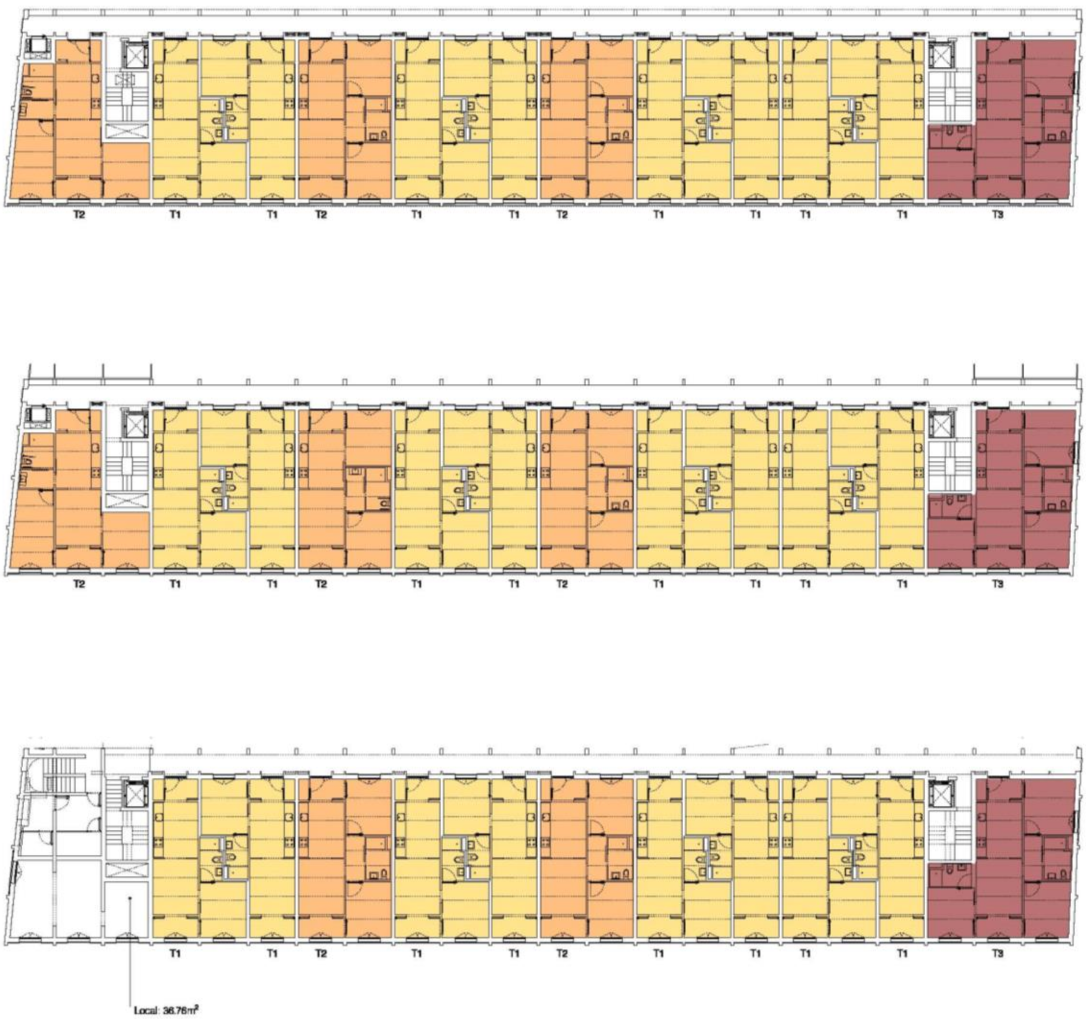


Figure 64. *Typological configuration strategy for the building: second floor (top image), first floor (middle image) and ground floor (bottom image).*

Sufficiency and adequacy of space

In terms of minimum area requirements, the project complies with the local Decree 20/2007 of the 23rd of March, which regulates the size conditions of indoor areas, hygiene and installations for the design and habitability of dwellings (**Table 26**).

Regarding the minimum area per person, there is no local law regulating this parameter. A comparison between dwelling typology, occupants and area can be found in

Table 27.

Table 26. *Comparison between the minimum area requirements of the local code and the project.*

Room	Local Code (min m^2)	Project (m^2)
Living-Dining-Kitchen	18	24-25
Single Bedroom	6	-
Double Bedroom	10	±10.0
Toilet	**2**	**±3.70**

Table 27. Areas per typology and occupants.

Typology	Quantity of dwellings	Occupants per dwelling	Area per dwelling (m^2)	Area per person (m^2)
Typology H1-A	12	2	42.54	28.36
Typology H1-B	12	2	42.52	28.34
Typology H2-A	5	3	56.75	18.92
Typology H2-B	1	3	56.58	18.86
Typology H2-C	2	3	58.73	19.58
Typology H3	3	4	71.18	17.80
Total	35	84	1 692.87	20.15 (average)

A qualitative assessment will be carried out with a Post Occupancy Evaluation (POE) survey (planned July 2025) (**Table 28**). The objective is to measure the level of satisfaction of the users with the dwelling after a few months of living in it. In order to have the results as soon as possible, the survey will be distributed in each flat and collected after one week.

Table 28. *Main aspects to be covered by the Post-Occupancy Evaluation survey.*

	Questions	Number of people surveyed	Level of satisfaction (1-5)
Quantity of space provided	**How satisfied are you with the quantity of space provided?**	Data to be collected	**Data to be collected**
Quality of space provided	**How satisfied with the qualities (privacy, openness, ceiling height, connectivity, materiality...)?**	Data to be collected	**Data to be collected**
Use	**How often are the spaces used (hours per week/day)?**	Data to be collected	**Data to be collected**

Accessibility

The project follows the regional and national accessibility standards (8/2017 Universal Accessibility of the Balearic Islands [23] and National Technical Building Code CTE DB SUA [24]) and summarised in **Table 29**.

In order to have an accessible route to both vertical cores, access to the building is done via the two short sides of the site, providing a comfortable and pleasant experience through the garden. Barrier-free paths lead from the cores to all units.

In terms of providing fully accessible/adapted dwellings, the project includes 3 adapted dwelling units (two bedrooms).

Table 29. Accessibility compliance with local code.

	Local codes	Project
% of exterior space accessible	100	100
Adapted dwellings	3	3
Adapted carpark units	3	3

Solar and daylight access

The proposal presents a plot, which supposes an elongated building with two longitudinal facades facing east and west. The north and south facades are smaller, giving little space for solar heat gain from the south. A major challenge in terms of solar protection comes from the east and west, especially in summer, while offering sufficient solar radiation during the winter.

In winter (**Figure 65** and **Figure 66**), the east facade lacks solar radiation on the lower floors due to the influence of the neighbouring buildings. The north facade, as might be expected, also lacks solar radiation incidence, hence it will be necessary to reduce the openings and to properly insulate the walls.

As with the east facade, the west façade has limited solar heat gain due to vegetation and other environmental factors, the overhangs of the walkways do not prevent the solar radiation from reaching the facade.

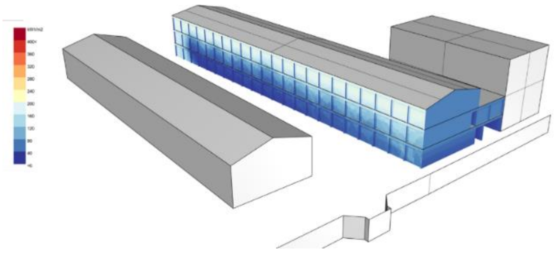


Figure 65. *Solar radiation in north and west facades during winter.*

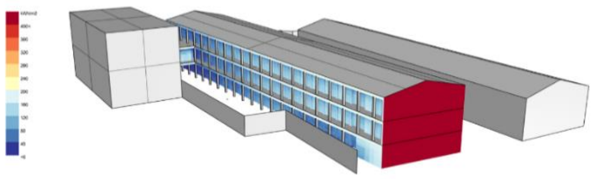


Figure 66. *Solar radiation in south and east facades during winter.*

Contrary in summer (**Figure 67** and **Figure 68**), the east facade needs to be protected from the solar incidence, as the morning sun is more intense than on the north and south facades. The west façade is more penalised by the afternoon sunshine therefore a sun protection solution is necessary.

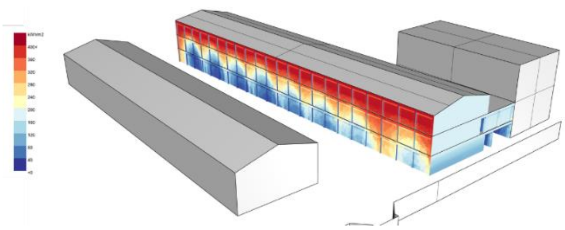


Figure 67. *Solar radiation in north and west facades during summer.*

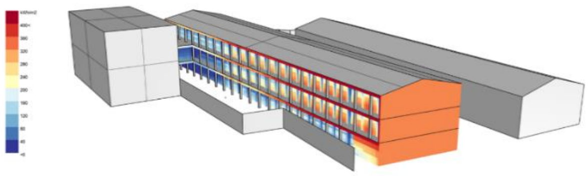


Figure 68. *Solar radiation in south and east facades during summer.*

- **Street facade**: Solar protection and shading are achieved with Mallorcan shutters, which are movable and give control to users. At the same time, they provide the necessary privacy on the ground floor, with the porticos on this floor divided into two sections to facilitate different levels of privacy and adaptability.

- **Garden façade (Figure 69** and **Figure 70)**: 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 the solar control is achieved by using sandstone ribs on the outer walls of the corridor. The direct solar radiation on the interior facade of the garden is greatly reduced thanks to the shadows cast by the vertical ribs.

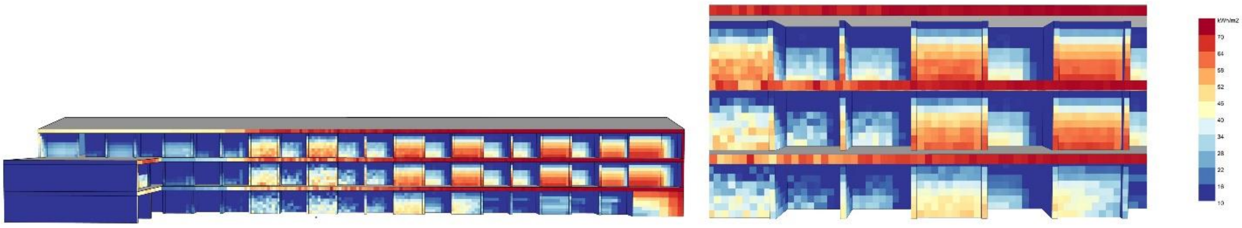


Figure 69. *Image of solar radiation without solar protection ribs in the garden facade.*

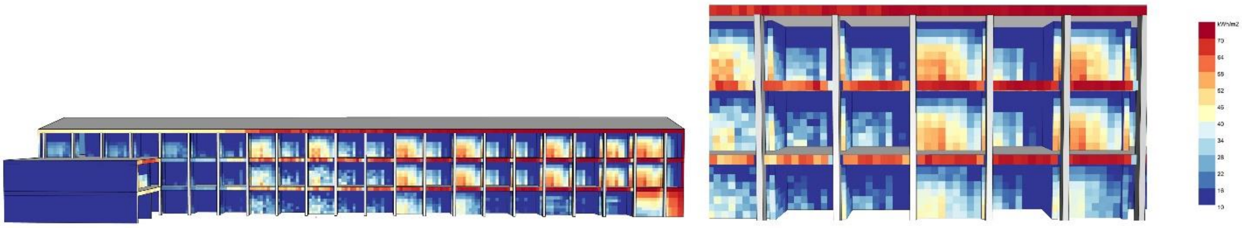


Figure 70. *Image of solar radiation with solar protection ribs in the garden facade.*

In terms of minimum illumination area, the project complies with the local code Decree 20/2007, 23rd March [25], which regulates the size conditions of indoor areas, hygiene and installations for the design and habitability of dwellings (**Table 30**).

Table 30. *Illumination compliance with local code.*

Room	Local Code (min m^2)	Project (m^2)
Living-Dining-Kitchen	**2.50**	**3.28**
Bedroom 1	**1.00**	**2.48**
Bedroom 2	**1.00**	**3.28**

5.2.4. MATERIAL SELECTION, RECYCÑED SOURCES AND REUSABILITY

The catalogue of sustainable materials was used as the basis for the project´s material selection, using as many local materials and components as possible (approximately 42% of the mass of building comes from the island).

The prefabrication of the horizontal Forest Stewardship Council (FSC) [26] certified wooden structures, the use of natural materials such as marés (Balearic sandstone) for the load-bearing walls and the reduced presence of concrete and metal in the works allow for a significant reduction of CO_2 emissions and waste during production.

Sandstone (mares). “Marés” is the most used material in traditional construction in Balearic Islands. It can be found scattered throughout the countryside, towns and cities of the islands, including in representative buildings and vernacular architecture. Consequently, marés is a reliable material that withstands the passage of time without changing its characteristics. The prototype in Fornaris is the first IBAVI project to use a 10 cm thick stone wall as a structural element (instead of 20 cm). This advance was possible thanks to the geometry of the building, which is very repetitive, has small spans and is structurally connected in both directions. In this way, the mass of the building (and the material extraction) is significantly reduced. On the other hand, a 10 cm thick block is lighter and facilitates construction as it can be assembled without a crane.

Wooden structures. The project proposes a prefabricated, one-way floor slab of joists (75 x 200 mm) and glulam panels (63 mm thickness) with FSC-PEFC forestry label. Although this is not a local product, as there is no industrialisation of this sector in the Balearic Islands, it is a natural, renewable and biodegradable material with a low environmental impact.

Posidonia insulation. In the Balearic Islands, dead Posidonia leaves are one of the most common types of residues, which is why dried oceanic Posidonia was used as thermal insulation, just as it was in traditional architecture. Although Posidonia is a protected plant and its use must be authorised by the Ministry of the Environment, Decree 25/2018 on the Conservation of Posidonia Oceanica [27], the abundance of dry Posidonia in the Balearic Islands allows for its traditional use as thermal insulation in construction. Moreover, it does not require artificial treatment, as sea salt acts as a preservative and biocide. In the new social housing building in Fornaris, this material will be used to insulate the roof (20 cm thickness compressed to achieve 150 kg/m^2 density).

A thorough analysis of all materials in the building has been carried out. An overview of the main materials in the Fornaris building can be found in (**Table 31**). An extended table can be found in Appendix **G.4. Materials inventory.**

Table 31. *Simplified material selection.*

	Material	Share of total building mass (%)	Local	Cycled source	Reusability	Life Span
Vertical Structure, facade & basement vaults	**Sandstone (mares)**	38.62	Yes	No	Reuse (preparing for)	200
Horizontal Structure	**Laminated timber**	2.22%	No	No	Reuse (direct)	80
Joists	**Precast concrete**	4.10%	No	No	Reuse (direct)	100
Basement structure	**Concrete**	26.25%	No	No	Recycling (mix stream)	100
Structural reinforcements	**Steel**	1.05%	No	No	Recycling (pure stream)	100
Screeds, stairs and other elements	**Concrete**	11.44%	No	No	Recycling (mix stream)	100
Roof Structure	**Galvanised steel**	0.05%	No	Yes	Recycling (pure stream)	100
Facade insulation	**Recycled Mineral wool**	0.08%	No	Partially	Recycling (mix stream)	100
Roof insulation	**Natural seagrass (Posidonia)**	0.48%	Yes	Yes	Reuse (direct)	100
Timber pallets for roof insulation	**Recycled timber**	0.43%	Yes	Yes	Reuse (direct)	80
Waterproofing	**EPDM waterproof sheet**	0.04%	No	No	Recycling (mix stream)	50
Roof finish	**Terracotta tiles**	0.81%	Yes	No	Reuse (direct)	50
Floor finishes	**Polished concrete**	7.87%	No	No	Recycling (mix stream)	100
Wall finishes (toilets)	**Ceramic tiles**	0.14%	Yes	No	Recycling (mix stream)	50
Doors, Window frames and solar protections	**Timber**	1.13%	No	No	Reuse (direct)	20

Materials from cycled sources
In terms of materials from cycled sources (considering reused, recycled or remanufactured materials), these are the materials considered from cycled sources:

- All galvanised steel: at least 80% has to be recycled.
- Mineral wool insulation: 50% considered from cycled sources.
- Neptune seagrass insulation.
- Timber pallets used as a frame for roof insulation.

Following circularity KPIs defined in Chapter 8.1 of the ARV deliverable D2.1 Assessment Framework for CPCC [28], the ratio of materials from cycled sources represents 1.06% of the total mass of the building.

Although these components represent large areas of the building, they are lightweight materials, therefore, the impact on total value is small. If the volume of materials (m^3) is considered instead of the mass (kg), the materials from recycled sources would account for 10.36%.

Reusability
IBAVI has included in several projects the direct reuse of sandstone blocks, ceramic tiles, timber beams and wooden carpentry. Other materials such as concrete, steel or glass could also be recycled. Considering the mass (kg), the total amount of reusable materials is 73.31%.

5.2.5. AFFORDABILITY

Affordability of energy
One of the main objectives of the project is to minimise the energy demand. By using passive measures, the combined annual demand for heating and cooling was reduced by 82.10% (6.21 kWh/m^2) compared to an average demand for all types of buildings (34.73 kWh/m^2).

The above-mentioned POE survey, which also accounts for energy affordability, will be conducted in 2025 including the following questions (**Table 32**). The number of “true" responses will be used to calculate the percentage of affordability of energy.

Table 32. *POE survey questions on affordability of energy.*

Survey questions	Number of respondents	Number of respondents with ”True”	Affordability of energy (%)
Question 1 (affordability of energy as indicated by composition of household expenditure). Compared to your last residence: Have you spent more or less or the same on expenses connected to annual energy production?	Data to be collected	Data to be collected	Data to be collected
Question 2 (affordability of energy	Data to be collected	Data to be collected	Data to be collected

as indicated by arrears in utility bills). Has your household been at any time unable to pay utility bills on time due to financial difficulties for the last year?

Affordability of housing

The dwellings of Fornaris building and all those currently under construction by IBAVI are on a rental basis for 7 years. Applicants must submit the necessary documentation to prove their annual income, personal and employment situation, family commitments, etc.

The price per m² varies depending on the municipality, the building and the size of the property. In any case, the maximum amount a tenant may spend on rent shall not exceed 30 % of their monthly income. This factor guarantees the affordability of housing in all IBAVI buildings.

The POE survey will be conducted with the following questions (planned for 2025).

Table 33. *POE survey questions on internal affordability of housing.*

Survey questions	Number of respondents	Average total cost of housing household	External affordability (1-10)
Question 1. How much do you spend on expenses related to your dwelling (for example rent, mortgage, maintenance), excluding energy costs?	Data to be collected	Data to be collected	Data to be collected

Table 34. *POE survey questions on external affordability of housing.*

Survey questions	Number of respondents	Number of respondents with "True answers"	Internal affordability %
Question 2. Compared to your last residence: have you spent more or less on expenses connected to your dwelling (for example rent, mortgage, maintenance), excluding energy costs?	Data to be collected	Data to be collected	Data to be collected

5.2.6. GLOBAL INVESTMENT COST

The project budget has been a major constraint from the design phase. The aim was to build as many dwellings as possible without compromising on sustainability and respect for the environment.

The use of local low impact materials implies an increase in the cost compared to other mass-produced products. To compensate for this, all non-elementary elements such as claddings and ceilings are removed, exposing structural elements. On the hand, a repetitive and standardised layout is proposed, minimising exceptions, and achieving a very efficient construction.

The improvement in thermal insulation and the production of energy through PV panels also mean an increase in the initial investment (**Table 35**). As a result, the building achieves an A energy certification, which substantially reduces energy costs for tenants. An estimate of the annual cost, including energy, operational and maintenance costs, will be made in the coming months.

Table 35. *Initial investment costs of the prototype.*

	Cost [€]	**Price [€/m²]**
Product and construction cost	5 229 980 €	1 586 €/m²
Taxes	522 998 €	
Management cost (architect fees, planning permits, licenses...)	774 010 €	
Total	**6 526 988 €**	

5.3. ENVIROMENTAL STRATEGY

The proposal suggests passing typologies along the east and west axis. These orientations, enforced by urban planning, do not have an ideal solar heat gain in winter, nor in summer. The proposal compensates for these constraints by generating in its volumetric definition movable elements, thermal intermediate spaces that give the building a dynamic form (compact in winter and more dissipative in summer) and an effective façade plan to obtain a more absorbent exterior in winter and a more protected interior in summer (**Figure 71**). Captured elements will generate hot air, which in turn will be used to ventilate the main spaces in contact with them via micro-ventilation. In addition, the orientation of the windows towards the south is maximised as much as possible.

In terms of energy saving, insulation is maximised in the spaces that are in contact with the outside and high thermal resistance windows are proposed in combination with a high solar factor.

To reduce cooling, external, and internal openings are proposed in the house to guarantee cross/ventilation features, as well as "Mallorcan-style" blinds to intercept solar radiation, while leaving a free passage for air and ventilation.

The vertical structure of the building is made of sandstone, which, in addition to the environmental benefits in terms of embedded CO_2 emissions reduction, also brings important advantages for indoor comfort. The resulting thermal inertia, as well as the hygroscopic behaviour of the materials used, allow the building to regulate the temperature fluctuations of day and night and provide high level of comfort to users during most of the year.

The initially estimated energy demand for heating and cooling during the design phase is 4.90 kWh/m^2, excluding the impact of cross ventilation features and fans' effects on the indoor comfort. Throughout the project, the design criteria have focused on reducing energy use as much as possible to create a building that provides users' comfort with minimal consumption **Figure 72**. As for strategies to reduce water consumption, the installation of efficient appliances and the reuse of rainwater are being considered. Through these strategies, it is estimated to reach a consumption of less than 65 l of water/person/day.

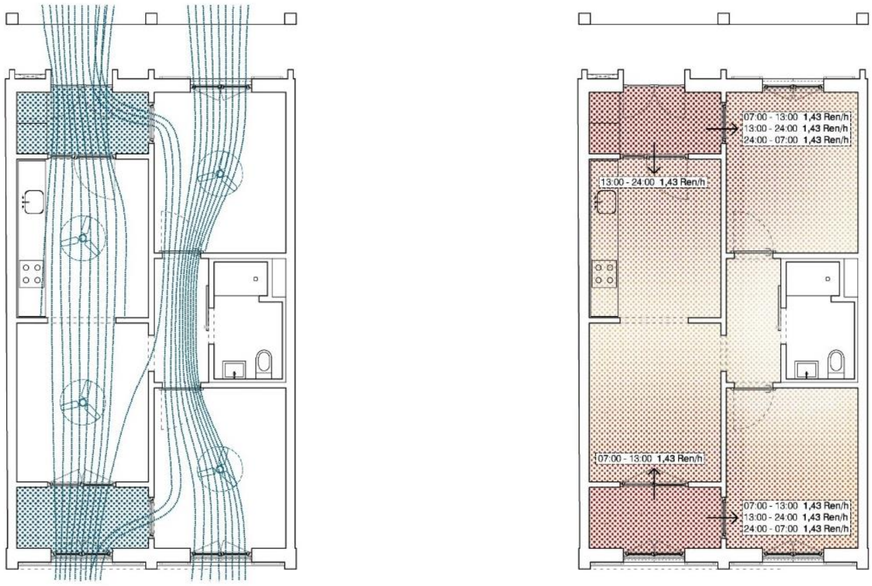


Figure 71. *Ventilation strategies in summer (left) and harvesting of solar gains in winter (right).*

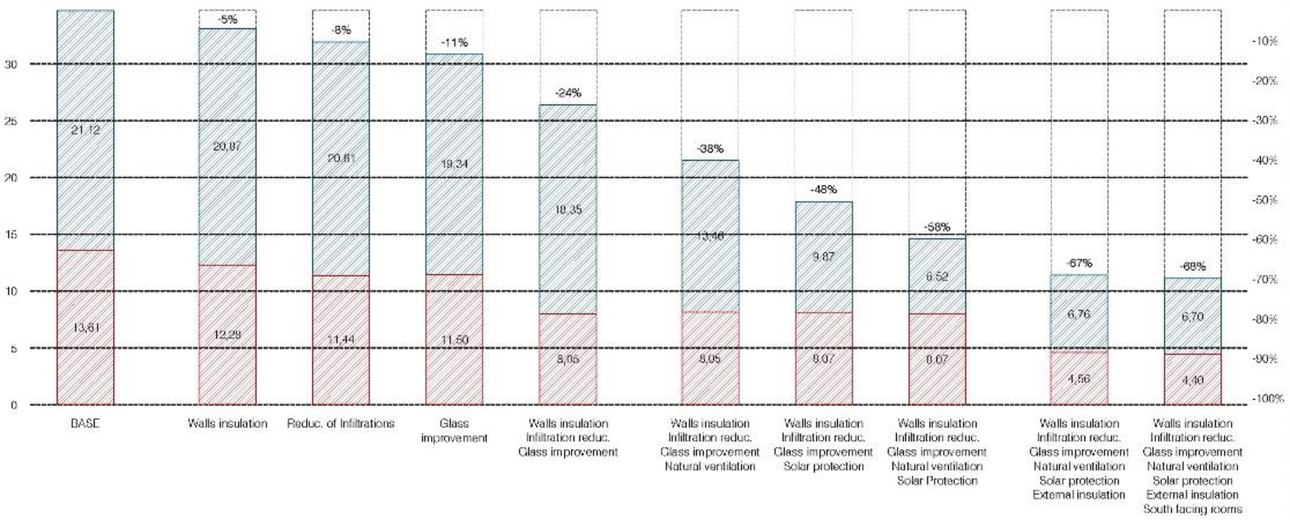


Figure 72. *Summary of passive and envelope improvement measures. Extracted from the project documentation.*

5.3.1. PASSIVE MEASURES

The building has been designed with a range of passive measures to ensure indoor comfort while enabling a highly energy efficient system. By combining thermal inertia and solar shading, this building achieves a high level of indoor comfort without cooling or heating systems.

Highly efficient envelope

A fundamental measure in the design is to increase the insulation performance of the materials to respond to a high level of demand, since the effort in terms of thermal loads will be optimised. Therefore, it is important not to lose the accumulated energy unnecessarily. To carry out the energy simulation, the construction details of the project report have been accounted. The project requires a good level of thermal transmittance of the enclosures in contact with the outside, based on the recommendations of the technical code for energy savings.

In summary, the following thermal envelope closures remain:

Table 36. Thermal transmittance of the envelope.

Element	U-value (W/m²K)	Total thickness (cm)
External wall	0.35	30
Internal wall	1.09	22
Internal slab on a parking lot	0.30	36
Internal slab of the house (on slab P1)	0.26	40
Pitched roof	0.19	40
Flat roof	0.25	25

Once the conditions of the building envelope were determined, the model was simulated using a dynamic energy simulation program that allows to extract the demand of each space and read off the elements that have the greatest impact on heat loss or gain. Both the variability and the management of the elements were considered.

Bioclimatic elements

One of the key points of the project is the adaptability of the building to the conditions of each season. The building was designed accounting for the orientation of the plot and making maximum use of the bioclimatic conditions offered by an environment, which is close to the sea. In this way, dwellings have two galleries facing east and west, which serve as thermal barrier to keep the apartments as isolated as possible from external conditions. Through an automatically controlled bioclimatic system (**Figure 73**), it is possible to ventilate these galleries in summer or to capture and conserve heat in winter for each flat individually, thus achieving a high level of comfort.

The problems associated with the heat loss during the winter are usually related to the minimum ventilation required by regulations. During the design process, three models were considered for the ventilation of the east/west galleries.

Model 1. An initial study has been carried out by applying the requirements of the CTE-HS3 [29] (Technical Building Code in Spain) for minimum ventilation. This method defines the number of air renovations per hour based on the use of the specific room and its volume.

Model 2. Once the demand of air renovations per hour has been calculated, a second study has been carried out, taking into account the solar gains in winter due to the orientation of the building. In the morning hours, priority will be given to the east gallery, as it has a greater solar gain. In the afternoon, the system is reversed and catchment from the west gallery is prioritised. During the night, air renovation is only required in the bedrooms.

Model 3. The strategy adopted is performed through an automatic indoor comfort system. Sensors will be installed to measure thermal (temperature and humidity) and air quality (CO_2) conditions. Based on predefined parameters, the windows to the galleries will be automatically opened/closed to allow air exchange and improve comfort levels.

__Table 37.__ Comparison between air renovation models.

2-bed typology	Model 1	Model 2			Model 3
		7-13h	*13-24h*	*24-07h*	
Gallery East (Ren/h)	2.85	2.85	2.85	1.43	dynamic
Gallery West (Ren/h)	1.43	1.43	1.43	1.43	dynamic

__Figure 73.__ Bioclimatic elements for the automatically regulated system.

The management of the thermal intermediate spaces is very important as they allow the optimisation of systems and the energy saving potential of building materials. However, if these spaces are not managed appropriately, imbalances can eventually occur inside, leading to overheating in summer (if there is no ventilation or adequate protection) or to cold temperatures in winter if the capturing potential is not used.

A simulation of the building (**Figure 74**) corresponding to the final version of the executive architecture project has been carried out without adequate management of this thermal cushion space in winter. An option has been simulated in which the user does not ventilate using this space but directly from the outside – with the understanding that he/she is not correctly managing the thermal cushion as a heat collector space but as a balcony. Even though in this case the function of the heat buffer is partially fulfilled, at the same time the solar radiation is impaired because the solar rays have to go through two glasses instead of one.

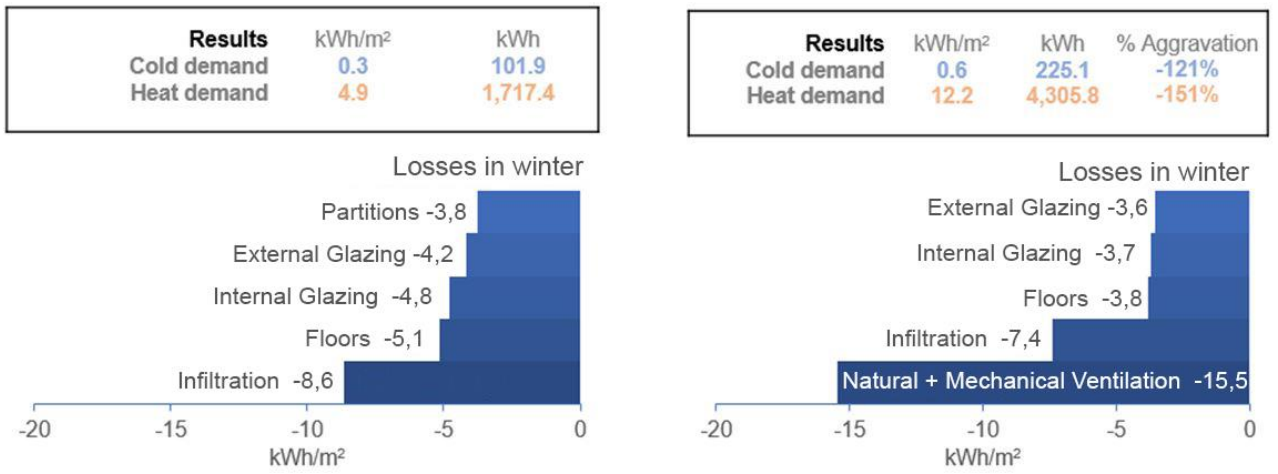


Figure 74. *Galleries with management (left) and galleries without management (right). Extracted from the project documentation.*

5.3.2. ACTIVE MEASURES

Domestic Hot Water System

The energy demand for hot water has been calculated on the basis of the Spanish Regulation and corresponds to a value of 38 454 kWh/year with a total DHW consumption of 1 028 l.

The production of hot water has been considered by using an air source heat pump installed in every dwelling, with a SCOP (Seasonal Coefficient of Performance) of 2.94 kWh/year. The energy demand for the air source heat pump will be generated by the PV panels installed on the roof of the building. **Table 38** summarises the results obtained.

Table 38. *Energy demand and electricity consumption for hot water.*

Concept	kWh/year
Hot Water Demand	38 454
COP	2.94
Electricity consumption	13 079

Even though the cost of the Aerothermal Heat Pump for DHW is higher than that of a conventional Domestic Hot Water Tank, the energy consumption will be drastically reduced (approximately -75%), balancing the initial additional costs of the system. Some other advantages and disadvantages are summarised below:

Advantages:

- Aerothermal Heat Pumps with PV energy systems are more efficient than thermal solar DHW.
- Less energy consumption means less CO_2 emissions.
- Demand and need can be potentially shifted to solar production hours.

Disadvantages:

- High initial installation costs.

Photovoltaic system

This building was designed to achieve an annual net zero energy demand to become NZEB. In the original project 52 PV panels were covering the 73.8% (23 241 kWh/year) of the energy demand (31 479 kWh/year). In August 2023, the project was revised to become a Positive Energy Building (PEB), so that the energy generated by the PV system will be, at least, equal to energy demand considering heating, cooling and DHW. A reduction coefficient of up to 87.5% due to plate degradation during its lifetime and a reduction coefficient for dirt and rain of 5% have been considered for the calculation.

The revised project considers the installation of a Building-Applied Photovoltaics (BAPV) system, consisting of 88 photovoltaic panels on the roof connected to the grid. Grid-connected production systems can be considered as one of the applications that have experienced the greatest market growth in the last few years, as they optimise the design and operation of products and complete installations.

Table 39. *Comparison between original and reviewed PV project*

	Energy production (kWh/year)	PV panels (units)	Energy production per panel (kWh/year)
Original Project	23 241	52	446.9
Reviewed Project	38 899	88	442.0

Based on geographical location, the daily irradiation depending on the date and time, the shadow study, and the orientation and inclination of the panels, the production of the installation per month can be estimated.

Table 40. *PV electricity produced per month (kWh/month)*

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 417	1 919	3 155	4 065	4 900	4 956	4 938	4 338	3 317	2 379	1 516	1 216

In addition, it should be noted that the estimated energy production has a daily average of 104.44 kWh, with the production fluctuating throughout the year, depending on the sun´s path, shade, etc. The theoretical total production is 38 121 kWh/year within the first year. Applying to this figure some average reduction coefficients (-12.5% average loss of efficiency in 25-years lifespan and -5% dirt and rain), we obtain a 25-years average total production of **31 688 kWh/year** per a building gross internal floor area of 1 688 m^2.

The renewable energy ratio is the amount of energy from renewable sources over the total primary energy demand and can be calculated as follows:

$$\boldsymbol{RER} = \frac{\boldsymbol{E_{p,ren}}}{\boldsymbol{E_{p,tot}}}$$

Where:

$\boldsymbol{RER}$ – Renewable Energy Ratio [-];

$\boldsymbol{E_{p,ren}}$ - renewable primary energy consumption [kWh/m^2 y];

$\boldsymbol{E_{p,tot}}$ - total primary energy consumption [kWh/m^2 y].

Table 41. *Renewable energy ratio.*

	kWh/m² y
Renewable Primary Energy	18.76
Total Primary Energy Demand	18.64
Renewable Energy Ratio	**1**

5.3.3. COMFORT PERFORMANCE

Indoor air quality

Controlling CO_2 levels is crucial to avoid health symptoms such as respiratory diseases, allergies, headaches, and others. As a general strategy, air renovation in winter will be done through the galleries to east/west, controlled by an automatic indoor comfort system. CO_2 sensors will be placed in each room to activate the opening/closing of the windows when levels exceed/decrease 1000 ppm. For air exhaust, there are mechanical exhaust systems in the bathrooms and kitchens.

Following the IEQ categories defined by the European Standard EN 16798-1-2019 [30], CO_2 levels will be measured in 9 dwellings for 12 months. The percentage of each category will be calculated, and the results will be summarised in **Table 42**. The goal will be to demonstrate that at least 80% of the time during full occupancy is in IEQ_I and IEQ_{II}.

***Table 42**. Air Quality levels, defined in ISO EN16798-1-2019.*

Percentage of time	Data to be collected during monitoring stage			
Air Quality IEQ	**IV**	**III**	**II**	**I**

Thermal Comfort

The analysis of the annual comfort serves as a global view of the comfort situation is in the entire building. Since the values are taken globally, the average of the good and bad performances in relation to the different floors is obtained. It also gives a representative picture of what values lie in between. In order to understand the overall situation, the most extreme periods are usually analysed, as the intermediate periods require a fine-tuned management of the façade systems, either automatically or manually. In these situations, management scheduled according to the calendar can generate great discomfort, whether due to heat in the "colder" periods or cold in the "hotter" episodes. Since an automatic control system is planned for the upper windows, but not for the other elements of the building envelope (sun protection and doors), an appropriate user's manual management is considered fundamental. The periods to be studied are therefore the most extreme in terms of external climate conditions (winter and summer).

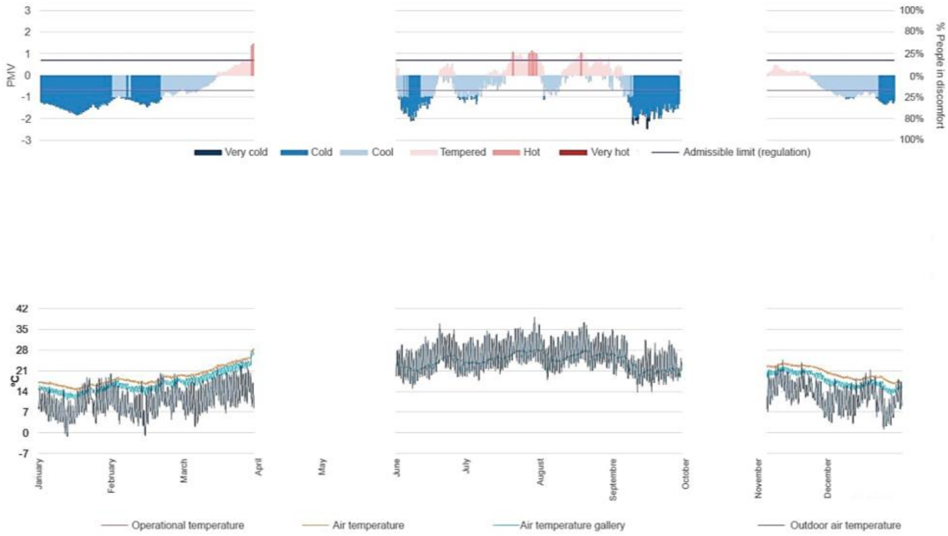


Figure 75. *Overview of the annual comfort analysis. Extracted from the project documentation.*

A comprehensive analysis of comfort in winter and summer has been carried out and can be found in **Appendix G – Calculations for new social housing building.**

Following the IEQ categories defined by the European Standard EN 16798-1-2019, air temperature levels will be measured in 9 dwellings for 12 months. The percentage of each category will be calculated, and the results will be summarised in **Table 43**. The goal will be to demonstrate that at least 80% of the time during full occupancy is in IEQ$_{I}$ and IEQ$_{II}$.

Table 43. *Operative temperature defined in ISO EN16798-1-2019.*

Percentage of time	**Data to be collected during monitoring stage**			
Operative temperature IEQ	**IV**	**III**	**II**	**I**

Overheating risk

In order to prevent overheating in dwellings, the building has been designed with traditional solar protections, allowing cross ventilation (coastal breeze) to regulate overheating and thermal discomfort in summer. According to the comfort study carried out, the greatest risk of overheating occurs in the flats under the roof during the heat peaks in summer, when 13% of the hours are above 27ºC. In this case, comfort is achieved by using a ceiling fan to increase the air speed.

Graphs and detailed analysis can be found in chapters *Summer comfort* and *Summer comfort in flats under the roof* in **Appendix G – Calculations for new social housing building**.

Humidex is an indicator that describes how hot the weather feels to the average person by combining the effect of temperature and humidity, derived from the dew point. The calculation and definition of the discomfort ranges are defined in chapter 7.8 in ARV deliverable D.2.1 Assessment Framework for CPCC. The percentage of each category will be calculated, and the results will be in **Table 44**. The goal will be to demonstrate that at least 60% during estimated occupied time, Humidex is <35 (little discomforts or noticeable discomfort).

Table 44. *Humidex percentages.*

Percentage of estimated occupied time	Data to be collected during monitoring stage					
	H<30 Little or no Discomfort	**30<H<35** Noticeable Discomfort	**35<H<40** Evident Discomfort	**40<H<45** Intense Discomfort	**45<H<55** Dangerous Discomfort	**H>45** Heat Stroke Probable

Acoustic Comfort

The envelope systems, partition walls and finishes of this project comply with the HR CTE (Technical Building Code in Spain) for noise protection and can be summarised in **Table 45**.

Table 45. *Acoustic reduction of the different elements of the building.*

Element	Acoustic reduction (dB)	Total thickness (m)
External wall	54	0.30
Windows	31	-
Internal wall – between different dwellings	59	0.22
Internal slab on a parking lot	53	0.355
Internal slab – between different dwellings	53	0.4
Pitched roof	43	0.4

Outdoor comfort

Access to sun or shade (depending on the season) was studied in this project. The description of fixed and moveable façade systems depending on orientation was given in the section **Architectural qualities.**

5.3.4. ENERGY PERFORMANCE

Methodology

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

Based on the energy simulations, the weak points are detected and the insulation thicknesses, finishing materials and specific thermodynamic properties of the materials have been reviewed. This analysis is reflected in the indoor comfort of the dwellings, which is the final indicator of the building's solvency.

Energy label

The CE3X tool was used to carry out the energy performance certificate (EPC). With this tool, energy simulation is required, but the model conditions are different, as the bioclimatic elements that contribute to reducing demand are not represented. The systems used by CE3X are conventional systems with scheduled patterns and air conditioning schedules. Although these are less favourable compared with the simulation made by the Design Builder, it can be observed that the energy rating obtained is a class A with an estimated primary energy consumption of 10.7 $kWh/m^2/year$, and carbon dioxide emissions of 2.8 $kgCO_2/m^2/year$.

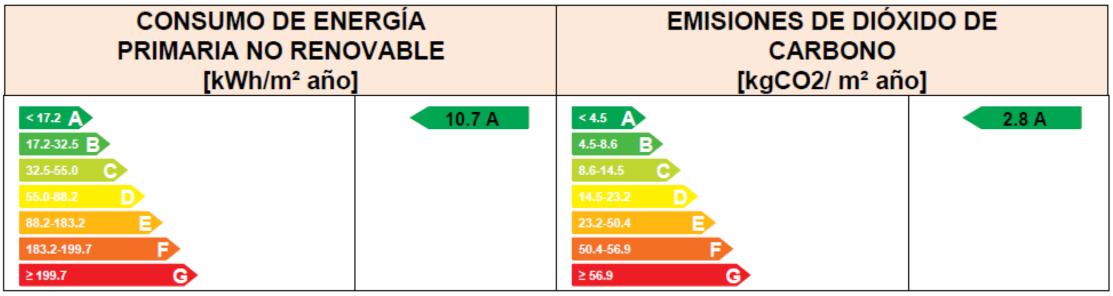


Figure 76. *Energy labelling of the analysed building. Non-renewable primary energy consumption (left) and CO_2 emissions (right).*

For the EPC, the following calculation parameters have been considered:

- Thermal bridges have been considered according to the *Therm* [31] calculation program and have been included in the calculation of 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 single envelope solution. Therefore, the capture has been generated on the outer plane where the insulation line is located, with a common transmittance of all elements.
- The seasonal shading defined in the openings is valid from June to October.
- A daily hot water consumption is 2016 l/day.

Table 46. *Indicators and percentage of reduction from average indicators.*

	Absolute number	**Reduction from average indicator**[6]
CO_2 emissions	561,2 kg CO_2/m^2	-25 %
Heating and cooling demand	6,21 kWh/m²	-82%
Water Consumption	72 l/pers. Day	-40%

As explained in section 5.3.2 Active measures, the project of the solar panels has been revised in August 2023, increasing the number of PVs from 52 to 88 units. The updated energy labelling shows a non-renewable primary energy consumption of 0 kWh/m²y, and carbon dioxide emissions of 0 $kgCO_2/m^2y$.

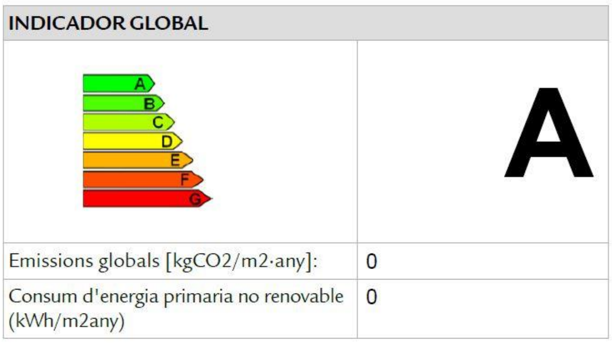


Figure 77. *Energy labelling after increasing the number of PV panels.*

[6] Reductions from emissions and consumption average of buildings metrics. Calculated from TCQ software.

5.3.5. GREENHOUSE GAS EMISSIONS

A project focused on sustainability, such as the one presented, must provide information on the resources required to achieve the desired conditions of use and comfort.

The building´s response to the physical requirements of sustainability, i.e., the environmental quality it will obtain throughout its life cycle, especially during the phases of extraction and the manufacturing of materials (where up to 90% of the environmental impact is concentrated), can be summarised by four basic indicators:

- **Materials:** the consumption of materials is equivalent to the final weight of the various elements that make up the building´s fabric, including waste during construction.
- **Energy:** the consumption associated with all processes throughout the life of the building, in particular, the extraction and production of materials and the daily use of the building (mainly air conditioning, DHW and lighting).
- **Water:** water consumption for sanitation, cleaning, irrigation, and air conditioning during the use of the building.
- **Waste:** generation and management of waste generated during the construction of the building.

In addition, an overall indicator is:

- **CO_2 emissions:** Release of carbon dioxide associated with the generation of energy used throughout the life cycle of the building.

5.3.6. LIFE CYCLE ANALYSIS (LCA)

Scope of evaluation

The scope of the evaluation activity is linked to the determination of the KPI **Lifecycle GHG emissions in CPCC**:

Documents from the Detail Design (Level 2) have been used for the calculation of the LCA with OneClick platform. This assessment addresses only GHG emissions.

Functional unit

In ARV, the functional unit that should be adopted is the square meter of gross internal area. Summary of gross internal floor areas can be found in **Table 47**.

Table 47. *Summary of gross internal floor areas.*

	Gross internal area (m^2)
Basement	Excluded as "open sided carpark"
Ground floor	637.71
Level 1	643.26
Level 2	643.26
TOTAL	**1 924.23**

The adoption of the number of people living or working in the building as an additional functional unit would permit a normalization for the actual capacity of the construction: the reduction of floor space per capita is, in fact, a good strategy to spread the environmental impacts associated to the building sector on a higher number of people, reducing so the overall burden. The expected capacity of the building can be found in

Table *27*.

LCA system boundaries

The system boundaries describe the unit processes to be included in the system. LCA system boundaries considered for the study can be found in **Table 48**.

Table 48. *LCA system boundaries considered for the study.*

Category	Stage	Description	Considered
Embodied upstream	A1	Raw material supply	**Yes**
Embodied upstream	A2	Transport to the manufacturer	**Yes**
Embodied upstream	A3	Manufacturing	**Yes**
Embodied upstream	A4	Transportation to the construction site	**Yes**
Embodied upstream	A5	Construction/installation process	**Yes**
Embodied downstream	B1	Use	**No**
Embodied downstream	B2	Maintenance	**No**
Embodied downstream	B3	Repair	**No**
Embodied downstream	B4	Replacement	**Yes**
Embodied downstream	B5	Refurbishment	**Yes**
Operational	B6	Operational energy use	**Yes**
Operational	B7	Operational water use	**No**
End-of-life	C1	Dismantling	**Yes**
End-of-life	C2	Transport to disposal	**Yes**
End-of-life	C3	Waste processing	**Yes**
End-of-life	C4	Waste disposal	**Yes**
Benefits	D	Energy exportation	**Yes**

Life Cycle Inventory (LCI)

The life span of the building is considered equal to 50 years for this assessment. If a building component has a useful life that is lower than 50 years, its substitution should be taken into account by adding the related environmental impacts as a whole (e.g., without any partial replacement). By default, OneClick does not consider components with higher service life, and applies as maximum the life span of the building considered for the assessment (in this case, 50 years). This consideration implies that materials with a long service life with no maintenance, such as stone, do not have the positive impact on the results that they should have.

For the life span of the materials, EPDs from OneClick database have been used. As a reference, service life of the main components can be checked in **Table 31**.

Results

Although the current LCA will be reviewed in the following months to make it more precise, initial results have been extracted.

As expected, most of the CO2 emissions (47%) are produced during the extraction, transport, and manufacturing of the materials (A1-A3 stages), accounting for 427 $kgCO_2/m^2$. This value is in line with the initially set targets of a -25% carbon emissions reduction in these stages compared to a reference value of 750 $kgCO_2/m^2$, achieving a -43% reduction.

Although it has been reduced substantially compared to a reference building, operational energy use (B3 stage) is also relevant accounting for 34%. A comparison of how each of the phases contributes to the overall GWP of conventional and eco retrofitting solutions is demonstrated in **Figure 78**.

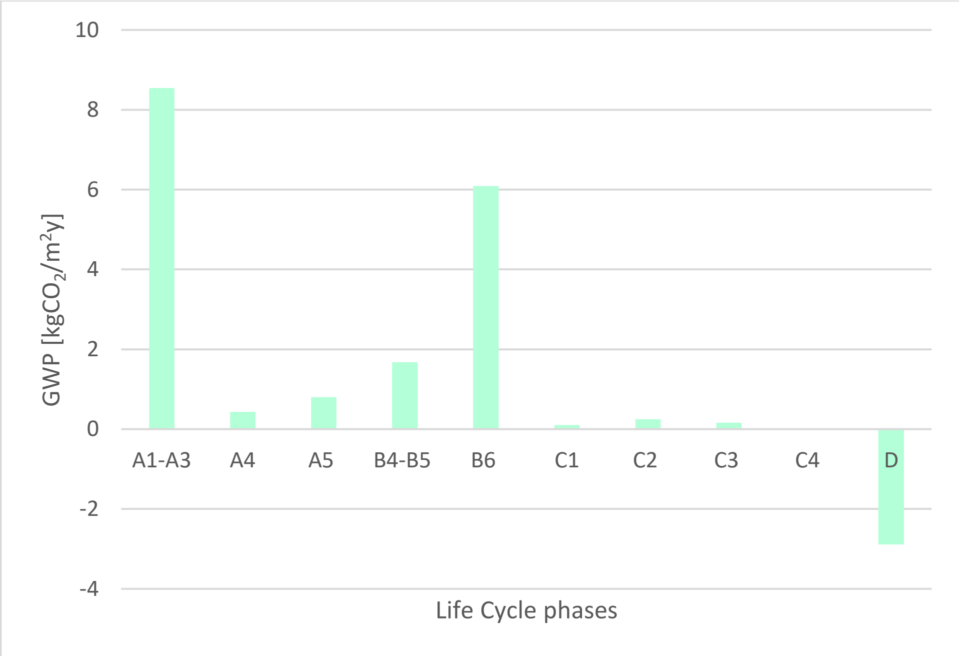


Figure 78*. Comparison of GWP for each of the life cycle phases.*

Regarding emissions allocated in different parts of the building, **Figure 79** shows how most of them are part of foundations, beams and columns. **Figure 80** shows the Sankey diagram, where the flow goes from the life-cycle stage to the classifications into the resource types.

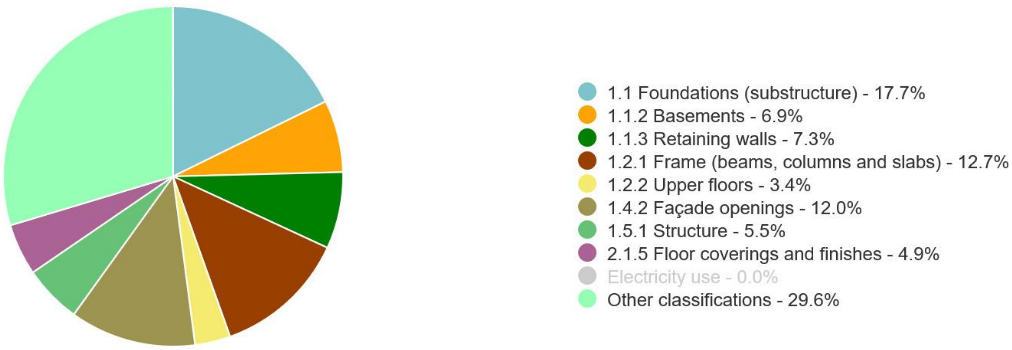


Figure 79*. Global warming kg CO_2e – Life-cycle stages. Image from OneClick.*

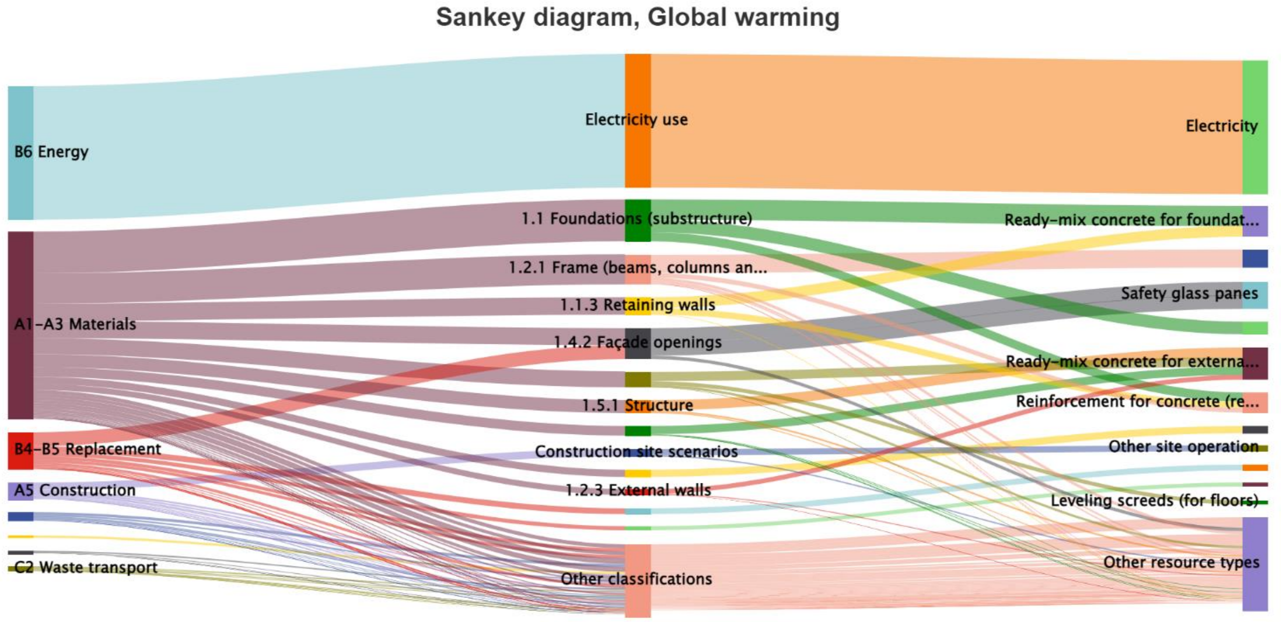


Figure 80. *Sankey diagram, Global warming. Image from OneClick.*

5.4. SUMMARY

This chapter explains 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, 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 process design and procedure are within the frame of public procurement procedures leaded by IBAVI. IBAVI is the public body in the Balearic Islands acting as promoter and owner of the building. It already 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.

Table 49*. 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. According to the cradle to grave Life Cycle Assessment carried out (including A1-A5, B4-B6 and C1-C4 stages), the building will produce 18.06 $kgCO_2/m^2y$. Embodied emissions achieve a **43% reduction** from the reference value of 750 $kgCO_2/m^2$
Construction/retrofitting costs	**At least 30% reduction** compared to local current practice.	
Natural low-impact materials	The use of **traditional local materials** represents around the 42% of the mass of the building, significantly reducing the emissions in transport and helping local industries. 10.3% of the volume of the building comes from **cycled sources**, while 73% could be **recycled or reused** at the end of the life of the building.	

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/ENEL. 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 81. *GESA building and surrounding areas. Adopted from* [32].

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 [33]. 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
The refurbishment of old office buildings with BIPV in the Mediterranean region is a topic scarcely tackled in the literature [31]. 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 82**.

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.

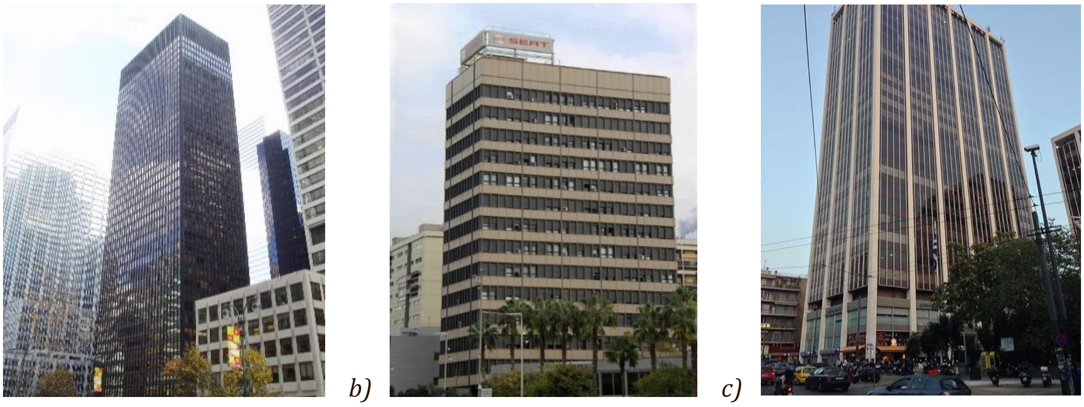


Figure 82. *Some images of Modern architecture buildings of the 60s. a) Seagram building in New York* [34], *picture by Steve Cadman licensed under CC BY-SA 2.0, b) SEAT building in Barcelona* [35], *picture by Albert Esteves and published with the permission of the author and c) Athens Tower in Athens* [36], *picture by Dimitris Kamaras licensed under CC BY-SA 2.0.*

The stakeholders that are part of the GESA building refurbishment project (**Figure 83**) 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 is in dialogue 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.
- **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 potentially host exhibition and office areas that will be used by the City Council of Palma. The building would also incorporate more offices and two restaurant/store areas. **Figure 84** and **Figure 85** show the proposed project.

Figure 83. *GESA building stakeholders.*

Figure 84*. Planning "use classes" (part 1).*

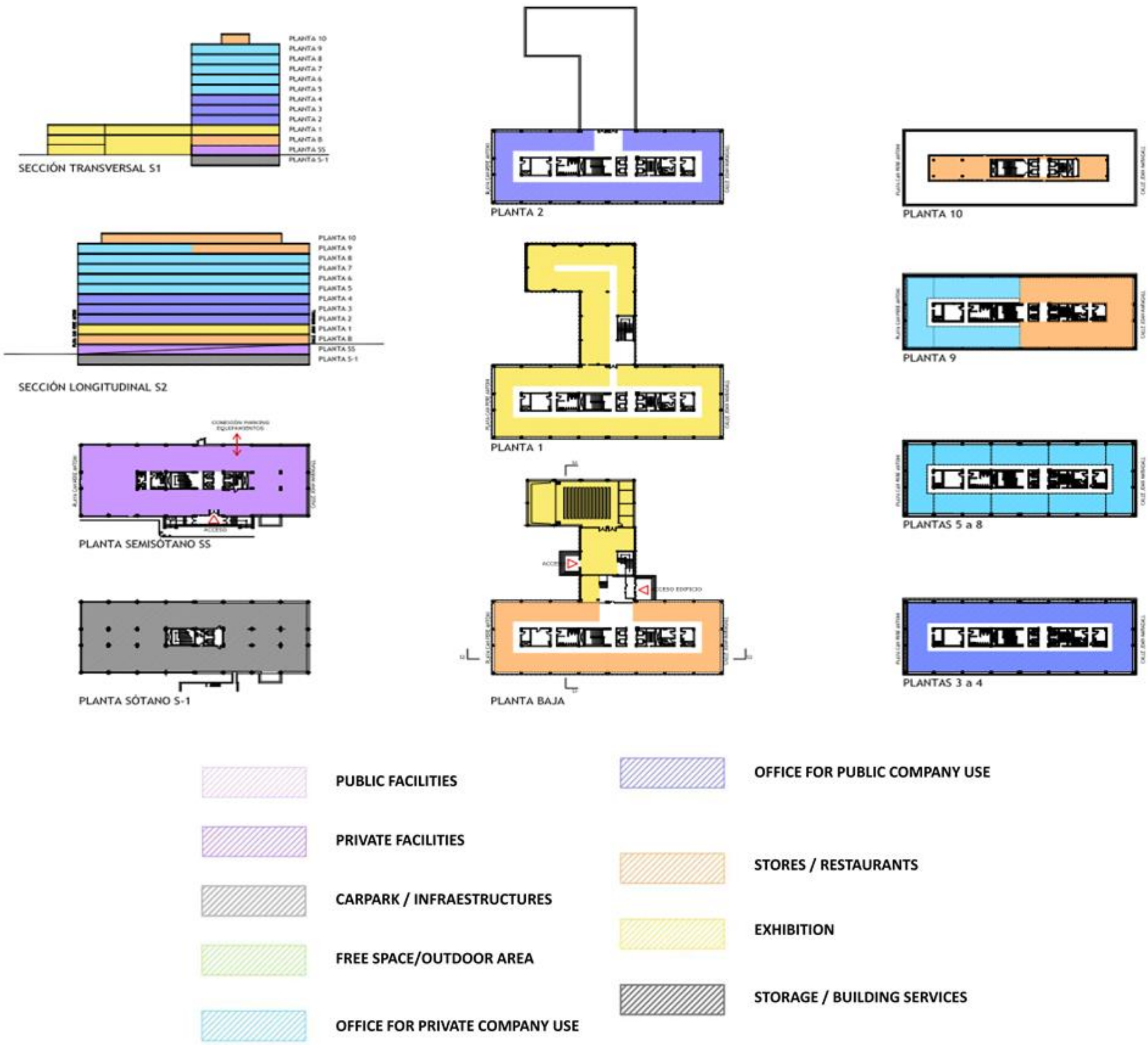


Figure 85. *Planning "use classes" (part 2).*

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).

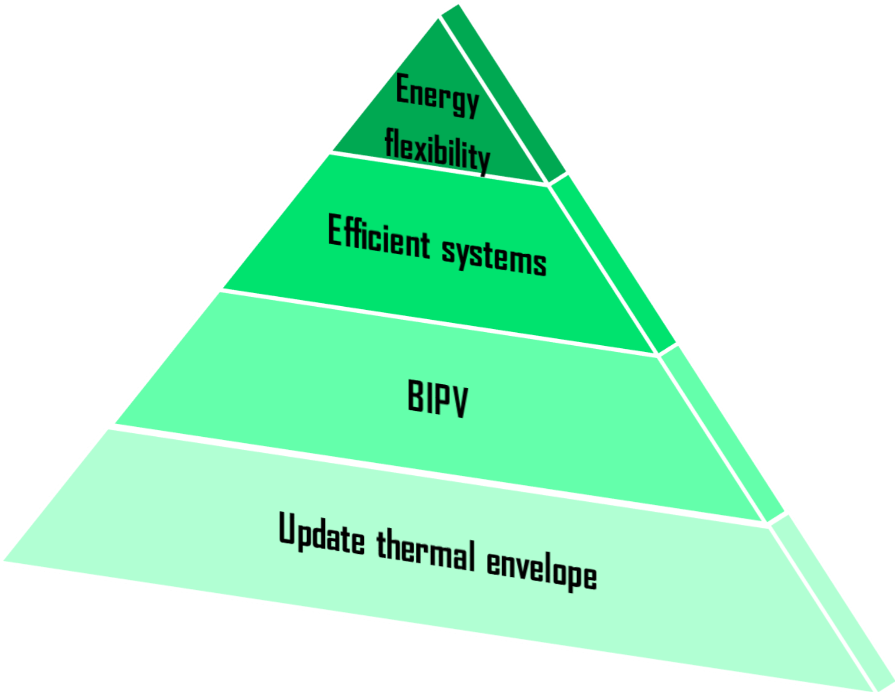


Figure 86. *The integrated energy design process strategy.*

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 [37], 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 [21]. 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.

Apart from that, the GESA building, and its refurbishment will be assessed under an environmental and economical perspective as well.

6.3. ENERGY AND ENVIRONMENTAL PERFORMANCE OF THE BUILDING IN ITS CURRENT STATE

In this chapter, the building in its current 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. Current 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 87. *Pictures of the façade*

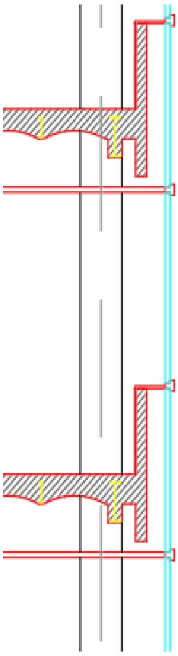


Figure 88. *Technical drawing – Detail of the façade section.*

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[7].
- 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.

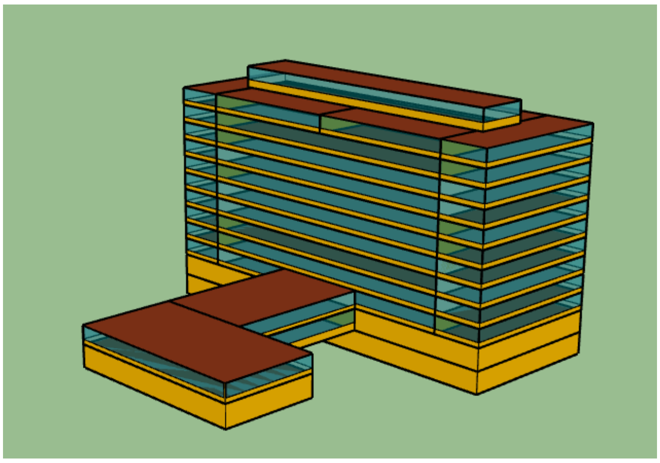


Figure 89. *3D model for the GESA building used in TRNSYS18.*

[7] 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.

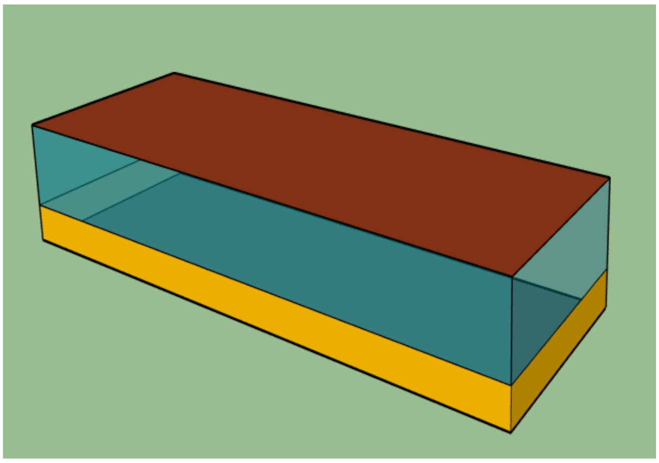


Figure 90. *3D model for the detailed zone used in TRNSYS18.*

6.3.3. ENERGY AND ENVIRONMENTAL RESULTS FOR THE GESA BUILDING IN ITS CURRENT 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 50. *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 51.__ 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 [38].
- Conversion factor for Primary Energy - 2.967 kWh_{EP}/ kWh EF.

The heat pump that has been used to have a preliminary look at the energy consumption and CO^2 emissions is just a theoretical model that is not linked to the final HVAC configuration that will be proposed on the next chapters.

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

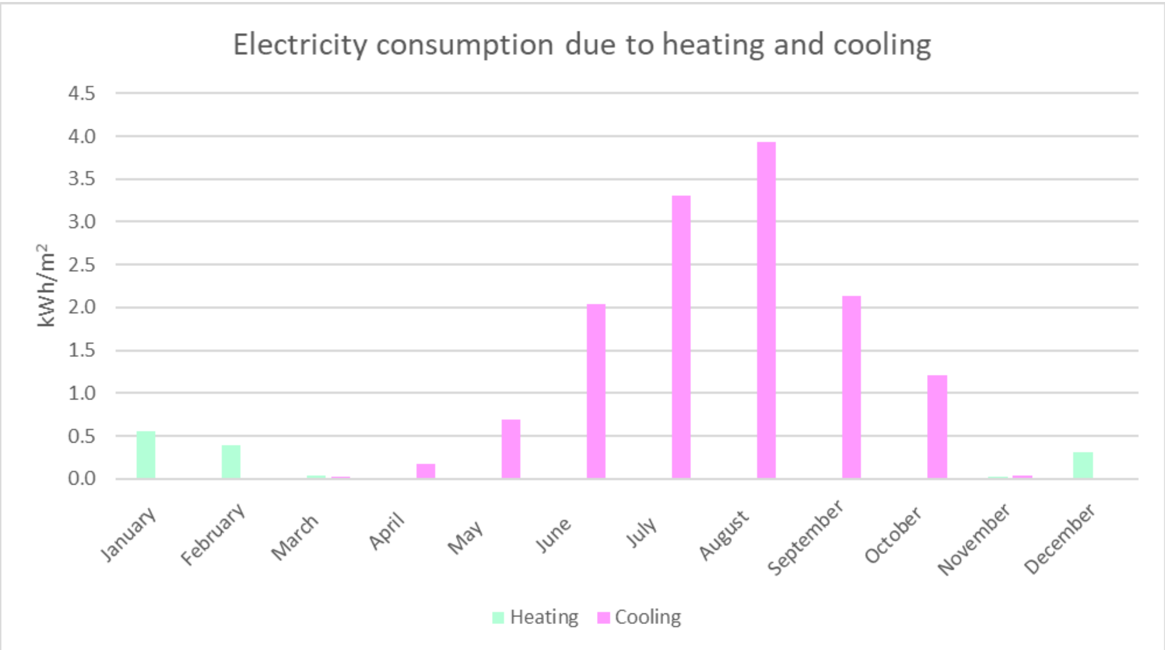


__Figure 91.__ Electricity consumption monthly distribution due to heating, cooling and humidity treatment.

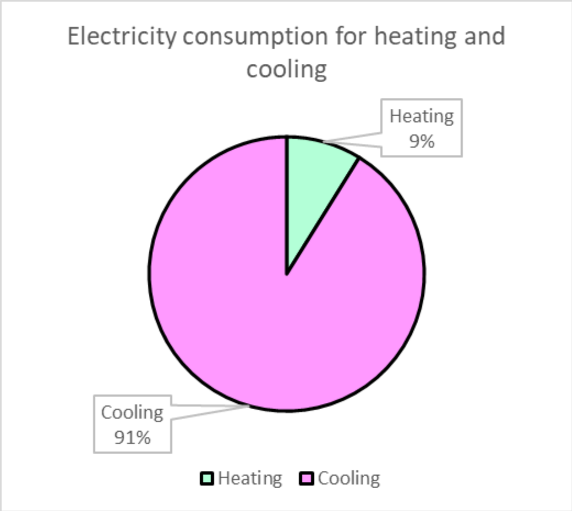


Figure 92. *Electricity consumption percentage due to heating, cooling and humidity treatment.*

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/m² year.
- Electricity consumption due to lighting - 19.0 kWh/m² year.
- Electricity consumption due to DHW - 3.86 kWh/m² year.

When only heating and cooling are considered in **Table 52**.

Table 52. *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/m² year*
Primary Energy consumption	44.1	*kWh/m² 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 53**).

Table 53. *Primary energy consumption by services.*

	Primary energy consumption				
	Heating & Cooling	**Ventilation**	**Lighting**	**DHW**	**Total**
	kWh/m² year	*kWh/m² year*	*kWh/m² year*	*kWh/m² year*	*kWh/m² year*
Offices in GESA Building	44.1	14.0	56.5	11.5	126.0

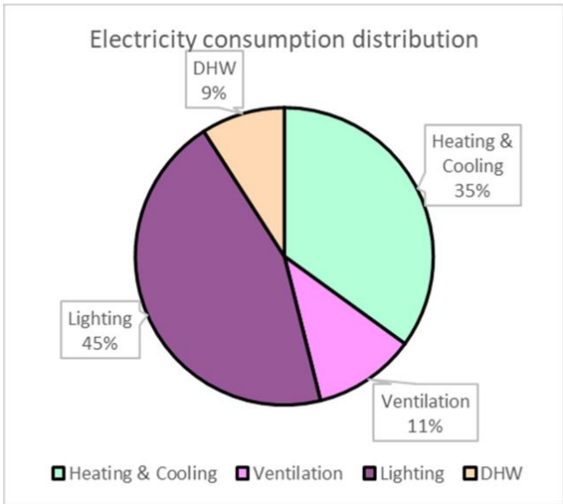


Figure 93. *Primary energy consumption for offices in the GESA Building.*

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 94**).

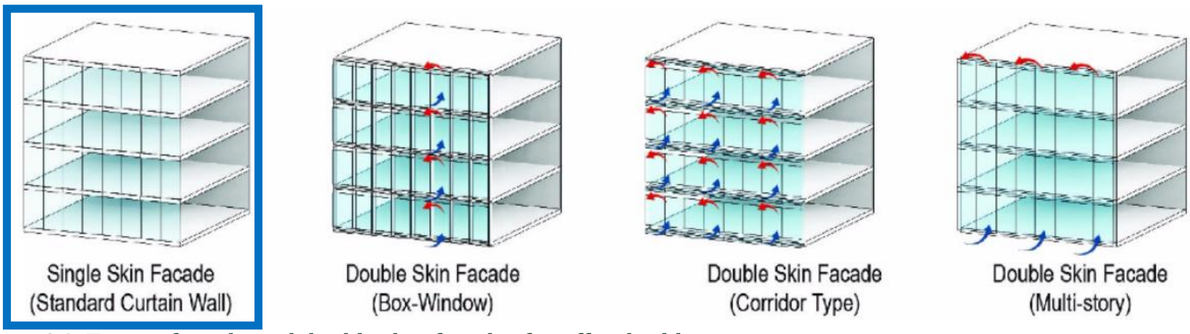


Figure 94. *Types of single and double skin façades for office buildings.*

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.

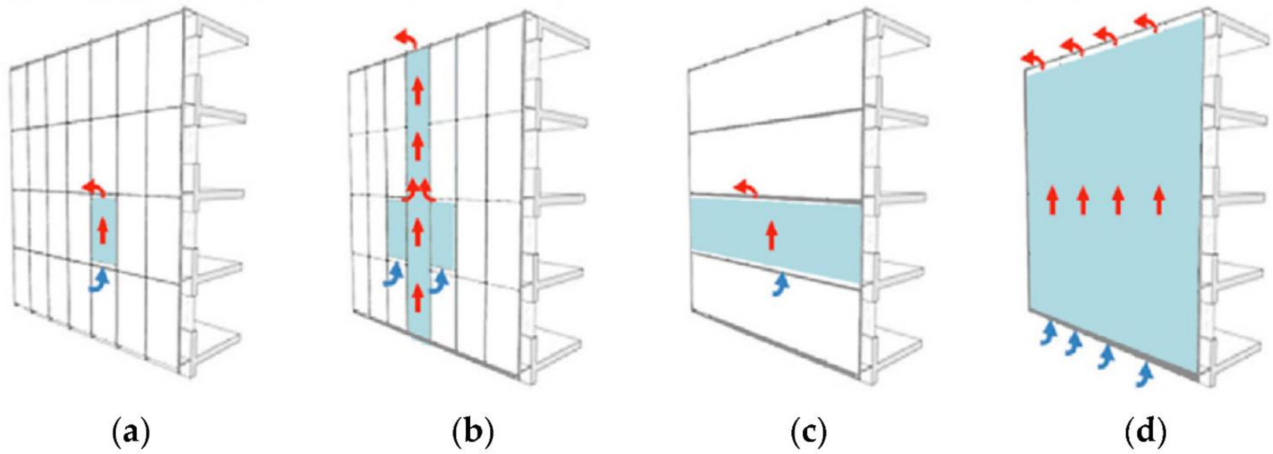
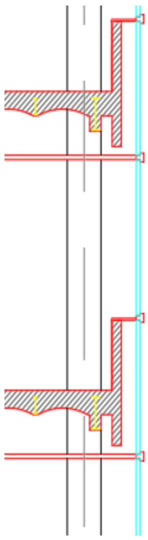
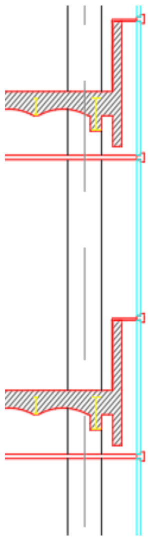
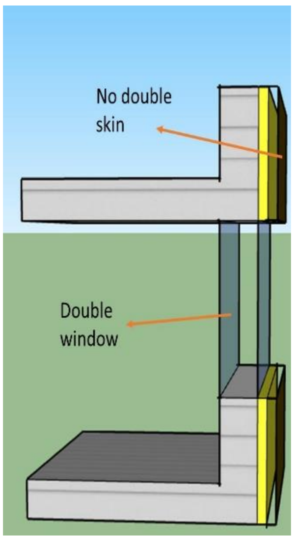
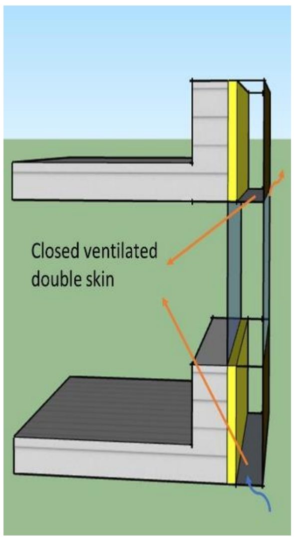
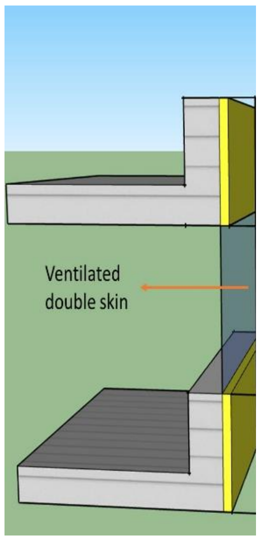
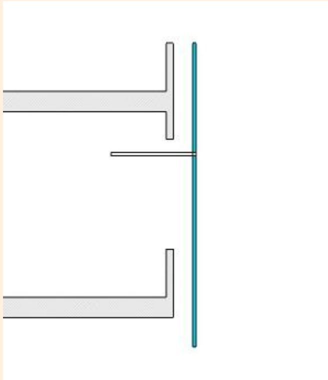
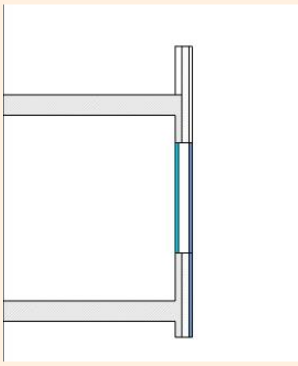
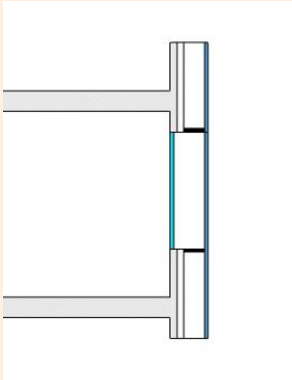
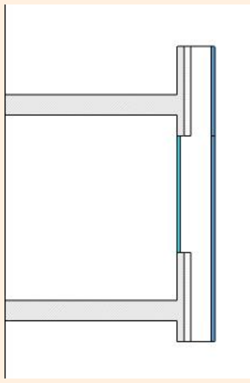


Figure 95. *Types of single and double skin façades for office buildings.*

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 54**).

Table 54. *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 glasses 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, both in the opaque and transparent parts of the façade.

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 55**).

Table 55. *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	Ventilated façade PV-glass single solution Interior glass PV panel on opaque façade	Ventilated double skin façade (slabs) PV glass single solution Interior glass	Ventilated double skin façade (continuous) PV glass single solution Interior glass

		PV panel on opaque façade Opaque façade insulated	Opaque façade insulated	PV panel on opaque façade Opaque façade insulated	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. PASSIVE SYSTEMS ANALYSIS AND PERFORMANCE

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 56**).

Table 56. *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 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
U_{wall} (W/m^2K)	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 96** and **Figure 97**):

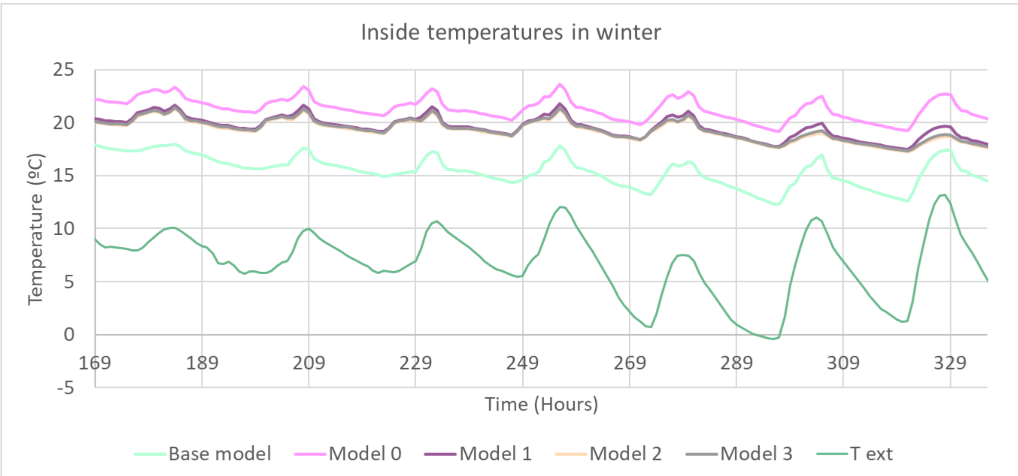


Figure 96. *Inside temperatures for a winter week.*

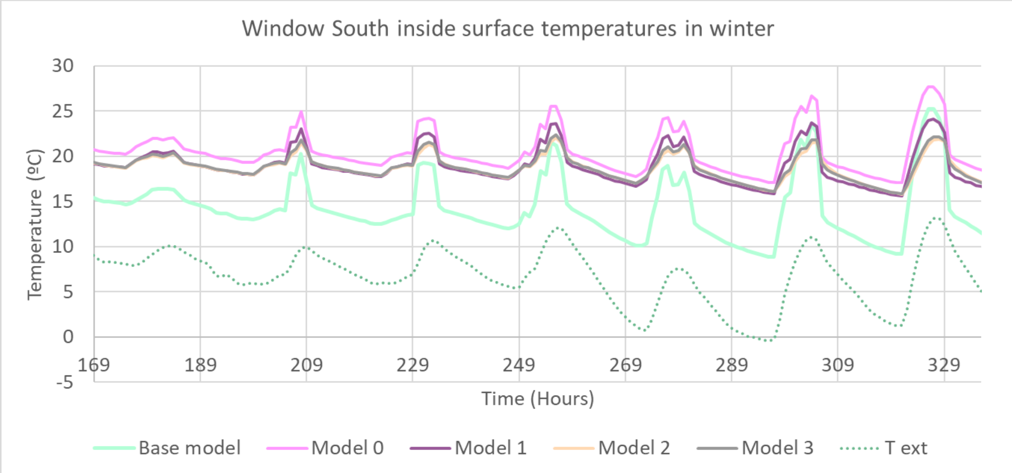


Figure 97. *Window inner surface temperatures for a winter week.*

For the summer season, temperatures (at free evolution) are shown below (**Figure 98** and **Figure 99**) for a summer week:

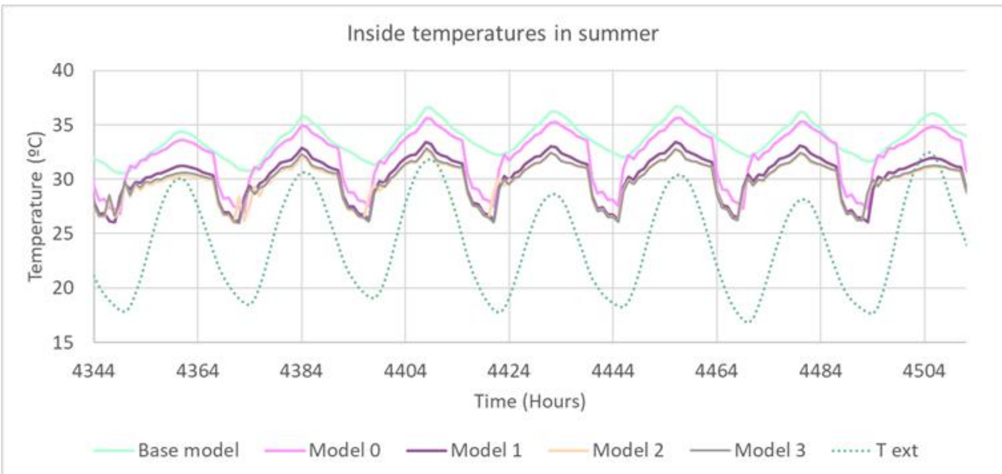


Figure 98. *Inside temperatures for a summer week.*

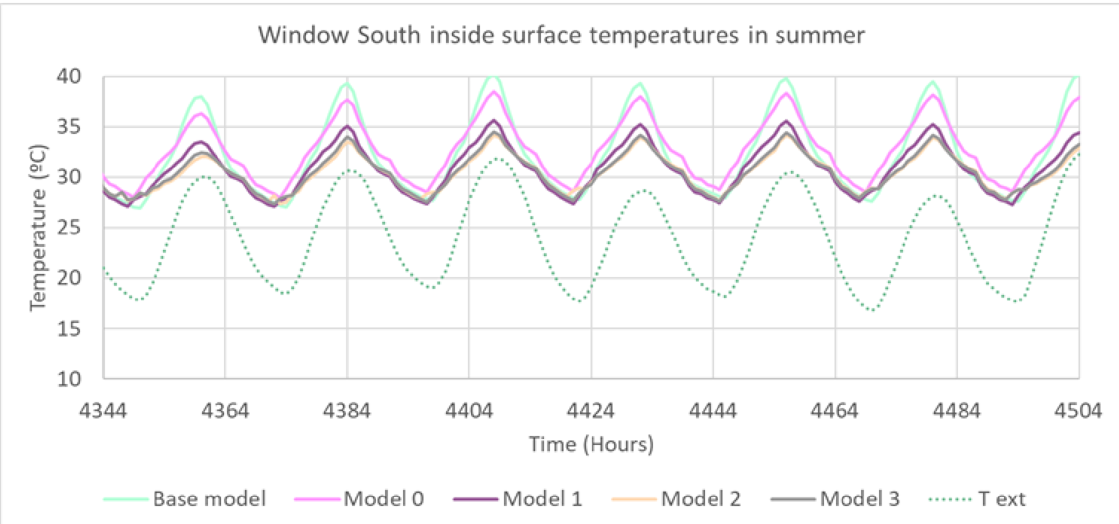


Figure 99. *Window inner surface temperatures for a summer week.*

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. The performance coefficients of this ideal energy system are shown below:

- 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 **Table 57**.

Table 57. *Simulation parameters values.*

Simulation parameters values		
CTE standards	***W/m²K***	0.56
90% $U_{wall\ CTE}$	***W/m²K***	0.50
$U_{glass\ FV}$	***W/m²K***	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/m²K***	1.47 0.52
U **glass option 1** **Solar factor** **option 1**	***W/m²K***	1.10 0.42
U **glass option 2** **Solar factor** **option 2**	***W/m²K***	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 58**).

Table 58. *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 **glass 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

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*
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 59. *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

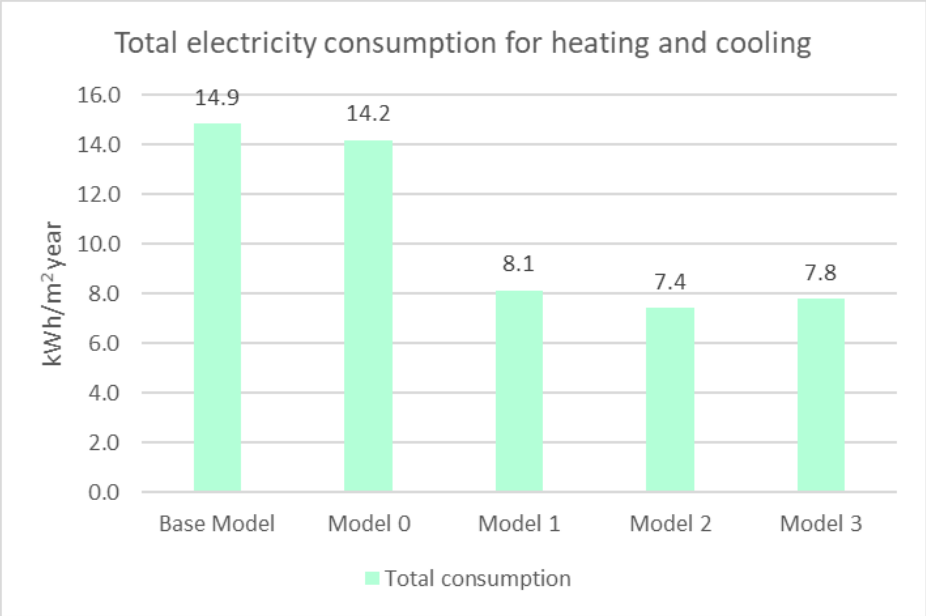


Figure 100. *Electricity consumption for the optimal scenarios.*

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 60). Results for final optimized model are shown below (**Table 61**):

Table 60. *Area of different uses in GESA building.*

Building uses	Area
	m²
Office	5 852
Public Office	3 901
Restaurant	2 304
Exhibition	2 705
GESA Building	**14 763**

Table 61*. Final energy consumption for the optimized GESA Building.*

	Office	Public office	Restaurant	Exhibition	Total consumption
	kWh/m²	*kWh/m²*	*kWh/m²*	*kWh/m²*	*kWh/m²*
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**

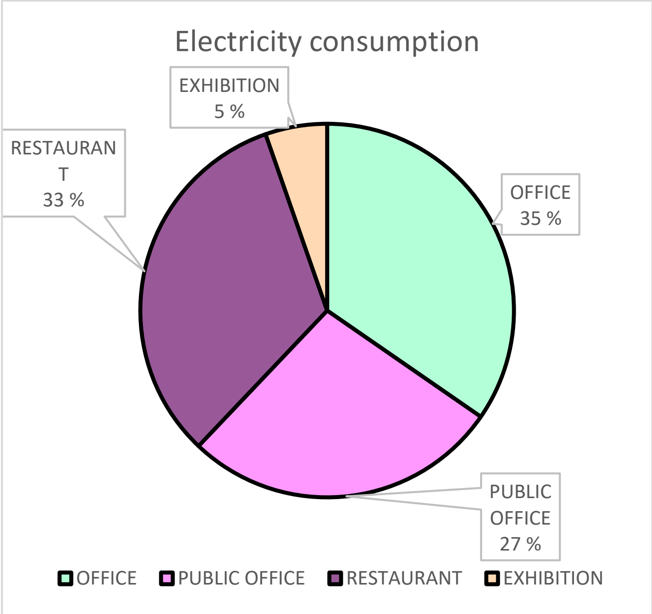


Figure 101. *Final energy consumption distribution for uses.*

The difference between office and public office is mainly the density occupancy. While the office uses has an occupancy density of 10 m^2/person, the public office increases the occupation with a density of 6 m^2/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 62**).

Table 62. *Savings in the final energy consumption due to the façade optimization*.

	Office	**Public office**	**Restaurant**	**Exhibition**	**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. POTENTIAL ACTIVE SYSTEMS FOR ENEGRGY SUPPLY: 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. In the **Appendix B – Active systems description for the GESA building** an overview of each technology proposed is described. 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 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.

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.

In this stage of the project, and without further information about the possibility of an open loop against the sea, a more realistic approach has been taken; it is considered that wells are surrounded by water, improving the efficiency of a conventional GSHP.

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 calculations at 50% 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:

- PV modules power rating 67 Wp (33 Wp/m2).
- Dimensions 1170 x 1730.
- Photovoltaic cell: thin film.

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

- PV modules power rating 165 Wp (95 Wp/m2).
- Dimensions 1480 x 1170.
- Photovoltaic cell: monocrystalline.

These kinds of buildings are high electricity consumers, overall, when all thermal systems are based on electricity energy vector. Also, the BIPV is a more expensive technology than conventional PV systems. For these reasons, and with the aim of the assess the optimal solution, several renewable energy production scenarios have been considered.

- A first scenario in which a conventional PV plant on the roof is considered. This is a conventional approach that aims to reduces the investment and optimize the energy production. This scenario will be used as a reference in order to check the benefits of a more sophisticated BIPV solution.
- A second scenario, with a Building Integrated PV is considered in the mentioned areas (south, east and west). In this scenario it is considered that the roof area is not available to place a photovoltaic field and will be used for other purposes

For the first scenario, with a conventional PV plant on the roof, some 3D models have been developed to ensure the correct placement and the optimal position / orientation to maximize the electricity production. Some images are shown below:

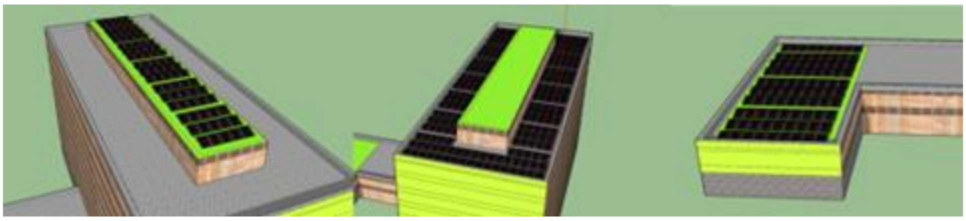


Figure 102. *Additional areas taken into consideration for location of PV panels.*

For the BIPV scenario, 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

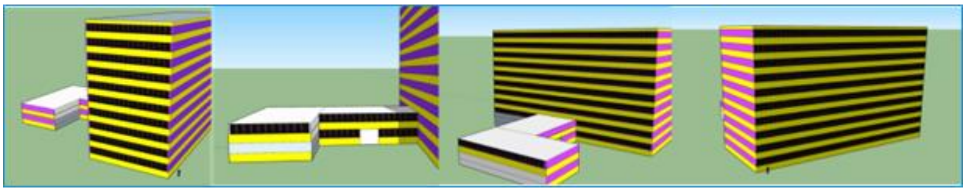


Figure 103. *Façades panels are placed: main south façade, secondary south façade, west and east façade.*

Both scenarios have been modelled and calculated using PVGis and Skellion software. The results for the energy production are shown in **Table 63**.

Table 63. *PV annual production.*

		PV roof	BIPV
Annual Production	***kWh/year***	86 253	185 902
Average Daily Production	***kWh/day***	236.3	509.3
Power	***kWp***	57.9	231.7
N. Panels	***n. panels***	423	2 383
Opaque Panels	***n. panels***	-	1 203
Transparent Panels	***n. panels***	-	1 180

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

The following table shows the different parametric options considered for the study.

Table 64. *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 65**).

Table 65. *Results for each scenario.*

		GSHP heating			GSHP cooling			ASHP heating			ASHP cooling			OPEX
GSHP	ASHP	C[8]	COP	W[9]	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	0.0	3.2	1	18.2	3.1	424	23.9
50	50	31.7	4.4	5 110	23	6	2 987	0.5	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	28.0
25	75	24.7	4.3	5 110	8.5	7.2	2 987	12.0	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.

[8] C for Energy Consumption
[9] W for working hours during a year

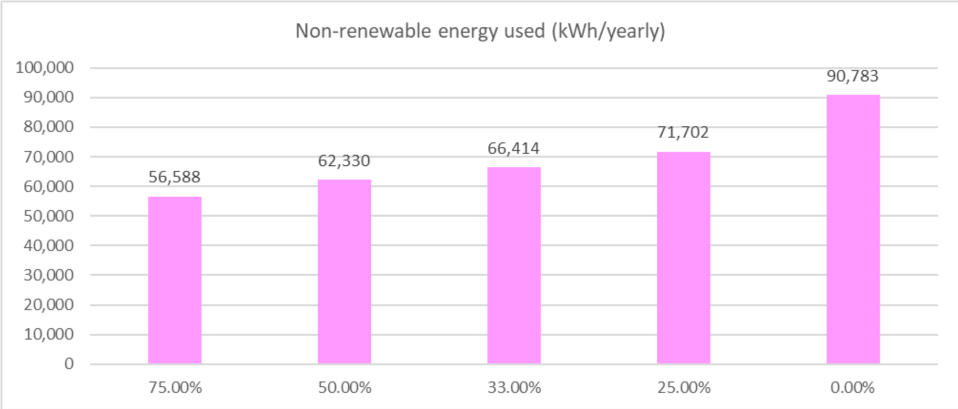


Figure 104. *Non-renewable energy used, and percentage of demand satisfied for each option.*

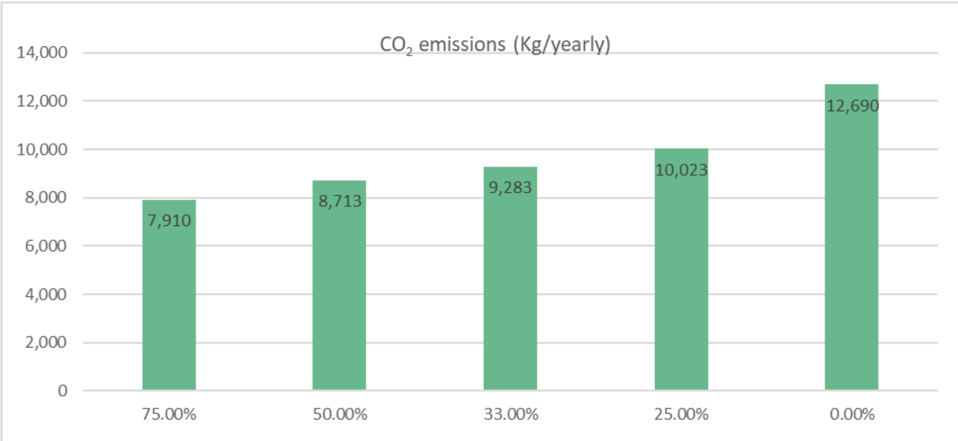


Figure 105. *CO_2 emissions and percentage of demand satisfied for each option.*

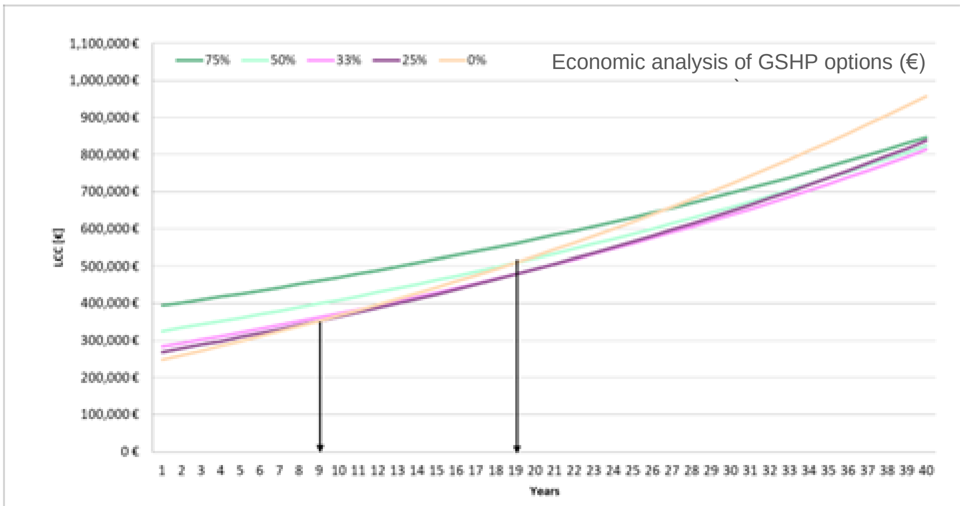


Figure 106. *Economic comparison of the different scenarios over the years.*

6.6.6. CONCLUSION OF THE ACTIVE TECHNOLOGIES SYSTEM ANALYSIS

Depending on the financial parameters of the investors, cost optimal best scenario can differ from the 25% GSHP option to a 50% GSPH option, with the latter allowing for greater CO2 emissions savings. However, other technical factors must be taken into consideration. It is advisable that the power of both systems does not differ significantly to facilitate their synchronized operation. This, combined with the need to consider a certain level of equipment redundancy, makes the 50% coverage scenario the most compelling.

Considering that a 100% ASHP is also the most conventional and less expensive scenario, two different scenarios will be assessed:

- 100% Aerothermal Source Heat Pump
- Optimal hybridization between ASHP and GSHP

Table 66. *Thermal capacity for the baseline and the proposed scenario.*

Scenario	Heating Capacity	Cooling Capacity
	kW	***kW***
100% ASHP	998	886
ASHP + GSHP	873+125	777+109

As a reminder, the 100% ASHP scenario is mainly showed as a reference scenario, in order to assess the performance of the optimized ASHP + GSHP proposed scenario.

6.7. HEATING, VENTILATION AND AIR CONDITIONING CONCEPT DESIGN

6.7.1. HVAC GENERAL SCHEMES

There will be a centralized system for thermal production based on a geothermal and aerothermal plant that will supply hot and cold water for the heating, cooling and DHW building demands. The geothermal plant will be designed for covering the main thermal demand and the purpose is to maximize the operational hours while two aerothermal polyvalent heat pumps, installed in the roof will be used to cover thermal power peaks.

- Main thermal energy production system → Geothermal heat pump
- Secondary thermal energy production system → Polyvalent aerothermal heat pump

According to the calculated hourly demands and assuming a percentile of 98%, the total power generation required by the system has been estimated at 886 kW. For this purpose, the installation of a 109 kW geothermal heat pump unit and three aerothermal heat pumps of 259 kW each is planned. This machine proposal will ensure to optimally partialize the compressor operation in order to efficiently adapt to the partial load operation associated with the different demand profiles of the building. The characteristics of the selected ground source heat pump are described below.

Table 67. Technical data of the ground source heat pumps (source: AERMEC).

Ground source heat pump		
Parameter	**Unit**	**Value**
Cooling		
Power	*kW*	109
Absorbed power	*kW*	24
EER	*W/W*	4.51
Heating		
Power	*kW*	125
Absorbed power	*kW*	29
COP	*W/W*	4.26
Simultaneous operation		
Cooling capacity	*kW*	96
Heating capacity	*kW*	124
Absorbed power	*kW*	28.9
TER	*W/W*	7.61

Figure 107. Ground source heat pump (source: AERMEC).

The generation system is supplemented by three aerothermal heat pumps with a total capacity of 777 kW. The unit characteristics of the aerothermal heat pump used are described below (**Table 68**).

Table 68. Technical data of aerothermal heat pumps (source: AERMEC).

Aerothermal heat pump		
Parameter	**Unit**	**Value**
Cooling		
Power	*kW*	259
Absorbed power	*kW*	89.4
EER	*W/W*	2.89
Heating		
Power	*kW*	291
Absorbed power	*kW*	89.01
COP	*W/W*	3.27
Simultaneous operation		
Cooling capacity	*kW*	282
Heating capacity	*kW*	366
Absorbed power	*kW*	89.65
TER	*W/W*	7.23

Figure 108. *Aerothermal heat pump (source: AERMEC).*

Characteristics of the generation system

A geothermal system is used as a base, harnessing the heat stored in the subsoil to cover the heating and cooling demand. In addition, an aerothermal system is implemented to provide additional support at times of peak demand, thus ensuring a constant and efficient supply of heat and cold.

The purpose of mixing these two technologies is to reduce the geothermal installed power and in consequence reduce the investment cost without compromising the energy efficiency of the whole system and the CO_2 emissions. The combination of geothermal and aerothermal systems, two technologies that, when working together, offer a versatile and high-performance solution.

All the HVAC scenarios (1, 2 and 3, that will be described in the followings chapters) start from the already explained thermal generation and involve the generation of heat and cold water using water-to-water ground source heat pumps and buffer tanks for energy storage. In this way, unnecessary start-up and shutdown of the heat pumps depending on the thermal demand of the building are avoided, the useful life of the compressors is extended, the energy efficiency is improved, and an additional lung is provided to cover peak thermal demands. The aerothermal heat pumps, located on the roof, have the function of covering the peak demand that may occur at times of high demand.

There are three different primary circuits:

- Cooling Loop working at 7-12ºC.
- Low temperature heating loop working at 45-40ºC.
- DHW loop working at 60-55ºC.

For hot water, it is proposed to operate with two working temperatures; one at low temperature, 45-40°C, supplying the terminal units such as: fan coils, low-profile convectors, inductors, etc. The other at high temperature, 60-55°C, supplying the different DHW substations located at the points of consumption, in such a way as to allow instantaneous DHW production while maintaining 50°C at the most unfavourable point of the installation.

There are four secondary circuits, a cooling and heating circuit to supply all the terminal units in the building and another cooling and heating circuit to supply the AHU[10]. For the cooling and heating of the terminal units in the building, new independent hydraulic circuits have to be designed for the different areas to be air-conditioned, which will allow a specific air treatment of the different rooms according to orientation, location, and time of use in the building.

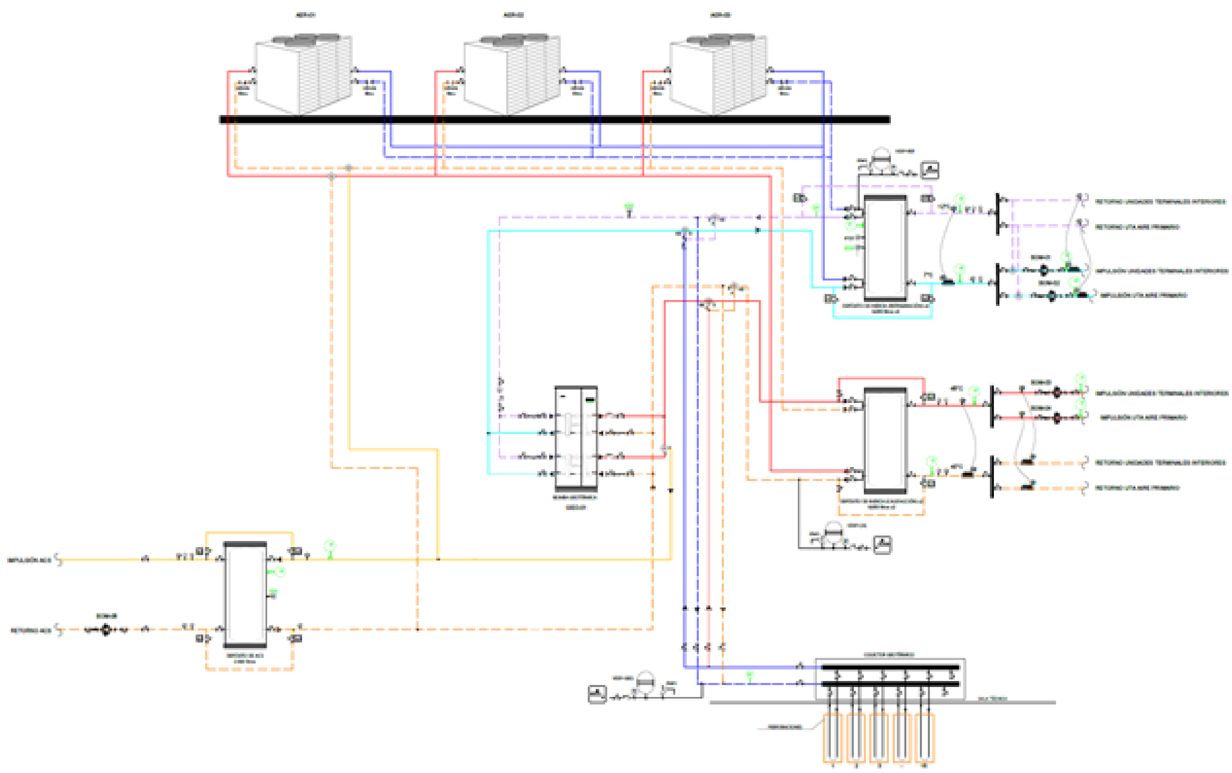


Figure 109. *Schematic diagram of the hydraulic system (source: AIGUASOL).*

The technical room is located on the basement level -2, where the GSHP unit, buffer tanks, impulsion and return collectors, hydraulic pumps, expansion tanks and the rest of the elements required for their correct operation will be installed. The estimated required space is 335m^2.

[10] Air Handling Units

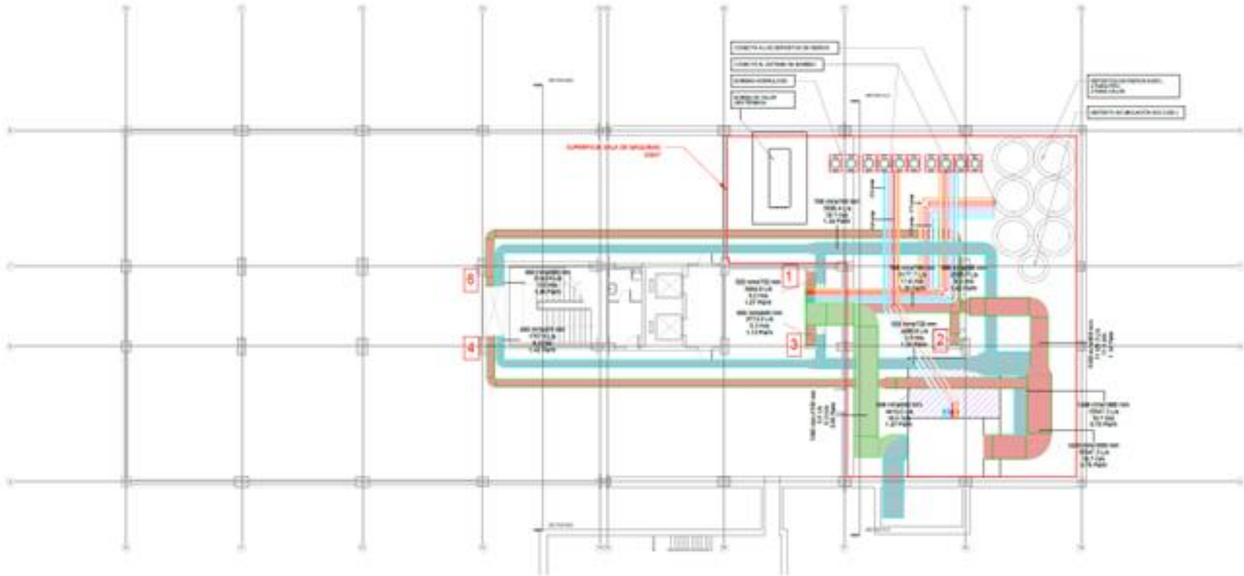


Figure 110. *Engine room on floor -2 (source: AIGUASOL).*

The polyvalent ASHP, capable of generating heat and cold water simultaneously, will be placed on the roof, as they need to be outside to work properly. The approximate space required is 80m^2.

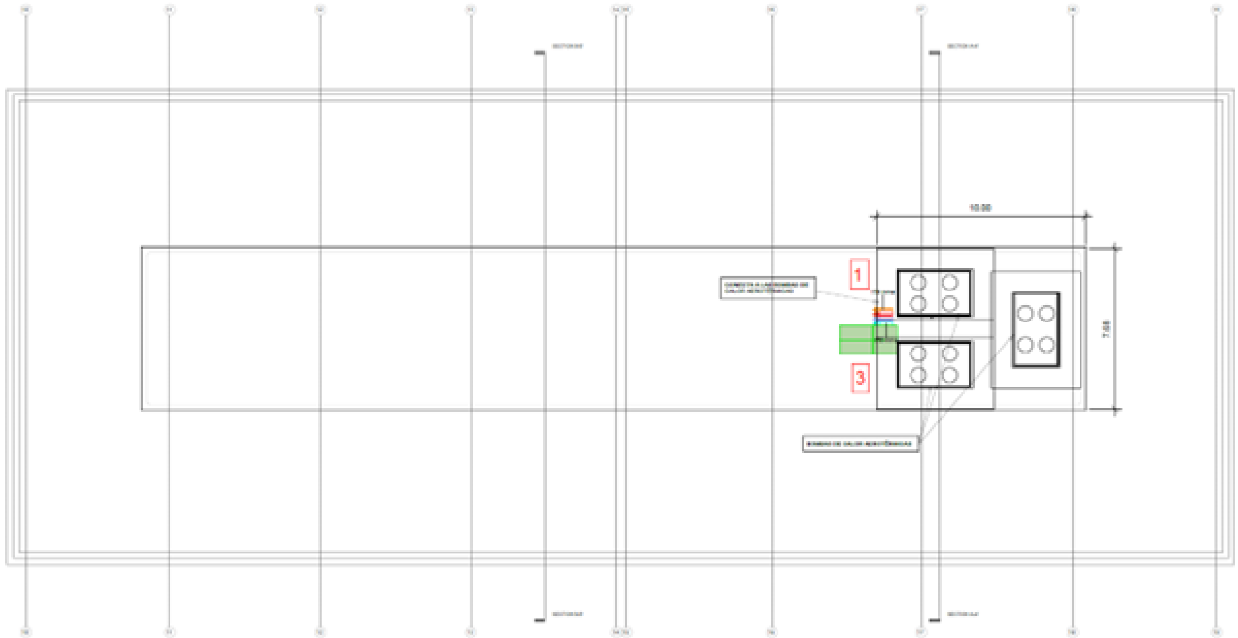


Figure 111*. Aerothermal equipment on roofed plant (source: AIGUASOL).*

6.7.2. PRIMARY AIR TREATMENT SYSTEMS DESCRIPTION

A system is proposed for primary air ventilation throughout the building by means of a centralised air handling unit (AHU), a network of ducts for supply and extraction, an enthalpy heat recovery unit, a cooling coil, and a heating coil to treat the air supplied at the established temperature and humidity conditions. Four variants of the system are proposed.

In alternatives 1, 2 and 4 a centralised ventilation system is considered, where the AHU will work at constant pressure and variable volume, each floor and/or zone will have its own variable volume damper controlled by a CO_2 probe. The air extraction fan will work at the same flow rate as the supply fan. In this way, two sensors will be placed to measure the flow rate, one in the supply and the other in the extraction in order to maintain the same flow rate.

In alternative 3, a partially centralised ventilation system is considered, where the air supply is provided by low velocity fans (individual units located close to the internal side of the façade). Air extraction is centralised by means of ducts differentiated by four uprights and every two uprights are connected to an extraction fan located on the roof. CO_2 sensors are incorporated to optimise ventilation consumption.

Compared to the previous alternatives, the supply and extraction flow will be 70% lower as the direct method has been considered, according to RITE; *"IT 1.1.4.2.3 minimum flow of outside ventilation air, B. Direct method by CO_2 concentration"*, complying with the required ppm.

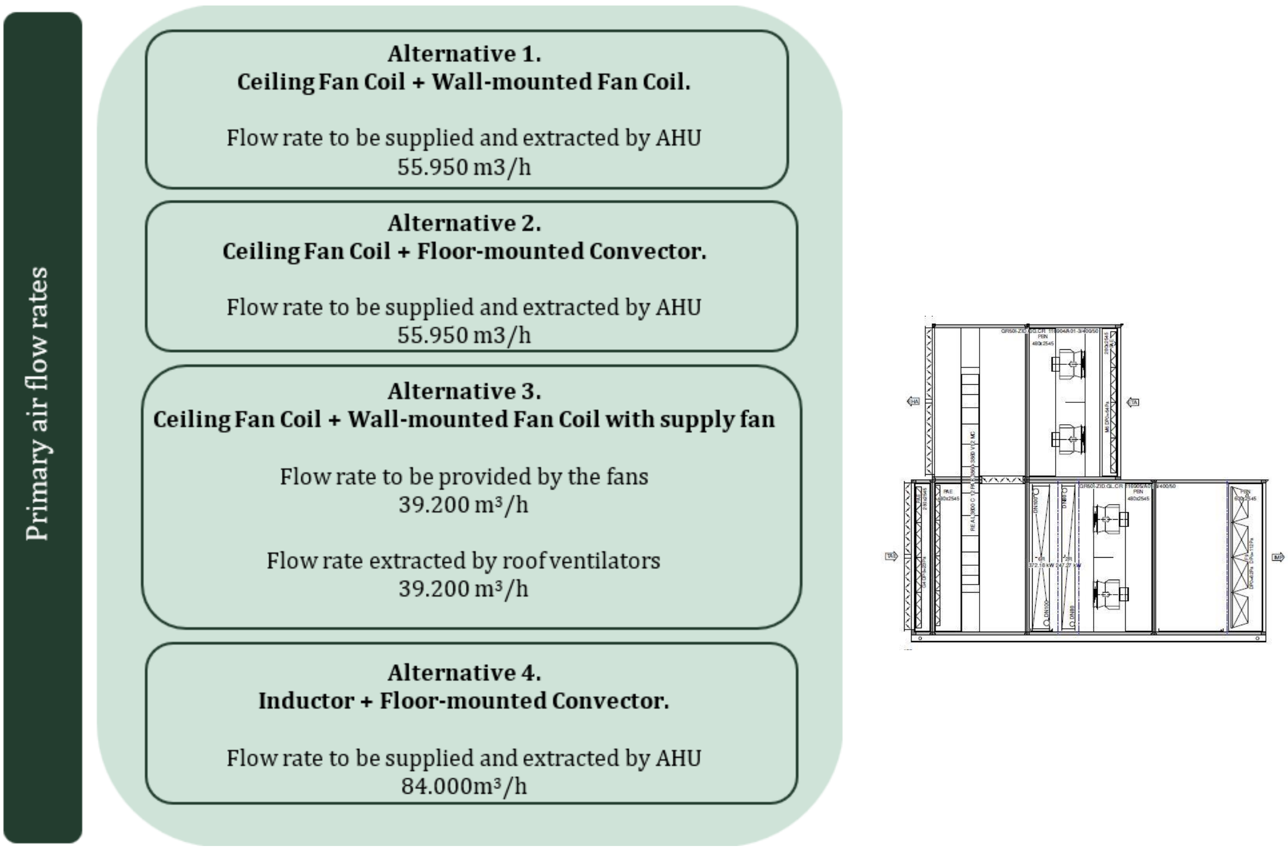


Figure 112. *Primary air flowrate (source: AIGUASOL).*

6.7.3. HVAC SYSTEMS DESCRIPTION

The four alternatives are described in detail in the following chapter. The four versions have in common the distribution from the technical room to the terminal units:

- From the technical room to the floor - hot and cold water distribution piping made of black steel pipe.
- Internal distribution within each floor - made of PPR cross-linked polypropylene.

Alternative 1. Ceiling Fan Coil + Wall-mounted Fan Coil

In alternative 1, the cooling and heating proposed is by means of fan coils throughout the building, ceiling fan coils in the interior areas and wall-mounted fan coils in the window area. This system will be able to control the sensible and latent heat of the different zones.

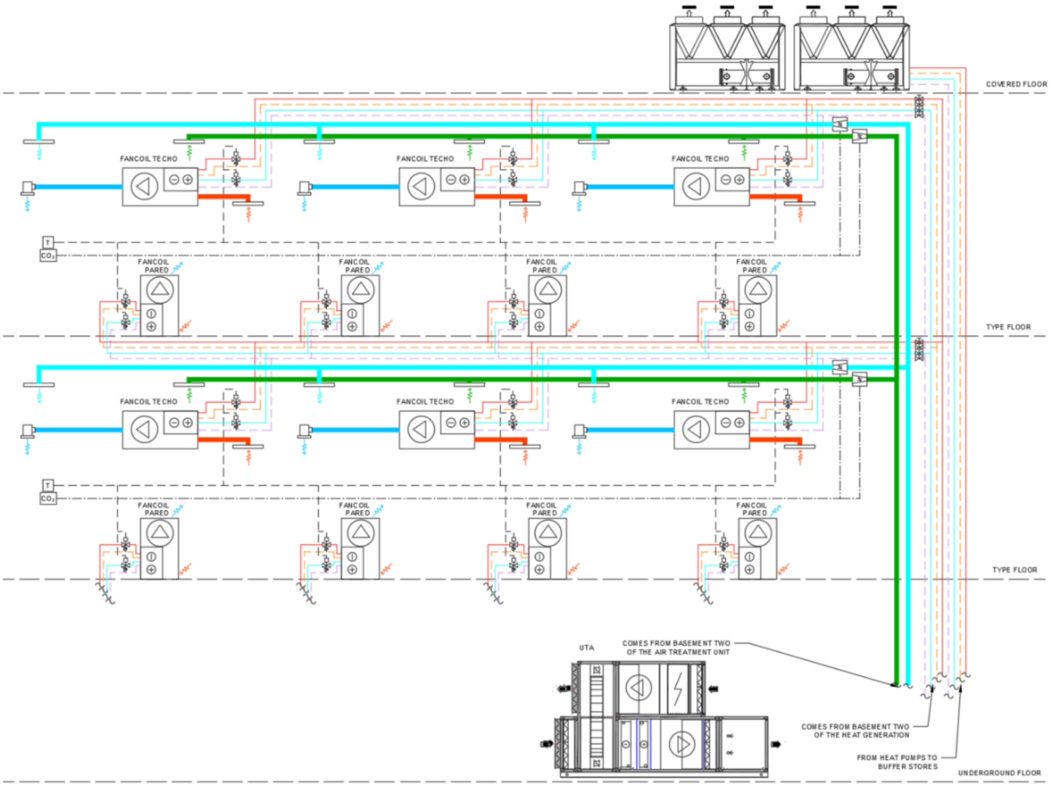
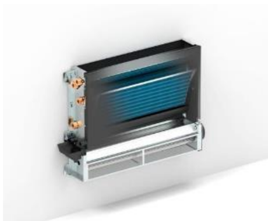


Figure 113. *Schematic diagram of alternative 1 (source: AIGUASOL).*

Table 69*. Technical specifications of the alternative 1 (source: JAGA).*

Technical specifications - Alternative 1	
Horizontal low-profile Fan Coil Unit, on the ceiling, 4-pipe connection, equipped with high pressure fans for ducted air applications. Air flow rates from 565 m3/h to 1365 m3/h. Dimensions length x depth x height; Variable x 545mm x 232mm.	
Low-profile wall-mounted fan coil, 4-pipe connection, equipped with high water flow with condensate tray. Air flow rates from 355 m3/h to 1345 m3/h. Dimensions length x depth x height; Variable x 545mm x 222mm.	

Alternative 2. Ceiling Fan Coil + Floor-mounted convector

In alternative 2, ceiling fan coils in the interior zones and low-profile convectors in the window zone will work for both heating and cooling. This system will be able to control the sensible and latent heat of the different zones.

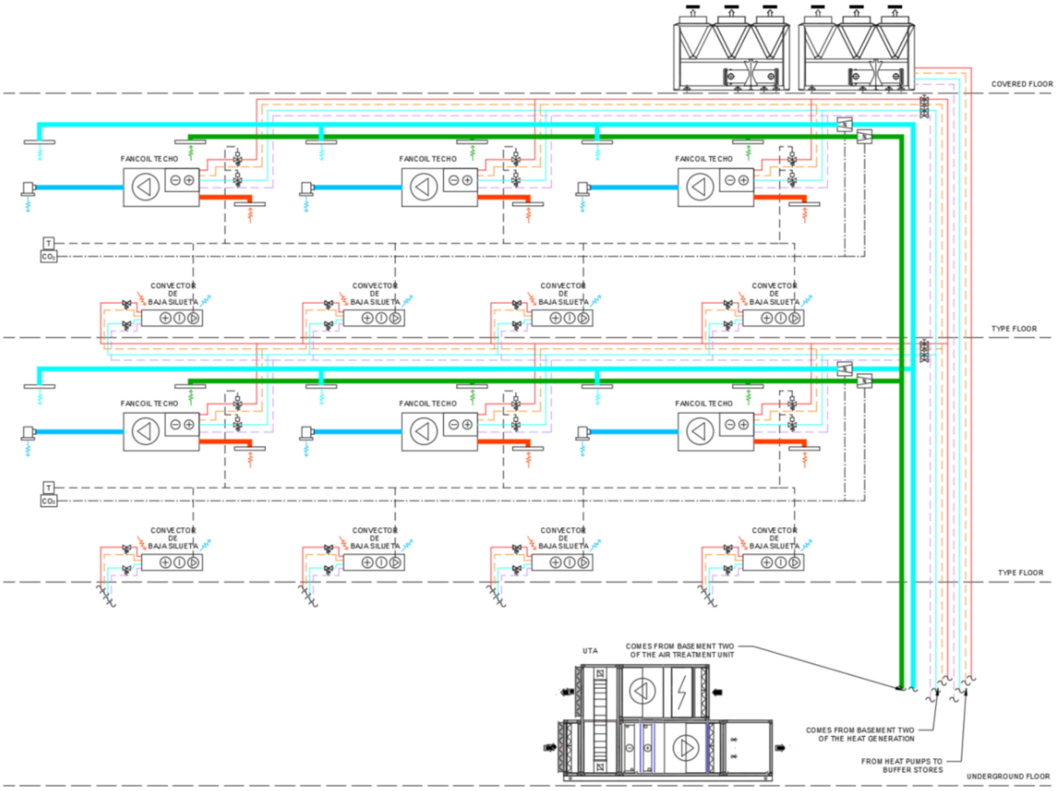
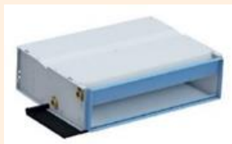


Figure 114. *Schematic diagram of alternative 2 (source: AIGUASOL).*

Table 70. *Technical specifications of the alternative 2 (source: JAGA).*

Technical specifications - Alternative 2	
Horizontal Low-profile Fan Coil Unit, on the ceiling, 4-pipe connection, equipped with high pressure fans for ducted air applications. Air flow rates from 565 m3/h to 1365 m3/h. Dimensions length x depth x height; Variable x 545mm x 232mm.	
Low-profile floor-mounted convector, equipped with fan, 4-pipe connection, equipped with condensate tray. Air flow rates from 260 m3/h to 433 m3/h. Dimensions length x depth x height; Variable x 320mm x 130mm.	

Alternative 3. Ceiling Fan Coil + Wall-mounted Fan Coil with fan

In alternative 3, ceiling fan coils in the interior areas and wall-mounted fan coils plus mini fans in the window area are proposed. One mini fan per wall fan coil will be installed and the fan coils will work in both modes, heating, and cooling. Mini fans located in the window areas will bring in 75 m^3/h outside fresh air, pushing it towards the return of the wall fan-coil so that it can treat the sensible heat and the latent heat of this air. This system will be able to control the sensible and latent heat of the different zones.

As the mini fans will introduce a large part of the air necessary to comply with health regulations, the primary air supply of the AHU will be reduced, but it must be considered that the extraction air will have to be equal to the supply air.

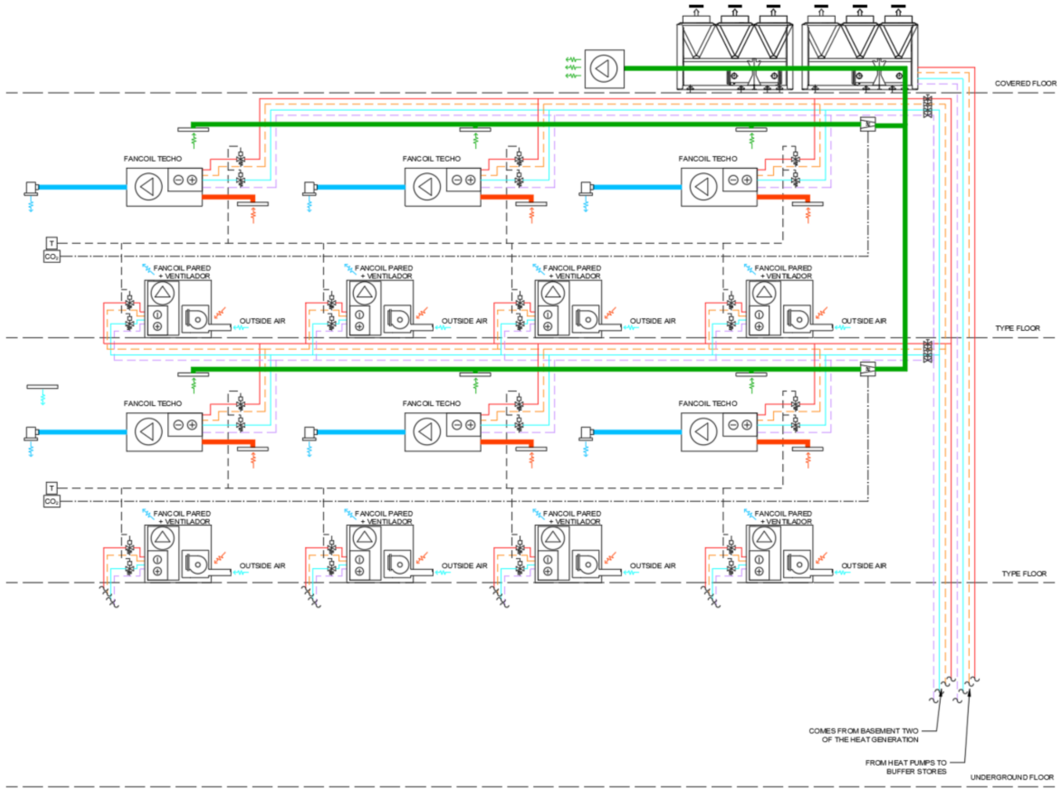
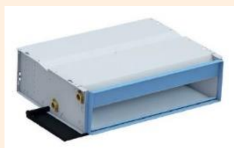


***Figure 115**. Schematic diagram of alternative 3 (source: AIGUASOL).*

***Table 71**. Technical specifications of the alternative 3 (source: JAGA).*

Technical specifications - Alternative 3	
Horizontal Low-profile Fan Coil Unit, on the ceiling, 4-pipe connection, equipped with high pressure fans for ducted air applications. **Air flow rates from 565 m3/h to 1365 m3/h.** **Dimensions length x depth x height; Variable x 545mm x 232mm**	
Low-profile wall-mounted fan coil, 4-pipe connection, equipped with high water flow with condensate tray, plus external air supply fan controlled by CO2 sensor. **Fan-coil. Air flow rates from 355 m3/h to 1345 m3/h.** **Dimensions length x depth x height; Variable x 545mm x 222mm** **Fan. Air flow rate from 75 m^3/h to 110 m^3/h.** **Dimensions length x depth x height; 480mm x 360mm x 104mm**	

Alternative 4. Inductor + Floor-mounted Convector

In alternative 4, it is proposed to place ceiling inductors in the interior zones and low-profile floor-mounted convectors in the window zone, which will work for both heating and cooling. This system will be able to control the sensible heat and will be able to control the latent heat of the different zones by means of the low-profile convectors.

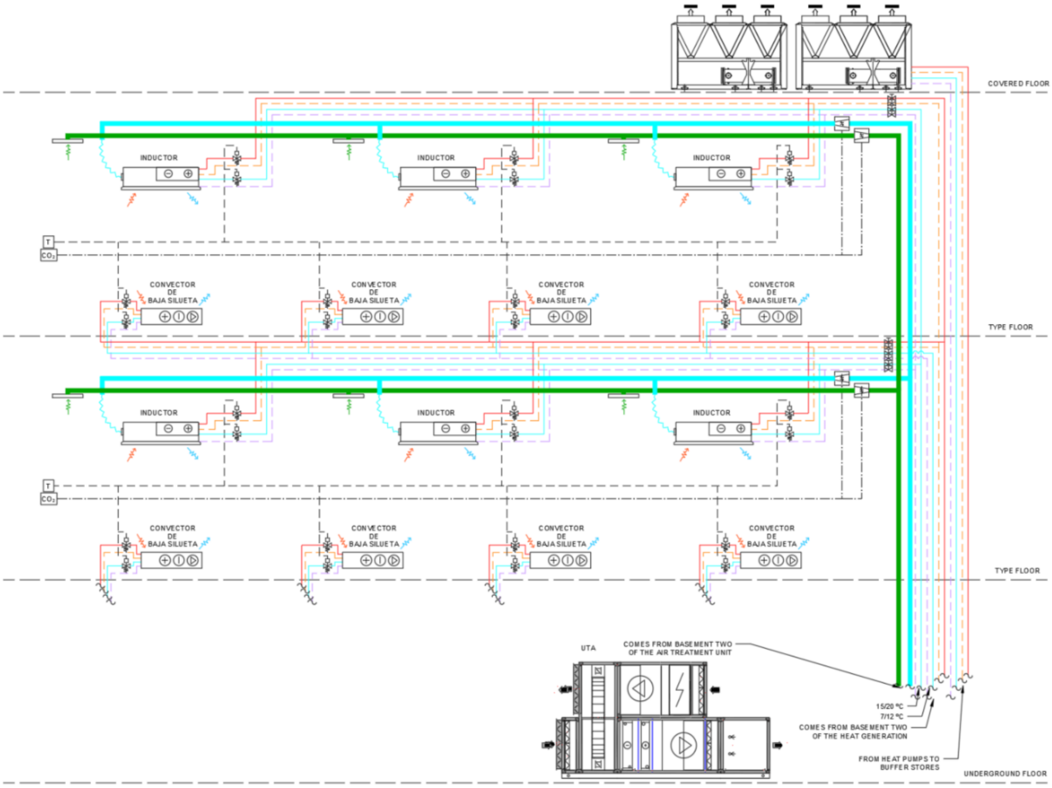


Figure 116. *Schematic diagram of alternative 4 (source: AIGUASOL).*

Table 72. *Technical specifications of the alternative 4 (source: TROX and JAGA).*

Technical specifications - Alternative 4	
Low-profile ceiling inductor, 4-pipe connection, fanless unit, operates by convective heat transfer, which is produced when water circulates through the coil. Primary air connection. **Air flow rates from 55 m3/h to 180 m3/h.** **Dimensions length x depth x height; 1500mm x 312mm x 312mm x 210mm**	
Low-profile floor-mounted convector, equipped with fan, 4-pipe connection, equipped with condensate tray. Air flow rates from 260 m3/h to 433 m3/h. **Dimensions length x depth x height; Variable x 320mm x 130mm**	

6.7.4. EMISSION SYSTEMS POSSIBILITIES IN THE GESA BUILDING

The criteria for designing the HVAC system takes into account:

- Specific weather conditions in Palma de Mallorca.
- Thermal loads and building needs.
- Actual requirements for thermal comfort and health.
- Actual technical building code in Spain.
- Floor to Ceiling height.
- Integration in the inner spaces.

for fitting the equipment has been based on thermal loads, the comfort of people, the free height between floors of the building and greater architectural integration of the equipment within the spaces.

Alternative 1. Ceiling Fan Coil + Wall-mounted Fan Coil.

The choice of low-profile ceiling fan coils is due to the limited space in the false ceiling. These units offer uniform air distribution as the supply and return is by means of ducts, and the diffusers and grilles can be placed where it is most convenient. The hydraulic and condensate connections are made from the same floor.

Wall-mounted fan coils located in the window area, within the double skin of the façade and attached to the floor slab, offer additional advantages in terms of design flexibility and accessibility for maintenance. Hydraulic and condensate connections will be made from the lower floor.

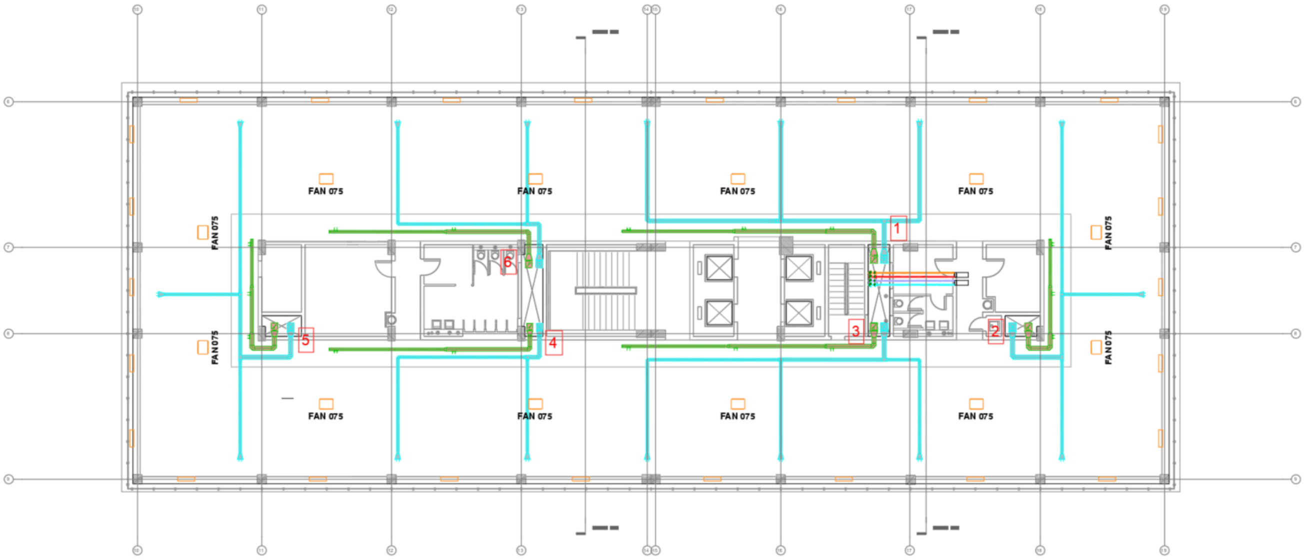


***Figure 117**. Plan view of standard plan, alternative 1 (source: AIGUASOL).*

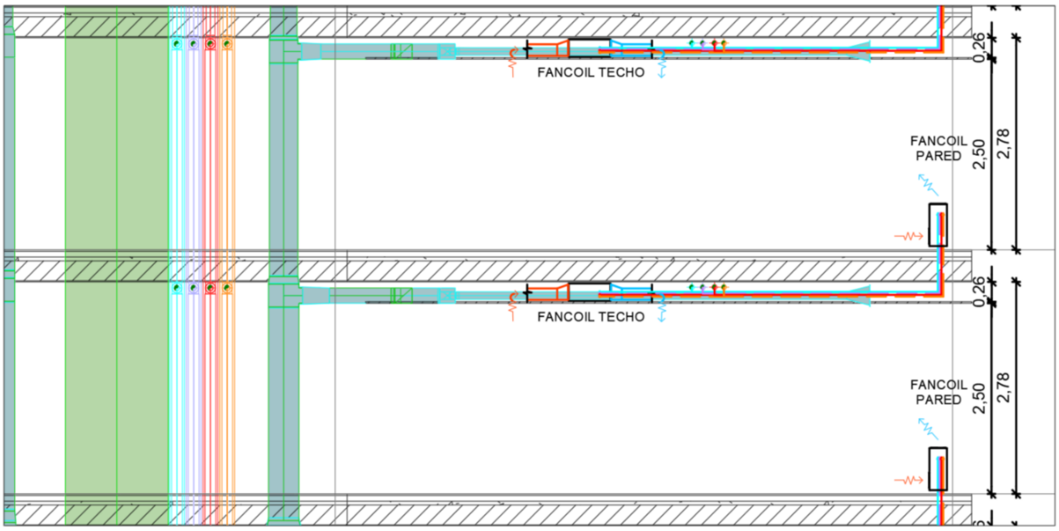


Figure 118. *Plan section of standard plan, alternative 1 (source: AIGUASOL).*

Alternative 2. Ceiling Fan Coil + Floor-mounted convector

As in the previous alternative, low-profile ceiling fan coils have been chosen, these offer a uniform distribution of the treated air, as well as being discreetly integrated into the false ceiling.

In the window area, low-profile convectors with a height of 13cm have been chosen, these will be recessed in the floor, minimising interference with the architectural design, being able to provide adequate air-conditioning power to maintain a comfortable temperature. The placement of convectors embedded in the floor has advantages in terms of space utilisation, greater flexibility in the distribution of workspaces. In addition, convectors offer vertical air distribution, avoiding draughts over the occupants.

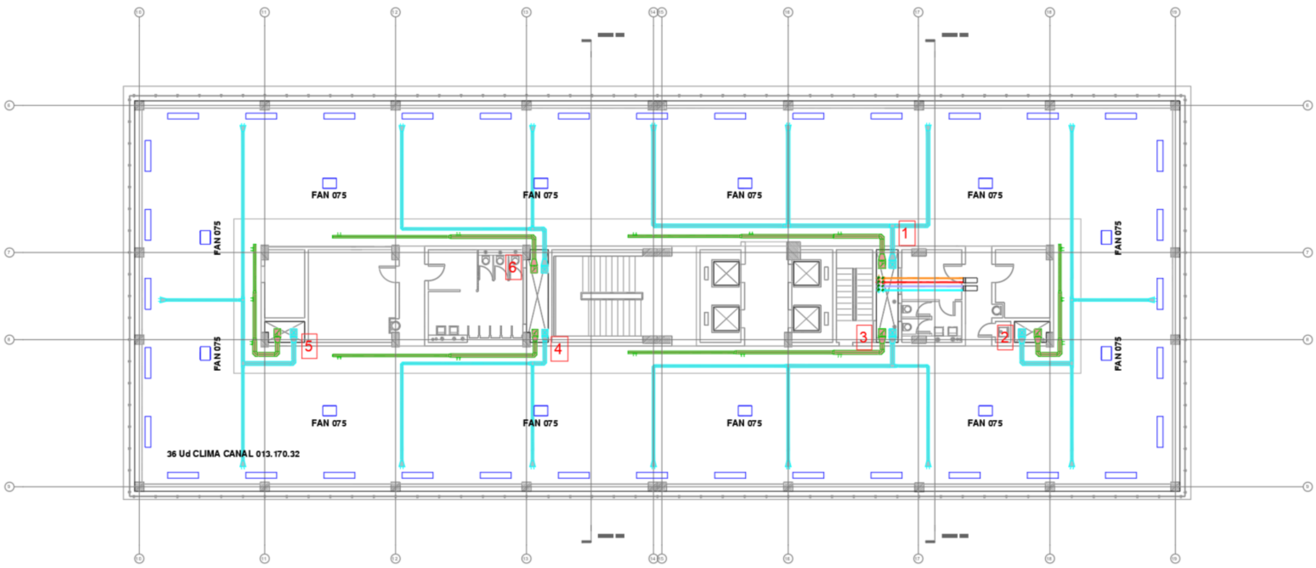


Figure 119*. Plan view of standard plan, alternative 2 (source: AIGUASOL).*

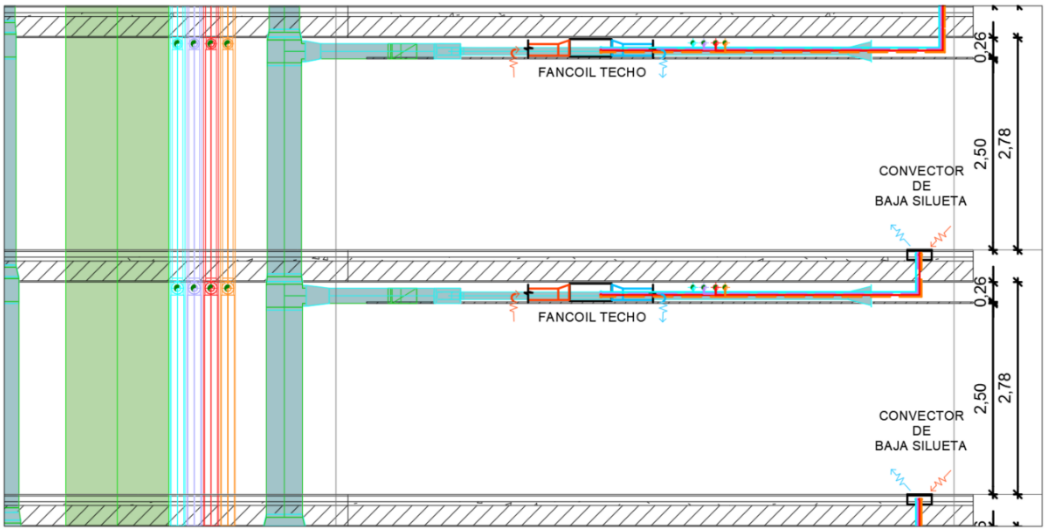


Figure 120. *Plan section of standard plan, alternative 2 (source: AIGUASOL).*

Alternative 3. Ceiling Fan Coil + Wall-mounted Fan Coil with fan

As in alternative 1, low-profile ceiling fan coils and wall-mounted fan coils located in the window area have been chosen, with the difference that a low power consumption fan has been added to the wall-mounted fan coils to supply primary air from outside to the fan coil return, the primary air that is introduced into the fan coil return is mixed with the room return air, pre-treating the air as it passes through the coils.

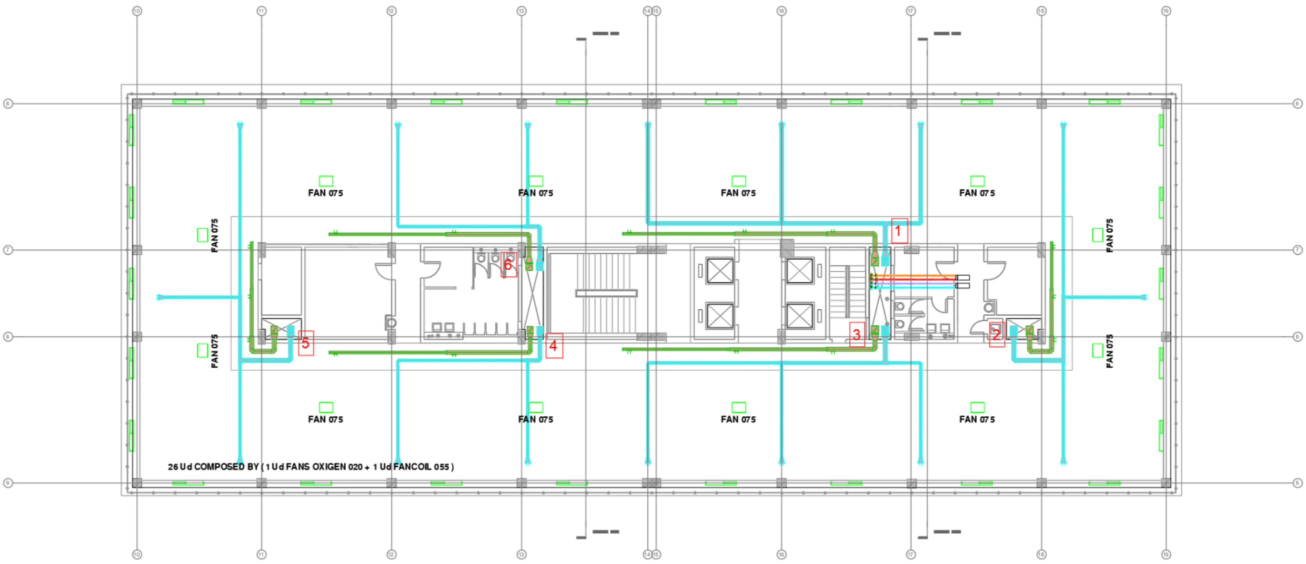


Figure 121. *Plan view of standard plan, alternative 3 (source: AIGUASOL).*

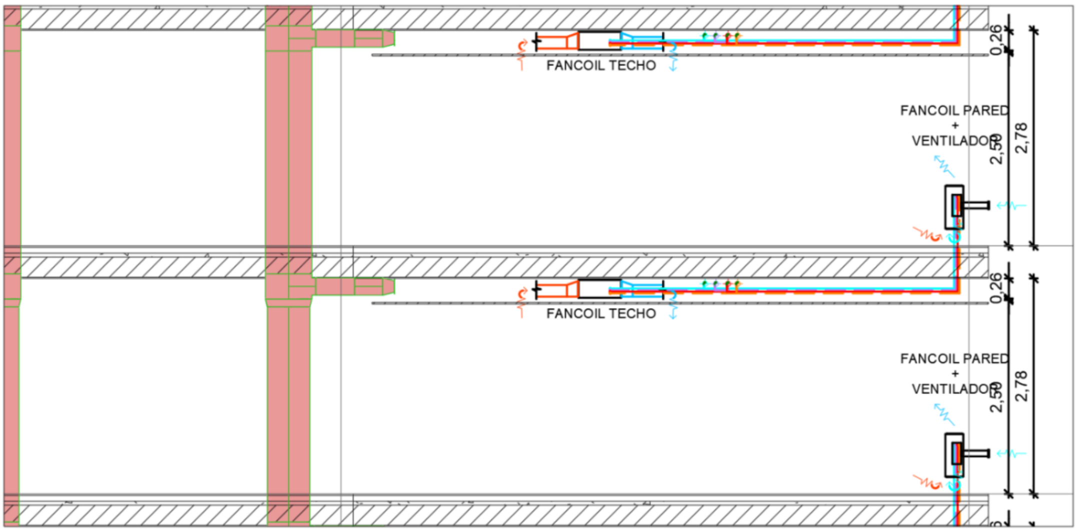


Figure 122. *Plan section of standard plan, alternative 3 (source: AIGUASOL).*

Alternative 4. Inductor + Floor-mounted Convector

In this last alternative, low-profile ceiling-mounted inductors have been proposed. These are more efficient than fan convectors as they have no associated power consumption. Inductors work by convective heat transfer, with a primary air connection that provides ventilation air. This air must be treated by the AHU so that it enters the inductor at the setpoint indoor temperature and without humidity, as the inductors do not treat latent loads. This primary air enters through the induction nozzle of the equipment, which acts as an air diffuser. The active inductor system can be used for both cooling and heating applications.

In the window area, low-profile convectors with a height of 13cm are designed to be recessed into the floor, minimising interference with the architectural design, and capable of providing adequate air-conditioning power to maintain a comfortable temperature. The placement of convectors embedded in the floor has advantages in terms of space utilisation, greater flexibility in the distribution of workspaces. In addition, they offer vertical air distribution, avoiding draughts over the occupants.

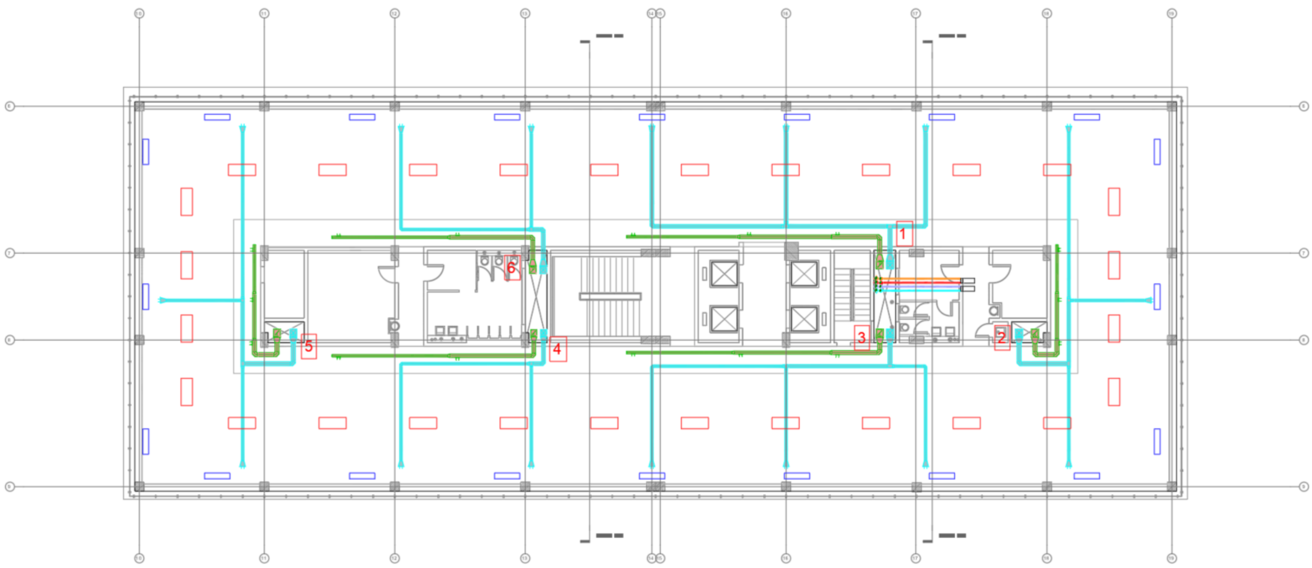


Figure 123. *Plan view of standard plan, alternative 4 (source: AIGUASOL).*

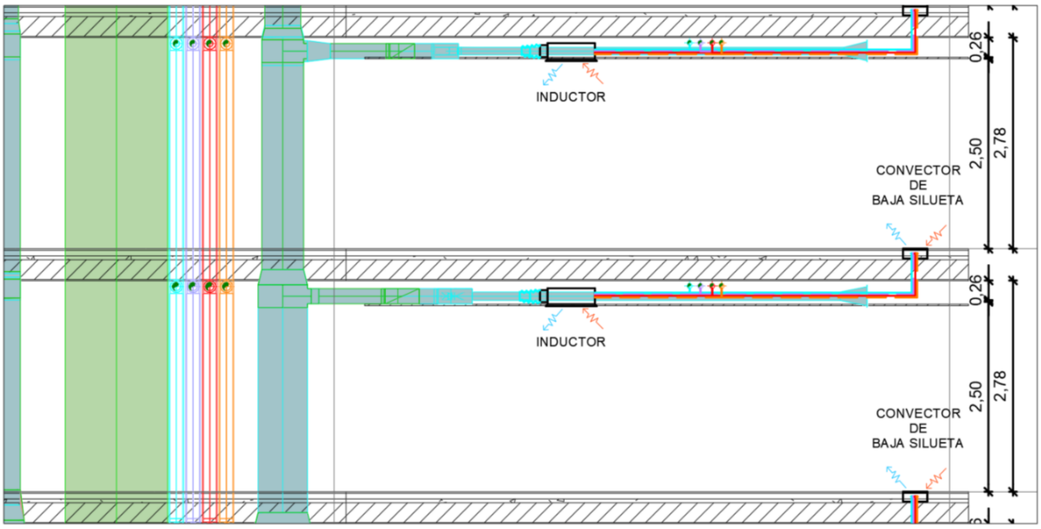


Figure 124*. Plan section of standard plan, alternative 4 (source: AIGUASOL).*

6.7.5. HOLISTIC ASSESSMENT OF HVAC OPTIONS INCLUDING ARCHITECTURAL INTEGRATION

In the design of the proposed air-conditioning systems, energy efficiency, architectural integration and the possibilities within the space have been considered. Advantages and disadvantages of the before mentioned air-conditioning alternatives will be evaluated properly.

The different HVAC systems variants present pros and cons in terms of economics, architectural integration, and possibilities within the building.

Alternative 1. Ceiling Fan Coil + Wall-mounted Fan Coil

Alternative 1 is widely used in air-conditioning systems. In the interior area of the office floors, a low-profile ceiling fan coil with a height of 23.2 cm, with ducted supply and return air, has been chosen because of its capacity to be integrated into the reduced space we have in the false ceiling, approximately 26 cm. In the window area, the wall-mounted fan coil has been selected as it offers greater individualised control of the temperature and a more enveloping air distribution.

The primary air ducts can exit each floor from the uprights without major difficulty, the distribution, and derivations of ducts on each floor can be carried out without any problem, coordinating with the rest of the installations and if necessary, the heights of the ducts can be reduced, conserving the passage area.

Figure 125*. Installation of ceiling fan coils (source: JAGA).*

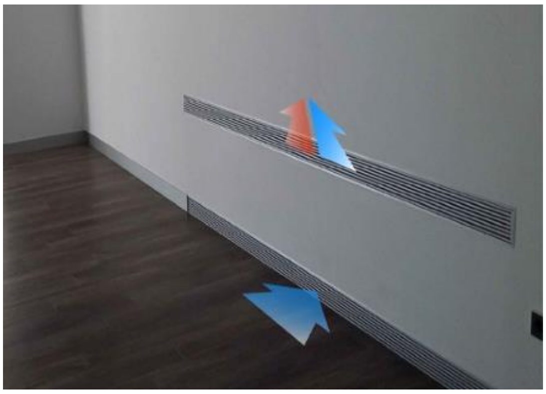


***Figure 126**. Wall-mounted fan coil (source: JAGA).*

***Table 73**. Advantages and disadvantages of alternative 1.*

Advantages	Disadvantages
1. Low cost of investment	1. Higher consumption of fans terminal units.
2. Acceptable architectural integration as low-profile unit.	2. Increased height and wall footprint of terminal units.
3. Widely used and well-known solution on the market.	3. Increased noise impact due to fan operation.
4. Standard and conventional maintenance.	
5. Ducted air discharge, choice of diffusion positioning.	

Alternative 2. Ceiling Fan Coil + Floor-mounted convector

Alternative 2 is similar to the previous one, in the interior area of the office floors the low-profile ceiling fan coil has been chosen and in the window area low-profile convectors with a height of only 13 cm have been selected, offering an effective solution. The convectors are recessed into the floor slab, allowing an almost invisible installation and minimising interference with the architectural design of the office space.

Despite their compact size, the low-profile convectors are able to provide adequate air-conditioning power to maintain a comfortable room temperature and offer vertical air distribution, which helps to avoid direct draughts on people.

In terms of energy efficiency, low-profile convectors are an outstanding choice. Thanks to their compact design and efficient heat exchange technology, they achieve optimum performance with reduced energy consumption. This translates into significant savings in the operating costs of the air-conditioning system over time.

The primary air ducts will be of the same size as in alternative 1, they will be able to exit each floor from the uprights without major difficulty, the distribution, and derivations of ducts on each floor can be executed without any problem coordinating with the rest of the installations and if necessary, the heights of the ducts can be reduced while conserving the passage area.

Figure 127. *Integration of the convector in the floor (source: JAGA).*

Table 74. *Advantages and disadvantages of alternative 2.*

Advantages	Disadvantages
1. Low noise impact.	1. Increased number of terminal units for air treatment.
2. Good architectural integration, they blend seamlessly into the floor slab, maximising usable space and avoiding interference.	2. Higher economic cost of terminal units.
3. Good heat or cold barrier in glazed areas.	3. They may require specific planning and coordination during the construction phase for proper installation.
4. Low supply air velocities in perimeter areas.	
5. Lower power consumption of terminal units.	
6. Low maintenance and easy to clean.	

Alternative 3. Ceiling Fan Coil + Wall-mounted Fan Coil with fan

Alternative 3 is the same as alternative 1, in the interior area of the office floors, a low-profile ceiling fan coil with a height of 23.2 cm has been chosen, with ducted supply and return air. In the window area, the wall-mounted fan coil has been selected, with the difference that a primary air supply fan is attached to it.

Wall-mounted fan coils with a built-in fan blowing primary air help to improve the efficiency of the system and the comfort of people. The primary air, which is introduced into the return of the wall-mounted fan coil, allows the air to be pre-treated before it is blown into the room. This ensures more efficient heat exchange and faster air conditioning. In addition, the installation of wall-mounted fan coils with a primary air fan offers greater individualised temperature control on each floor or zone.

In terms of installation and maintenance, wall-mounted fan coils with primary air fan also have advantages, their compact design and easy accessibility facilitate installation and regular maintenance of the equipment.

Ductwork will be considerably reduced as we will not have the primary air supply ductwork, only the extract ductwork. The ducts will come out from the uprights on each floor without any major difficulty, the distribution and derivations of ducts on each floor can be carried out without any problem. The extraction fans will be located on the roof.

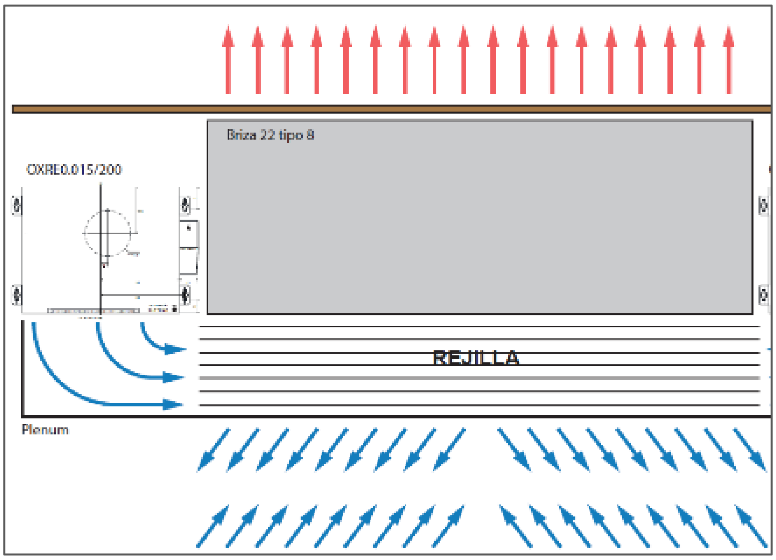


Figure 128*. Wall-mounted fan coil and fan configuration (source: JAGA).*

Table 75*. Advantages and disadvantages of alternative 3.*

Advantages	Disadvantages
1. Equipment with similar investment cost to alternative 1.	1. Increased number of terminal units for air treatment.
2. Elimination of AHU and reduction of primary air ducts by decentralised air supply.	2. Higher economic cost of terminal units.
3. Less space occupied in the engine room.	3. They may require specific planning and coordination during the construction phase for proper installation.
4. Less space taken up in the mullioned skirting and false ceiling.	

Alternative 4. Inductor + Floor-mounted Convector

Alternative 4 combines low-profile ceiling inductors and low-profile convectors embedded in the floor slab. These systems offer discreet and efficient solutions for the distribution of conditioned air.

Low-profile ceiling-mounted inductors are characterised by their unobtrusive design and their ability to mix primary and ambient air, achieving a uniform distribution of conditioned air, and have no associated power consumption, operating by convective heat transfer. Natural convection is based on the natural circulation of air achieved by the temperature differential. As the air in the space heats up, it rises and comes into contact with the cooling coil, as the air cools it falls back into the occupied space, heating up and repeating the cycle. The inductors have a primary air connection, this air must enter the inductor completely dehumidified as the equipment does not treat latent loads.

Low-profile convectors are able to provide an adequate air conditioning power to maintain a comfortable temperature in the room, they offer a vertical air distribution, which helps to avoid direct air currents on people.

Figure 129. *Integration of the convector in the floor (source: JAGA).*

Table 76. *Advantages and disadvantages of alternative 4.*

Advantages	Disadvantages
1. Low noise impact.	1. Installation of more pipes and ducts.
2. Good architectural integration. Low space requirement in height (21 cm).	2. Strict control of relative humidity to avoid condensation.
3. Low energy consumption due to the absence of fans.	3. Larger primary air AHU, latent load elimination.
4. Excellent uniform air distribution in the room.	4. Major occupancy of equipment in the engine room and small courtyards.
5. Very low maintenance as there are no moving parts.	
6. Low power consumption. Cooling temperatures of 15-20ºC.	

CAPEX for each alternative is shown below.

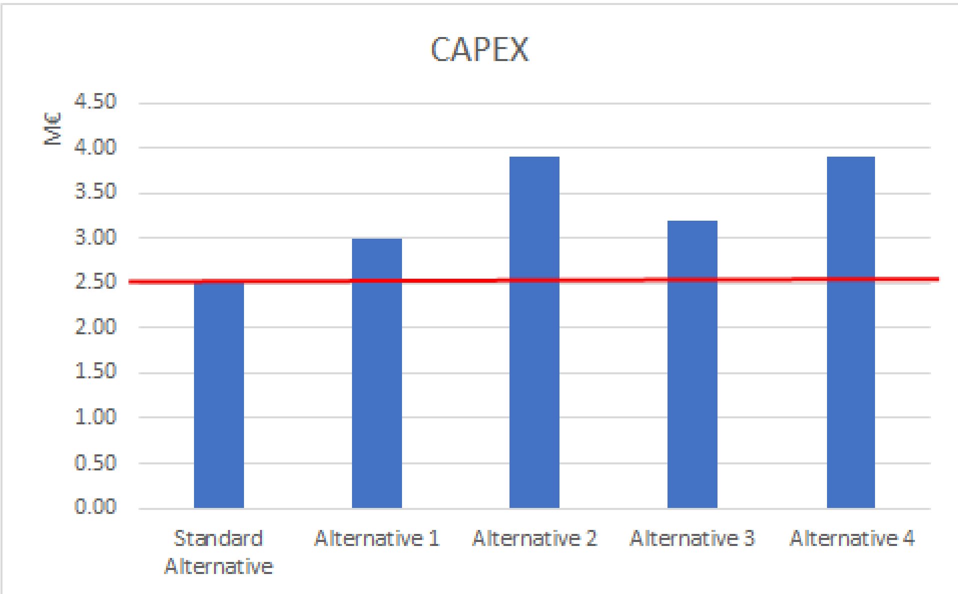


Figure 130. *Economic comparison of the different alternatives considered.*

6.8. DEFINITION OF THE FINAL SCENARIO FOR GESA BUILDING

This chapter describes the baseline scenario and the alternative proposed scenarios for the GESA building. Different configurations can be proposed by accounting for the possible combinations of technologies and performance strategies to inform the different available solutions (both passive and active measures) for the GESA deep renovation.

The selected passive strategy, consisting of the refurbishment of the curtain wall, is considered invariant within the different scenarios, the baseline and the proposed alternatives. The architectural solution for the façade refurbishment is based on the Model 3 with a full ventilated façade. According to the outcomes of section 6.4 that showed the lack of significant differences between the two ventilated chamber configurations, it has been considered that the installation of a homogeneous façade solution will be more feasible from a technical point of view.

The difference between the baseline scenario and the scenarios with a PV production system is that the exterior layer of glazing in the baseline is upgraded to a Building Integrated Photovoltaic (BIPV) module integrated in the façade.

The general configuration of the thermal production system is also shared between the different scenarios. It is assumed that the best option is a centralized system due to better efficiency and less needs of intermediate distribution equipment. Different options for this thermal generation are considered and described below:

- Centralized thermal production that foresees a 100% coverage of the thermal demand with Aerothermal Source Heat Pump (ASHP).
- Centralized thermal production that foresees a mixed coverage of the thermal demand between an Aerothermal and a Geothermal Source Heat Pump (GSHP).

Regarding the HVAC system within the building and due to the analysis performed in the previous chapters, the selected option is the Ceiling Fan Coil + Wall-mounted Fan Coil.

The different alternatives for the renewable energy production systems are:

- PV plant installed on the roof.
- Building Integrated Photovoltaic (BIPV) in the façade of the building.

Then, crossing the presented options, the different scenarios are listed below:

- Baseline: 100% ASHP
- Alternative 1 – 100% ASHP + PV
- Alternative 2 – GSHP + ASHP
- Alternative 3 – GSHP + ASHP + PV
- Alternative 4 – GSHP + ASHP + BIPV

6.9. MULTI-CRITERIA ASSESSMENT OF SCENARIOS

Once the different scenarios have been determined, the selected Key Performance Indicators (KPIs) will be assessed to inform scenario selection process. The KPIs are:

- The energy balance in terms of Primary Energy consumption in a yearly time basis
- The operational CO_2 emissions along service life and the CO_2 emissions savings compared to the baseline scenario
- The upfront investment and the CAPEX overspending

- The total cost under a life cycle perspective
- The cost and environmental impact effectiveness

The energy consumption and generation has been addressed for the baseline scenario and the proposed alternatives. To understand how the scenario performs in terms of the renewable energy ratio (RER), expressed as a percentage of the HVAC electricity consumption and of the total electricity consumption, has been obtained. This expresses the rate of electricity consumption offset by on-site renewable energy generation from a net balance perspective. Results are summarised below (**Table 77**).

Table 77. *Energy* consumption *and renewable energy ratio for the different scenarios in the GESA building.*

Scenario	HVAC Electricity consumption	Total Electricity consumption	Electricity generation	RER / HVAC	RER / Total	Net Energy Balance (Total – RER)
	MWh/year	*MWh/year*	*MWh/year*	*%*	*%*	*MWh/year*
Baseline AHSP 100%	210 608	458 825	0.00	0.00%	0.00%	458 825
ALT 1 – ASHP 100% + PV	210 608	458 825	86 253	40.95%	18.80%	372 572
ALT 2 – GSHP / ASHP	183 773	430 726	0.00	0.00%	0.00%	430 726
ALT 3 – GSHP / ASHP + PV	183 773	430 726	86 253	46.93%	20.02%	344 473
ALT 4 – GSHP / ASHP + BIPV	183 773	430 726	185 902	101.16%	43.16%	244 824

Regarding the net energy balance, which illustrates the electricity consumption once the PV production is discounted, the previous **Table 77** shows that the optimal scenario is the alternative 4 with 244 824 kWh/year.

Under this perspective, the alternative 2/3/4 has an HVAC electricity consumption of 183 773 MWh/year, which means a reduction of 12% over the baseline energy consumption (100% AHSP). Such small improvement can be explained by the good energy efficiency of the baseline scenario.

When it comes to the net electricity consumption, i.e., taking into account the BIPV electricity generation, the alternative 4 (GSHP / AHSP + BIPV) achieves a 101% of the HVAC consumption coverage, and over the 43% of total electricity consumption. If alternative 2 is taken as a standard configuration of a new building (ASHP 100% + PV in the roof), the difference in the RER-TOTAL indicator is substantial, improving the renewable energy coverage from nearly 19% of alternative 2 to 43% of alternative 4.

From an environmental impact perspective, operational CO_2 emissions and emissions reduction potential of the proposed scenarios with respect to baseline reference are studied in **Table 78**.

Table 78. *CO_2 emissions for the optimal scenarios in the GESA building.*

Scenario	Operational CO_2 emissions	Operational CO_2 emissions savings
	tCO_2eq	*%*

Baseline AHSP 100%	8 553	-
ALT 1 – ASHP 100% + PV	6 945	18.80%
ALT 2 – GSHP / ASHP	8 029	6.12%
ALT 3 – GSHP / ASHP + PV	6 421	24.92%
ALT 4 – GSHP / ASHP + BIPV	4 564	46.64%

CO_2 emissions analysis shows that the potential for CO_2 emissions reduction with respect to the baseline reference is 46.6% reduction for the proposed alternative 4.

The shape of the building and the limited possibilities for a PV plant for electricity production makes the BIPV solution as the most impacting solution in the reduction of CO2 emissions due to the available area and the production capacity.

From an investment perspective, there are three main aspects to take into account, which are further detailed in the **Appendix B – Active systems description for the GESA building**:

- The façade refurbishment
- The photovoltaic energy renewable plant (conventional PV or BIPV)
- The active systems (generation and HVAC)

It is worth mentioning that CAPEX does not take into account other interior adaptations necessary to upgrade the building.

The CAPEX of the proposed scenarios and the absolute and relative differences between them and the baseline reference are studied in **Table 79**.

***Table 79**. CAPEX (initial investment) for the different scenarios in the GESA building.*

Scenario	CAPEX	CAPEX Overspending	
	€	€	%
Baseline AHSP 100%	2 847 521.02	0.00	0.00%
ALT 1 – ASHP 100% + PV	2 992 396.02	144 875.00	5.09%
ALT 2 – GSHP / ASHP	2 996 095.59	148 574.57	5.22%
ALT 3 – GSHP / ASHP + PV	3 140 970.59	293 449.57	10.31%
ALT 4 – GSHP / ASHP + BIPV	3 569 976.23	722 455.21	25.37%

CAPEX overspending is significant, with the most optimized scenario in terms of environmental impact (Alt 4) with a capex overspending of 25.37%. This overspending in CAPEX could be balanced in the OPEX reduction that can be seen in **Table 80**.

Table 80. Cost assessment for the scenarios and LCC at 20 years.

Scenario	CAPEX	OPEX	Replacements	RE Savings & revenues	LCC 20 years
	€	€/year	€/year	€/year	€
Baseline AHSP 100%	2 847 521	201 803	0.00	0.00	5 472 567
ALT 1 – ASHP 100% + PV	2 992 396	203 252	0.00	- 25 272	5 307 549
ALT 2 – GSHP / ASHP	2 996 096	195 042	0.00	0.00	5 533 187
ALT 3 – GSHP / ASHP + PV	3 140 971	153 825	0.00	- 25 272	4 813 181
ALT 4 – GSHP / ASHP + BIPV	3 569 976	158 115	0.00	- 54 469	4 918 196

Also, the differential LCC is investigated. This aims at providing clear guidance on the extra investment that must be faced and how it pays off during operation in a 20-year time horizon. Results are shown numerically and graphically below (**Table 81**).

Table 81. Differential LCC assessment 20 years.

Scenario	CAPEX	OPEX	Replacements	RE Savings & revenues	LCC 20 years
	€	€	€	€	€
Baseline AHSP 100%	0.00	0.00	0	0.00	0.00
ALT 1 – ASHP 100% + PV	144 875	18 845	0	- 328 738	- 165 017
ALT 2 – GSHP / ASHP	148 575	- 87 954	0	0.00	60 620
ALT 3 – GSHP / ASHP + PV	293 450	- 624 098	0	- 328 738	- 659 386
ALT 4 – GSHP / ASHP + BIPV	722 455	- 568 293	0	- 708 533	- 554 371

The cost items considered in the analysis are:

- CAPEX: the upfront costs to be faced in the renovation, including HVAC equipment and BIPV system.
- OPEX: the costs of Operation and Maintenance (O&M) costs, including the energy consumption costs. The energy price inflation has not been included in the analysis due to the fact that discounted cash-flow analysis partially outweighs such effect.
- Replacements: the costs of asset replacement foreseen during the timeframe of the analysis, 20 years.
- Renewable Energy Savings and revenues: the savings arisen from on-site RE generation, accounted under the assumption of net balance (all energy produced is discounted from energy generation).

- LCC 20 years: the Life Cycle Costs at 20 years, considering a Discount Rate of 4.5% aligned with current Weighted Average Cost of Capital (WACC) in the EU.

From a life cycle perspective, the best scenarios are the alternative 3 and alternative 4, both with the hybridization on the thermal generation but with different approaches in the photovoltaic generation. In this case, the overspending in the investment of the BIPV lets the alternative 4 slightly behind. Both scenarios clearly show that with a significant overspending in CAPEX comparing with the baseline reference, with a 20 years life span analysis, becomes a better solution, not only from the environmental perspective but also from an economical point of view.

The cost and environmental impact effectiveness is assessed based on the Operational CO_2 emissions / annualised costs [tCO_{2eq}/M€] and Environmental impact on CAPEX [€/tCO_{2eq}].

Scenarios with **lower Operational CO_2 emissions / annualised costs** ratio are those with greater environmental impact effectiveness. Likewise, scenarios with higher **CAPEX / operational CO_2 emissions** ratio show greater investment cost effectiveness to obtain lower operational CO_2 emissions. Results are shown in **Table 82**.

***Table 82**. Cost and Environmental impact effectiveness assessment.*

Scenario	Operational CO2 Emissions / Annualised costs	CAPEX Efficiency on operational CO2 Emissions	LCC 20 Years	CO2 Emissions
	tCO_2EQ/M€	***€/TCO_2EQ***	***€***	***tCO_2eq***
Baseline AHSP 100%	1 563	333	5 472 567	8 553
ALT 1 – ASHP 100% + PV	1 308	431	5 307 549	6 945
ALT 2 – GSHP / ASHP	1 451	373	5 533 187	8 029
ALT 3 – GSHP / ASHP + PV	1 334	489	4 813 181	6 421
ALT 4 – GSHP / ASHP + BIPV	928	782	4 918 196	4 564

It is possible to see that the optimal scenario **from an environmental impact effectiveness perspective is the alternative 4 scenario**, with the lower amount of $tnCO_2$ per annualized cost (**Figure 131**).

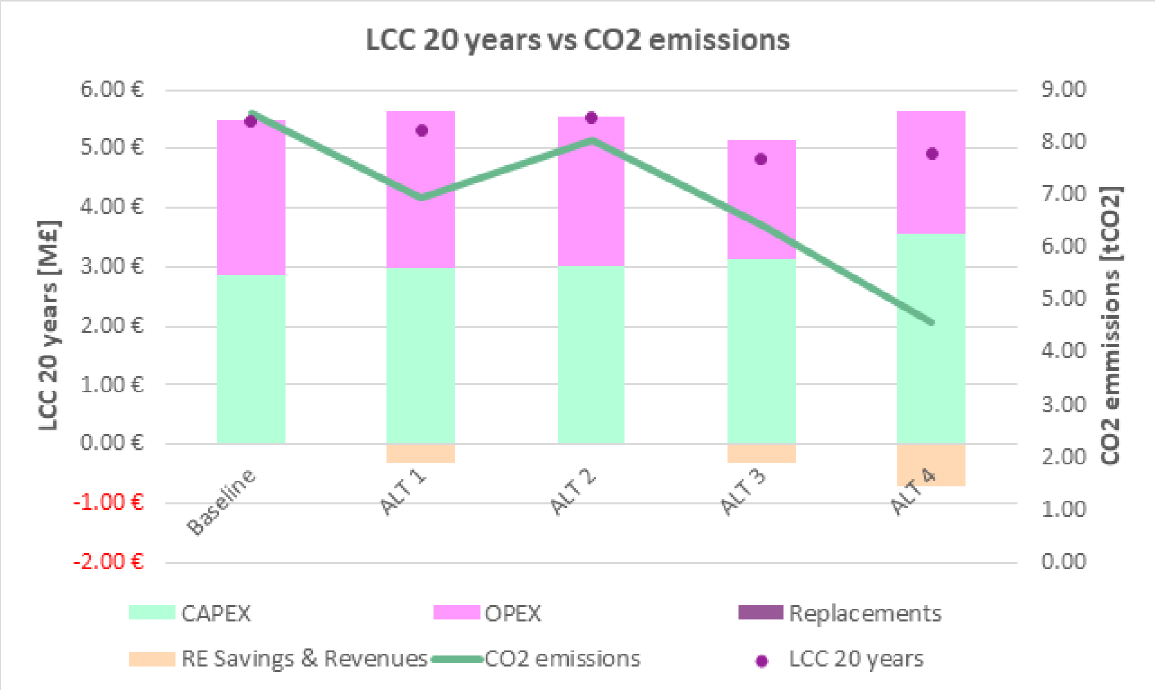


Figure 131. LCC compared with CO2 emissions.

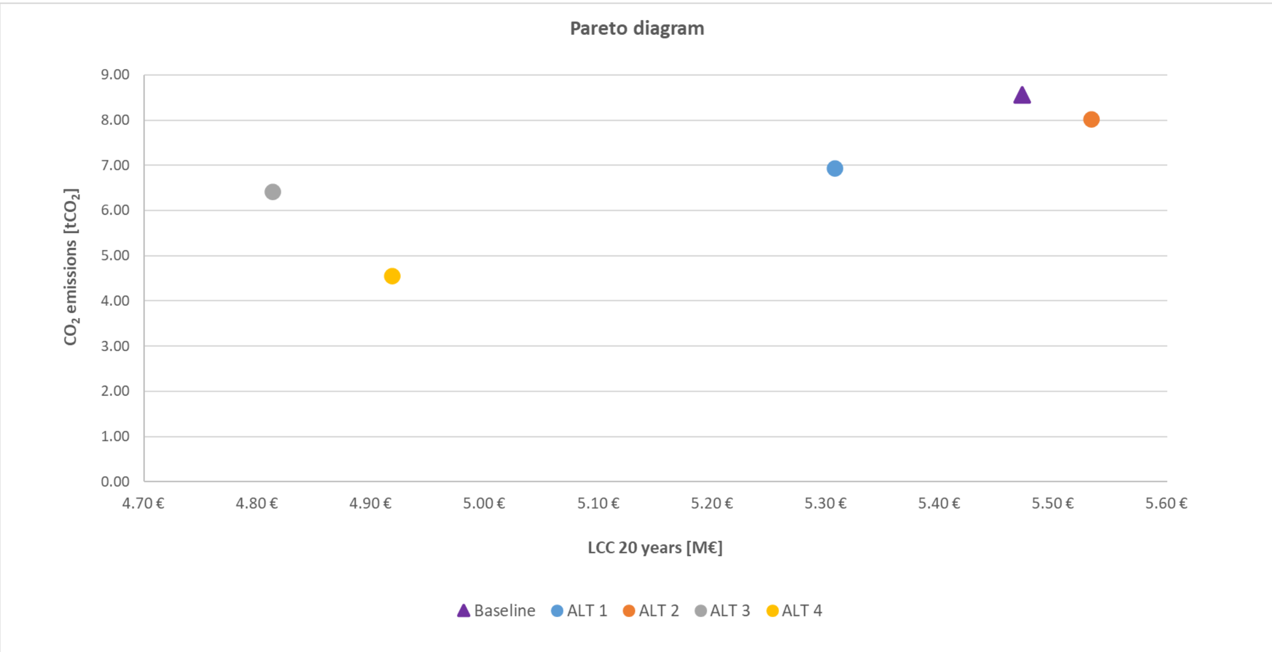


***Figure 132**. Pareto diagram comparing cumulative CO2 emissions and LCC.*

When a multi-variable analysis is carried out, it is not always easy to consider and choose just one scenario as the optimal one. In this case, the Pareto optimal solutions (**Figure 132**) with the combined multi-criteria objective of reaching minimum operational CO2 emissions and minimum life cycle costs are going to be found in the plot as the alternatives closer to the coordinate origin. In this case, and in alignment with the project, the aim is to reduce the environmental impact of the building sector by reducing the energy demand, producing energy from renewable sources and extending the life cycle of the buildings and connecting these buildings into renewable communities, it has been considered that the **Alternative 4 is the proposed optimal scenario for the GESA building**.

6.10. OVERALL PERFORMANCE AND CONCLUSIONS

In this chapter the results of the different assessments carried out are summarized.

From a passive refurbishment perspective, looking at these results presented, it can be concluded that:

- Models with ventilated chambers present 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 such as: embodied carbon, ease of installation, better maintenance, etc.

In the **Table 83**, taken from the previous chapter, results for the different models are shown:

Table 83. *Results for the passive actions for the GESA building refurbishment.*

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

For these reasons, the proposed refurbishment scenario is defined by:

- 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.
- Glass properties
    - U = 1.10 W/m²K
    - g = 0.24

With this optimal scenario for the passive refurbishment, several studies have been carried out in order to select the optimal HVAC system (thermal generation, distribution, and emissions). In a previous iteration, without concerning about the architectural restrictions, a thermal generation parametric study has been carried out. If only the heating, cooling and DHW demands are considered, it can be concluded that after 19 years a 33% GSPH option would be more beneficial approach than a 25% GSHP option. However, other technical factors must be taken into consideration. It is advisable that the power of both systems does not differ significantly to facilitate their synchronized operation. This, combined with the need to consider a certain level of equipment redundancy, makes a scenario like a 50% coverage more advisable, with a GSHP power of 90kW.

After comparing different solutions for thermal energy production (GSHP and ASHP) and renewable energy production (rooftop PV and BIPV layouts), **it is considered the alternative 4 as the optimal scenario for the GESA building**. Once the optimal scenario has been determined, all the KPIs are provided to have a clear vision for the results. The final assessment of the optimal scenario presents the Energy consumption and generation analysis, the multi-criteria LCC and operational CO_2 emissions balance and the differential LCC and CO_2 of the optimal scenarios with respect to the reference Baseline.

From an environmental impact perspective, operational CO_2 emissions and emissions reduction potential of the optimal scenario with respect to baseline reference is provided in **Table 84**.

Table 84. *CO_2 emissions for the optimal scenarios in the GESA building.*

Scenario	CO_2 Emissions during life cycle	CO_2 Emissions savings
	tCO_2eq	*%*
BASELINE AHSP 100%	8 552.50	-
ALT 4 – GSHP / ASHP + BIPV	4 563.52	46.64

The CO_2 emissions analysis shows that the potential for CO_2 emissions reduction with respect to the baseline reference is about the 46.6% reduction for the optimal scenario proposal.

From a cost perspective, the CAPEX and CAPEX difference between the proposed scenario and the baseline reference are studied in **Table 85**.

Table 85. *CAPEX (initial investment) for the different scenarios in the GESA building.*

Scenario	CAPEX	CAPEX Overspending	
	€	€	%
BASELINE ASHP 100%	2 847 521	-	-
ALT 4 – GSHP / ASHP + BIPV	3 569 976	722 455	25.37%

CAPEX overspending is significant and stands over 25% from the baseline reference costs. Comparing costs from a life cycle perspective it is possible to see that the proposed optimal scenario obtains a better cashflow than the reference baseline. Hence, it is clearly shown that the CAPEX overspending is completely outweighed by the operational energy savings, reaching a lower cost at 20-year time period (**Table 86**).

Table 86. *Differential LCC assessment.*

Scenario	CAPEX	OPEX	Replacements	RE Savings & revenues	LCC 20 years
	€	€	€	€	€
ALT 4 – GSHP / ASHP + BIPV	722 455	- 568 293	0	- 708 533	- 554 371

Having a look at all the indicators, it is possible to conclude that the proposed optimal scenario presents:

- A higher initial investment compared with an already efficient baseline
- A clear reduction in operational CO_2 emissions in a yearly basis and overall, from a life cycle perspective.
- A better life cycle cost results in comparison with the baseline when a 20-years life span is considered.

It is possible that other factors such as the results of a geotechnical study can be relevant in both ways: ensuring a higher presence of water and improving the efficiency of the GSHP or increasing the investment related with the wells due to the terrain condition.

For the exposed reasons, it is important to go further on a detailed project in order to fine tune the definitive solution.

Finally, a complete energy balance is shown as the final result of the step-by-step refurbishment developed in the GESA building (**Table 87**).

Table 87. *A complete energy balance for the GESA building.*

Usage	*kWh/m²/yearly*	*kWh yearly*
Heating, Cooling and Hot Water (51% GSHP and 49% ASHP)	7.92	116 908
Ventilation only	4.71	60 060
Dehumidification	0.9	11 476
Lighting	19	242 282
TOTAL	**29.18**	**430 727**
Electricity produced (only façade)	-5.84	**-185 902**
Net Energy Balance	**16.58**	**244 824**

More than 40% of the final energy consumption is covered by the electricity produced just in the façade areas. Although the selected alternative is compliant with the condition of reaching a NZEB building, the possibility of increasing the PV system areas to include a rooftop PV system should be considered in order to achieve a yearly net energy balance criterion.

In the **Table 88**, the achieved results are summarized:

***Table 88**. 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 the Nearly Zero Energy Building (**NZEB**) standard is achieved.	The primary energy results in a value of **49 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 / highly 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 and 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 evaluate 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 the affordable price for the owners, which is one of the main requirements for social housing. Other challenges is to look for 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 36 (December 2024, third version) of the ARV project.

REFERENCES

[1] “New European Bauhaus: beautiful, sustainable, together.” https://europa.eu/new-european-bauhaus/index_en (accessed Jul. 21, 2022).

[2] P. V. Dorizas, M. De Groote, and J. Volt, “The inner value of a building: Linking Indoor Environmental Quality and Energy Performance in Building Regulation,” 2018.

[3] City Council of Palma, “Special interior reform plan for the La Soledat sector and the Llevant polygon.” p. 186, 2003.

[4] Ministerio de Transportes y Movilidad Urbana, “Real Decreto 853/2021, de 5 de octubre, por el que se regulan los programas de ayuda en materia de rehabilitación residencial y vivienda social del Plan de Recuperación, Transformación y Resiliencia,” *Boe*, pp. 122127–122197, 2021, [Online]. Available: https://www.boe.es/buscar/doc.php?id=BOE-A-2021-16233

[5] J. Salom and J. Pascual, “Residential Retrofits at District Scale Business Models under Public Private Partnerships,” p. 41, 2018, [Online]. Available: https://scholar.google.com/scholar?hl=es&as_sdt=0%2C5&q=Residential+Retrofits+at+District+Scale+Business+Models+under+Public+Private+Partnerships+&btnG=#d=gs_cit&u=%2Fscholar%3Fq%3Dinfo%3AE8yF7hMkhtwJ%3Ascholar.google.com%2F%26output%3Dcite%26scirp%3D0%26

[6] “Rehabilitació energètica a les illes residencials de Santa Coloma de Gramenet ”.

[7] IDAE, *CE3X Existing Building Energy Rating User Manual*. 2012.

[8] J. Ortiz and A. Fonseca, “OptiHab,” no. March 2015.

[9] DAIKIN, “R32 Multi Split MXM-M/N.”

[10] “CYPE Ingenieros, S.A., Software para Arquitectura, Ingeniería y Construcción.” https://www.cype.es/ (accessed Dec. 20, 2022).

[11] “PVPC | ESIOS electricidad · datos · transparencia.” https://www.esios.ree.es/es/pvpc (accessed Dec. 20, 2022).

[12] “¿Cuál es el Precio del Gas Natural HOY? | Evolución en 2022.” https://preciogas.com/suministro-gas/tarifas-gas/precio-kwh (accessed Dec. 20, 2022).

[13] “World’s fastest Building Life Cycle Assessment software - One Click LCA.” https://www.oneclicklca.com/ (accessed Dec. 09, 2023).

[14] “EN 15804:2012+A1:2013 - Sustainability of construction works - Environmental product declarations -.” https://standards.iteh.ai/catalog/standards/cen/a7de5991-2e9f-4e93-b34c-f1d794cbca02/en-15804-2012a1-2013 (accessed Dec. 09, 2023).

[15] “Level(s).” https://environment.ec.europa.eu/topics/circular-economy/levels_en (accessed Dec. 09, 2023).

[16] “BREEAM® España valida el software de CYPE que calcula el impacto ambiental generado en la edificación - CYPE.” https://info.cype.com/es/noticias/breeam-espana-valida-el-software-de-cype-que-calcula-el-impacto-ambiental-generado-en-la-edificacion/ (accessed Dec. 09, 2023).

[17] S. General de Planificación Energética Seguimiento, “Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España [PDF][647,80 KB]”.

[18] “Observatorio de Vivienda y Suelo | Ministerio de Transportes, Movilidad y Agenda Urbana.” https://www.mitma.gob.es/arquitectura-vivienda-y-suelo/urbanismo-y-politica-de-suelo/estudios-y-publicaciones/observatorio-de-vivienda-y-suelo (accessed Dec. 04, 2023).

[19] “Comunidad autónoma | Ministerio de Transportes, Movilidad y Agenda Urbana.” https://www.mitma.gob.es/vivienda/alquiler/indice-alquiler/comunidad_autonoma (accessed Dec. 04, 2023).

[20] “Datos estadísticos : Economía : Construcción y Vivienda : Precios de la vivienda : Precio medio del metro cuadrado de suelo urbano por periodo y tamaño de municipio.” https://ibestat.caib.es/ibestat/estadistiques/4d44b223-19ed-4bac-8ebb-5bda96d41c19/52330ffe-f8e0-44e6-a817-4b15a92b0b75/es/E20007_00001.px (accessed Dec. 04, 2023).

[21] Ministerio de Fomento - España, “Código Técnico de la Edificación DB-HE,” *Código Técnico la Edif.*, pp. 1–129, 2019, [Online]. Available: http://www.arquitectura-tecnica.com/hit/Hit2016-2/DBHE.pdf
[22] Palma, “Pla d’Ordenació Detallada”.
[23] “BOE-A-2017-10541 Ley 8/2017, de 3 de agosto, de accesibilidad universal de las Illes Balears.” https://www.boe.es/diario_boe/txt.php?id=BOE-A-2017-10541 (accessed Dec. 04, 2023).
[24] D. Básico SUA, “MINISTERIO DE TRANSPORTES, MOVILIDAD Y AGENDA URBANA”.
[25] Num, “Secció I-Comunitat Autònoma Illes Balears 1.-Disposicions generals CONSELLERIA D’OBRES PÚBLIQUES, HABITATGE I TRANSPORTS,” 2007.
[26] “Home | Forest Stewardship Council.” https://fsc.org/en (accessed Dec. 04, 2023).
[27] “BOIB, boletín oficial.” https://www.caib.es/eboibfront/es/2018/10851/611989/decreto-25-2018-de-27-de-julio-sobre-la-conservaci (accessed Dec. 04, 2023).
[28] “D2.1 Assessment framework for CPCC (DRAFT - pending European Commission approval) · ARV.” https://greendeal-arv.eu/library/d2-1-assessment-framework-for-cpcc-2/ (accessed Dec. 04, 2023).
[29] D. Básico and H. S. Salubridad, “MINISTERIO DE TRANSPORTES, MOVILIDAD Y AGENDA URBANA”.
[30] CEN, *EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acous*. 2019.
[31] “Software Tools | Windows & Daylighting.” https://windows.lbl.gov/software-tools#therm-heading (accessed Dec. 10, 2023).
[32] I. Paricio, “Report on the facade of the old GESA headquarters building,” Barcelona, 2015.
[33] A. Ramos and J. Salom, “Energy Impact of building integrated photovoltaics on high rise office building in the Department of Graphic and Design Engineering , Barcelona School of Industrial Catalonia Institute for Energy Research (IREC), Thermal Energy and Building”.
[34] “File:Seagrambuilding.jpg - Wikimedia Commons.” https://commons.wikimedia.org/wiki/File:Seagrambuilding.jpg (accessed Dec. 13, 2022).
[35] “Edifici Seat - Barcelona | La Marina de Port - Pobles de Catalunya.” https://www.poblesdecatalunya.cat/element.php?e=10314 (accessed Dec. 13, 2022).
[36] “Athens Towers - Structure | RouteYou.” https://www.routeyou.com/en-gr/location/view/50626890/athens-towers (accessed Dec. 13, 2022).
[37] “Energy performance of buildings directive.” https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en (accessed Dec. 07, 2022).
[38] Ministry of Industry, “CO2 emission factors and step coefficients to primary energy from different final energy sources consumed in the building sector in Spain (in Spanish),” *Doc. Reconocido del Reglam. Instal. Térmicas en los Edif.*, pp. 16, 17, 18, 2016, [Online]. Available: http://www.minetad.gob.es/energia/desarrollo/EficienciaEnergetica/RITE/Reconocidos/Reconocidos/Otros documentos/Factores_emision_CO2.pdf
[39] “Creative Commons — Attribution-NoDerivs 2.0 Generic — CC BY-ND 2.0.” https://creativecommons.org/licenses/by-nd/2.0/ (accessed Dec. 08, 2022).
[40] P. R. Puckorius, “Water Corrosion Mechanisms,” *Water Treat.*, vol. Vol.5, p. pp.57-61, 1999.
[41] M. D. Vanderheyden and G. D. Schuyler, “Evaluation and quantification of the impact of cooling tower emissions on indoor air quality,” *ASHRAE Trans.*, vol. Vol.100, no. Pt.2, p. pp.9, 1994.
[42] Neo Solar Power, “Mono-Crystalline Photovoltaic Module,” pp. 5–6, 2016, [Online]. Available: www.MitsubishiElectricSolar.com
[43] I. P. V Solutions, “60 Cells - VE160PVMR,” pp. 24–25, 2019.
[44] “Solar module Standard-PV-Module - Lof Solar - Color Solar Cell.” http://www.lofsolar.com/Standard-PV-Module#6 (accessed Dec. 21, 2022).
[45] “Lof Solar Corporation - 6x6 BIPV Module”.
[46] R. E. C. Alpha *et al.*, “Packaging & shipment Specifications,” pp. 2–11.

[47] R. E. C. N. B. Series, “rec N-Peak 2 Black Series”.
[48] “Solar panels | custom size and flexible shapes modules | metsolar.eu.” https://metsolar.eu/customization-options/ (accessed Dec. 08, 2022).
[49] MiaSole, “FLEX SERIES -01W CIGS Flexible Modules : High Power Density in a Flexible Form Factor,” pp. 1–2, 2017, [Online]. Available: https://miasole.com/products/
[50] S. Technology, “eFlex - Flexible CIGS Solar PV modules,” vol. 41, no. 0.
[51] “eMetal 1.6m – for Buildings & BIPV,” vol. 41, no. 0, pp. 3000–3001.
[52] Novocarbo, “Product Data Sheet Product Data Sheet Uses,” 試薬, vol. 3, no. 0, pp. 6–7, 2011.
[53] “HeliaSol.” https://www.heliatek.com/en/products/heliasol/ (accessed Dec. 08, 2022).
[54] “HeliaFilm.” https://www.heliatek.com/en/products/heliafilm/ (accessed Dec. 08, 2022).
[55] “Home » Antec Solar.” https://www.antec.solar/ (accessed Dec. 09, 2022).
[56] “SKALA - Empower your facade”.
[57] “ONYX SOLAR.” https://www.onyxsolar.es/ (accessed Dec. 09, 2022).
[58] "Functional building glass - energy savings and photovoltaic power generation".
[59] “Flexible solar cell & transparent photovoltaic film | ASCA.” https://www.asca.com/asca-technology/ (accessed Dec. 09, 2022).

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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

GWP	Global-warming Potential
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
POE	Post Occupancy Evaluation
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 – ACTIVE SYSTEMS DESCRIPTION FOR THE GESA BUILDING

B.1. 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.

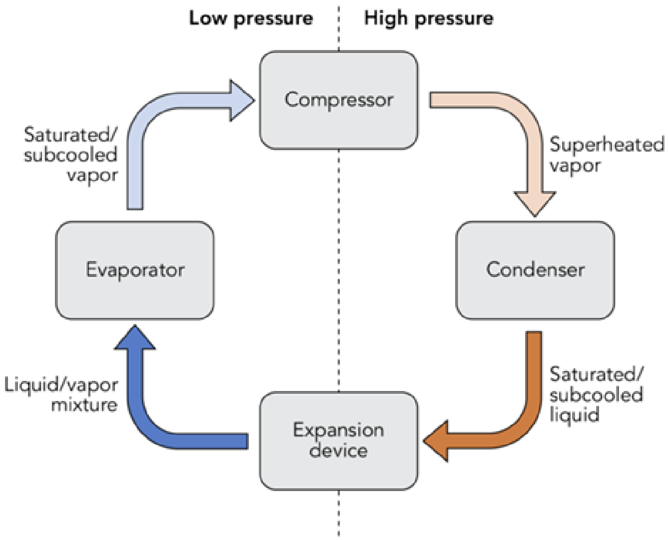


Figure 133. *Heat pumps under Creative Commons Licence* [39].

B.2. 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 [40].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 [41].

B.3. 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.

B.4. 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 into 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.

B.5. 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.

B.6. 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.

B.7. 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.

B.8. INVESTMENT COSTS ASSESSMENT FOR PV, BIPV AND FAÇADE REFURBISHMENT OPTIONS

Regarding the façade refurbishment, only ad-hoc solutions have been found to imply a higher cost. A prototype of 8 modules of 1 250 mm x 3 400mm per module from an industrial provider has the following cost breakdown (**Table 89**).

Table 89. *Prototype of 8 modules - cost breakdown.*

Concept	Cost
Technical development	26 095 €
Prototype	103 632 €
Total cost	**129 727 €**

Due to the “prototype” interpretation of the industrial solution, the total cost expected for the refurbishment of all the façade surface is not reliable. To avoid wrong assumptions in this concept, an approach of CAPEX overspending has been assumed. It is stablished that all the assessed scenarios will incorporate an optimized façade solution, with the same characteristics (thermal properties, air leakages, etc). For this reason, in the capital expenditure only the overspending associated to regular glass (no BIPV) replacement with Building Integrated Photovoltaic glass will be considered. The BIPV solution presents the following cost breakdown (**Table 90**).

***Table 90**. BIPV solution - cost breakdown.*

Glass	Units	Glass modules	Glass configuration	Peak Power	Surface	Cost
		mm		kWp	m2	€/m2
GL01 (a-Si)	1180	1730 x 1 170	6mm + 3.2 floated PV 30% translucent + 6mm / 12mm argon chamber / 4+4mm with low-e.	66.88	2 388	301.96
GL02 (c-Si)	1230	1480 x 1170	6mm + 6mm / 12mm air chamber / 4+4mm with low-e.	164.81	2 083	450.29

The equivalent glass solutions without PV finishing are described below (**Table 91**):

***Table 91**. Glass solutions without PV finishing.*

Glass	Units	Glass modules	Glass configuration	U	Surface	Cost [11]
		mm		W/m2K	m2	€/m2
GL01	1180	1730 x 1 170	6mm + 6mm / 12mm argon chamber / 4+4mm with low-e.	1.3	2 388	239.97
GL02	1230	1480 x 1170	6mm + 6mm / 12mm air chamber / 4+4mm with low-e.	1.6	2 083	245.85

The overspending of the BIPV scenario is calculated from the difference between the two cases described above, assuming that the cost of the façade (insulation, frame, etc) is the same. The overspending investment for the BIPV scenario is calculated in 573 881€.

For the rooftop PV plant scenario, a cost of 144 875€ is obtained considering a PV plant of 58 kWp and a ratio of 2 498 €/kWp.

[11] http://www.generadordeprecios.info/rehabilitacion

APPENDIX C – BIPV COMMERCIAL SOLUTIONS FOR GESA BUILDING

C.1. 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.

C.2. 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 92** 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 134** some examples of BIPV products are shown.

Table 92. 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)	[42]
VGS	60 Cells - VE160PVMR	5BB Polycrystalline - Red	Si	15.2-15.85 (power 250-260 Wp)	[43]
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)	[44]
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)	[45]
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)	[46]
REC	N-PEAK 2 BLACK SERIES	Black	Si	19.1-20.3 (350-370 Wp)	[47]
METSOLAR	CUSTOM	Wide range of colours	Si	Range of efficiencies and power	[48]
MIASOLE	FLEX SERIES-02WS	Blue/Black	CIGS	14-17 (210-250 Wp)	[49]
MIASOLE	FLEX SERIES-03W 1 METER	Blue/Black	CIGS	14-18 (160-200 Wp)	[49]
FLISOM	eFLEX	Black	CIGS	(55 Wp)	[50]

FLISOM	eMETAL	Black	CIGS	(50-60 Wp)	[51]
MIDSUMMER	SLIM SERIES	Solar film with opaque solar area and black coloured edge	CIGS	(65-160 Wp)	[52]
HELIATEK	HELIASOL	blueish	Organics	(50-55 Wp)	[53]
HELIATEK	HELIAFILM	blueish	Organics	No details	[54]
ANTECSOLAR	CUSTOM	Range of colours	CIGS-custom	Various efficiencies and power	[55]
AVANCIS	SKALA	Range of colours	CIGS	11.4-13.3 (120-140 Wp)	[56]
ONYX	CUSTOM	Wide range of homogeneous colours	Si	(80-140 Wp/m^2)	[57]

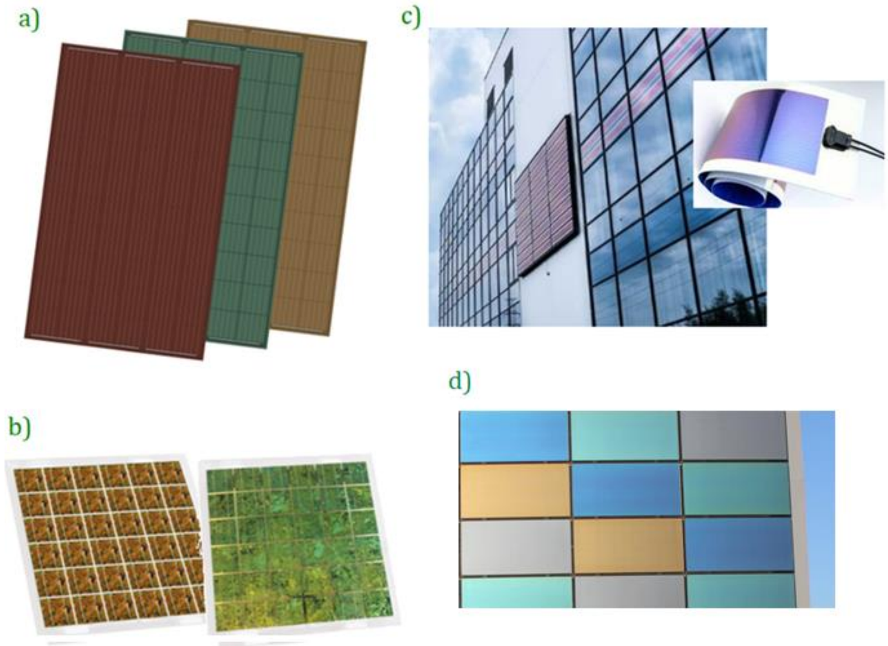


Figure 134. *Examples of opaque BIPV solutions: a) Solarday – coloured monocrystalline Si [11], b) coloured LOF – polycrystalline Si (information requested), c) Heliatek – coloured organics on flexible substrate [19] and d) Antec Solar – CIGS [21].*

For the transparent part, the offer is more limited, and very few commercial products can be found as standard. Available products generally consist of 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 93** summarizes the main identified manufacturers of such solutions. However, since these solutions are typically customized, details are only available upon request. In **Figure 135** some examples of semi-transparent BIPV products are presented.

Table 93. *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	[57]
Kaneka	CUSTOM	Range of colours	a-Si	No details	[58]
Armor Asca	CUSTOM	Range of colours	Organics	40 Wp/m^2	[59]
METSOLAR	CUSTOM	Wide range, cell cladding	Si	different Si technologies possible	[48]
ANTECSOLAR	CUSTOM	Wide range of colours	Several	No details	[55]

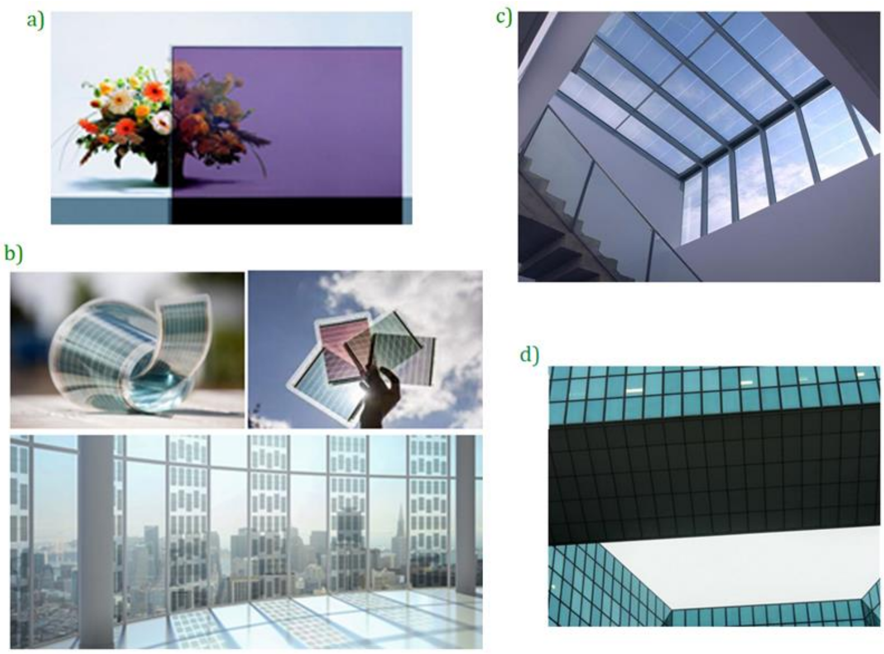


Figure 135. *Examples of semi-transparent BIPV solutions: a) Onyx – coloured amorphous Si* [57], *b) Kaneka - coloured amorphous Si on flexible substrate* [58], *c) Armor Asca – coloured organics* [59] *and Antec Solar – CIGS* [55].

APPENDIX D – GSHP CALCULATIONS FOR GESA BUILDING

D.1. 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 136**).

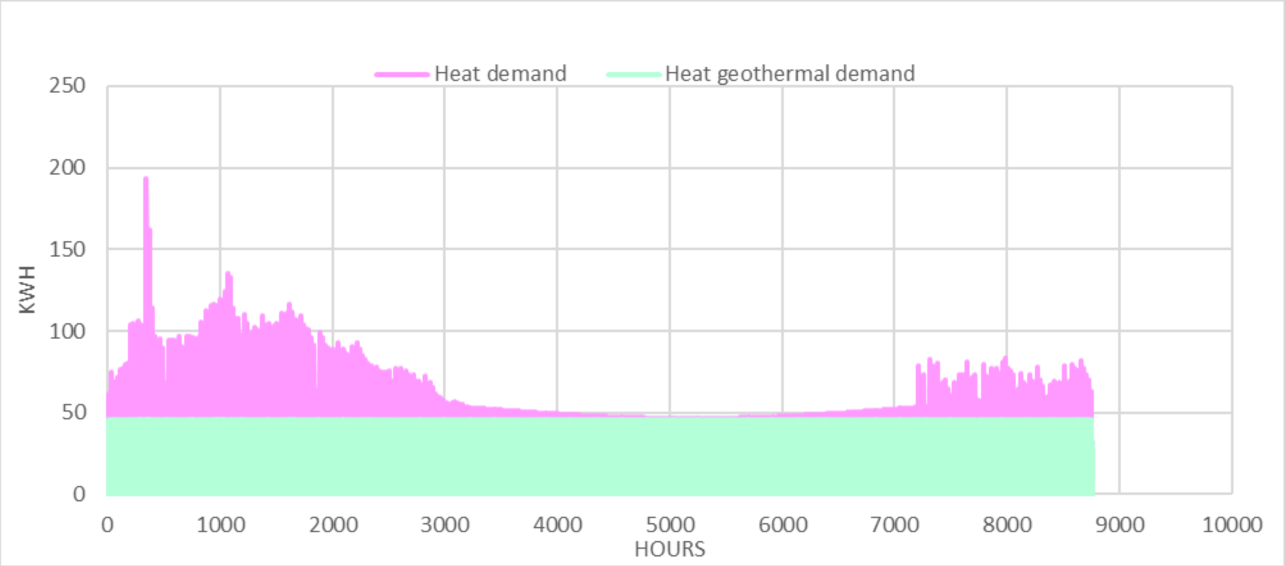


***Figure 136**. Heating loads.*

Cooling energy loads are shown below (**Figure 137**).

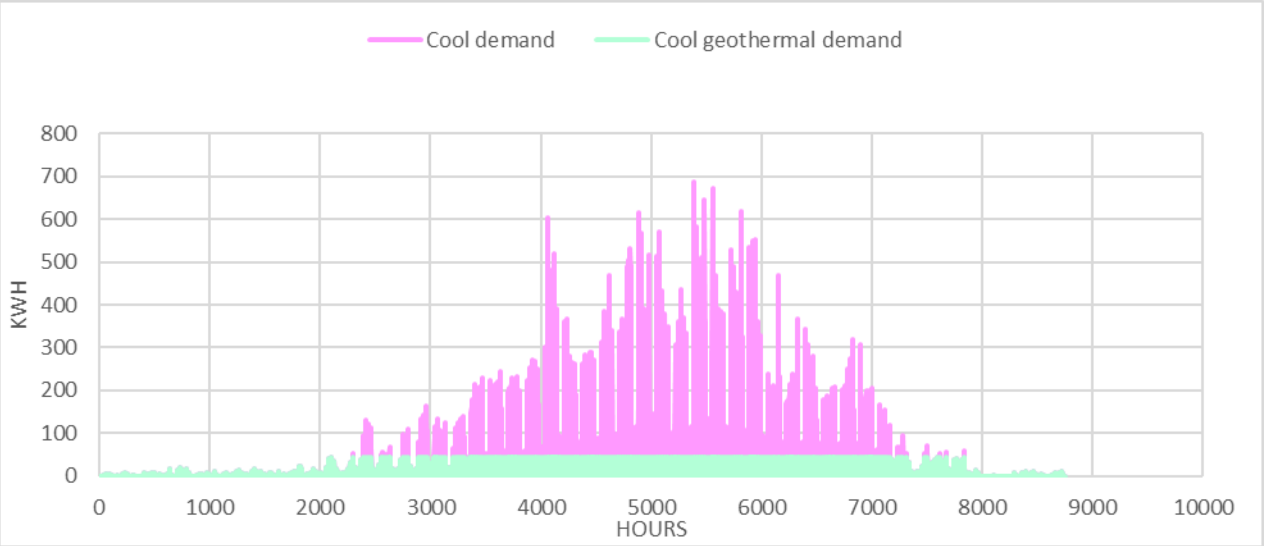


***Figure 137**. Cooling loads.*

D.2. GSHP DATA

Table 94. *GSHP Data.*

Heating		
Thermal power	125	kW
COP	4.26	
Temperature range	40-30	º C
Cooling		
Thermal power	109	kW
EER	4.51	
Temperature range	7-17	º C

D.3. CONFIGURATION OF THE BOREHOLES FIELD

Table 95. *Boreholes configuration.*

Geothermal boreholes field		
Line length	48	m
Number of boreholes	14	
Distance between boreholes	8	m
Boreholes depth	150	m

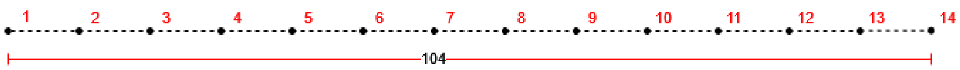


Figure 138. *Boreholes configuration.*

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

D.4. 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.

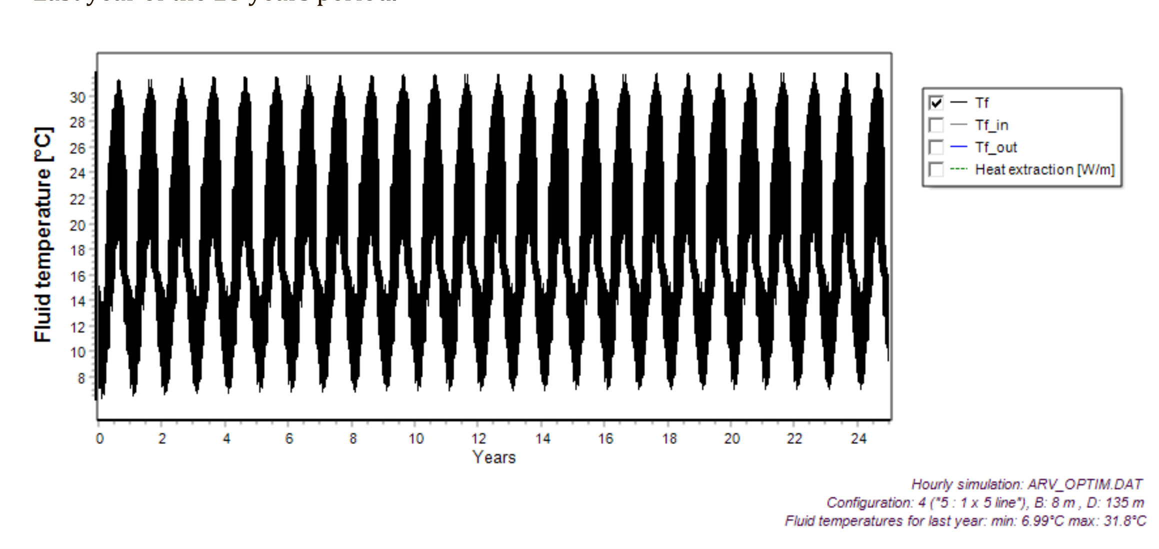


Figure 139. *25 years temperature fluid analysis extracted from the ground.*

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.

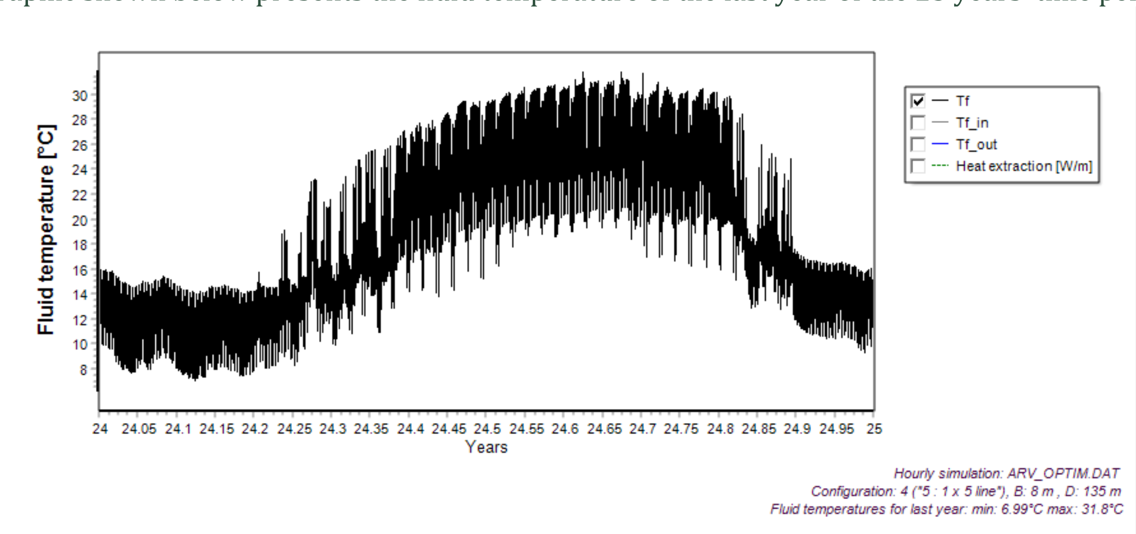


Figure 140. *One year temperature fluid analysis extracted from the ground (25 years).*

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.

D.5. 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/m^2 depending on the conductivity of the ground.

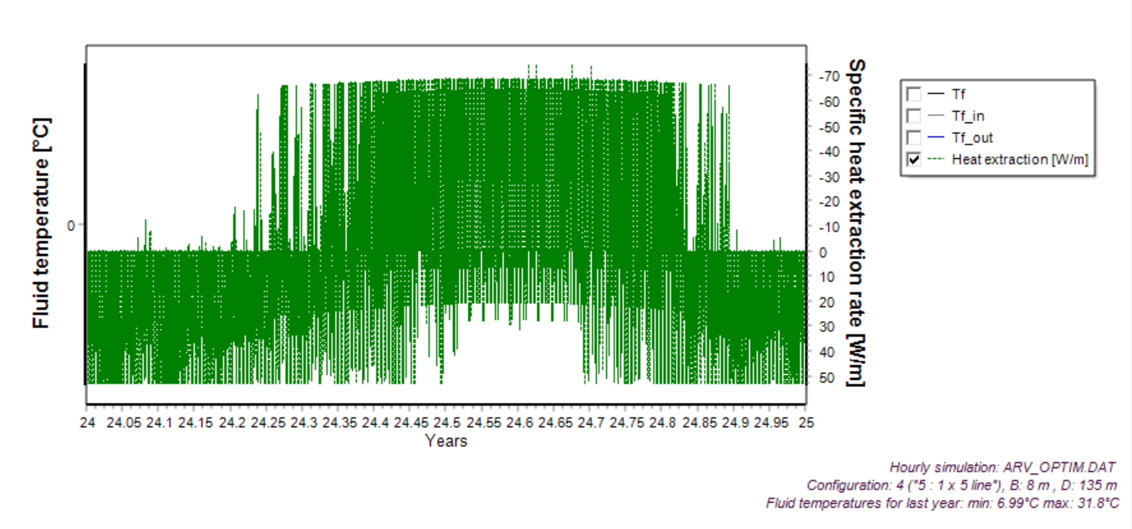


Figure 141. *Heat extraction analysis for 25 years in W/m.*

D.6. 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.

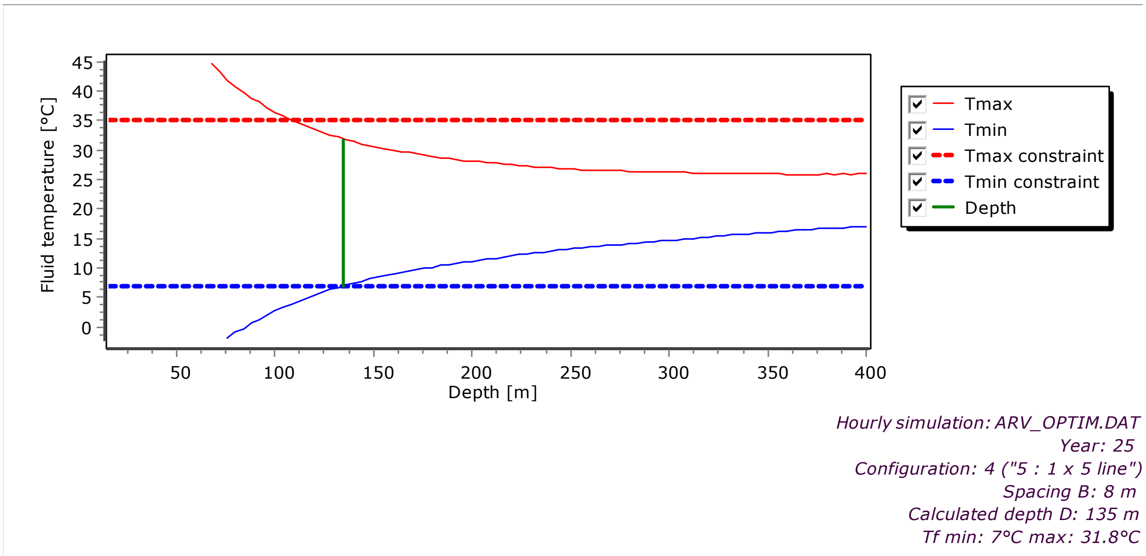


Figure 142. *Depth analysis for geothermal boreholes.*

APPENDIX E – DETAILED DATA FOR ECONOMICAL CALCULATIONS FOR LARGE SCALE RETROFITTING ACTIONS

Table 96. *Material costs for different solutions (Archetypes 1 and 2).*

Package & Surface	Material	Insulation Thickness (mm)	Global cost (€/m²) [10]
P1.1.1 & P2.1.1 Wall Conventional	EPS insulation (expanded polystyrene insulation)	60	79.57
		80	83.31
		100	87.55
		120	91.01
		140	93.42
P1.1.2 & P2.1.2 Wall Conventional (Archetype 1)	Rock wool	80	92.74
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
P2.1 Windows Conventional	PVC window frame + glass 4-14-6 LE	-	512.86

P2.2 Windows Ecological	Pinewood window frame + glass 4-14-6 LE	-	963.902

Table 97. Material costs for different solutions (Archetypes 3 and 4).

Package & Surface	Material	Insulation Thickness (mm)	Global cost (€/m²) [10]
P1.1 & P2.1 Wall Conventional	Rock wool	80	92.74
P1.2 & P2.2 Wall Ecological	Lime insulating mortar	60	137.54
		80	154.63
P1.1.1 & P2.1.1 Roof Conventional (Archetype 3)	Rock wool	80	181.49
P1.1.1 & P2.1.1 Roof Conventional (Archetype 4)	XPS (Extruded Polystyrene)	60	142.35
		80	145.68
		100	148.81
		120	151.95
		140	155.13
P1.1.2 & P2.1.2 Roof Conventional (Archetype 4)	XPS + Arlite mortar	100	171.41
P1.2.1 & P2.2.1 Roof Ecological (Archetype 3)	Wood panel + Graphite EPS	80	222.10
P1.2.1 & P2.2.1 Roof Ecological (Archetype 4)	Graphite EPS	100	169.99
P1.2.2 & P2.2.2 Roof Ecological (Archetype 4)	Recycled insulating mortar	100	151.81
P2.1 Windows Conventional	PVC window frame + glass 4-14-6 LE	1 unit	676.97
P2.2 Windows Ecological	Pinewood window frame + glass 4-14-6 LE	1 unit	1272.35

Table 98. *Global average retrofitting investment cost per dwelling without grants (Archetype 1).*
(Note: In the second and the third column, the number after W and R refers to the thickness in cm of insulation).

Package	Wall Insulation Thickness (cm)	Roof Insulation Thickness (cm)	Wall cost (€)	Roof cost (€)	Windows (€)	Floor cost (€)	Total cost (€)
BC0	0	0	0	0	0	0	0
P111	W6	R6	3 507	3 253	0	1 568	8 328
P121	W6	R6	3 613	3 814	0	1 547	8 973
P211	W6	R6	3 507	3 253	6 375	1 568	14 702
P221	W6	R6	3 613	3 814	11 981	1 547	20 955
P111	W6	R8	3 507	3 329	0	1568	8 404
P121	W6	R8	3 613	4 062	0	1 547	9 221
P211	W6	R8	3 507	3 329	6 375	1 568	1 4779
P221	W6	R8	3 613	4 062	11 981	1 547	21 203
P111	W6	R10	3 507	3 400	0	1 568	8 475
P121	W6	R10	3 613	4 330	0	1 547	9 490
P211	W6	R10	3 507	3 400	6 375	1 568	14 850
P221	W6	R10	3 613	4 330	11 981	1 547	21 471
P111	W6	R12	3 507	3 472	0	1 568	8 547
P121	W6	R12	3 613	4 599	0	1 547	9 758
P211	W6	R12	3 507	3 472	6 375	1 568	14 922
P221	W6	R12	3 613	4 599	11 981	1 547	21 739
P111	W6	R14	3 507	3 545	0	1 568	8 620
P121	W6	R14	3 613	4 866	0	1 547	10 026
P211	W6	R14	3 507	3 545	6 375	1 568	14 995
P221	W6	R14	3 613	4 866	11 981	1 547	22 007
P111	W8	R6	3 671	3 253	0	1 568	8 493
P112	W8	R6	4 087	3 253	0	1 568	8 908
P121	W8	R6	3 793	3 814	0	1 547	9 153
P211	W8	R6	3 671	3 253	6 375	1 568	14 867
P212	W8	R6	4 087	3 253	6 375	1 568	15 283
P221	W8	R6	3 793	3 814	11 981	1 547	21 134
P111	W8	R8	3 671	3 329	0	1 568	8 569

P112	W8	R8	4 087	3 329	0	1 568	8 984
P121	W8	R8	3 793	4 062	0	1 547	9 401
P211	W8	R8	3 671	3 329	6 375	1 568	14 943
P212	W8	R8	4 087	3 329	6 375	1 568	15 359
P221	W8	R8	3 793	4 062	11 981	1 547	2 1383
P111	W8	R10	3 671	3 400	0	1 568	8 640
P112	W8	R10	4 087	3 400	0	1 568	9 056
P121	W8	R10	3 793	4 330	0	1 547	9 669
P211	W8	R10	3 671	3 400	6375	1 568	15 015
P212	W8	R10	4 087	3 400	6375	1 568	15 430
P221	W8	R10	3 793	4 330	11981	1 547	21 651
P111	W8	R12	3 671	3 472	0	1 568	8 712
P112	W8	R12	4 087	3 472	0	1 568	9 127
P121	W8	R12	3 793	4 599	0	1 547	9 938
P211	W8	R12	3 671	3 472	6 375	1 568	15 087
P212	W8	R12	4 087	3 472	6 375	1 568	15 502
P221	W8	R12	3 793	4 599	11 981	1 547	21 919
P111	W8	R14	3 671	3 545	0	1 568	8 785
P112	W8	R14	4 087	3 545	0	1 568	9 200
P121	W8	R14	3 793	4 866	0	1 547	10 205
P211	W8	R14	3 671	3 545	6 375	1 568	15 159
P212	W8	R14	4 087	3 545	6 375	1 568	15 575
P221	W8	R14	3 793	4 866	11 981	1 547	22 187
P111	W10	R6	3 858	3 253	0	1 568	8 679
P121	W10	R6	3 969	3 814	0	1 547	9 329
P211	W10	R6	3 858	3 253	6 375	1 568	15 054
P221	W10	R6	3 969	3 814	11 981	1 547	21 311
P111	W10	R8	3 858	3 329	0	1 568	8 755
P121	W10	R8	3 969	4 062	0	1 547	9 578
P211	W10	R8	3 858	3 329	6 375	1 568	15 130
P221	W10	R8	3 969	4 062	11 981	1 547	21 559
P111	W10	R10	3 858	3 400	0	1 568	8 827

P121	W10	R10	3 969	4 330	0	1 547	9 846
P211	W10	R10	3 858	3 400	6 375	1 568	15 202
P221	W10	R10	3 969	4 330	11 981	1 547	21 827
P111	W10	R12	3 858	3 472	0	1 568	8 899
P121	W10	R12	3 969	4 599	0	1 547	10 114
P211	W10	R12	3 858	3 472	6 375	1 568	15 274
P221	W10	R12	3 969	4 599	11 981	1 547	22 095
P111	W10	R14	3 858	3 545	0	1 568	8 971
P121	W10	R14	3 969	4 866	0	1 547	10 382
P211	W10	R14	3 858	3 545	6 375	1 568	15 346
P221	W10	R14	3 969	4 866	11 981	1 547	22 363
P111	W12	R6	4 011	3 253	0	1 568	8 832
P121	W12	R6	4 144	3 814	0	1 547	9 504
P211	W12	R6	4 011	3 253	6 375	1 568	15 207
P221	W12	R6	4 144	3 814	11981	1 547	21 486
P111	W12	R8	4 011	3 329	0	1 568	8 908
P121	W12	R8	4 144	4 062	0	1 547	9 753
P211	W12	R8	4 011	3 329	6375	1 568	15 283
P221	W12	R8	4 144	4 062	11 981	1 547	21 734
P111	W12	R10	4 011	3 400	0	1 568	8 979
P121	W12	R10	4 144	4 330	0	1 547	10 021
P211	W12	R10	4 011	3 400	6 375	1 568	15 354
P221	W12	R10	4 144	4 330	11 981	1 547	22 002
P111	W12	R12	4 011	3 472	0	1 568	9 051
P121	W12	R12	4 144	4 599	0	1 547	10 289
P211	W12	R12	4 011	3 472	6 375	1 568	15 426
P221	W12	R12	4 144	4 599	11 981	1 547	22 270
P111	W12	R14	4 011	3 545	0	1 568	9 124
P121	W12	R14	4 144	4 866	0	1 547	10 557
P211	W12	R14	4 011	3 545	6 375	1 568	15 499
P221	W12	R14	4 144	4 866	11 981	1 547	22 538
P111	W14	R6	4 117	3 253	0	1 568	8 938

P211	W14	R6	4 117	3 253	6 375	1 568	15 313
P111	W14	R8	4 117	3 329	0	1 568	9 014
P211	W14	R8	4 117	3 329	6 375	1 568	15 389
P111	W14	R10	4 117	3 400	0	1 568	9 086
P211	W14	R10	4 117	3 400	6 375	1 568	15 460
P111	W14	R12	4 117	3 472	0	1 568	9 157
P211	W14	R12	4 117	3 472	6 375	1 568	15 532
P111	W14	R14	4 117	3 545	0	1 568	9 230
P211	W14	R14	4 117	3 545	6 375	1 568	15 605

Table 99. *Global average retrofitting investment cost per dwelling without grants (Archetype 2).*
(Note: In the second and the third column, the number after W and R refers to the thickness in cm of insulation).

Package	Wall Insulation Thickness (cm)	Roof Insulation Thickness (cm)	Wall cost (€)	Roof cost (€)	Windows (€)	Floor cost (€)	Total cost (€)
BC0	0	0	0	0	0	0	0
P111	W6	R6	7 242	5 501	0	0	12 744
P211	W6	R6	7 242	5 501	10 247	0	22 991
P111	W8	R6	7 583	5 501	0	0	13 084
P211	W8	R6	7 583	5 501	10 247	0	23 331
P111	W10	R6	7 969	5 501	0	0	13 470
P211	W10	R6	7 969	5 501	10 247	0	23 717
P111	W12	R6	8 284	5 501	0	0	13 785
P211	W12	R6	8 284	5 501	10 247	0	24 032
P111	W14	R6	8 503	5 501	0	0	14 004
P211	W14	R6	8 503	5 501	1 0247	0	24 251
P111	W6	R8	7 242	5 630	0	0	12 872
P211	W6	R8	7 242	5 630	10 247	0	23 119
P111	W8	R8	7 583	5 630	0	0	13 213
P211	W8	R8	7 583	5 630	10 247	0	23 460
P111	W10	R8	7 969	5 630	0	0	13 599
P211	W10	R8	7 969	5 630	10 247	0	23 846
P111	W12	R8	8 284	5 630	0	0	13 914

P211	W12	R8	8 284	5 630	10 247	0	24 161
P111	W14	R8	8 503	5 630	0	0	14 133
P211	W14	R8	8 503	5 630	10 247	0	24 380
P111	W6	R10	7 242	5 751	0	0	12 993
P211	W6	R10	7 242	5 751	10 247	0	23 240
P111	W8	R10	7 583	5 751	0	0	13 334
P211	W8	R10	7 583	5 751	10 247	0	23 581
P111	W10	R10	7 969	5 751	0	0	13 720
P211	W10	R10	7 969	5 751	10 247	0	23 967
P111	W12	R10	8 284	5 751	0	0	14 035
P211	W12	R10	8 284	5 751	10 247	0	24 282
P111	W14	R10	8 503	5 751	0	0	14 254
P211	W14	R10	8 503	5 751	10 247	0	24 501
P111	W6	R12	7 242	5 872	0	0	13 115
P211	W6	R12	7 242	5 872	10 247	0	23 362
P111	W8	R12	7 583	5 872	0	0	13 455
P211	W8	R12	7 583	5 872	10 247	0	23 702
P111	W10	R12	7 969	5 872	0	0	13 841
P211	W10	R12	7 969	5 872	10 247	0	24 088
P111	W12	R12	8 284	5 872	0	0	14 156
P211	W12	R12	8 284	5 872	10 247	0	24 403
P111	W14	R12	8 503	5 872	0	0	14 375
P211	W14	R12	8 503	5 872	10 247	0	24 622
P111	W6	R14	7 242	5995	0	0	13 238
P211	W6	R14	7 242	5995	10247	0	23 484
P111	W8	R14	7 583	5 995	0	0	13 578
P211	W8	R14	7 583	5 995	10 247	0	23 825
P111	W10	R14	7 969	5 995	0	0	13 964
P211	W10	R14	7 969	5 995	10 247	0	24 211
P111	W12	R14	8 284	5 995	0	0	14 279
P211	W12	R14	8 284	5 995	10 247	0	24 526
P111	W14	R14	8 503	5 995	0	0	14 498

P211	W14	R14	8 503	5 995	10 247	0	24 745
P121	W6	R6	7 462	6 450	0	0	13 912
P221	W6	R6	7 462	6 450	19 259	0	33 171
P121	W8	R6	7 833	6 450	0	0	14 283
P221	W8	R6	7 833	6 450	19 259	0	33 542
P121	W10	R6	8 197	6 450	0	0	14 647
P221	W10	R6	8 197	6 450	19 259	0	33 906
P121	W12	R6	8 559	6 450	0	0	15 009
P221	W12	R6	8 559	6 450	19 259	0	34 268
P121	W6	R8	7 462	6 870	0	0	14 332
P221	W6	R8	7 462	6 870	19 259	0	33 590
P121	W8	R8	7 833	6 870	0	0	14 703
P221	W8	R8	7 833	6 870	19 259	0	33 962
P121	W10	R8	8 197	6 870	0	0	15 067
P221	W10	R8	8 197	6 870	19 259	0	34 326
P121	W12	R8	8 559	6 870	0	0	15 429
P221	W12	R8	8 559	6 870	19 259	0	34 687
P121	W6	R10	7 462	7 323	0	0	14 785
P221	W6	R10	7 462	7 323	19 259	0	34 044
P121	W8	R10	7 833	7 323	0	0	15 156
P221	W8	R10	7 833	7 323	19 259	0	34 415
P121	W10	R10	8 197	7 323	0	0	15 520
P221	W10	R10	8 197	7 323	19 259	0	34 779
P121	W12	R10	8 559	7 323	0	0	15 882
P221	W12	R10	8 559	7 323	19 259	0	35 141
P121	W6	R12	7 462	7 777	0	0	15 239
P221	W6	R12	7 462	7 777	19 259	0	34 498
P121	W8	R12	7 833	7 777	0	0	15 610
P221	W8	R12	7 833	7 777	19 259	0	34 869
P121	W10	R12	8 197	7 777	0	0	15 974
P221	W10	R12	8 197	7 777	19 259	0	35 233
P121	W12	R12	8 559	7 777	0	0	16 336

P221	W12	R12	8 559	7 777	19 259	0	35 595
P121	W6	R14	7 462	8 230	0	0	15 691
P221	W6	R14	7 462	8 230	19 259	0	34 950
P121	W8	R14	7 833	8 230	0	0	16 063
P221	W8	R14	7 833	8 230	19 259	0	35 322
P121	W10	R14	8 197	8 230	0	0	16 427
P221	W10	R14	8 197	8 230	19 259	0	35 686
P121	W12	R14	8 559	8 230	0	0	16 788
P221	W12	R14	8 559	8 230	19 259	0	36 047

***Table 100**. Global average retrofitting investment cost per dwelling without grants (Archetype 3).*
(Note: In the second and the third column, the number after W and R refers to the thickness in cm of insultation).

Package	Wall Insulation Thickness (cm)	Roof Insulation Thickness (cm)	Wall cost (€)	Roof cost (€)	Windows (€)	Floor cost (€)	Total cost (€)
BC0	0	0	0	0	0	0	0
P111	W8	R8	3 194	9 354	0	0	12 548
P121	W8	R8	5 325	11 446	0	0	16 772
P121	W6	R8	4 737	11 446	0	0	16 183
P211	W8	R8	3 194	9 354	3 877	0	16 425
P221	W8	R8	5 325	11 446	7 287	0	24 059
P221	W6	R8	4 737	11 446	7 287	0	23 470

***Table 101**. Global average retrofitting investment cost per dwelling without grants (Archetype 4).*
(Note: In the second and the third column, the number after W and R refers to the thickness in cm of insulation).

Package	Wall Insulation Thickness (cm)	Roof Insulation Thickness (cm)	Wall cost (€)	Roof cost (€)	Windows (€)	Floor cost (€)	Total cost (€)
BC0	0	0	0	0	0	0	0
P111	W8	R6	1 903	15 540	0	0	17 443
P211	W8	R6	1 903	15 540	7 939	0	25 382
P111	W8	R8	1 903	15 904	0	0	17 807
P211	W8	R8	1 903	15 904	7 939	0	25 746
P111	W8	R10	1 903	16 246	0	0	18 149
P211	W8	R10	1 903	16 246	7 939	0	26 088

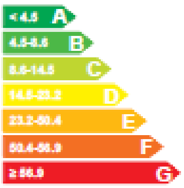
P122	W6	R10	2 822	16 573	0	0	19 396
P222	W6	R10	2 822	16 573	14 921	0	34 317
P122	W8	R10	3 173	16 573	0	0	19 746
P222	W8	R10	3 173	16 573	14 921	0	34 667
P111	W8	R12	1 903	16 588	0	0	18 491
P211	W8	R12	1 903	16 588	7 939	0	26 430
P111	W8	R14	1 903	16 936	0	0	18 838
P211	W8	R14	1 903	16 936	7 939	0	26 777
P121	W6	R10	2 822	18 558	0	0	21 380
P221	W6	R10	2822	18 558	14 921	0	36 302
P121	W8	R10	3 173	18 558	0	0	21 731
P221	W8	R10	3 173	18 558	14 921	0	36 652
P112	W8	R10	1 903	18 713	0	0	20 615
P212	W8	R10	1 903	18 713	7 939	0	28 555

APPENDIX F – ENERGY SIMULATIONS - OFFICIAL EPC

Archetype 1 – Base case

Zona climática	B3	Uso	Residencial

1. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN EMISIONES

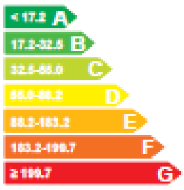
INDICADOR GLOBAL		INDICADORES PARCIALES			
	32.6 E	CALEFACCIÓN		ACS	
		Emisiones calefacción [kgCO2/m² año] 18.50	E	*Emisiones ACS [kgCO2/m² año]* 10.48	G
		REFRIGERACIÓN		ILUMINACIÓN	
Emisiones globales [kgCO2/m² año]		*Emisiones refrigeración [kgCO2/m² año]* 3.66	C	*Emisiones iluminación [kgCO2/m² año]* -	-

La calificación global del edificio se expresa en términos de dióxido de carbono liberado a la atmósfera como consecuencia del consumo energético del mismo.

	kgCO2/m² año	kgCO2/año
Emisiones CO2 por consumo eléctrico	3.66	12273.55
Emisiones CO2 por otros combustibles	28.98	97111.11

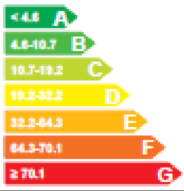
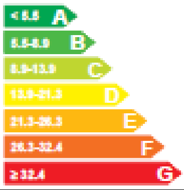
2. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE

Por energía primaria no renovable se entiende la energía consumida por el edificio procedente de fuentes no renovables que no ha sufrido ningún proceso de conversión o transformación.

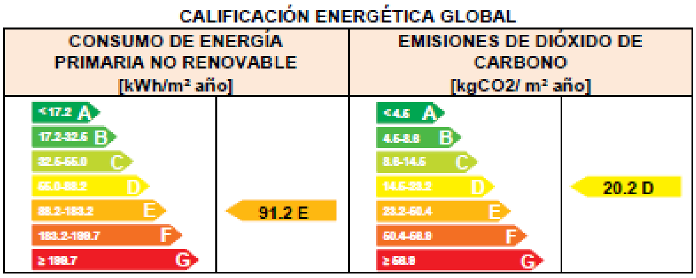
INDICADOR GLOBAL		INDICADORES PARCIALES			
	148.5 E	CALEFACCIÓN		ACS	
		Energía primaria calefacción [kWh/m²año] 87.35	E	*Energía primaria ACS [kWh/m² año]* 49.50	G
		REFRIGERACIÓN		ILUMINACIÓN	
Consumo global de energía primaria no renovable [kWh/m² año]		*Energía primaria refrigeración [kWh/m² año]* 11.66	B	*Energía primaria iluminación [kWh/m²año]* -	-

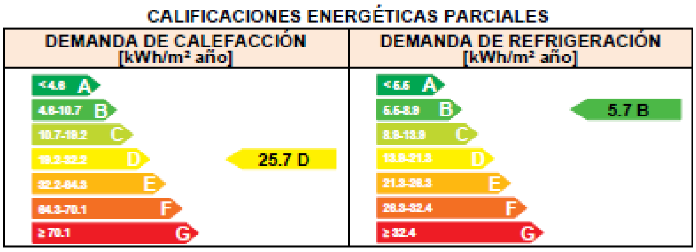
3. CALIFICACIÓN PARCIAL DE LA DEMANDA ENERGÉTICA DE CALEFACCIÓN Y REFRIGERACIÓN

La demanda energética de calefacción y refrigeración es la energía necesaria para mantener las condiciones internas de confort del edificio.

DEMANDA DE CALEFACCIÓN		DEMANDA DE REFRIGERACIÓN	
	67.5 F		7.9 B
Demanda de calefacción [kWh/m² año]		*Demanda de refrigeración [kWh/m² año]*	

Archetype 1 *- Reduction of consumption between 30% and 45%*





ANÁLISIS TÉCNICO

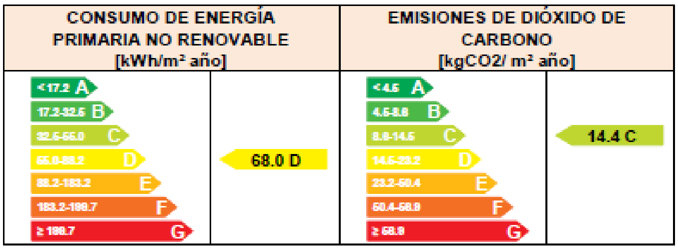
Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	27.91		62.0%	2.86		27.2%	41.60		0.0%	-		-%	72.37		39.1%
Consumo Energía primaria no renovable [kWh/m² año]	33.22	D	62.0%	8.49	B	27.2%	49.50	G	0.0%	-	-	-%	91.21	E	38.6%
Emisiones de CO2 [kgCO2/m² año]	7.03	C	62.0%	2.66	B	27.2%	10.48	G	0.0%	-	-	-%	20.18	D	38.2%
Demanda [kWh/m² año]	25.68	D	62.0%	5.72	B	27.2%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

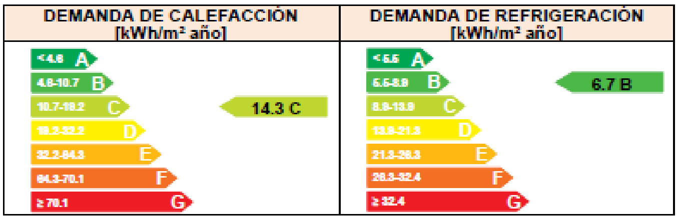
DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
Conjunt de millores passives sobre l'envolupant tèrmica de l'edifici consistent en instal·lació d'aïllament tèrmic exterior amb 10 cm de gruix a façanes i coberta.

Archetype 1 *- Reduction of consumption between 45% and 60%*

CALIFICACIÓN ENERGÉTICA GLOBAL



CALIFICACIONES ENERGÉTICAS PARCIALES



ANÁLISIS TÉCNICO

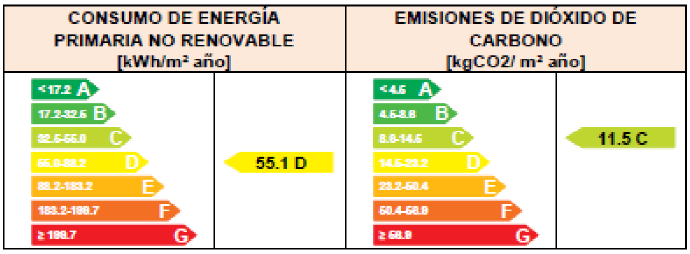
Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	15.52		78.9%	3.34		14.9%	41.60		0.0%	-		-%	57.12		52.0%
Consumo Energía primaria no renovable [kWh/m² año]	18.47	C	78.9%	9.92	B	14.9%	49.50	G	0.0%	-	-	-%	67.97	D	54.2%
Emisiones de CO2 [kgCO2/m² año]	3.91	B	78.9%	3.12	B	14.9%	10.48	G	0.0%	-	-	-%	14.39	C	55.9%
Demanda [kWh/m² año]	14.28	C	78.9%	6.69	B	14.9%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

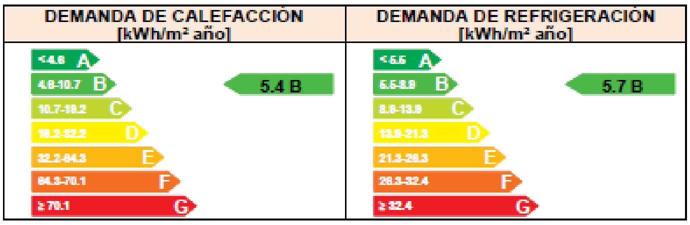
DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
Conjunt de millores passives sobre l'envolupant tèrmica de l'edifici consistent en instal·lació d'aïllament tèrmic exterior amb 10 cm de gruix a façanes, coberta i intrados sostre planta baixa. I incorporació d'un sistema fotovoltaic de 8 kWp.

Archetype 1 *- Reduction of consumption of more than 60%*

CALIFICACIÓN ENERGÉTICA GLOBAL



CALIFICACIONES ENERGÉTICAS PARCIALES



ANÁLISIS TÉCNICO

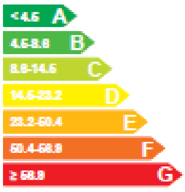
Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	5.92		91.9%	2.86		27.3%	41.60		0.0%	-		-%	47.03		60.5%
Consumo Energía primaria no renovable [kWh/m² año]	7.05	A	91.9%	8.48	B	27.3%	49.50	G	0.0%	-	-	-%	55.11	D	62.9%
Emisiones de CO2 [kgCO2/m² año]	1.49	A	91.9%	2.66	B	27.3%	10.48	G	0.0%	-	-	-%	11.52	C	64.7%
Demanda [kWh/m² año]	5.45	B	91.9%	5.71	B	27.3%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
Conjunt de millores passives sobre l'envolupant tèrmica de l'edifici consistent en instal·lació d'aïllament tèrmic exterior amb 12 cm de gruix a façanes i coberta. I incorporació d'un sistema fotovoltaic de 8 kWp.

***Archetype 2** – Base case*

1. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN EMISIONES

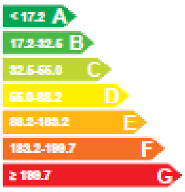
INDICADOR GLOBAL		INDICADORES PARCIALES			
 	38.1 E	CALEFACCIÓN		ACS	
		Emisiones calefacción [kgCO2/m² año]	E	*Emisiones ACS [kgCO2/m² año]*	G
		22.23		8.96	
		REFRIGERACIÓN		ILUMINACIÓN	
Emisiones globales [kgCO2/m² año]		*Emisiones refrigeración [kgCO2/m² año]*	D	*Emisiones iluminación [kgCO2/m² año]*	-
		6.87		-	

La calificación global del edificio se expresa en términos de dióxido de carbono liberado a la atmósfera como consecuencia del consumo energético del mismo.

	kgCO2/m² año	kgCO2/año
Emisiones CO2 por consumo eléctrico	6.87	3515.50
Emisiones CO2 por otros combustibles	31.18	15966.15

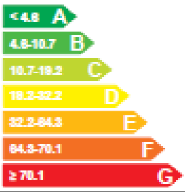
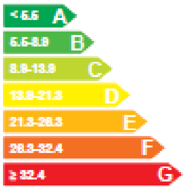
2. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE

Por energía primaria no renovable se entiende la energía consumida por el edificio procedente de fuentes no renovables que no ha sufrido ningún proceso de conversión o transformación.

INDICADOR GLOBAL		INDICADORES PARCIALES			
 	169.2 E	CALEFACCIÓN		ACS	
		Energía primaria calefacción [kWh/m²año]	E	*Energía primaria ACS [kWh/m² año]*	G
		104.95		42.36	
		REFRIGERACIÓN		ILUMINACIÓN	
Consumo global de energía primaria no renovable [kWh/m² año]		*Energía primaria refrigeración [kWh/m² año]*	D	*Energía primaria iluminación [kWh/m²año]*	-
		21.87		-	

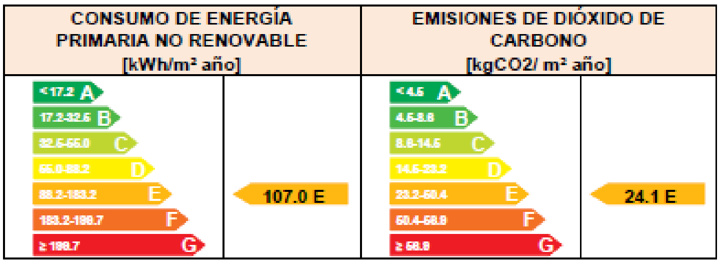
3. CALIFICACIÓN PARCIAL DE LA DEMANDA ENERGÉTICA DE CALEFACCIÓN Y REFRIGERACIÓN

La demanda energética de calefacción y refrigeración es la energía necesaria para mantener las condiciones internas de confort del edificio.

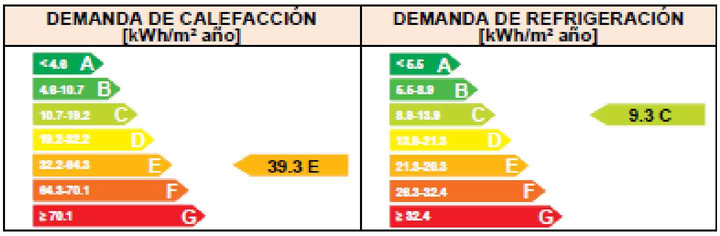
DEMANDA DE CALEFACCIÓN		DEMANDA DE REFRIGERACIÓN	
 	81.1 G	 	14.7 D
Demanda de calefacción [kWh/m² año]		*Demanda de refrigeración [kWh/m² año]*	

Archetype 2 *- Reduction of consumption between 30% and 45%*

CALIFICACIÓN ENERGÉTICA GLOBAL



CALIFICACIONES ENERGÉTICAS PARCIALES



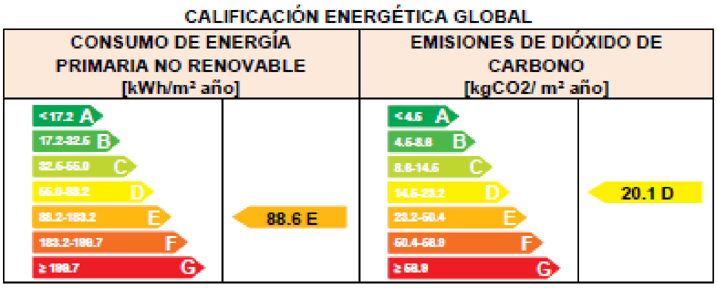
ANÁLISIS TÉCNICO

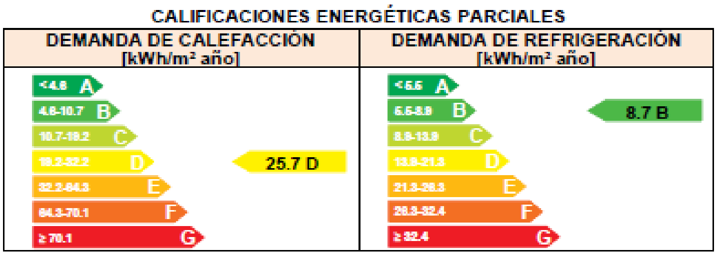
Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	42.69		51.6%	4.66		36.8%	35.27		0.0%	-		-%	82.62		36.9%
Consumo Energía primaria no renovable [kWh/m² año]	50.80	E	51.6%	13.83	C	36.8%	42.36	G	0.0%	-	-	-%	106.9 8	E	36.8%
Emisiones de CO2 [kgCO2/m² año]	10.76	D	51.6%	4.34	C	36.8%	8.96	G	0.0%	-	-	-%	24.06	E	36.8%
Demanda [kWh/m² año]	39.27	E	51.6%	9.32	C	36.8%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
ENVOLVENTE: sate 8 cm

Archetype 2 *- Reduction of consumption between 45% and 60%*





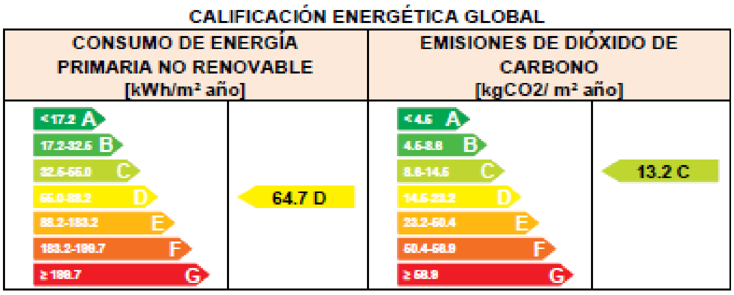
ANÁLISIS TÉCNICO

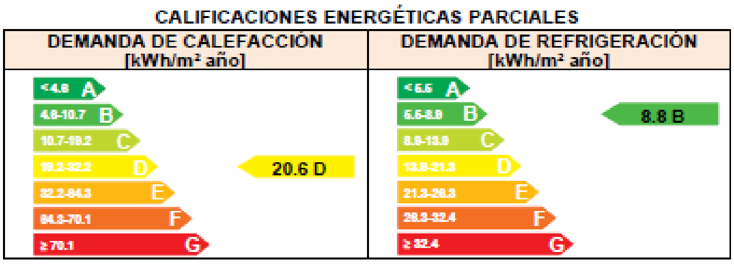
Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	27.96		68.3%	4.36		40.8%	35.27		0.0%	-		-%	67.59		48.3%
Consumo Energía primaria no renovable [kWh/m² año]	33.27	D	68.3%	12.93	C	40.8%	42.36	G	0.0%	-	-	-%	88.57	E	47.6%
Emisiones de CO2 [kgCO2/m² año]	7.05	C	68.3%	4.06	C	40.8%	8.96	G	0.0%	-	-	-%	20.07	D	47.3%
Demanda [kWh/m² año]	25.72	D	68.3%	8.72	B	40.8%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
ENVOLVENTE: SATE 8 CM + CUBIERTA

Archetype 2 *- Reduction of consumption of more than 60%*





ANÁLISIS TÉCNICO

Indicador	Calefacción		Refrigeración		ACS		Iluminación		Total	
	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	22.43	74.6%	4.39	40.4%	35.27	0.0%	-	-%	56.24	57.0%
Consumo Energía primaria no renovable [kWh/m² año]	26.69 C	74.6%	13.04 C	40.4%	42.36 G	0.0%	- -	-%	64.70 D	61.8%
Emisiones de CO2 [kgCO2/m² año]	5.65 C	74.6%	4.09 C	40.4%	8.96 G	0.0%	- -	-%	13.25 C	65.2%
Demanda [kWh/m² año]	20.64 D	74.6%	8.79 B	40.4%						

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
SATE+CUBIERTA+VENTANAS+FOTOVOLTAICA

Archetype 3 – *Base case*

1. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN EMISIONES

INDICADOR GLOBAL		INDICADORES PARCIALES			
<4.5 A 4.5-8.8 B 8.8-14.5 C 14.5-23.2 D 23.2-50.4 E 50.4-58.9 F ≥ 58.9 G	45.3 E	CALEFACCIÓN		ACS	
		Emisiones calefacción [kgCO2/m² año]	E	*Emisiones ACS [kgCO2/m² año]*	G
		31.68		7.20	
		REFRIGERACIÓN		ILUMINACIÓN	
Emisiones globales [kgCO2/m² año]		*Emisiones refrigeración [kgCO2/m² año]*	D	*Emisiones iluminación [kgCO2/m² año]*	-
		6.47		-	

La calificación global del edificio se expresa en términos de dióxido de carbono liberado a la atmósfera como consecuencia del consumo energético del mismo.

	kgCO2/m² año	kgCO2/año
Emisiones CO2 por consumo eléctrico	22.56	4080.65
Emisiones CO2 por otros combustibles	22.79	4122.18

2. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE

Por energía primaria no renovable se entiende la energía consumida por el edificio procedente de fuentes no renovables que no ha sufrido ningún proceso de conversión o transformación.

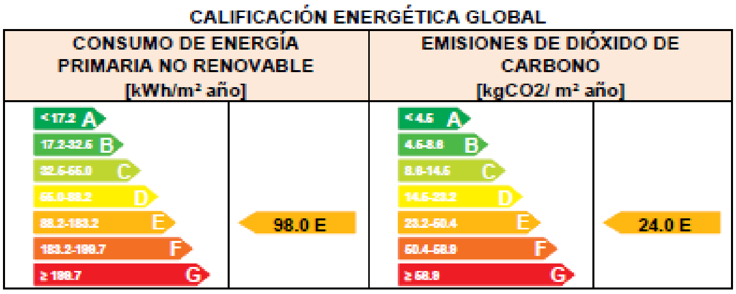
INDICADOR GLOBAL		INDICADORES PARCIALES			
<17.2 A 17.2-32.5 B 32.5-55.0 C 55.0-88.2 D 88.2-183.2 E 183.2-189.7 F ≥ 189.7 G	179.5 E	CALEFACCIÓN		ACS	
		Energía primaria calefacción [kWh/m²año]	E	*Energía primaria ACS [kWh/m² año]*	G
		124.85		34.02	
		REFRIGERACIÓN		ILUMINACIÓN	
Consumo global de energía primaria no renovable [kWh/m² año]		*Energía primaria refrigeración [kWh/m² año]*	D	*Energía primaria iluminación [kWh/m²año]*	-
		20.61		-	

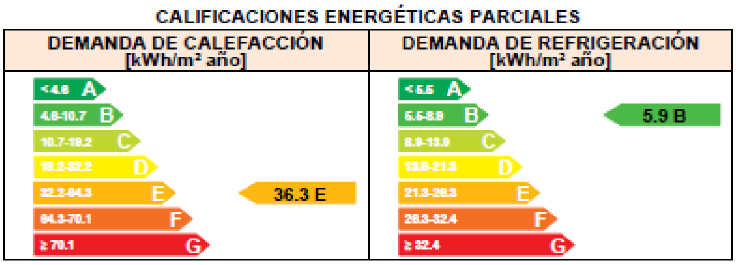
3. CALIFICACIÓN PARCIAL DE LA DEMANDA ENERGÉTICA DE CALEFACCIÓN Y REFRIGERACIÓN

La demanda energética de calefacción y refrigeración es la energía necesaria para mantener las condiciones internas de confort del edificio.

DEMANDA DE CALEFACCIÓN		DEMANDA DE REFRIGERACIÓN	
<4.8 A 4.8-10.7 B 10.7-19.2 C 19.2-32.2 D 32.2-64.3 E 64.3-70.1 F ≥ 70.1 G	82.3 G	<6.5 A 6.5-8.8 B 8.8-13.8 C 13.8-21.3 D 21.3-28.3 E 28.3-32.4 F ≥ 32.4 G	13.6 C
Demanda de calefacción [kWh/m² año]		*Demanda de refrigeración [kWh/m² año]*	

Archetype 3 *- Reduction of consumption between 30% and 45%*





ANÁLISIS TÉCNICO

Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	34.94		55.8%	2.99		56.9%	28.33		0.0%	-		-%	66.26		42.1%
Consumo Energía primaria no renovable [kWh/m² año]	55.12	E	55.8%	8.88	B	56.9%	34.02	G	0.0%	-	-	-%	98.03	E	45.4%
Emisiones de CO2 [kgCO2/m² año]	13.99	E	55.8%	2.79	B	56.9%	7.20	G	0.0%	-	-	-%	23.97	E	47.1%
Demanda [kWh/m² año]	36.33	E	55.8%	5.88	B	56.9%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA

Características de la medida (modelo de equipos, materiales, parámetros característicos)

ENVOLVENTE

Archetype 3 *- Reduction of consumption between 45% and 60%*

CALIFICACIÓN ENERGÉTICA GLOBAL

CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE [kWh/m² año]		EMISIONES DE DIÓXIDO DE CARBONO [kgCO2/ m² año]	
<17.2 A		<4.6 A	
17.2-32.5 B		4.6-8.8 B	
32.5-55.0 C		8.8-14.5 C	
55.0-88.2 D	82.5 D	14.5-23.2 D	20.5 D
88.2-183.2 E		23.2-50.4 E	
183.2-199.7 F		50.4-58.8 F	
≥ 199.7 G		≥ 58.8 G	

CALIFICACIONES ENERGÉTICAS PARCIALES

DEMANDA DE CALEFACCIÓN [kWh/m² año]		DEMANDA DE REFRIGERACIÓN [kWh/m² año]	
<4.8 A		<5.5 A	
4.8-10.7 B		5.5-8.9 B	
10.7-19.2 C		8.9-13.9 C	11.0 C
19.2-32.2 D	21.1 D	13.9-21.3 D	
32.2-64.3 E		21.3-28.3 E	
64.3-70.1 F		28.3-32.4 F	
≥ 70.1 G		≥ 32.4 G	

ANÁLISIS TÉCNICO

Indicador	Calefacción		Refrigeración		ACS		Iluminación		Total	
	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original	Valor	ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	20.26	74.4%	5.57	19.8%	28.33	0.0%	-	-%	54.16	52.7%
Consumo Energía primaria no renovable [kWh/m² año]	31.97 D	74.4%	16.54 C	19.8%	34.02 G	0.0%	- -	-%	82.53 D	54.0%
Emisiones de CO2 [kgCO2/m² año]	8.11 D	74.4%	5.19 C	19.8%	7.20 G	0.0%	- -	-%	20.50 D	54.8%
Demanda [kWh/m² año]	21.07 D	74.4%	10.95 C	19.8%						

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
ENVOLVENTE+VENTANAS

Archetype 4 – *Base case*

1. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN EMISIONES

INDICADOR GLOBAL		INDICADORES PARCIALES			
<4.5 A 4.5-8.8 B 8.8-14.5 C 14.5-23.2 D 23.2-50.4 E 50.4-58.9 F ≥ 58.9 G	24.4 E	CALEFACCIÓN		ACS	
		Emisiones calefacción [kgCO2/m² año]	E	*Emisiones ACS [kgCO2/m² año]*	E
		14.00		3.70	
		REFRIGERACIÓN		ILUMINACIÓN	
Emisiones globales [kgCO2/m² año]		*Emisiones refrigeración [kgCO2/m² año]*	D	*Emisiones iluminación [kgCO2/m² año]*	-
		6.71		-	

La calificación global del edificio se expresa en términos de dióxido de carbono liberado a la atmósfera como consecuencia del consumo energético del mismo.

	kgCO2/m² año	kgCO2/año
Emisiones CO2 por consumo eléctrico	6.71	1180.71
Emisiones CO2 por otros combustibles	17.70	3114.99

2. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE

Por energía primaria no renovable se entiende la energía consumida por el edificio procedente de fuentes no renovables que no ha sufrido ningún proceso de conversión o transformación.

INDICADOR GLOBAL		INDICADORES PARCIALES			
<17.2 A 17.2-32.5 B 32.5-55.0 C 55.0-88.2 D 88.2-183.2 E 183.2-189.7 F ≥ 189.7 G	105.0 E	CALEFACCIÓN		ACS	
		Energía primaria calefacción [kWh/m²año]	E	*Energía primaria ACS [kWh/m² año]*	E
		66.12		17.49	
		REFRIGERACIÓN		ILUMINACIÓN	
Consumo global de energía primaria no renovable [kWh/m² año]		*Energía primaria refrigeración [kWh/m² año]*	D	*Energía primaria iluminación [kWh/m²año]*	-
		21.36		-	

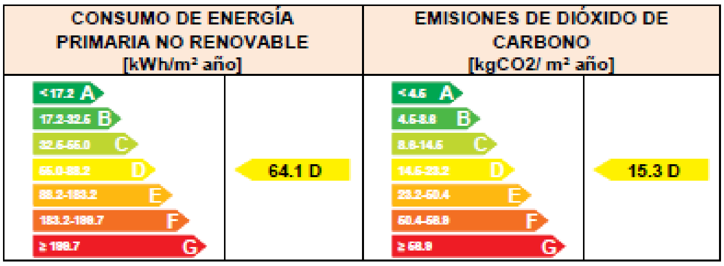
3. CALIFICACIÓN PARCIAL DE LA DEMANDA ENERGÉTICA DE CALEFACCIÓN Y REFRIGERACIÓN

La demanda energética de calefacción y refrigeración es la energía necesaria para mantener las condiciones internas de confort del edificio.

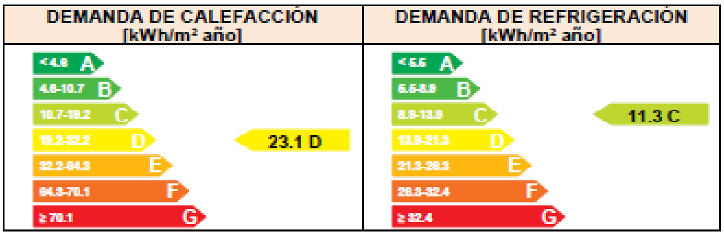
DEMANDA DE CALEFACCIÓN		DEMANDA DE REFRIGERACIÓN	
<4.8 A 4.8-10.7 B 10.7-19.2 C 19.2-32.2 D 32.2-64.3 E 64.3-70.1 F ≥ 70.1 G	51.1 E	<5.5 A 5.5-8.9 B 8.9-13.9 C 13.9-21.3 D 21.3-28.3 E 28.3-32.4 F ≥ 32.4 G	14.4 D
Demanda de calefacción [kWh/m² año]		*Demanda de refrigeración [kWh/m² año]*	

Archetype 4 *- Reduction of consumption between 30% and 45%*

CALIFICACIÓN ENERGÉTICA GLOBAL



CALIFICACIONES ENERGÉTICAS PARCIALES



ANÁLISIS TÉCNICO

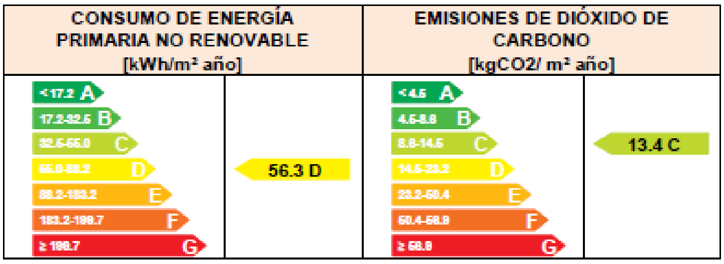
Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	25.14		54.7%	5.63		21.8%	14.56		0.0%	-		-%	45.33		41.4%
Consumo Energía primaria no renovable [kWh/m² año]	29.92	D	54.7%	16.71	C	21.8%	17.49	E	0.0%	-	-	-%	64.11	D	38.9%
Emisiones de CO2 [kgCO2/m² año]	6.34	C	54.7%	5.25	C	21.8%	3.70	E	0.0%	-	-	-%	15.28	D	37.4%
Demanda [kWh/m² año]	23.13	D	54.7%	11.26	C	21.8%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

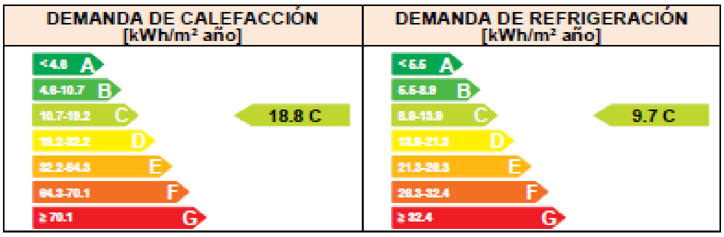
DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
ENVOLVENTE

Archetype 4 *- Reduction of consumption between 45% and 60%*

CALIFICACIÓN ENERGÉTICA GLOBAL



CALIFICACIONES ENERGÉTICAS PARCIALES



ANÁLISIS TÉCNICO

Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	20.47		63.2%	4.87		32.3%	14.56		0.0%	-		-%	39.90		48.4%
Consumo Energía primaria no renovable [kWh/m² año]	24.36	C	63.2%	14.46	C	32.3%	17.49	E	0.0%	-	-	-%	56.31	D	46.4%
Emisiones de CO2 [kgCO2/m² año]	5.16	C	63.2%	4.54	C	32.3%	3.70	E	0.0%	-	-	-%	13.40	C	45.1%
Demanda [kWh/m² año]	18.83	C	63.2%	9.75	C	32.3%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos) ENVOLVENTE+VENTANAS

Archetype 4 *- Reduction of consumption of more than 60%*

CALIFICACIÓN ENERGÉTICA GLOBAL

CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE [kWh/m² año]		EMISIONES DE DIÓXIDO DE CARBONO [kgCO2/ m² año]	
<17.2 A		<4.6 A	
17.2-32.6 B	23.7 B	4.6-8.8 B	4.9 B
32.6-55.0 C		8.8-14.6 C	
55.0-88.2 D		14.6-23.2 D	
88.2-183.2 E		23.2-60.4 E	
183.2-199.7 F		60.4-68.8 F	
≥ 199.7 G		≥ 68.8 G	

CALIFICACIONES ENERGÉTICAS PARCIALES

DEMANDA DE CALEFACCIÓN [kWh/m² año]		DEMANDA DE REFRIGERACIÓN [kWh/m² año]	
<4.8 A		<6.6 A	
4.8-10.7 B		6.6-8.9 B	
10.7-19.2 C		8.9-13.9 C	11.4 C
19.2-32.2 D	19.5 D	13.9-21.3 D	
32.2-64.3 E		21.3-28.3 E	
64.3-70.1 F		28.3-32.4 F	
≥ 70.1 G		≥ 32.4 G	

ANÁLISIS TÉCNICO

Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m² año]	21.18		61.9%	5.70		20.9%	2.87		80.3%	-		-%	20.66		73.3%
Consumo Energía primaria no renovable [kWh/m² año]	25.21	C	61.9%	16.91	C	20.9%	8.52	D	51.3%	-	-	-%	23.65	B	77.5%
Emisiones de CO2 [kgCO2/m² año]	5.34	C	61.9%	5.31	D	20.9%	2.68	E	27.7%	-	-	-%	4.85	B	80.1%
Demanda [kWh/m² año]	19.49	D	61.9%	11.39	C	20.9%									

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE LA MEDIDA DE MEJORA
Características de la medida (modelo de equipos, materiales, parámetros característicos)
ENVOLVENTE+VENTANAS+ aerotermia+ fotovoltaica

APPENDIX G – CALCULATIONS FOR NEW SOCIAL HOUSING BUILDING

G.1. COMFORT

Winter comfort

The least unfavourable dwellings in the winter season are those that require a higher heating demand. In this case, there are the flats that are in contact with the parking lot that can be explained by the following 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. Room 2 on the ground floor with a heating demand of 7.31 kWh/m^2 can be taken as an example.

In the least unfavourable dwelling, the overall distribution of temperature and comfort during the winter hours are as follows:

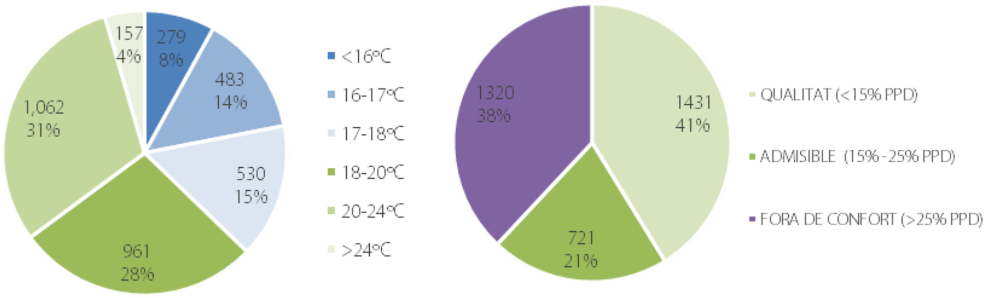


Figure 143. *Distribution of the number of hours in each temperature interval (left) and in each comfort range (right). Extracted from the project documentation (in Catalan language). Qualitat = quality, admisible = admissible, fora de confort = out of comfort zone.*

It can be observed that 38% of the comfort hours are below 18 ºC, which causes discomfort due to the cold. From the further study, it can be concluded that the temperature is not high enough to be within the comfort zone. Nevertheless, it can be observed that the temperature trend remains extremely stable during the week and hardly fluctuates in the day-night interval.

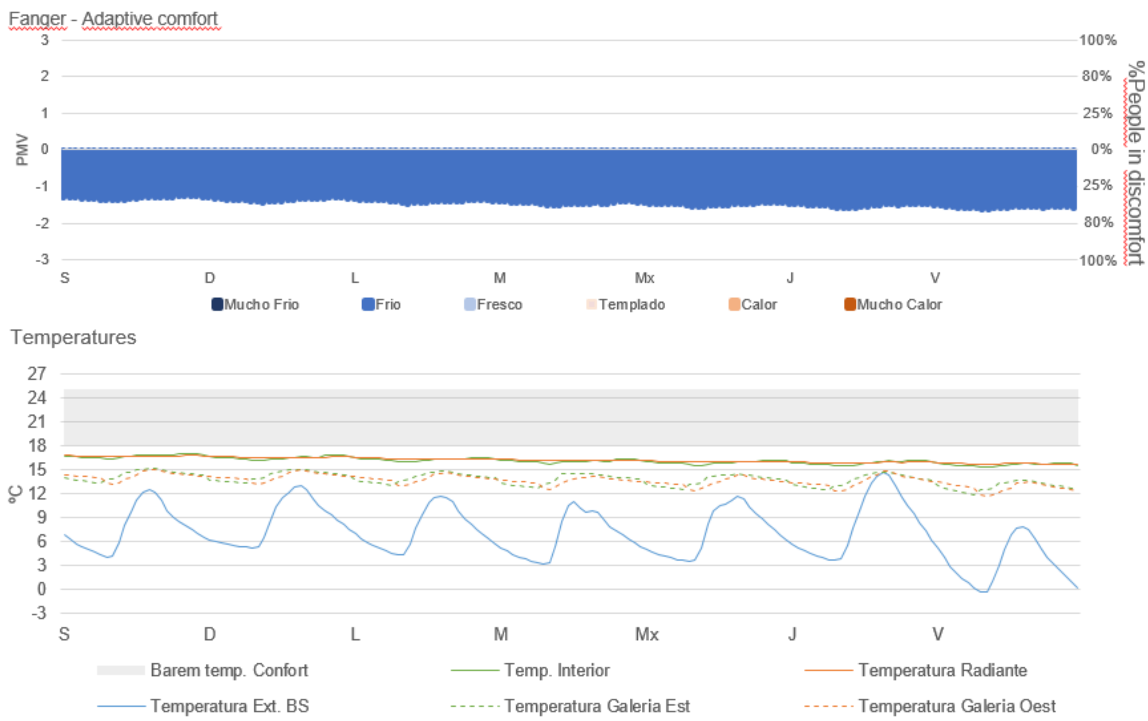


Figure 144. *Adaptive comfort model. Temperature fluctuations.*

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, the building is able to store and maintain the little energy it contains by passively creating thermal differences of up to 15ºC. Regarding the minimum requirement to achieve a comfort, it can be observed from the outset that it would be possible to maintain this temperature within the comfort range with the small amount of energy generated in the house.

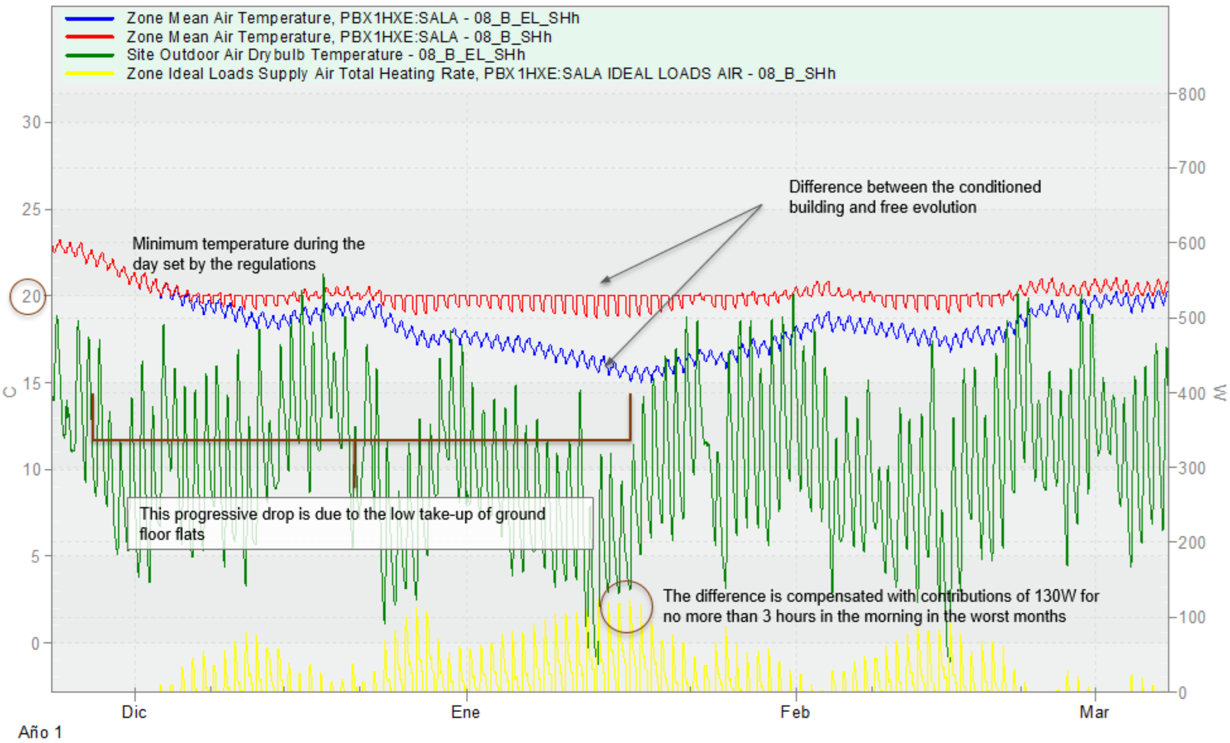


Figure 145. *Analysis of heat demand in winter without air conditioning systems.*

The graph above shows that comfort conditions in the room can be maintained with a small daily contribution of less than 200 W, which is an equivalent to 3 light bulbs or a desktop computer. There is so little need for a minimal space that it is not considered necessary to install any heating systems.

Summer comfort

The study of summer comfort, like the study of winter comfort, attempts to analyse the number of hours spent in a situation of discomfort and to identify the critical temperature ranges. Based on the results, passive strategies were sought to increase the comfort range.

For the study, the flat with the greatest cooling demand was selected, which is located under a roof.

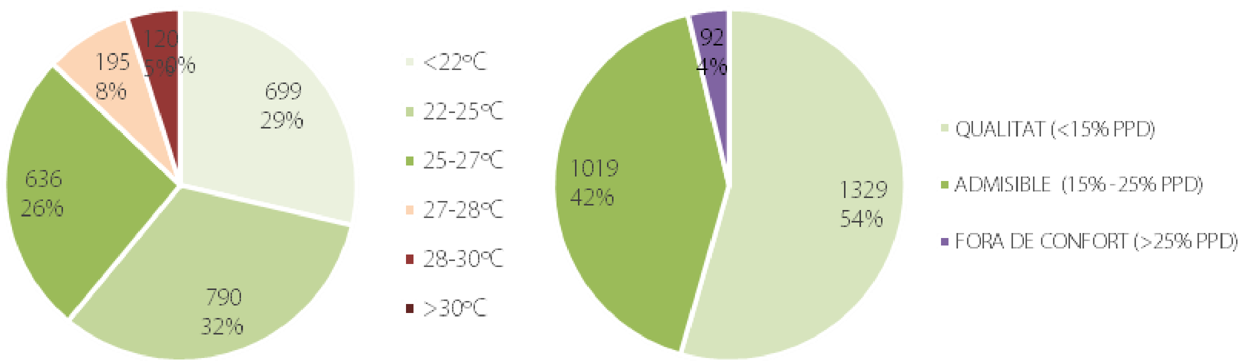


Figure 146. *Distribution of the number of hours in each temperature interval (left) and in each comfort range (right). Extracted from the project documentation (in Catalan language). Qualitat = quality, admisible = admissible, fora de confort = out of comfort ranges.*

It can be concluded that 13% of the hours exceed an indoor temperature of 27ºC, and that on average the entire dwelling never exceeds 30ºC. It should also be noted that 30% of the hours were below 22ºC. This behaviour is clearly due to the good inertia of the building and its ability to regulate indoor humidity. This greatly reduces the sweltering sensation of a humid climate found in the coastal regions of Mallorca.

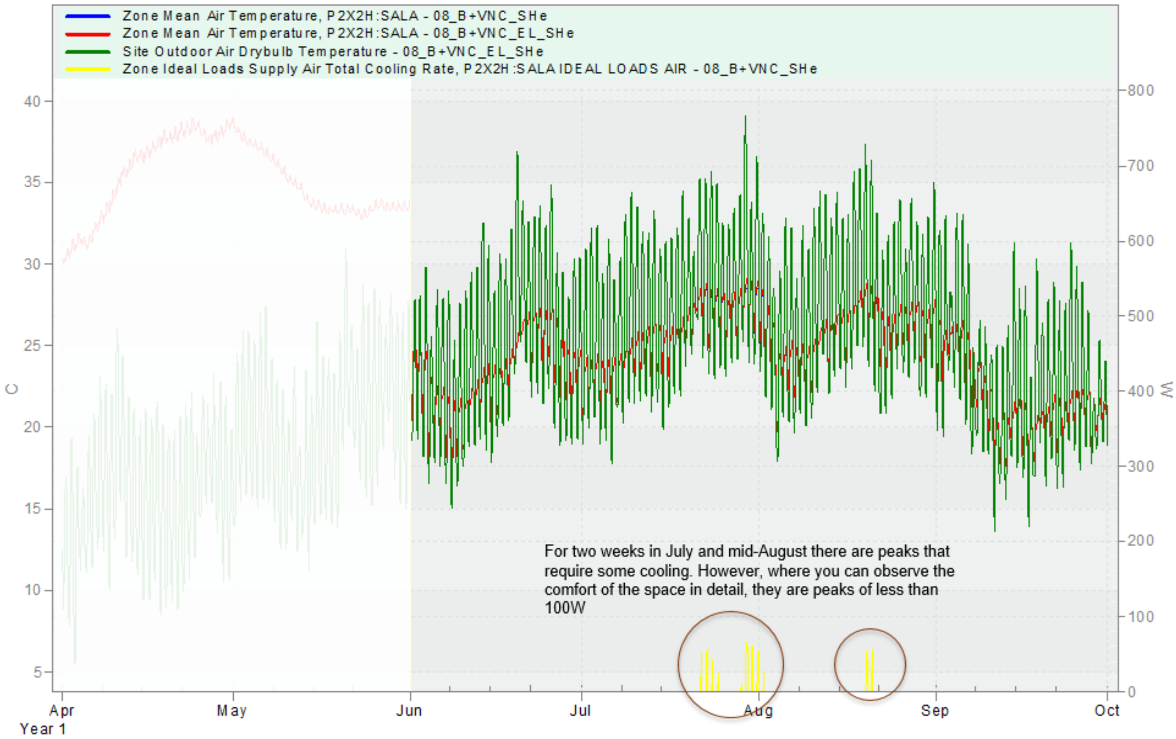


Figure 147. *Analysis of heat demand in summer without air conditioning systems.*

If the analysis is focused on the typical week. Peaks in demand that could cause discomfort at certain times of the day can be observed. This situation needs to be analysed to ensure the feasibility of the proposed solutions.

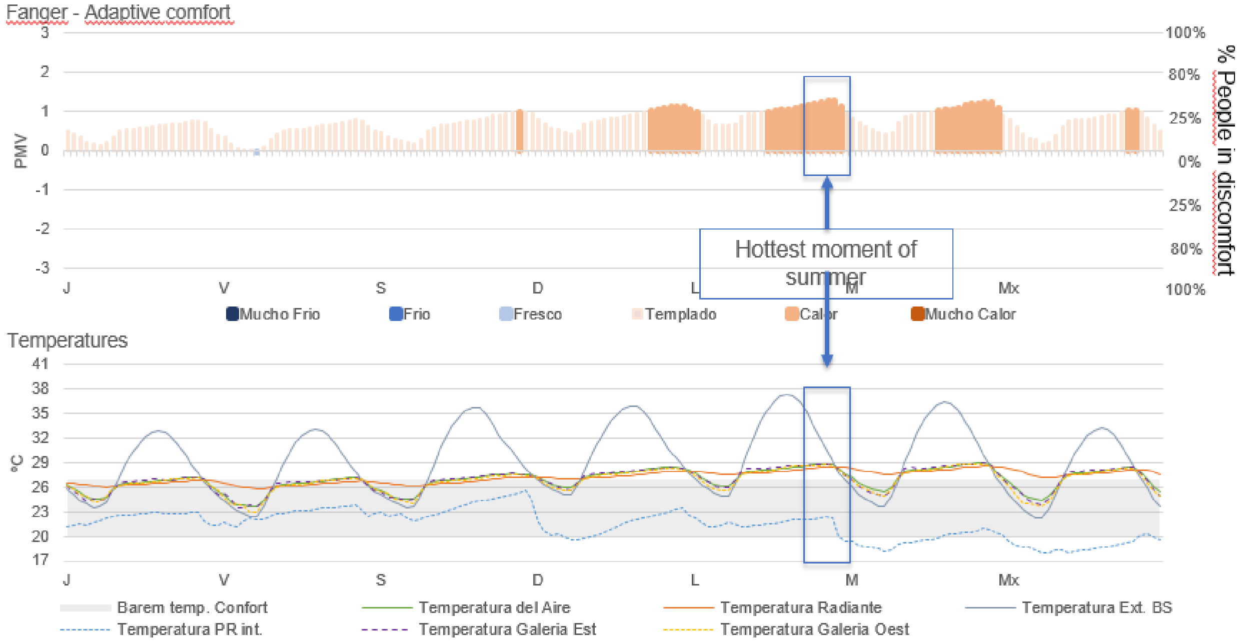


Figure 148. *Detailed analysis of peak demand during a typical week in summer.*

The simulation program optimises the management of the façade elements by closing the windows when the outdoor temperature exceeds 27 ºC. Therefore, the temperature of the walls maintains the indoor air temperature and reduces the sensation of heat. As can be seen in the graphs of the evolution of temperatures, if the external windows are closed when the outside temperature is very high, up to 8º C difference with the outside can be obtained.

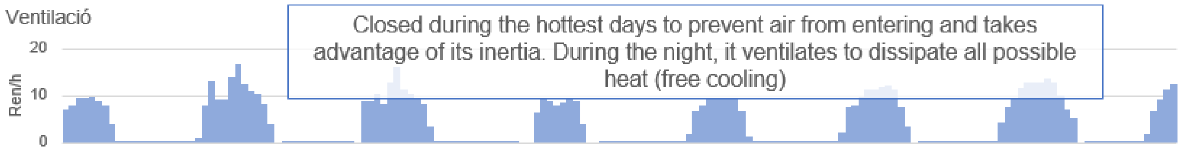


Figure 149. *Evolution of temperatures.*

In the hottest moments, comfort is achieved through passive strategies and the use of a ceiling fan to increase air velocity. The following diagrams compare thermal sensation without and with ceiling fans.

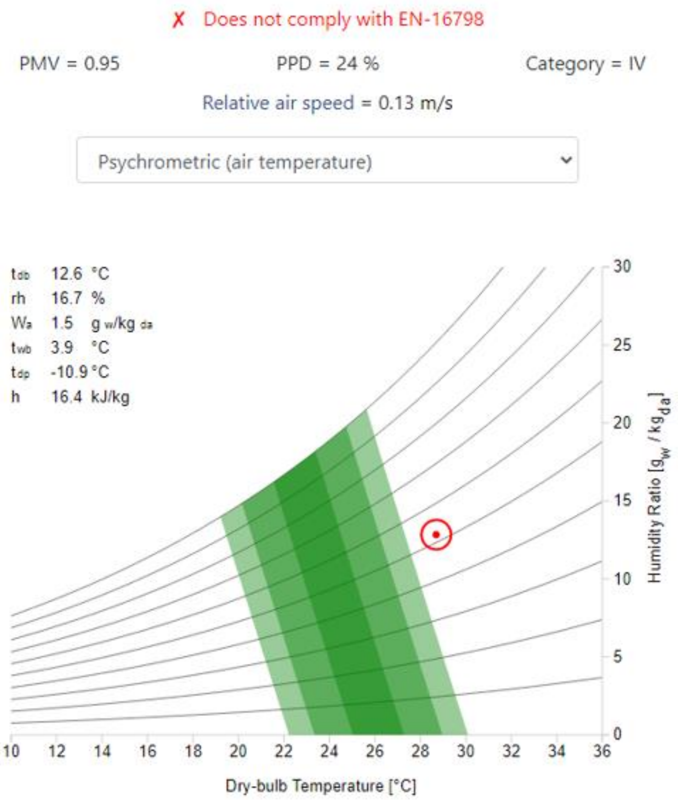


Figure 150. *Comfort analysis without ceiling fans. Templado = warm, calor = hot, mucho calor = very hot.*

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

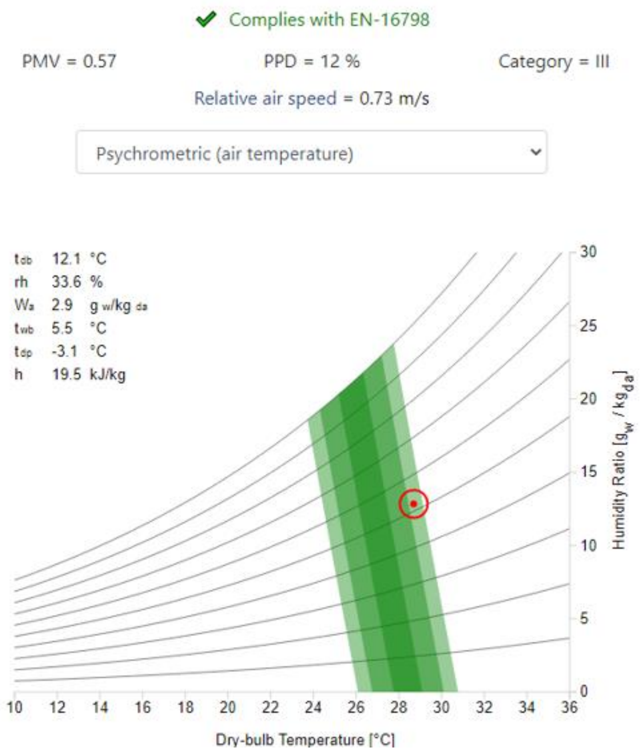


Figure 151. *Comfort analysis with ceiling fans.*

It can be concluded that the ceiling fan can prevent overall heat discomfort even in the most extreme moments. In any case, the average value for dwelling with the worst performance is not representative of the entire building and not all floors share the same conditions.

Summer comfort in flats under roof

ACFD (Asymptotic Computational Fluid Dynamics) module tool is used to observe the distribution and behaviour of indoor air, especially in flats under the roof.

A detailed analysis shows that the building does not dissipate the heat to the interior and even at 37ºC outside temperature, 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 analysis of the renovation of this space is crucial to determine 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. If there is a pressure difference due to temperature or wind, these infiltrations increase up to 0.2 Ren/h.

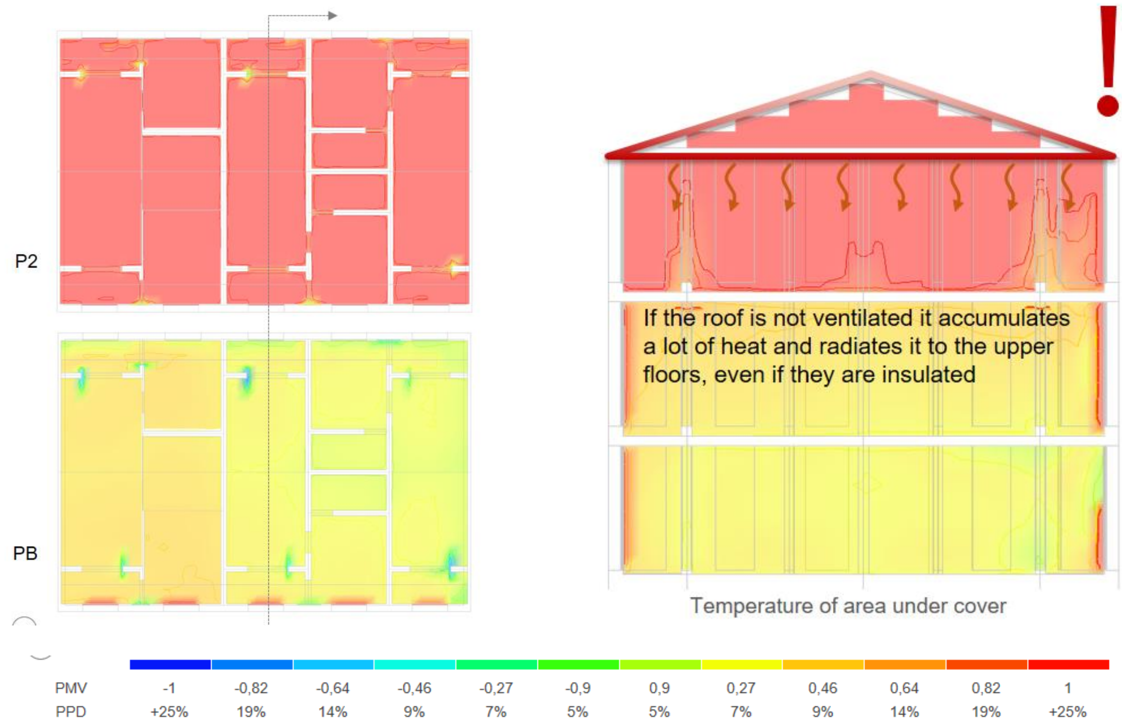


Figure 152. *CFD analysis of temperatures under the roof.*

When comparing 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 0.5x0.5 m every 4 m in length have been considered. This arrangement of openings has resulted in increased air renewal from 0.2 Ren/h to 20 Ren/h.

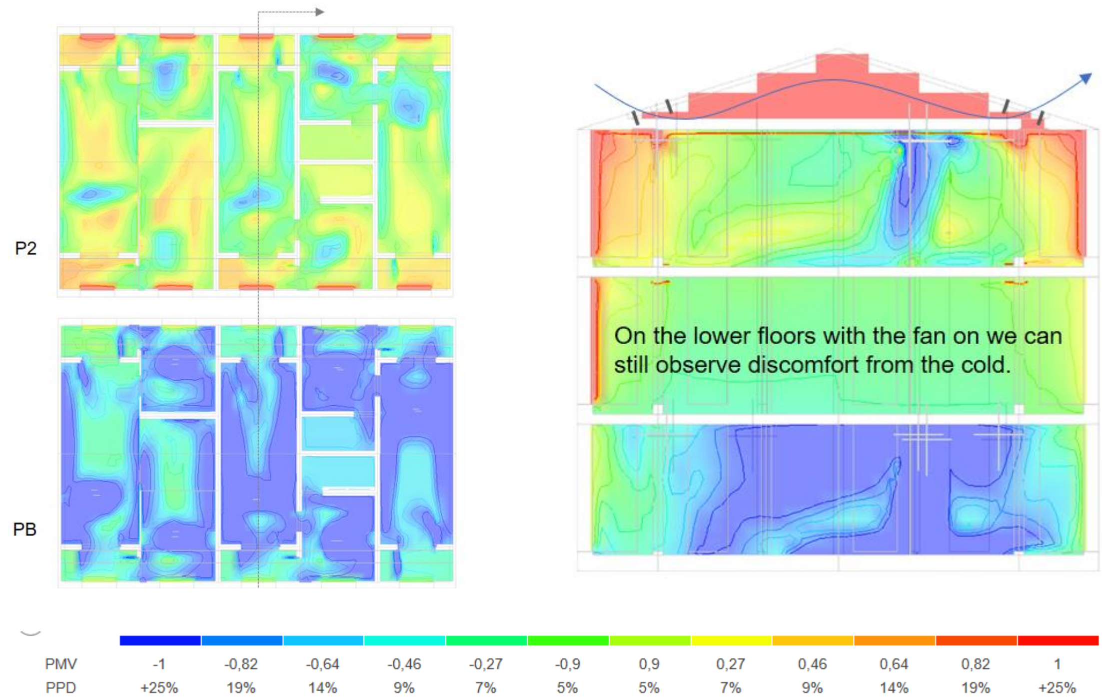


Figure 153. *CFD analysis of temperatures.*

At the comfort levels of each floor, in many cases the upper floor improves considerably, and the ceiling fans even create a feeling of cold. It can be concluded that theoretically 100% of the summer hours are in comfort range.

G.2. ENERGY DEMAND

Energy demand analysis

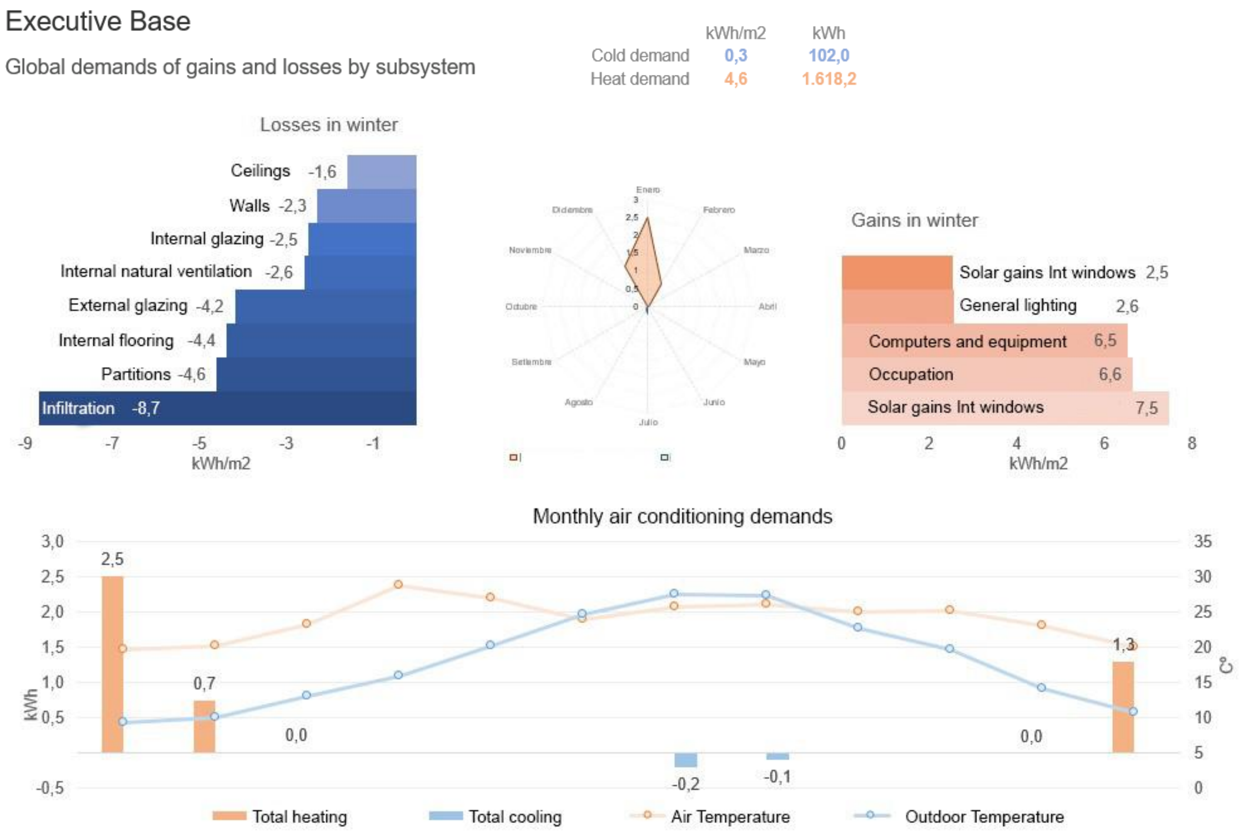


Figure 154. Energy demand analysis. Extracted from the project documentation.

In this graph, it can be seen that heat losses in winter are well resolved by the thermal envelope and that the heat supply from the east and west is well utilised, resulting in a sufficiently low energy demand so that the project is within the limits of energy class A.

The fields corresponding to the thermal envelope are reduced and the greatest losses remain infiltration, which depends greatly on the quality of the work's execution.

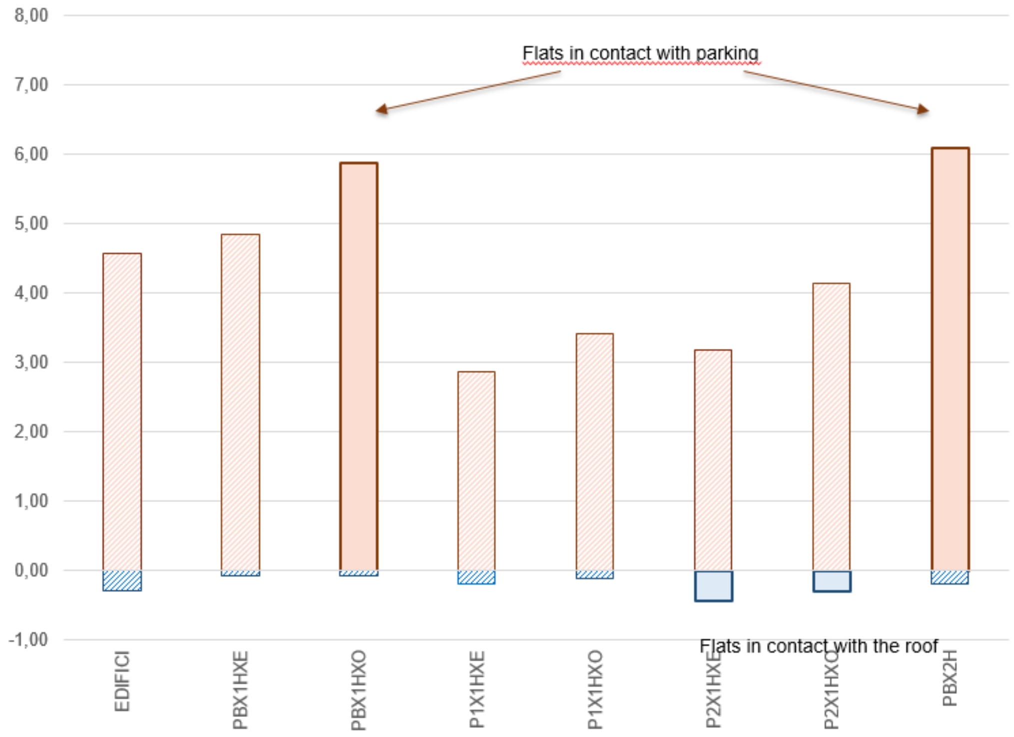


***Figure 155.** Distribution of building demands.*

Figure 155 shows the distribution of the different demands for each part of the building. The differences between the flats in contact with the ground are shown, where the heating demand is higher, and the flats under the roof, where the cooling demand is increased compared to other parts. Therefore, the different solutions that optimise the economic and construction aspects that give coherence to the proposal are reviewed.

The optimisation of the insulation was part of a process in which the relationship of the CO_2 emissions generated between the energy savings of the building and the impact associated with the production of the material is not linear. The more centimetres of insulation added, the lower the impact on energy savings. Therefore, it is important not to "waste" material and to find the optimal value of thickness.

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

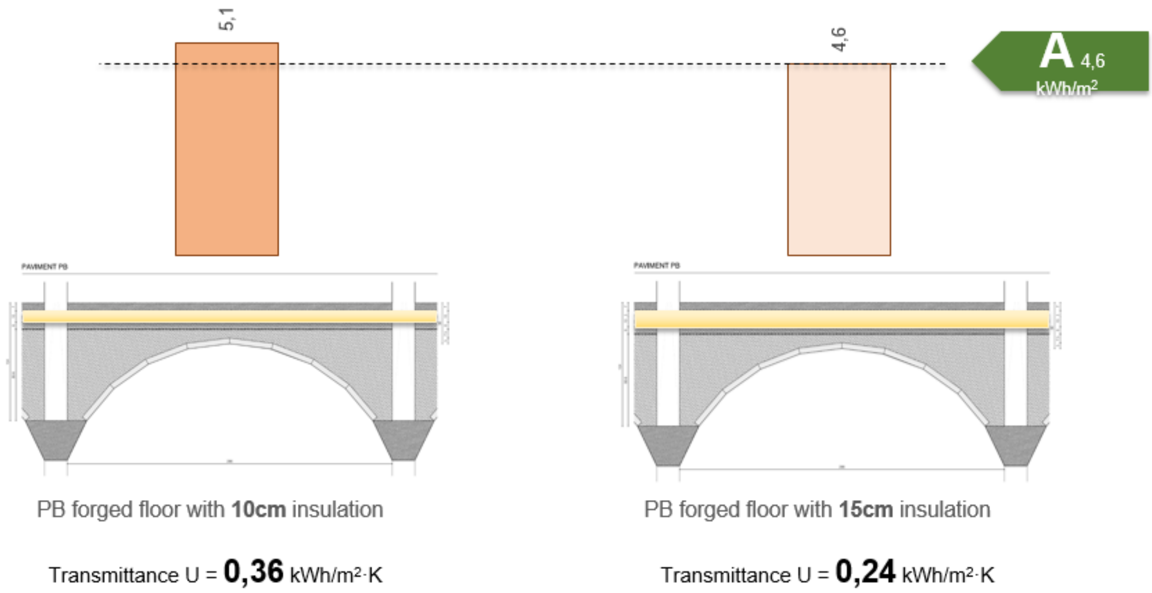


Figure 156. *Insulation tested for the partition between the car park and the ground floor of the dwellings.*

In terms of total demand, it can be seen that demand increases by 11% with 10 cm of insulation. However, for the dwellings that come into contact with the car park, the overall decrease is more than 10%.

A possible alternative to 10 cm thick insulation is to use insulation with a lower thermal conductivity to optimise the thickness without decreasing the thermal performance, but with a higher environmental footprint. Finally, 10 cm thick XPS insulation with a conductivity of 0.034 W/m/K can be considered. This means a change in the transmittance of the shutter from 0.24 kWh/(m^2·K) to 0.30 kWh/(m^2·K).

An optimisation of the transmittance of the internal glazing in relation to the space serving as a thermal buffer is proposed. In the base model, a high transmittance is proposed for the external side of this space, as the solar heat gain is secondary to the conservation of stored energy due to its orientation. The internal glazing becomes a thermal buffer, and the regulation of air intake can be reviewed to determine the extent to which it is favourable to have good light transmittance in this internal area. In relation to the base, for which a transmittance of 3.1 kWh/(m^2·K) is proposed, a single glass of 5.7 kWh/(m^2·K) is used.

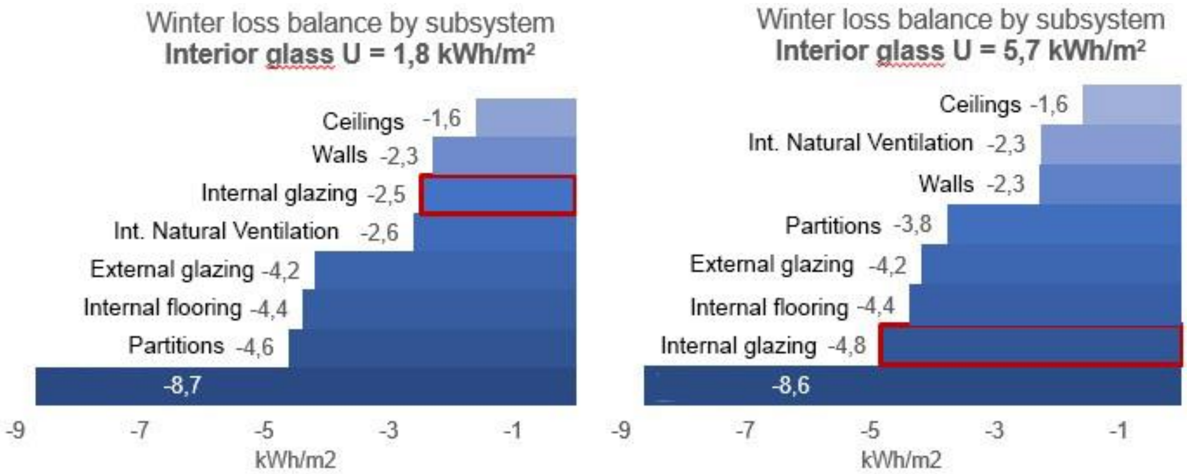


Figure 157. *Comparison of the internal loss balance depending on the performance of the glass. Extracted from the project documentation).*

G.3. AIR RENOVATION

As explained in 5.3.1Passive measures, two options for air renewal were studied prior to the current hybrid system. **Figure 158** shows air renewal strategy following local codes. **Figure 159** shows air renewal strategy applying local code and the orientation of the building (solar gain in east galleries during the morning, and in west galleries during the afternoon).

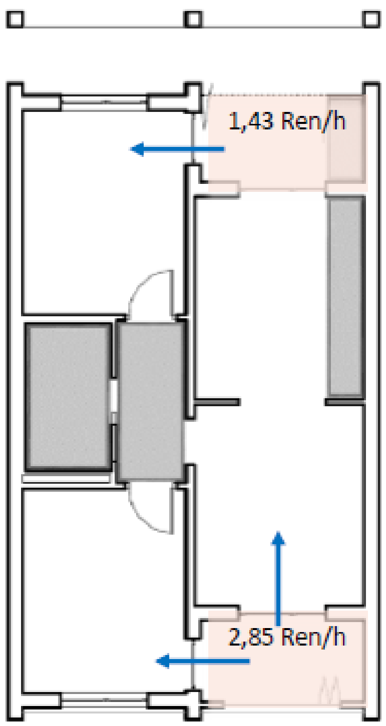


Figure 158. *Initial study of air renewal following the CTE-HS3 and using galleries as collector elements.*

Figure 159. *Air renewal taking into account the orientation of the building.*

G.4. MATERIALS INVENTORY

In addition to the Life Cycle Assessment carried out with OneClick, a material inventory was done using the quantity survey from the project. **Table 102** shows the results taking into account the mass of the materials (in kg). **Table 103** uses the volume to calculate the percentage of every material.

Table 102. Material inventory based on mass (kg).

Materials	Mass (kg)	Reusability (kg)	Cycled (kg)	Local (kg)	% mass	% mass most used materials
Aluminium	110				0.00%	
Aluminium (flexible)	0.97				0.00%	
Appliances	3 437				0.07%	
Cement mortar	8 377				0.17%	
Ceramic (brick)	17 437	8 718		17 165	0.35%	1.28%
Ceramic (roof tile)	39 878	39 878		39 878	0.79%	
Ceramic (tile)	6 986	3 493		6 986	0.14%	
Concrete	575 919	287 959			11.44%	49.67%
Concrete (pavement)	396 458	198 229			7.87%	
Concrete (precast joists)	206 712	206 712			4.11%	
Concrete (structure)	1 321 787	660 893			26.25%	
Cork	75	37			0.00%	
Cotton	7 083	7 083	5 666		0.14%	
EPDM	11 508				0.23%	
EPE	93				0.00%	
Fibrocement (natural fibres)	12 046				0.24%	
Glass	27 490	13 745			0.55%	
Gravel	59 210	59 210			1.18%	1.18%
Mineral wool	4 224				0.08%	
Plaster	23 462	10 810			0.47%	
Polyester	237				0.00%	
Polyethylene	218				0.00%	
Polyethylene (expanded)	1 341				0.03%	

Polyethylene (PEAD)	21				0.00%	
Polypropylene (PP)	400				0.01%	
Polystyrene (XPS)	2 459				0.05%	
Porcelain	1 755	1 755		1 755	0.03%	
Posidonia	23 700	23 700	23 700	23 700	0.47%	
PVC	10 277				0.20%	
Sand	71 322			71 322	1.42%	1.42%
Steel	52 999	26 499			1.05%	
Steel (Galvanised)	9 208	4 604	2 328		0.18%	1.23%
Steel (Stainless)	241	120			0.00%	
Stone	26 417	26 417		26 417	0.52%	38.62%
Stone (marés)	1 893 169	1 893 169		1 893 169	37.60%	
Tierra vegetal	25 208	25 208		25 208	0.50%	
Wood	54 414	54 156			1.08%	
Wood (microlaminated)	111 840	111 840			2.22%	3.84%
Wood (plywood)	6 025	6 025			0.12%	
Wood (recycled)	21 330	21.330	21 330	21 330	0.42%	
Zinc	13				0.00%	
Total	**5 034 902**	**3 691 599**	**53 024**	**2 126 932**	100%	
		73.32%	**1.05%**	**42.24%**		

Table 103. Materials inventory based on volume (m^3).

Materials	Mass (kg)	Reusability (kg)	Cycled (kg)	Local (kg)	% Volume	% Volume most used materials
Aluminium	0.03				0.00%	
Aluminium (flexible)	0.06				0.00%	
Appliances					0.00%	
Cement mortar	7				0.23%	
Ceramic (brick)	22	11		22,0	0.72%	**1.46%**
Ceramic (roof tile)	19	19		20	0.65%	
Ceramic (tile)	3	1		3	0.09%	
Concrete	374	187			12.13%	**39.89%**
Concrete (pavement)	198,18	99			6.42%	
Concrete (precast joists)	84	84			2.73%	
Concrete (structure)	575	287			18.61%	
Cork	0.63	0.32			0.02%	
Cotton	118	118	94		3.82%	**3.82**
EPDM	6				0.18%	
EPE					0.00%	
Fibrocement (natural fibres)	7				0.24%	
Glass	6	3			0.20%	
Gravel	38	38			1.24%	**1.24%**
Mineral wool	49				1.60%	**1.60%**
Plaster	51	14			1.65%	**1.65%**

Polyester	-				0.00%	
Polyethylene	0.16				0.01%	
Polyethylene (expanded)	4				0.13%	
Polyethylene (PEAD)					0.00%	
Polypropylene (PP)					0.00%	
Polystyrene(XPS)	75				2.41%	
Porcelain	0.74	0.74		0.74	0.02%	
Posidonia	158	158	158	158	5.12%	**5.12%**
PVC					0.00%	
Sand	45			45	1.44%	**1.44%**
Steel	0.81	0.51			0.03%	
Steel (Galvanised)	1.15	0.58	0.29		0.04%	
Steel (Stainless)					0.00%	
Stone	11	11		11	0.34%	**28.56%**
Stone (marés)	853	853		853	27.62%	
Tierra vegetal	18	18		18	0.60%	
Wood	92	92			2.98%	**11.65%**
Wood (microlaminated)	216	216			6.99%	
Wood (plywood)	9	9			0.30%	
Wood (recycled)	43	43	43	43	1.38%	
Zinc	-				0.00%	
(en blanco)	2				0.06%	

Total general	**3 087**	**2 265**	**295**	**1 172**	100.0%	
		73.36%	**9.57%**	**37.98%**		

APPENDIX H – DETAILED DATA FOR ENERGY CALCULATIONS FOR ENERGY RETROFITTING PACKAGES

***Table 104**. Summary of energy improvements by passive packages and real orientation Archetypes.*

Archetype	Package	Insulation Thickness (cm)	Non-renewable primary energy (% reduction)	Heating demand (% reduction)	Cooling demand (% reduction)	Domestic hot water (% reduction)
1	P111	W6-R8	44%	66%	28%	0%
	P121	W6-R8	44%	67%	28%	0%
	P211	W6-R8	52%	81%	25%	0%
	P221	W6-R8	52%	81%	25%	0%
2	P111	W6-R8	41%	76%	16%	0%
	P121	W6-R8	42%	77%	16%	0%
	P211	W6-R8	44%	89%	3%	0%
	P221	W6-R8	44%	90%	3%	0%
3	P111	W8-R8	34%	49%	13%	0%
	P121	W8-R8	35%	51%	13%	0%
	P211	W8-R8	47%	71%	7%	0%
	P221	W8-R8	48%	72%	7%	0%
4	P111	W8-R10	34%	43%	19%	0%
	P121	W8-R10	33%	42%	19%	0%
	P211	W8-R10	45%	58%	17%	0%
	P221	W8-R10	44%	57%	17%	0%

***Table 105**. Primary energy and demands by passive scenarios in kWh/m² for real orientation-North/South (Archetype 1).*

Scenario	Non-renewable Primary Energy	Heating demand	Cooling demand	DHW demand	Heating non-renewable primary energy	Cooling non-renewable primary energy	DHW non-renewable primary energy
BC	199.6	55.3	28.8	20.4	115.3	42.8	41.5
P111_W10_R10	108.1	17.3	20.6	20.4	36.0	30.6	41.5
P111_W10_R12	107.5	17.0	20.5	20.4	35.5	30.4	41.5
P111_W10_R14	107.0	16.9	20.4	20.4	35.2	30.3	41.5
P111_W10_R6	110.2	18.1	21.0	20.4	37.6	31.1	41.5
P111_W10_R8	108.9	17.6	20.7	20.4	36.7	30.8	41.5

P111_W12_R10	107.2	16.9	20.6	20.4	35.2	30.5	41.5
P111_W12_R12	106.6	16.7	20.5	20.4	34.7	30.4	41.5
P111_W12_R14	106.1	16.5	20.4	20.4	34.4	30.3	41.5
P111_W12_R6	109.4	17.7	20.9	20.4	36.8	31.0	41.5
P111_W12_R8	108.1	17.2	20.7	20.4	35.8	30.7	41.5
P111_W14_R10	106.6	16.6	20.5	20.4	34.6	30.5	41.5
P111_W14_R12	106.0	16.4	20.4	20.4	34.1	30.3	41.5
P111_W14_R14	105.5	16.2	20.4	20.4	33.8	30.2	41.5
P111_W14_R6	108.7	17.4	20.9	20.4	36.2	31.0	41.5
P111_W14_R8	107.4	16.9	20.7	20.4	35.3	30.7	41.5
P111_W6_R10	110.6	18.4	20.7	20.4	38.4	30.7	41.5
P111_W6_R12	110.0	18.2	20.6	20.4	37.9	30.6	41.5
P111_W6_R14	109.5	18.0	20.5	20.4	37.6	30.5	41.5
P111_W6_R6	113.4	19.5	21.1	20.4	40.6	31.3	41.5
P111_W6_R8	112.1	19.0	20.9	20.4	39.6	31.0	41.5
P111_W8_R10	109.3	17.8	20.7	20.4	37.2	30.7	41.5
P111_W8_R12	108.7	17.6	20.6	20.4	36.7	30.5	41.5
P111_W8_R14	108.3	17.4	20.5	20.4	36.4	30.4	41.5
P111_W8_R6	111.5	18.6	21.0	20.4	38.8	31.2	41.5
P111_W8_R8	110.2	18.1	20.8	20.4	37.8	30.9	41.5
P112_W8_R10	110.5	18.3	20.7	20.4	38.3	30.7	41.5
P112_W8_R12	109.8	18.1	20.6	20.4	37.8	30.6	41.5
P112_W8_R14	109.4	18.0	20.5	20.4	37.4	30.5	41.5
P112_W8_R6	112.6	19.1	21.0	20.4	39.9	31.2	41.5
P112_W8_R8	111.3	18.7	20.8	20.4	38.9	30.9	41.5
P121_W10_R10	107.1	16.8	20.6	20.4	35.1	30.6	41.5
P121_W10_R12	106.5	16.6	20.5	20.4	34.6	30.4	41.5
P121_W10_R14	106.1	16.4	20.4	20.4	34.3	30.3	41.5
P121_W10_R6	109.3	17.6	20.9	20.4	36.8	31.1	41.5
P121_W10_R8	108.0	17.1	20.7	20.4	35.8	30.8	41.5
P121_W12_R10	106.3	16.5	20.6	20.4	34.3	30.5	41.5

P121_W12_R12	105.7	16.2	20.5	20.4	33.8	30.4	41.5
P121_W12_R14	105.3	16.1	20.4	20.4	33.5	30.3	41.5
P121_W12_R6	108.5	17.3	20.9	20.4	36.0	31.0	41.5
P121_W12_R8	107.2	16.8	20.7	20.4	35.0	30.7	41.5
P121_W6_R10	110.1	18.2	20.7	20.4	37.9	30.7	41.5
P121_W6_R12	109.5	17.9	20.6	20.4	37.4	30.6	41.5
P121_W6_R14	109.1	17.8	20.6	20.4	37.1	30.5	41.5
P121_W6_R6	112.3	19.0	21.1	20.4	39.6	31.3	41.5
P121_W6_R8	111.0	18.5	20.9	20.4	38.6	30.9	41.5
P121_W8_R10	108.3	17.4	20.6	20.4	36.2	30.6	41.5
P121_W8_R12	107.7	17.1	20.6	20.4	35.7	30.5	41.5
P121_W8_R14	107.3	17.0	20.5	20.4	35.4	30.4	41.5
P121_W8_R6	110.5	18.2	21.0	20.4	37.9	31.2	41.5
P121_W8_R8	109.2	17.7	20.8	20.4	36.9	30.8	41.5
P211_W10_R10	92.9	9.4	21.5	20.4	19.6	31.8	41.5
P211_W10_R12	92.3	9.2	21.4	20.4	19.1	31.7	41.5
P211_W10_R14	91.9	9.0	21.3	20.4	18.8	31.6	41.5
P211_W10_R6	94.9	10.1	21.8	20.4	21.0	32.4	41.5
P211_W10_R8	93.7	9.7	21.6	20.4	20.1	32.1	41.5
P211_W12_R10	92.3	9.1	21.5	20.4	18.9	31.9	41.5
P211_W12_R12	91.7	8.9	21.4	20.4	18.5	31.7	41.5
P211_W12_R14	91.3	8.7	21.3	20.4	18.2	31.6	41.5
P211_W12_R6	94.3	9.8	21.8	20.4	20.4	32.4	41.5
P211_W12_R8	93.1	9.4	21.6	20.4	19.5	32.1	41.5
P211_W14_R10	91.9	8.9	21.5	20.4	18.5	31.9	41.5
P211_W14_R12	91.3	8.7	21.4	20.4	18.1	31.7	41.5
P211_W14_R14	90.9	8.5	21.3	20.4	17.8	31.6	41.5
P211_W14_R6	93.9	9.6	21.8	20.4	20.0	32.4	41.5
P211_W14_R8	92.7	9.2	21.6	20.4	19.1	32.1	41.5
P211_W6_R10	95.1	10.5	21.4	20.4	21.8	31.8	41.5
P211_W6_R12	94.5	10.3	21.3	20.4	21.4	31.7	41.5

P211_W6_R14	94.1	10.1	21.3	20.4	21.1	31.5	41.5
P211_W6_R6	97.1	11.2	21.8	20.4	23.3	32.3	41.5
P211_W6_R8	95.9	10.8	21.6	20.4	22.4	32.0	41.5
P211_W8_R10	93.7	9.8	21.4	20.4	20.4	31.8	41.5
P211_W8_R12	93.2	9.6	21.3	20.4	20.0	31.7	41.5
P211_W8_R14	92.8	9.4	21.3	20.4	19.7	31.6	41.5
P211_W8_R6	95.8	10.5	21.8	20.4	21.9	32.3	41.5
P211_W8_R8	94.5	10.1	21.6	20.4	21.0	32.0	41.5
P212_W8_R10	94.5	10.2	21.4	20.4	21.3	31.8	41.5
P212_W8_R12	94.0	10.0	21.3	20.4	20.8	31.6	41.5
P212_W8_R14	93.5	9.8	21.2	20.4	20.5	31.5	41.5
P212_W8_R6	96.6	10.9	21.8	20.4	22.8	32.3	41.5
P212_W8_R8	95.3	10.5	21.6	20.4	21.9	32.0	41.5
P221_W10_R10	92.1	9.0	21.5	20.4	18.8	31.9	41.5
P221_W10_R12	91.6	8.8	21.4	20.4	18.4	31.7	41.5
P221_W10_R14	91.2	8.7	21.3	20.4	18.0	31.6	41.5
P221_W10_R6	94.1	9.7	21.8	20.4	20.3	32.4	41.5
P221_W10_R8	92.9	9.3	21.6	20.4	19.4	32.1	41.5
P221_W12_R10	91.6	8.7	21.5	20.4	18.2	31.9	41.5
P221_W12_R12	91.0	8.5	21.4	20.4	17.8	31.8	41.5
P221_W12_R14	90.6	8.4	21.3	20.4	17.5	31.7	41.5
P221_W12_R6	93.6	9.5	21.8	20.4	19.7	32.4	41.5
P221_W12_R8	92.4	9.0	21.6	20.4	18.8	32.1	41.5
P221_W6_R10	94.2	10.0	21.4	20.4	20.9	31.8	41.5
P221_W6_R12	93.6	9.8	21.3	20.4	20.5	31.7	41.5
P221_W6_R14	93.2	9.7	21.3	20.4	20.2	31.6	41.5
P221_W6_R6	96.2	10.8	21.8	20.4	22.4	32.3	41.5
P221_W6_R8	95.0	10.3	21.6	20.4	21.5	32.0	41.5
P221_W8_R10	92.9	9.4	21.5	20.4	19.6	31.8	41.5
P221_W8_R12	92.4	9.2	21.4	20.4	19.2	31.7	41.5
P221_W8_R14	92.0	9.0	21.3	20.4	18.9	31.6	41.5

P221_W8_R6	95.0	10.1	21.8	20.4	21.1	32.3	41.5
P221_W8_R8	93.7	9.7	21.6	20.4	20.2	32.0	41.5

Table 106. Primary energy and demands by passive scenarios in kWh/m² for real orientation-East (Archetype 2).

Scenario	Non-renewable Primary Energy	Heating demand	Cooling demand	DHW demand	Heating non-renewable primary energy	Cooling non-renewable primary energy	DHW non-renewable primary energy
BC0	180.3	42.0	33.8	21.0	87.6	50.1	42.6
P111_W6_R6	105.8	10.1	28.3	21.0	21.2	42.0	42.6
P211_W6_R6	100.6	4.5	32.7	21.0	9.4	48.6	42.6
P111_W10_R6	102.7	8.7	28.3	21.0	18.1	42.0	42.6
P211_W10_R6	98.8	3.4	33.1	21.0	7.1	49.1	42.6
P111_W12_R6	101.9	8.3	28.3	21.0	17.3	42.0	42.6
P211_W12_R6	98.4	3.1	33.2	21.0	6.5	49.2	42.6
P111_W14_R6	101.2	8.0	28.3	21.0	16.6	42.0	42.6
P211_W14_R6	98.0	2.9	33.3	21.0	6.1	49.4	42.6
P111_W6_R8	105.8	10.1	28.3	21.0	21.1	42.0	42.6
P211_W6_R8	100.6	4.5	32.7	21.0	9.4	48.6	42.6
P111_W8_R8	103.9	9.2	28.3	21.0	19.3	42.0	42.6
P211_W8_R8	99.5	3.8	32.9	21.0	8.0	48.9	42.6
P111_W10_R8	102.7	8.7	28.3	21.0	18.1	42.0	42.6
P211_W10_R8	98.8	3.4	33.1	21.0	7.1	49.1	42.6
P111_W12_R8	101.8	8.3	28.3	21.0	17.2	42.0	42.6
P211_W12_R8	98.3	3.1	33.2	21.0	6.5	49.2	42.6
P111_W14_R8	101.2	8.0	28.3	21.0	16.6	42.0	42.6
P211_W14_R8	98.0	2.9	33.3	21.0	6.1	49.4	42.6
P111_W6_R10	105.8	10.1	28.3	21.0	21.1	42.0	42.6
P211_W6_R10	100.6	4.5	32.7	21.0	9.4	48.6	42.6
P111_W8_R10	103.9	9.2	28.3	21.0	19.3	42.0	42.6
P111_W8_R6	103.9	9.3	28.3	21.0	19.3	42.0	42.6
P121_W6_R8	105.2	9.9	28.3	21.0	20.6	42.0	42.6
P211_W8_R10	99.4	3.8	32.9	21.0	8.0	48.9	42.6
P111_W10_R10	102.7	8.7	28.3	21.0	18.1	42.0	42.6

P211_W10_R10	98.8	3.4	33.1	21.0	7.1	49.1	42.6
P111_W12_R10	101.8	8.3	28.3	21.0	17.2	42.0	42.6
P211_W12_R10	98.3	3.1	33.2	21.0	6.5	49.2	42.6
P111_W14_R10	101.2	8.0	28.3	21.0	16.6	42.0	42.6
P211_W14_R10	98.0	2.9	33.3	21.0	6.0	49.4	42.6
P111_W6_R12	105.8	10.1	28.3	21.0	21.1	42.0	42.6
P211_W6_R12	100.6	4.5	32.7	21.0	9.4	48.6	42.6
P111_W8_R12	103.9	9.2	28.3	21.0	19.2	42.0	42.6
P211_W8_R12	99.4	3.8	32.9	21.0	8.0	48.9	42.6
P111_W10_R12	102.7	8.7	28.3	21.0	18.0	42.0	42.6
P211_W10_R12	98.7	3.4	33.1	21.0	7.1	49.1	42.6
P111_W12_R12	101.8	8.3	28.3	21.0	17.2	42.0	42.6
P211_W12_R12	98.3	3.1	33.2	21.0	6.5	49.2	42.6
P111_W14_R12	101.2	8.0	28.3	21.0	16.6	42.0	42.6
P211_W14_R12	98.0	2.9	33.3	21.0	6.0	49.4	42.6
P111_W6_R14	105.8	10.1	28.3	21.0	21.1	42.1	42.6
P211_W6_R14	100.6	4.5	32.7	21.0	9.4	48.6	42.6
P111_W8_R14	103.9	9.2	28.3	21.0	19.2	42.0	42.6
P211_W8_R14	99.4	3.8	32.9	21.0	7.9	48.9	42.6
P111_W10_R14	102.7	8.6	28.3	21.0	18.0	42.0	42.6
P211_W10_R14	98.7	3.4	33.1	21.0	7.1	49.1	42.6
P111_W12_R14	101.8	8.2	28.3	21.0	17.2	42.0	42.6
P211_W12_R14	98.3	3.1	33.2	21.0	6.4	49.2	42.6
P111_W14_R14	101.2	8.0	28.3	21.0	16.6	42.0	42.6
P211_W14_R14	98.0	2.9	33.3	21.0	6.0	49.4	42.6
P121_W6_R6	105.2	9.9	28.3	21.0	20.6	42.0	42.6
P221_W6_R6	100.3	4.3	32.8	21.0	9.0	48.7	42.6
P121_W8_R6	103.4	9.0	28.3	21.0	18.9	42.0	42.6
P221_W8_R6	99.2	3.7	33.0	21.0	7.7	49.0	42.6
P121_W10_R6	102.3	8.5	28.3	21.0	17.7	42.0	42.6
P121_W12_R6	101.5	8.1	28.3	21.0	16.9	42.0	42.6
P221_W12_R6	98.2	3.0	33.2	21.0	6.3	49.3	42.6

P211_W8_R6	99.5	3.8	33.0	21.0	8.0	48.9	42.6
P221_W6_R8	100.3	4.3	32.8	21.0	9.0	48.7	42.6
P121_W8_R8	103.4	9.0	28.3	21.0	18.8	42.0	42.6
P221_W8_R8	99.2	3.7	33.0	21.0	7.7	48.9	42.6
P121_W10_R8	102.3	8.5	28.3	21.0	17.7	42.0	42.6
P221_W10_R8	98.6	3.3	33.1	21.0	6.8	49.1	42.6
P121_W12_R8	101.5	8.1	28.3	21.0	16.9	42.0	42.6
P221_W12_R8	98.2	3.0	33.2	21.0	6.3	49.3	42.6
P121_W14_R10	100.9	7.8	28.3	21.0	16.3	42.0	42.6
P121_W6_R10	105.2	9.9	28.3	21.0	20.6	42.0	42.6
P221_W6_R10	100.2	4.3	32.8	21.0	9.0	48.7	42.6
P221_W10_R6	98.6	3.3	33.1	21.0	6.8	49.1	42.6
P121_W8_R10	103.4	9.0	28.3	21.0	18.8	42.0	42.6
P221_W8_R10	99.2	3.7	33.0	21.0	7.6	48.9	42.6
P121_W10_R10	102.3	8.5	28.3	21.0	17.7	42.0	42.6
P221_W10_R10	98.6	3.3	33.1	21.0	6.8	49.1	42.6
P121_W12_R10	101.5	8.1	28.3	21.0	16.9	42.0	42.6
P221_W12_R10	98.1	3.0	33.2	21.0	6.2	49.3	42.6
P121_W6_R12	105.2	9.9	28.3	21.0	20.6	42.0	42.6
P221_W6_R12	100.2	4.3	32.8	21.0	8.9	48.7	42.6
P121_W8_R12	103.4	9.0	28.3	21.0	18.8	42.0	42.6
P221_W8_R12	99.2	3.7	33.0	21.0	7.6	49.0	42.6
P121_W10_R12	102.3	8.5	28.3	21.0	17.7	42.0	42.6
P221_W10_R12	98.5	3.3	33.1	21.0	6.8	49.1	42.6
P121_W12_R12	101.5	8.1	28.3	21.0	16.9	42.0	42.6
P221_W12_R12	98.1	3.0	33.2	21.0	6.2	49.3	42.6
P121_W6_R14	105.2	9.9	28.3	21.0	20.5	42.1	42.6
P221_W6_R14	100.2	4.3	32.8	21.0	8.9	48.7	42.6
P121_W8_R14	103.4	9.0	28.3	21.0	18.8	42.0	42.6
P221_W8_R14	99.2	3.6	33.0	21.0	7.6	49.0	42.6
P121_W10_R14	102.3	8.5	28.3	21.0	17.7	42.0	42.6
P221_W10_R14	98.5	3.3	33.1	21.0	6.8	49.2	42.6

P121_W12_R14	101.5	8.1	28.3	21.0	16.9	42.0	42.6
P221_W12_R14	98.1	3.0	33.2	21.0	6.2	49.3	42.6

Table 107. *Primary energy and demands by passive scenarios in kWh/m2 for real orientation-East Archetype 3).*

Scenario	Non-renewable Primary Energy	Heating demand	Cooling demand	DHW demand	Heating non-renewable primary energy	Cooling non-renewable primary energy	DHW non-renewable primary energy
BC0	213.7	66.8	23.1	19.7	139.3	34.3	40.1
P211_W8_R8	112.7	19.6	21.5	19.7	40.8	31.8	40.1
P111_W8_R8	140.4	33.8	20.2	19.7	70.4	29.9	40.1
P121_W6_R8	140.4	33.8	20.2	19.7	70.4	30.0	40.1
P121_W8_R8	138.2	32.7	20.1	19.7	68.2	29.8	40.1
P221_W6_R8	112.9	19.6	21.5	19.7	40.9	31.9	40.1
P221_W8_R8	110.8	18.6	21.5	19.7	38.9	31.8	40.1

Table 108. *Primary energy and demands by passive scenarios in kWh/m² for real orientation-West (Archetype 4).*

Scenario	Non-renewable Primary Energy	Heating demand	Cooling demand	DHW demand	Heating non-renewable primary energy	Cooling non-renewable primary energy	DHW non-renewable primary energy
BC0	256.5	90.9	23.1	16.1	189.6	34.3	32.6
P111_W8_R10	169.4	52.3	18.7	16.1	109.0	27.8	32.6
P111_W8_R12	167.0	51.2	18.6	16.1	106.7	27.6	32.6
P111_W8_R14	165.1	50.3	18.5	16.1	105.0	27.5	32.6
P111_W8_R6	177.4	55.8	19.0	16.1	116.5	28.2	32.6
P111_W8_R8	172.7	53.7	18.8	16.1	112.1	28.0	32.6
P112_W8_R10	171.9	53.4	18.8	16.1	111.3	27.9	32.6
P121_W6_R10	173.0	53.9	18.9	16.1	112.4	28.0	32.6
P121_W8_R10	171.3	53.2	18.8	16.1	110.9	27.8	32.6
P122_W6_R10	193.6	63.2	19.7	16.1	131.7	29.2	32.6
P122_W8_R10	192.0	62.5	19.6	16.1	130.3	29.1	32.6
P211_W8_R10	140.7	38.2	19.2	16.1	79.6	28.5	32.6
P211_W8_R12	138.3	37.1	19.1	16.1	77.3	28.4	32.6
P211_W8_R14	136.5	36.2	19.1	16.1	75.6	28.3	32.6
P211_W8_R6	148.6	41.8	19.4	16.1	87.1	28.8	32.6

P211_W8_R8	143.9	39.6	19.3	16.1	82.7	28.6	32.6
P212_W8_R10	143.1	39.3	19.3	16.1	81.9	28.6	32.6
P221_W6_R10	144.4	39.8	19.3	16.1	83.1	28.6	32.6
P221_W8_R10	142.7	39.1	19.2	16.1	81.6	28.5	32.6
P222_W6_R10	165.1	49.3	20.0	16.1	102.8	29.7	32.6
P222_W8_R10	163.5	48.6	19.9	16.1	101.3	29.5	32.6

APPENDIX I – LIFE CYCLE ANALYSIS DATA

A summary of the transportation distances considered for the LCA is presented in **Table 109**.

Table 109. *Transportation distances for retrofitting solutions/energy systems used for phase A4.*

Provider	Material	Production site	Length 1 by truck (km)	Length 2 by ship (km)
Conventional solutions				
GRUPO PUMA	SATE (ETICS) con Poliestirero expandido (EPS) local (REH CONVENCIONAL)	Porreras (Mallorca)	40,6	-
ROCKWOOL	Aislamiento interior lana de roca+trasdos cartón yeso 15 mm (70,71)	Navarra	469	256
KÖMMERLING	Fusteries de PVC, practicable 2 fulles, mides exteriors (1,20 x 1,10 m), amb vidrio 4/14/6 baja emisividad	Madrid	360	275
URSA IBERICA	Doble lámina asfáltica + XPS (60 mm)+ baldosa gres	Tarragona	95,1	256
Eco solutions				
GRUPO PUMA	SATE con Poliestireno expandido grafitado (EPS) local (REH ECO)	Porreras (Mallorca)	40,6	-
GRUPO PUMA	Lámina poliofelinas + panel corcho natural (80 mm) + baldosa gres	Girona	101	256
GRUPO PUMA	Panel de corcho expandido bajo forjado fijado mecánicamente (60 mm) + pladur pintado	Girona	101	256
EUROBLOCK	Marcos de ventana de madera de pino	Valencia	-	275
Active measures				
DAIKIN	Multipsplit for heating and cooling	Belgium	1.299	256
SUNRISE ENERGY CO	PV panels	China	9.244	548,99
HUAWEY	Huawei SUN2000L-33KTL	China	9.244	548,99
BAXI	BAXI BC 200 IN	Gavà (Barcelona)	21	256

PARTNER LOGOS

WWW.GREENDEAL-ARV.EU