SUstainable solutions for affordable REtroFIT of domestic buildings

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WP9 - Deliverable D 9.6

Report on case studies of retrofitted buildings

Dissemination Level

PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

Document History

Version	Date	Authors	Description
1	30/01/2025	KOST	First draft of D9.6
2	22/02/2025	AALTO, AMS, CJR, FSM and UNOTT	Additions to the document
3	27/02/2025	AMS	Reviewed by WP leader
4	28/02/2025	ISQ, Sérgio Tadeu	Final version for the Coordinator

Disclaimer

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Abbreviations

EPS	Expanded Polystyrene
GSHP	Ground Source heat pump
LCC	Life Cycle Cost
PCM	Phase Change Material
PV	Photovoltaic
PV/T	Photovoltaic/thermal system
PV-VG	Photovoltaic – vacuum glazing system
SAHP	Solar Assisted heat pump
TRV	Thermostatic Radiator Valve
WHR	Window Heat Recovery

Publishable summary

Under the given structural conditions, each property placed different demands on the planners to develop the energy-saving concepts and the resulting measures.

In the context of this final report, it should be noted that the strategies and measures developed in the planning process for the individual properties were all successfully implemented.

It has been shown that passive building envelope optimisation is a very economical and sustainable measure from a cost perspective. This applies in particular to warmer countries, which traditionally have a lighter construction method and where lower requirements have been placed on the thermal insulation of the building envelope to date. While the airtightness of buildings in northern European countries has long been subject to high requirements, simple residential buildings in the warmer climates of southern European countries have some catching up to do. New airtight windows and doors achieve significant energy savings and comfort improvements not only in winter but also in summer.

The following new technologies for improved insulation have been implemented in Spain, Portugal and Greece in particular:

- Vacuum glazing
- Silica Aerogel Insulation
- Bio-aerogel insulation
- Water vapour permeable films combined with insulation systems

An increase in comfort has been achieved by damping temperature amplitudes with:

- PCM.

A key measure was the renovation of windows with better insulation and increased airtightness, in some cases using the following innovative approaches:

- Thermodynamic panels with thermal break
- Vacuum glazed windows with heat recovery
- Daylight shading technologies for the windows.

The latest hybrid systems are used in solar collector technology, combining electricity generation using semiconductors and recuperative hot water generation to improve electrical efficiency, i.e. PV/T systems combined with heat pumps and hot water storage.

- PV/T systems combined with heat pumps and hot water storage.

New approaches to heat pump development have also been trialled in the UK, such as:

- Ground source heat pump
- Solar-assisted heat pump
- Energy storage
- Thermostatic valves.

However, reports on individual projects in each country also highlight the weaknesses of different technologies, particularly in the context of retrofitting in occupied dwellings.

Introduction

Leading Beneficiary: KOST

Participants: UNOTT, FSM, AMS, CJR, ISQ, AALTO

Deliverable description:

This deliverable report aims to report the case studies of the five renovated buildings, and it is related to the activities that were realised throughout the whole project in the framework of Task 5.2, 6.1 and 6.2.

1 British case study

The UK evaluation home is a 3-bedroom freehold semi-detached house located in Nottingham, UK. The house has a total 92m^2, was constructed in 1948, with three bedrooms, two bathrooms, and two reception rooms. According to the UK government EPC evaluation, this house is assessed as band D (score:56) and the current primary energy consumption used for only lighting, heating and hot water is estimated as 306 kWh/m^2 per year. Based on estimations, the house currently produces approximately 5.5 tonnes of carbon emission every year. It is built with solid brick external wall without any insulation, with non-insulated pitched roof and 100mm insulated loft. The ground floor is all solid with no insulation. All the windows are fully renovated with double glazing in 2012. The house uses a natural gas boiler and radiators as the main heating system to provide both space heating and hot water. The room radiators can be controlled with room thermostat and TRVs. And low energy lighting is fixed in each room. The NG8 district is mainly owned by local people of Nottingham with three quarters of houses are owned by the owners, and only one quarter of houses are privately or socially rented houses.

Figure 1 - Front and rear photos of Nottingham house

Figure 2 - Front and rear elevation drawings

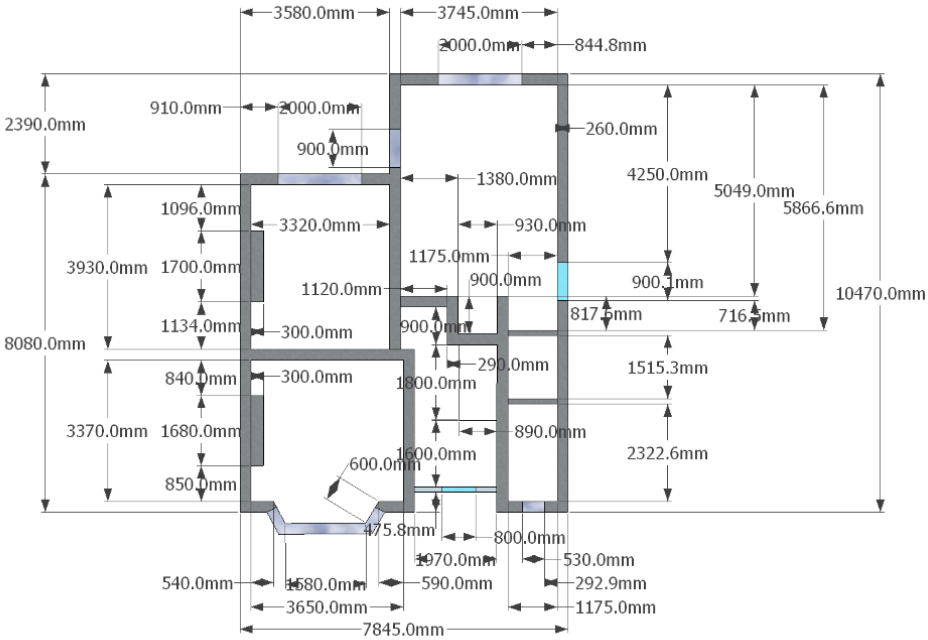


Figure 3 - Floor plan of ground floor

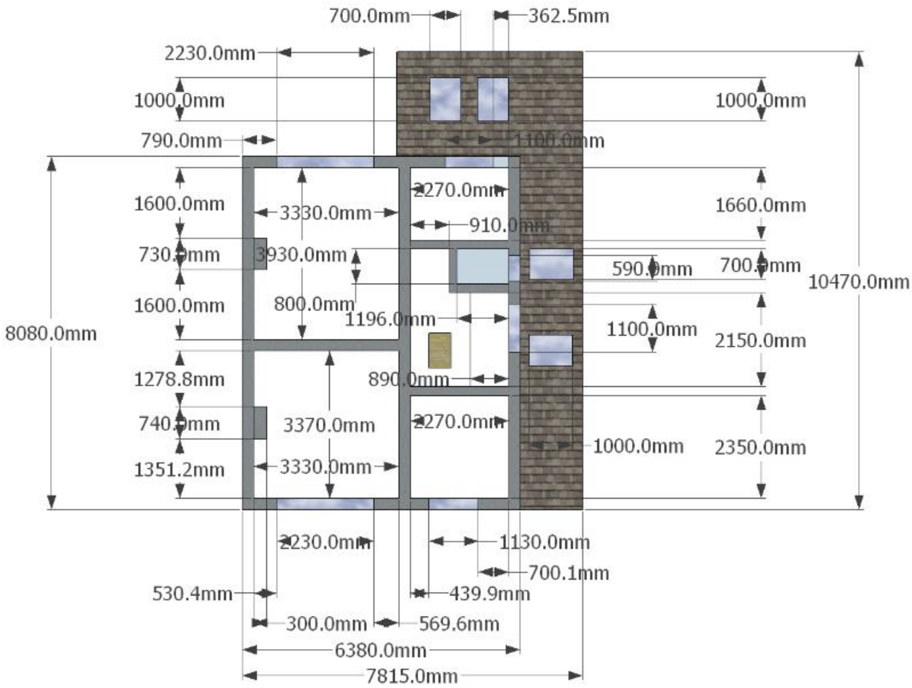


Figure 4 - Floorplan of first story

- **UK building needs**

The brick-built building provided poor insulation. This was identified as a primary need for upgrade were the SUREFIT exterior insulation panels were well suited. The small rooms typical of UK housing of that era also provided an opportunity to demonstrate the advantages of bio-aerogel insulation, where the very low U-value would allow very thing aerogel sheets that could be installed on the interior of the rooms yet not reduce the floor space significantly.

The owner wished to remove the gas boiler system and replace this with a heat pump unit. It was determined that a solar PV installation would be ideal for the home, making use of the main roof's south and west facing slopes. The options of both the SUREFIT Solar Assisted Heat Pump and the Ground Source Heat Pump were considered. The home had a separate garage which allowed space for the heat pump units and the roof sufficient space for the solar thermal panels of the solar assisted heat pump. The small rear garden allows sufficient space for the ground source heat pump ground loop array. This too was installed to allow evaluation of both systems, both as independent systems and to supplement each other, providing optimal heating depending on seasonal conditions.

The owner noted that it was often required to open the windows for proper ventilation, even in the winter. With the planed installation of exterior insulation, which would provide less passive ventilation, it was decided to install Window Heat Recovery Units to allow for ventilation yet minimize heat loss in the winter and loss of cool air in the summer.

1..1 Initial Building Assessment

As part of the initial home evaluations, assessment of current insulation properties of the windows, floor, ceiling/roof, and walls were completed through direct measurements and thermal scans. A selection of the results is shown below.

1) Double glazing window type 1 U-value=2.4 W/m^{2}K according to on-site measurement (Figure 5)

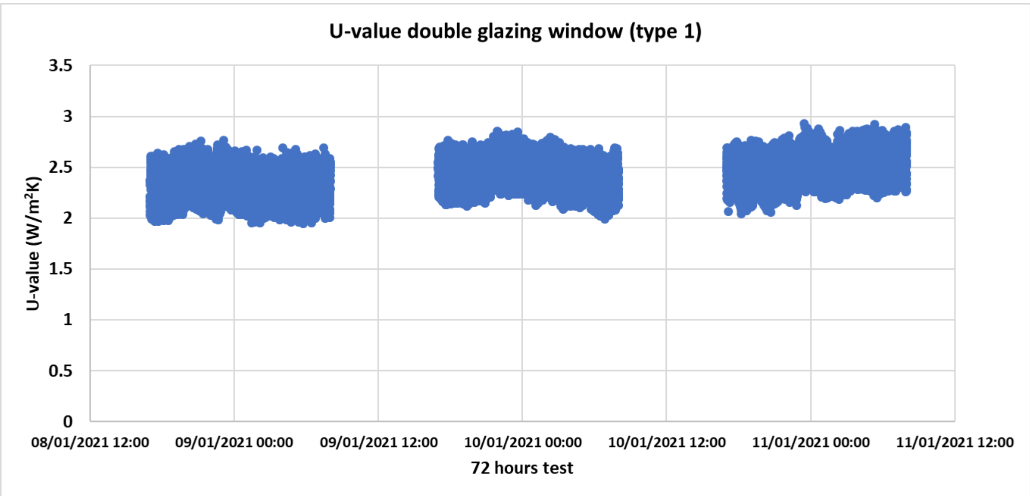


Figure 5 - U-value of the double-glazing window type-1

2) South/North side external wall (type 1) U-value=2.1 W/m^{2}K according to on-site measurement (Figure 6)

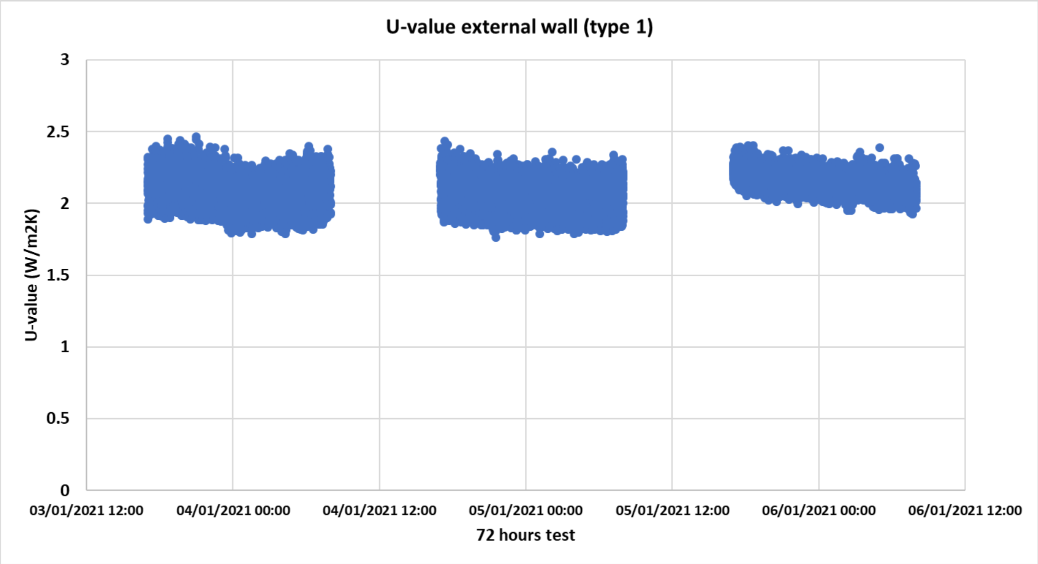


Figure 6 - U-value of the South/North side external wall

3) Attic floor U-value=0.89 W/m^{2}K according to on-site measurement (Figure 7)

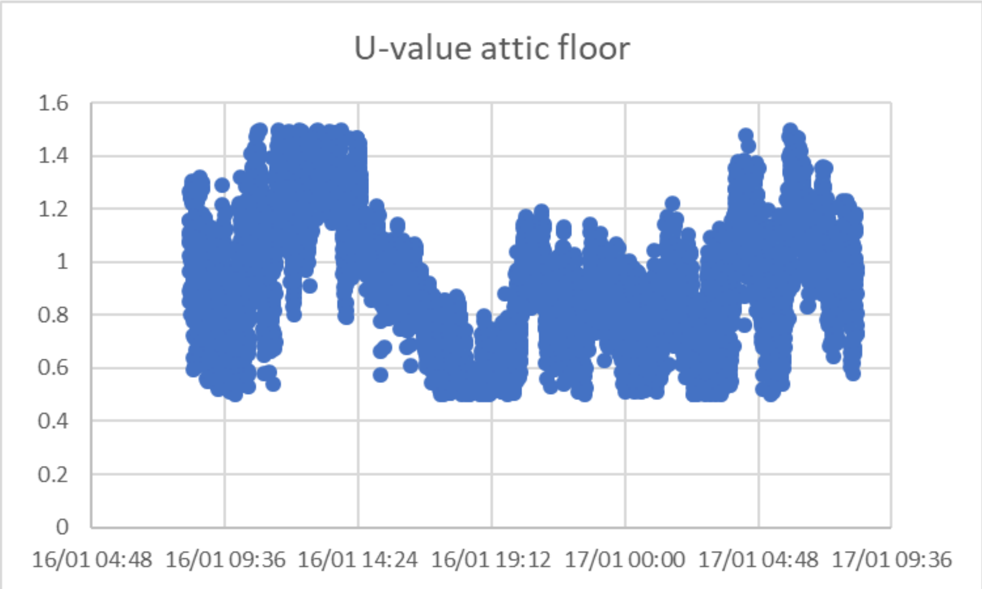


Figure 7 - U-value of the attic floor

4) Roof U-value=0.22 W/m^{2}K according to on-site measurement (Figure 8)

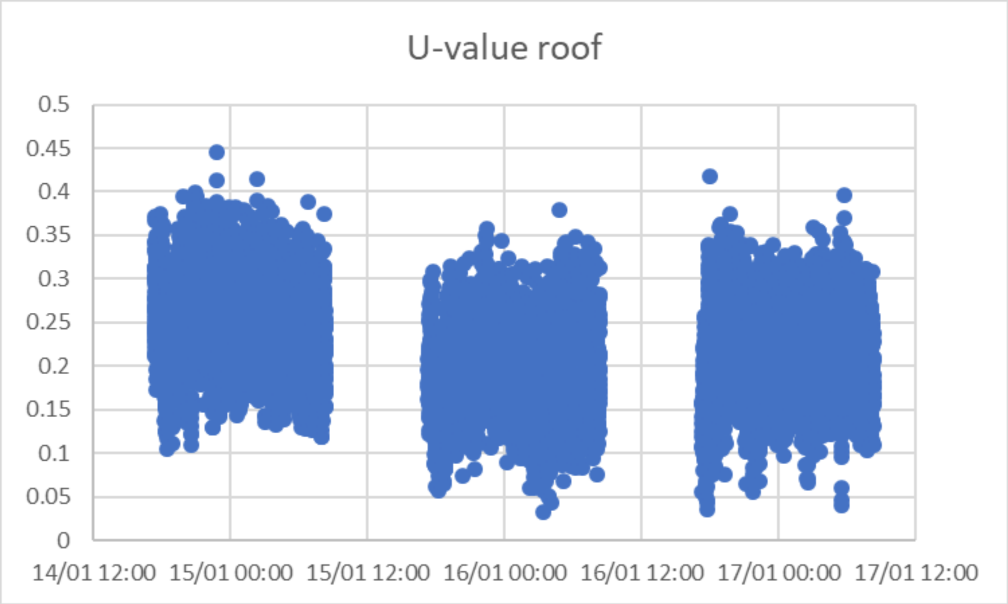


Figure 8 - U-value of the roof

1..1.1 Thermography

Aiming for the detection of thermal bridges with the use of thermographic images

Equipment used: Fluke TiS20+ Thermal Imaging Camera, with accuracy of ± 2 °C, and operation temperature ranging from -20 to +150 °C

Figure 9 and Figure 10 shows the results of the thermographic imaging done at the pilot building, with visible thermal bridges on the window frames.

Figure 9 - Thermographic imaging of the back side

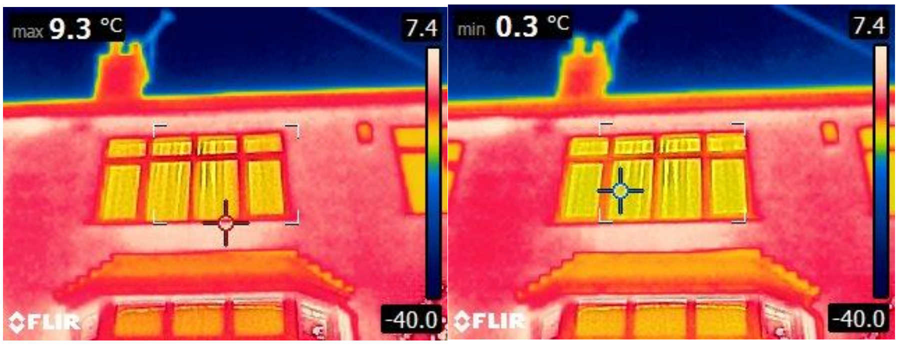


Figure 10 - Thermographic imaging of the front side

1..1.2 Air tightness

The pulse technique (Figure 11) measures the building airtightness at low pressures by releasing a known volume of air into the test building over 1.5 seconds from an air tank to create an instant pressure rise within the test building and reach a "quasi-steady" flow. Pressure variations in the building and tank are monitored and used for establishing a correlation between leakage and pressure. The method used for the adjustment, which accounts for changes in background pressure, is achieved by deducting background pressure from the raw data.

Figure 11 - Pulse airtightness test equipment

The airtightness test results of the UK pilot building are summarized as below with average of 2.69ACH under pressure difference of 4Pa (refers to 10.76ACH under 50Pa pressure difference), with an accuracy of ±0.58%. The results are calculated via three test experiments and outputs shown in Figure 73-75.

Table 1 - Airtightness results for the UK pilot building

Results	**Test 1**	**Test 2**	**Test 3**	**Average**	**Units**
Pressure difference	4 Pa	4 Pa	4 Pa	4 Pa	
Air Leakage Rate	0.189	0.188	0.185	0.187	m^3/s

Results	Test 1	Test 2	Test 3	Average	Units
Pressure difference	4 Pa	4 Pa	4 Pa	4 Pa	
Leakage per Hour	680	676	666	674	m^3/h
Air Permeability	2.02	2.01	1.98	2.00	m^3/m^2h
Air Change Rate	2.71	2.70	2.65	2.69	1/h
Effective Leakage Area	1.47	1.46	1.44	1.46	m^2
Uncertainty	0.52	0.62	0.61	0.58	±%

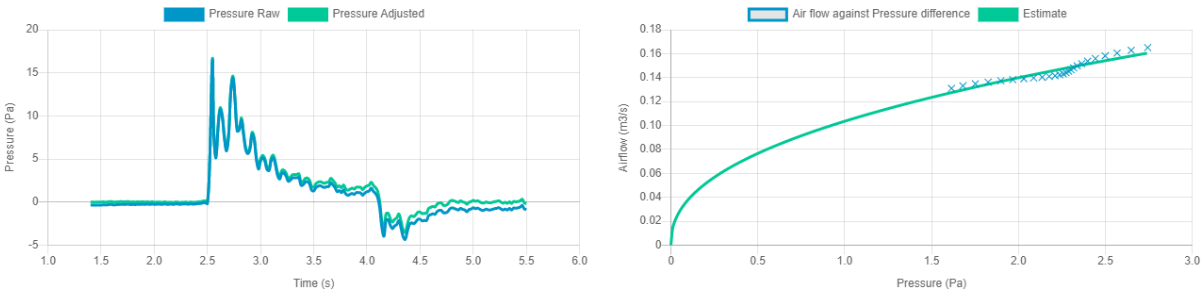


Figure 12 - Building airtightness measurement under Test 1

1..2 Energy use and consumption monitoring – baseline data

Before any retrofit work, the whole house energy consumption was monitored from **1st June 2021 to 31st May 2022**. During this period, the house relied primarily on natural gas for heating, with minimal use of electric heating systems. The key findings from the pre-retrofit phase are as follows:

- **Natural Gas Consumption**: The household consumed **24,153 kWh** of natural gas annually, reflecting a heavy reliance on fossil fuels for space heating and domestic hot water.
- **Electricity Consumption**: The total electricity consumption was **4,172 kWh**, primarily used for lighting, appliances, and minor heating loads.

- **Total Energy Demand**: The overall energy demand for the house stood at **28,324 kWh**, with a significant portion attributed to space heating during the winter months.
- **Winter Heating Demand**: From December to February, natural gas heating dominated energy usage, leading to peak consumption levels in colder months.

These findings highlight the inefficiencies of the pre-retrofit energy system, particularly the high dependency on gas-based heating. The results provided a baseline for assessing the impact of the subsequent retrofit interventions.

Table 2 - Monthly energy consumption

	Before-retrofit electricity consumption (kWh) (01/06/2021-31/05/2022)	Before-retrofit natural gas consumption (kWh) (01/06/2021-31/05/2022)	Before-retrofit final energy consumption (kWh) (01/06/2021-31/05/2022)
Jun	352	476	828
Jul	340	211	551
Aug	305	440	745
Sep	314	630	944
Oct	352	2091	2443
Nov	379	2466	2844
Dec	528	3787	4316
Jan	490	3953	4443
Feb	315	3260	3575
Mar	309	3073	3382
Apr	249	2650	2899
May	238	1117	1355
12-month total	4172	24153	28324

1..3 Interior Air Quality Monitoring

Interior air quality was measured for three rooms of the house, upstairs bedroom, kitchen, and living room. The monitored data included temperature, relative humidity, and CO_2 concentrations. These were monitored for the year prior to renovations and for the post-renovation evaluation period.

- **UK building energy simulation results**

Permutations of the technologies were modelled to assess the optimum combination for the SUREFIT project. Besides the energy costs, primary energy consumption, and CO_2 emissions reductions, factors such as suitability for the property and owner preferences were considered. The following permutations were modelled:

- Exterior insulation panels only
- Exterior insulation panels and vacuum glassing windows
- Exterior insulation panels, vacuum glassing windows, and PCM
- 50% exterior membrane
- 100% exterior membrane
- Window heat recovery unit
- Solar PV system with smart controls
- Passive + Infiltration + PV/T
- Passive + Infiltration + SAHP

Table 3 - UK home modelling results

The latter two showed the greatest performance improvement with the modelling results shown below:

	Combinations		
	Original	**Passive + Infiltration + PV/T**	**Passive + Infiltration + SAHP**
Purchased energy (kWh/m2)	206.8	81	51.8
Reduction (%)	-	**61%**	**75%**
Primary energy (kWh/m2)	242.7	94.9	72.8
Reduction (%)	-	**61%**	**70%**
CO2 Emissions (kg/m2)	42.7	16.7	11.6
Reduction (%)	-	**61%**	**73%**

2 UK building performed renovation

The renovation of the UK home included the following SUREFIT technologies:

- PV Vacuum Glassing
- Window Heat Recovery Unit
- Daylight Louvers
- Smart Controls
- Solar Assisted Heat Pump
- Evaporative Cooler
- Prefabricated Exterior Panel Insulation
- Solar PV System with Smart Controls
- Ground Source Heat Pump

With the number of technologies to be evaluated in the Nottingham house, additional instrumentation and monitoring systems beyond the standard instrumentation were installed in the home. The additional equipment allowed monitoring of:

- Measure of generated electricity from PV panels
- Measure of home used electricity from PV panels
- Measure of PV exported electricity to grid
- Measure of imported electricity from main grid
- Measure of solar assisted heat pump electricity consumption
- Measure of ground source heat pump electricity consumption
- Measure of space heating supply and return water temperatures
- Measure of Domestic hot water inlet and supply temperatures
- Measure of space heating water volume demand
- Measure of Domestic hot water volume demand
- Measure of natural gas demand

2..1.1 Renewable Energy Generation (PV and PV-VG Performance)

The roof PV panels are installed in November 2021, and the performance monitoring start on 1st January 2022 to 31st December 2024 with monthly power output. The PV-Vacuum Glassing window was only installed in the bedroom, with the performance is monitored from 1st January 2024 to 31st December 2024 for a whole year test.

Figure 13 - PV panels installed on the west (Left) and south (Right) roof

Figure 14 - Installation of the PV-Vacuum Glassing Windows unit

2..1.2 Impact of External Wall Insulation

The external wall insulation using bio/silica-aerogel materials is in July 2022, and the monitoring performance start from 1st August 2022 to 31st December 2022, which is used to compare the energy performance between 1st August 2021 to 31st December 2021.

Figure 15 - External wall insulation and Solar PV Front (Left) and Back (Right)

The transition to **Solar-Assisted Heat Pumps (SAHP) and Ground Source Heat Pumps (GSHP)** successfully replaced traditional gas heating while maintaining high efficiency.

Both SAHP and GSHP are installed in May 2023, and the performance monitoring starts from 1st Jun 2023 to 31st May 2024 for 12-month monitoring and analysis.

Figure 16 - Installation of the thermodynamic panels of the SAHP system

Figure 17 - Installation of the heat-pipe and water circulation pipes of the GSHP system underneath the soil

Figure 18 - Installation of both SAHP and GSHP unit and a hot water cylinder inside the garage space

2..1.3 Evaporative cooler

The evaporative cooler is installed in May 2023, and the performance monitoring is start in the hottest week from 23rd July 2023 to 29th July 2023.

Figure 19 - Installation of the evaporative cooler

2..1.4 Window heat recovery unit and Indoor Air Quality (IAQ) Improvements

The window heat recovery unit is operated to balance the CO_2 content inside the bedroom. The indoor air is ventilated when CO_2 concentration is high. The installation of window heat recovery unit is in December 2023, and the bedroom indoor air CO_2 content is monitored from 1st Jan 2024 to 31st Dec 2024. As all the electrical power of the window heat recovery unit is only supported by the power generation from the PV-VG unit, the electrical power is required of only 12W, which is too small and not an energy consumed unit in this project, therefore, no specific power monitored is used for this unit and only indoor air quality is monitored to evaluate the performance after the installation.

Figure 20 - Installation of the Window heat recovery inside the bedroom

Figure 21 - Integration of Window heat recovery unit with the PV-VG unit inside the bedroom

- **Energy savings**

The final overall energy consumption for the home is compared to the pre-renovation values. The significant reduction possible with the SUREFIT technologies can be seen below.

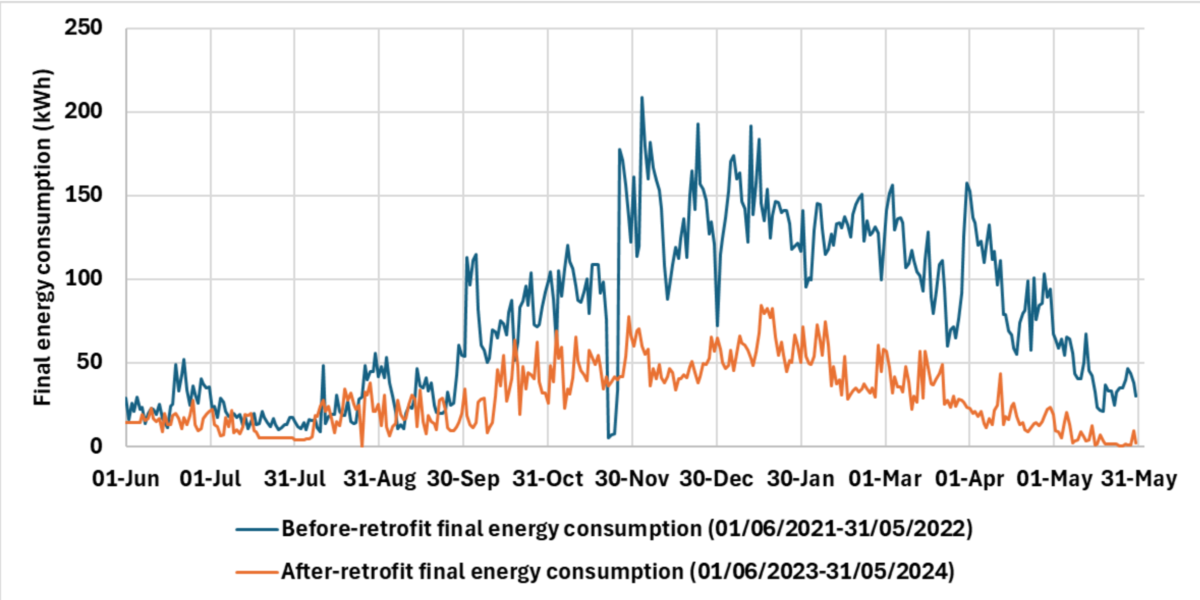


Figure 22 - 12-month comparison of final energy consumption before and after retrofit

Table 4 - Monthly energy consumption

	Before-retrofit electricity consumption (kWh) (01/06/2021-31/05/2022)	Before-retrofit natural gas consumption (kWh) (01/06/2021-31/05/2022)	Before-retrofit final energy consumption (kWh) (01/06/2021-31/05/2022)	After-retrofit electricity consumption (kWh) (01/06/2023-31/05/2024)	After-retrofit natural gas consumption (kWh) (01/06/2023-31/05/2024)	After-retrofit final energy consumption (kWh) (01/06/2023-31/05/2024)
Jun	352	476	828	248	229	478
Jul	340	211	551	189	129	318
Aug	305	440	745	322	256	578
Sep	314	630	944	288	246	534
Oct	352	2091	2443	798	213	1011
Nov	379	2466	2844	1095	326	1421
Dec	528	3787	4316	1141	379	1520
Jan	490	3953	4443	1404	472	1876
Feb	315	3260	3575	855	393	1248
Mar	309	3073	3382	768	375	1143
Apr	249	2650	2899	285	257	542
May	238	1117	1355	91	83	174
12-month total	4172	24153	28324	7484	3359	10843

Table 5 - Monthly energy reduction rate

	Electricity reduction rate	Natural gas reduction rate	Final energy reduction rate
Jun	29%	72%	42%
Jul	44%	77%	42%
Aug	-6%	66%	22%
Sep	8%	74%	43%
Oct	-127%	91%	59%
Nov	-189%	89%	50%

Dec	-116%	91%	65%
Jan	-186%	89%	58%
Feb	-172%	89%	65%
Mar	-148%	89%	66%
Apr	-14%	91%	81%
May	62%	94%	87%
12-month total	-79%	86%	62%

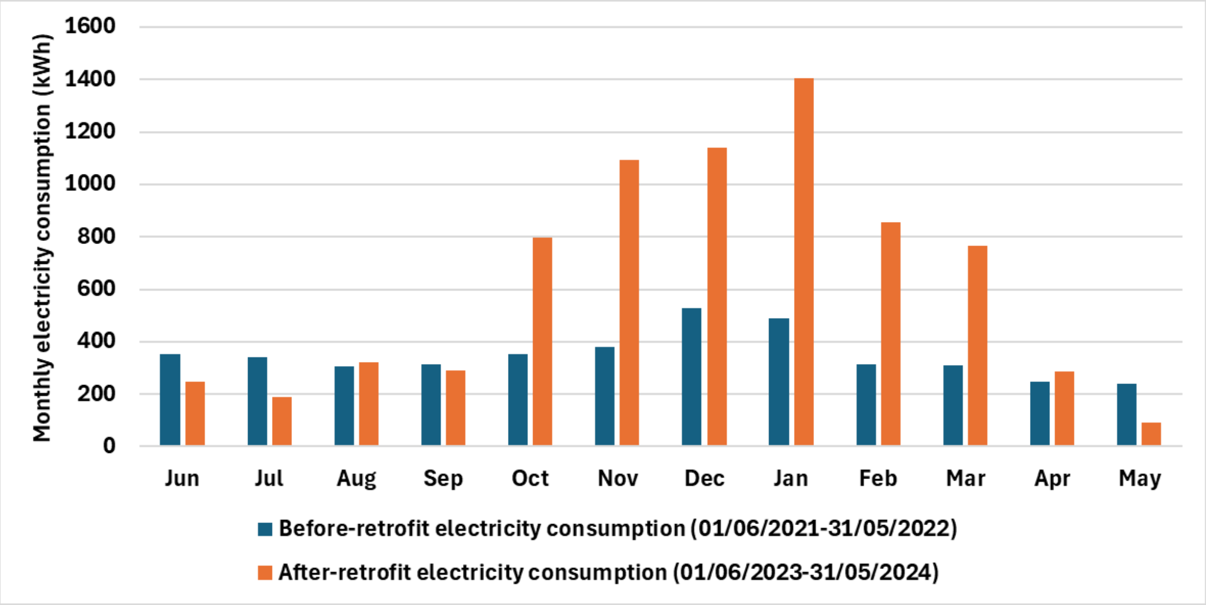


Figure 23 - Monthly electricity consumption before and after retrofit

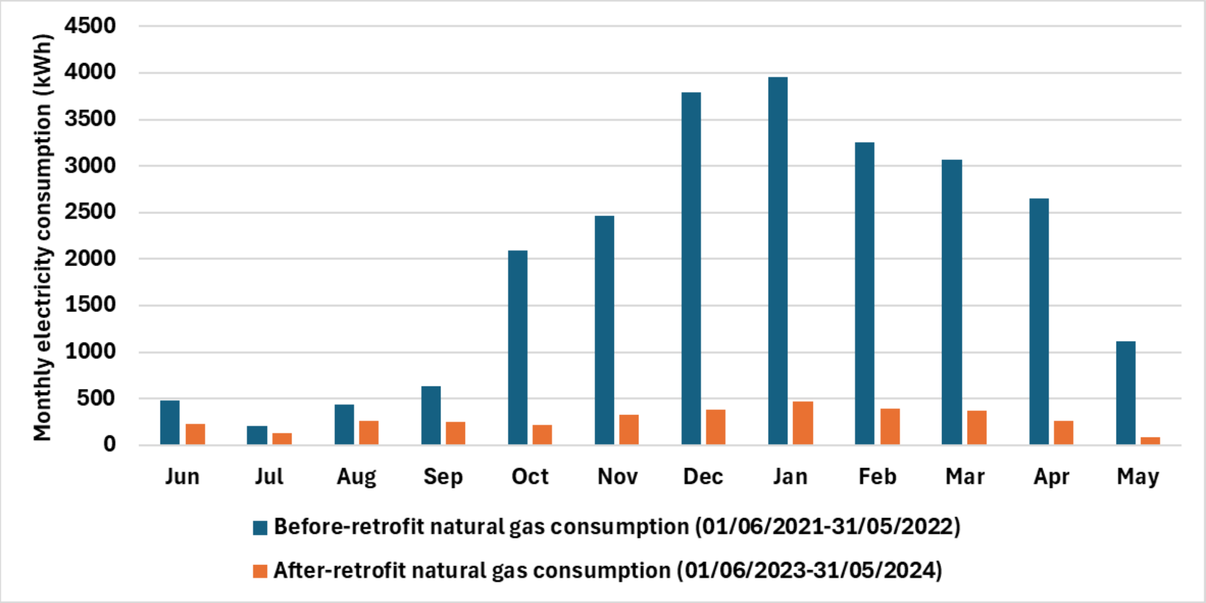


Figure 24 - Monthly natural gas consumption before and after retrofit

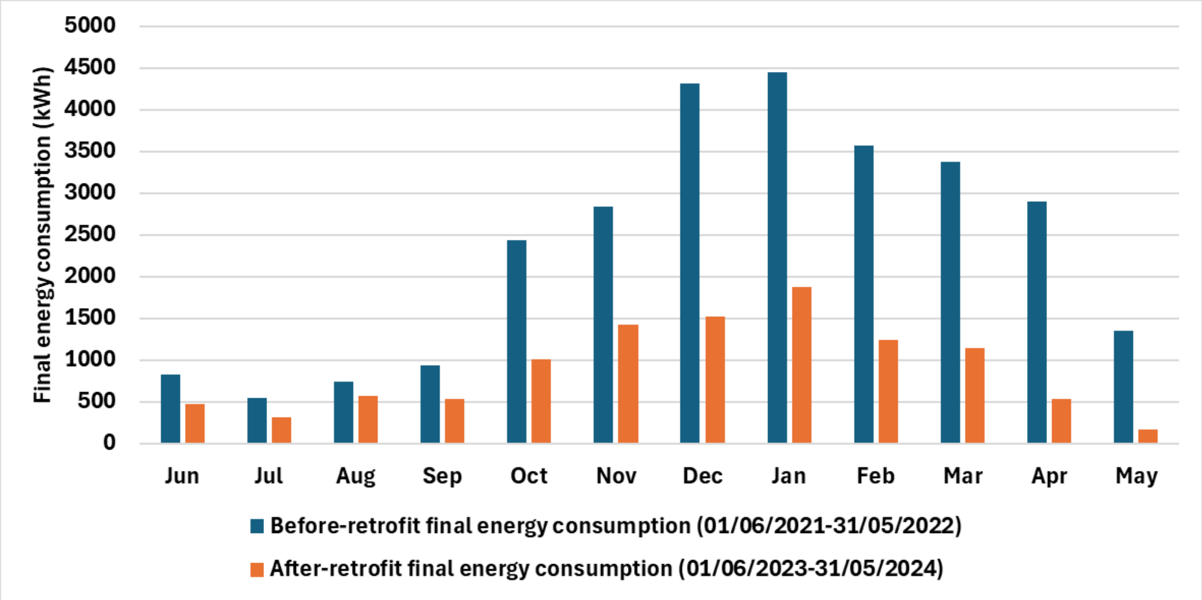


Figure 25 - Monthly final energy consumption before and after retrofit

- **Feedback from the occupants after renovation**

Overall, the occupants were satisfied with the SUREFIT retrofits. The greatest benefits were from the exterior insulation and solar PV system, passive systems that require no input from the homeowner. The PV Vacuum Glassing in the bedroom provided increases insulation, PV electrical power while the reduced light transmission was not an issue for the occupants. Both the ground source and solar assisted heat pumps were appreciated. Little interaction was required. With the systems being installed in a separate garage, no noise issues were noted. The Window heat recover system was problematic. The noise made operating the system problematic and was generally avoided. Also, the air exchange rate, that is fresh air was not appreciated by the occupants. Test data showed the system was perhaps undersized for the room. The evaporative cooler was only trialled a few days and it was not powerful enough to provide sufficient cooling. It was trailed on the hottest days of the year.

- **Economic evaluation**

The UK, during the previous months of the project, had a quite high inflation rate which had a direct impact in the products' prices. During the year 2023, the inflation rate changed many times, with great fluctuations. In order to avoid any misleading results, these inflation and interest rate fluctuations were used in the definition of the discount rate of the LCC calculation, in terms of conducting a sensitivity analysis. This procedure was used to eliminate the risk of uncertainty. The latest values that were used for the inflation and interest rates are those corresponding to December 2023, when the inflation rate became lower than the interest rate, after almost one year of really high values.

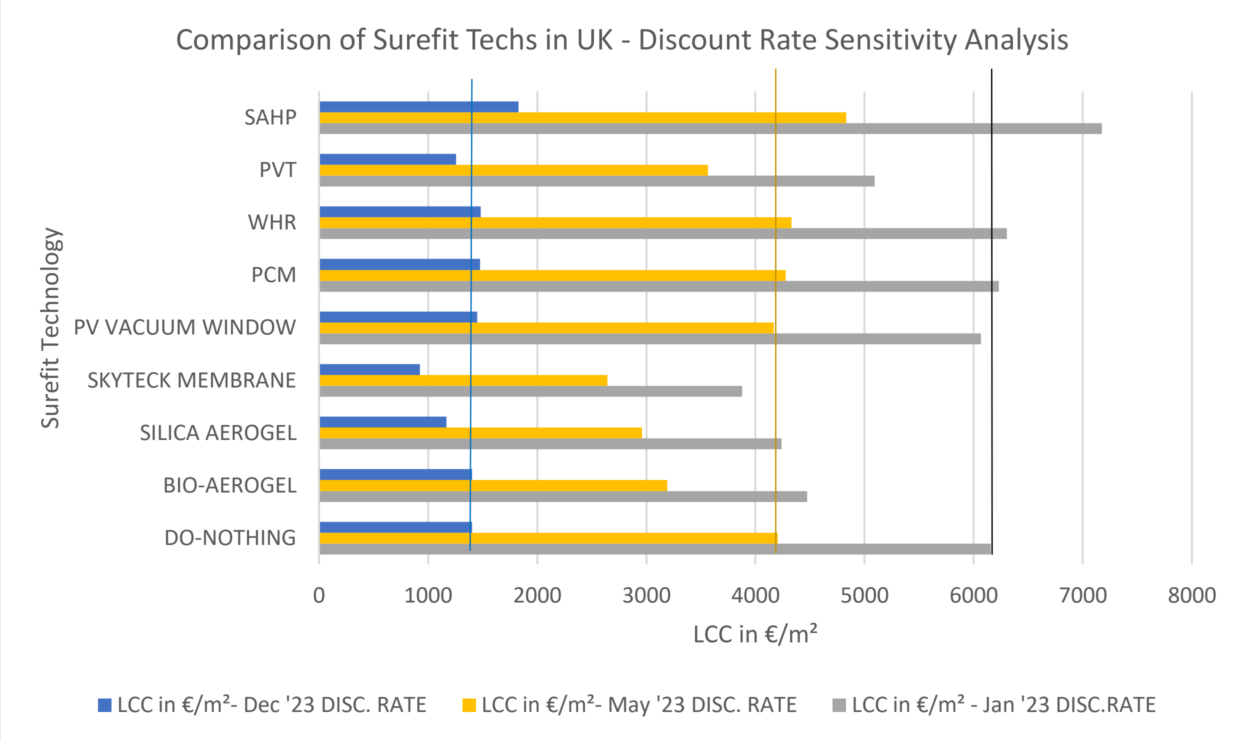


Figure 26 - Sensitivity analysis with variation in the discount rate (interest & inflation rate fluctuations) for the different SUREFIT technologies

From the diagram above, it is concluded that bio aerogel, silica aerogel, Skytech membrane and PVT panels are cost efficient technologies from a LCC point of view, regardless the fluctuations in the discount rate. On the other hand, SAHP, Window Heat Recovery (WHR) and PCM do not seem to be economically viable, whatever the discount rate is.

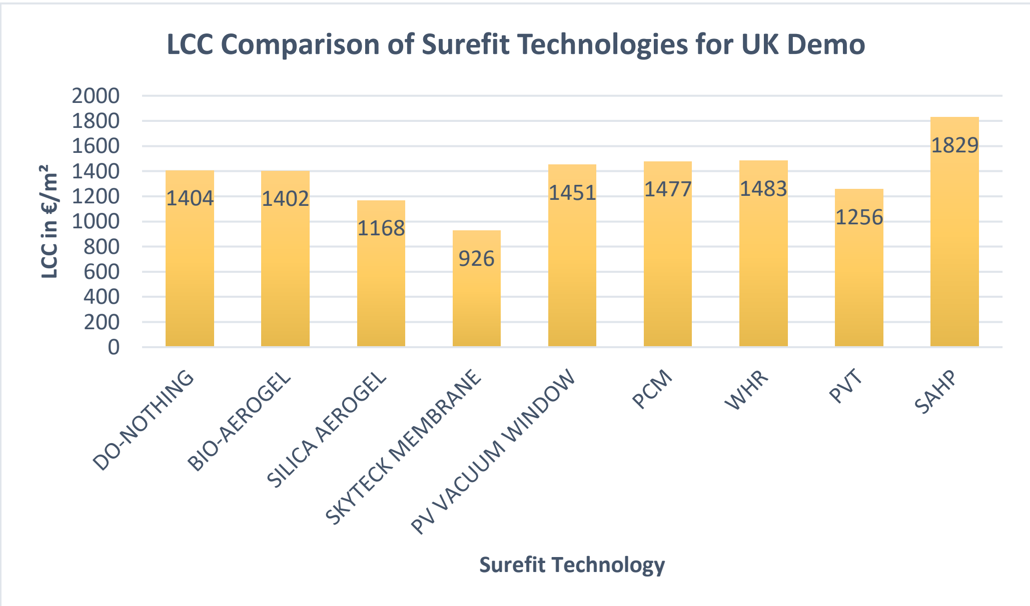


Figure 27 - LCC comparison of SUREFIT Technologies for UK demo building

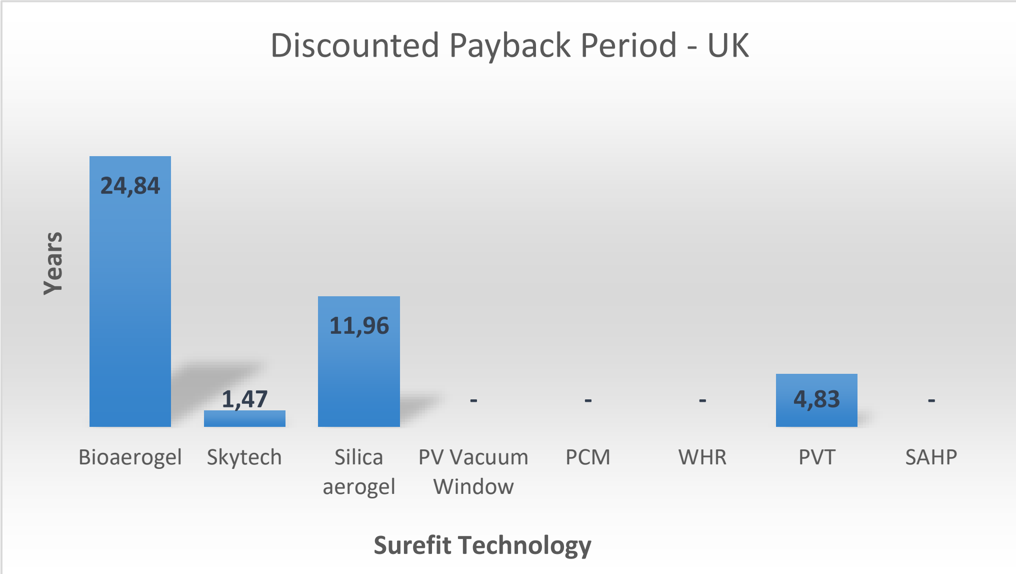


Figure 28 - Discounted Payback Period of the SUREFIT Technologies for UK demo building

Diagram 4 indicates the LCC of the different SUREFIT technologies for the UK demonstration building, for a study period of 30 years, interest (5,25%) and inflation (4%) rates of December 2023 and the energy prices of December 2023 – January 2024. As was also revealed from the sensitivity analysis, the best performing technologies by an economic point of view are Skytech membrane, PVT panels and silica aerogel. This is illustrated in both the diagrams 4 and 5 above.

Another conclusion that is derived from the energy and economic assessment of the examined SUREFIT technologies, is that SAHP and WHR are producing no energy or economic savings since the electricity consumption of the building is increased in these two cases and this is translated as bigger expenses, since the electricity price in UK is greater than that of the natural gas.

The dash symbol that is depicted in diagram 5 indicates that there are no payback periods below the line, as there are no savings from the application of the technology.

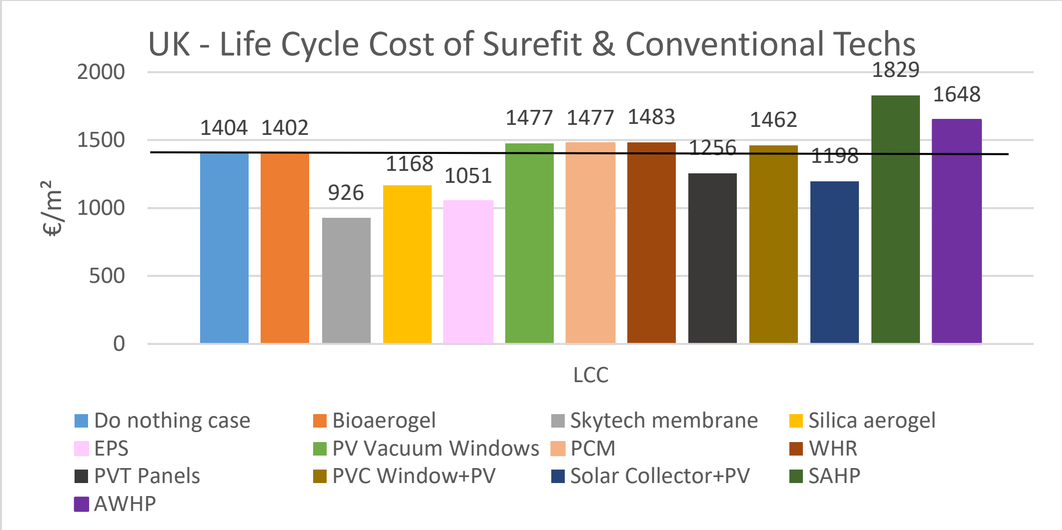


Figure 29 - Comparison of LCCs of the SUREFIT Technologies with Conventional Ones – UK

For UK building, the most cost effective is shown to be Skytech membrane, silica aerogel, EPS, PVT panels and the combination of solar collectors with PV modules.

- **Overall evaluation and final conclusions**

The SUREFIT retrofit project successfully reduced energy consumption, enhanced IAQ, and improved thermal comfort. By implementing high-performance insulation, heat pumps, PV-VG technology, and advanced ventilation systems, the project achieved a holistic upgrade of building performance. However, further advancements in renewable energy storage, smart ventilation control, and hybrid PV solutions could further optimize energy efficiency and occupant well-being. These findings highlight the importance of integrated, data-driven retrofitting strategies in achieving sustainable, low-carbon buildings for the future.

3 Spanish case study

These three rectangular buildings have a depth of 7.10 m and a width of 4.40 m. Since the houses are located at Avenida de Santander 40, 42, and 44, we will refer to them throughout this document as H40, H42, and H44 to distinguish the different owners.

Each home is arranged across three levels: basement, ground floor, and first floor. The kitchen is situated on the ground floor, while the bathroom is on the first floor. The remaining rooms serve residential purposes, with layouts varying according to each owner's preferences.

The staircase is positioned perpendicular to the longer side of the rectangle, located at one-third of its length, and extends from the basement to the first floor.

The main façade faces Avenida de Santander, while the rear façade leads to a backyard, individually assigned to each home.

The construction consists of load-bearing walls composed of two layers of brick: an interior layer of single hollow brick, an air cavity, and an exterior layer of solid half-brick, resulting in a total thickness of 200 mm. The party wall is made of perforated half-brick (110 mm).

Unlike most homes in the neighbourhood, the floors are built using precast reinforced concrete beams and concrete filler blocks.

The roof comprises brick parapets, flat brick tiles, and a cement mortar compression layer, finished with concrete tiles. These tiles have been recently installed in the homes included in this intervention.

The carpentry varies between homes, with materials ranging from PVC, with or without thermal break, to natural-coloured aluminium, with one or two panes.

Table 6 - Dimensions and characteristics of the Spanish dwellings

Dwellings Avenida de Santander. Spain Pilot														
Number	40				42				44					Totals
Facades			P1	P2			P1	P2			P1	P2		
	N-E				N-E				N-E		20,62 m^2	23,64 m^2	44,26 m^2	
	N-W		8,93 m^2	9,59 m^2	N-W		8,93 m^2	9,59 m^2	N-W		8,93 m^2	9,59 m^2	55,56 m^2	
	S-W				S-W				S-W					
	S-E		8,25 m^2	9,25 m^2	S-E		8,25 m^2	9,25 m^2	S-E		8,25 m^2	9,25 m^2	52,50 m^2	152,32 m^2
Windows	N-E				N-E				N-E					
	N-W	2 ud	1,25 m^2	1,25 m^2	N-W	2 ud	1,25 m^2	1,25 m^2	N-W	2 ud	1,25 m^2	1,25 m^2	7,50 m^2	6 ud
	S-W				S-W				S-W					
	S-E	4 ud	1,46 m^2	1,60 m^2	S-E	4 ud	1,46 m^2	1,60 m^2	S-E	4 ud	1,46 m^2	1,60 m^2	9,18 m^2	12 ud
Roof			34,00 m^2				34,00 m^2				34,00 m^2		102,00 m^2	102,00 m^2
Basement			30,00 m^2				30,00 m^2				30,00 m^2		90,00 m^2	90,00 m^2
Bedroom			8,51 m^2				8,51 m^2				8,51 m^2		25,53 m^2	25,53 m^2
Heating	1 Natural Gas condensing boiler + Water				1 Electric radiators. 1 Electric Boiler				1 Natural Gas condensing boiler + Water					
Windows	PVC + Climalit				Double Aluminium. Simple Glass				Double Aluminium. Simple Glass					
Inhabitants	A couple and a dog				A single with irregular use of the house				A couple and a dog					

Figure 30 - Front part of the houses

Figure *31* - Rear side of the houses

Figure 32 - San Pedro Regalado neighbourhood

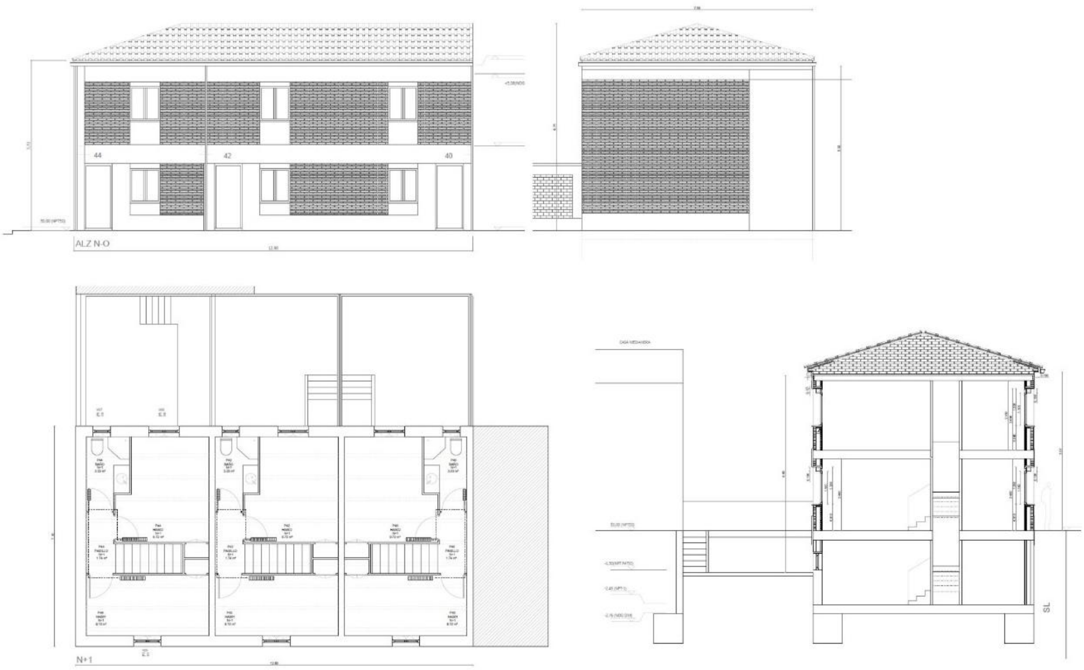


Figure 33 - Floor plans, facades and cross section

- **Spanish building needs**

Before the renovation, the building presented several deficiencies identified through on-site inspections and occupant feedback. The on-site assessments, including air tightness tests, revealed issues with insulation and thermal performance, leading to significant heat losses in winter and excessive heat retention in summer. The lack of airtightness contributed to uncontrolled air infiltration, reducing energy efficiency and comfort levels. Occupant feedback further reinforced these findings, highlighting discomfort due to extreme indoor temperatures, with reports of excessive heat in summer and severe cold in winter. Ventilation issues were also a concern, with descriptions of poor air quality, humidity problems, and, in some cases, the presence of mold. Noise disturbances, particularly from external traffic and neighbouring activities, were reported, though they varied among respondents. The need for improved heating and cooling solutions was a recurring theme, with occupants expressing dissatisfaction with the efficiency of their existing systems. Based on the questionnaires, key renovation priorities included improving the thermal envelope, upgrading insulation, enhancing ventilation, and integrating renewable energy solutions to optimize indoor comfort and reduce energy dependency.

Table 7 - Answers from the owners to the characteristic's questionnaire

House	Cooling System	Spring Temperature	Summer Temperature	Autumn Temperature	Winter Temperature	Air Quality - Humidity	Air Quality - Odor	Air Quality - Ventilation	Noise from Traffic	Noise from Neighbors	Natural Light Satisfaction	Artificial Light Satisfaction	Sun Exposure	Overheating Issues	Preferred Improvements	Willing to Pay for Renovation
40	No	Somewhat Cold	Too Hot	Somewhat Cold	Cold	Somewhat Humid	Neutral	Neutral	Slightly	Slightly	Satisfactory	Satisfactory	Good Amount	Yes	Better insulation, solar panels, improved windows	No
42	No	Neutral	Too Hot	Neutral	Cold	Somewhat Humid	Somewhat Malodorous	N/A	Moderately	Slightly	Satisfactory	Satisfactory	Good Amount	Yes	Everything	No
44	No	Hot	Too Hot	Somewhat Cold	Very Cold	Humid	Malodorous	Poorly Ventilated	Slightly	Slightly	Very Satisfactory	Very Satisfactory	Good Amount	No	Full thermal envelope improvement, mechanical ventilation	20,000€

Air Tightness Test (Blower Door Test)

The air tightness test was conducted following the EN13829 standard to evaluate the infiltration rate of the buildings. This test measures the uncontrolled air leakage through the building envelope, which can significantly impact energy efficiency and indoor comfort. The test results indicate the presence of considerable air infiltration before renovation, suggesting a lack of sealing in windows, doors, and other envelope components. High infiltration rates contribute to heat losses in winter and overheating in summer, leading to inefficient energy use and reduced thermal comfort.

The measured flow rates at different pressure levels confirm that air leakage was a critical issue, reinforcing the necessity of improving airtightness through enhanced insulation and sealing solutions. These findings align with occupant feedback, which reported drafts, humidity issues, and difficulty in maintaining stable indoor temperatures.

Thermofluxmeter Test (Thermal Transmittance Measurement)

The thermofluxmeter test was performed to assess the thermal transmittance (U-value) of the building envelope before renovation. The test was conducted on an exterior wall using heat flow sensors over a 24-hour period. The results indicate a high U-value of **1.4 W/m²K**, suggesting poor thermal insulation and significant heat transfer between the interior and exterior environments.

Thermal imaging prior to the test revealed notable thermal bridges, particularly around window perimeters and structural junctions, confirming weak points in the insulation. The analysis also showed a clear difference in temperatures between interior-facing and exterior-facing surfaces, further emphasizing heat loss areas. These findings support the need for a comprehensive thermal envelope improvement, including enhanced insulation, window replacement, and sealing of thermal bridges.

Both tests confirm that the pre-renovation state of the buildings was characterized by poor airtightness and inadequate thermal insulation, leading to high energy losses and discomfort for occupants. These results justify the necessity of the implemented renovation measures aimed at improving building

- **Spanish building energy simulation results**

The dynamic simulations conducted for the Spanish demonstration building, a terraced house in Valladolid, aimed to assess its energy performance before and after the retrofit interventions. The simulations were performed using IDA-ICE, considering different retrofit packages and their impact on energy consumption, CO_2 emissions, and indoor conditions.

Pre-Renovation Energy Performance

Before the renovation, the building exhibited high heating demand due to poor insulation and air infiltration. The heating system relied mainly on gas boilers, and some apartments also used electric radiators. The absence of cooling systems meant that summer overheating was a critical issue. The simulations indicated significant heat losses through the envelope, particularly from the external walls and windows. Infiltration values were based on literature sources due to the lack of direct measurements, suggesting that uncontrolled air exchange contributed to inefficiencies in maintaining stable indoor temperatures.

Impact of Retrofit Measures

The retrofit measures implemented in the Spanish case aimed to improve thermal insulation, enhance airtightness, and integrate renewable energy solutions. The results demonstrated that adding bio-aerogel insulation to the external walls and installing high-performance PV glazing significantly reduced heating demand. The bio-aerogel insulation alone contributed to a 43% reduction in CO_2 emissions, while the addition of PV glazing further improved energy efficiency, leading to an overall 49% reduction in emissions. The impact of PV glazing was somewhat limited due to the smaller window area compared to other parts of the envelope.

The introduction of a breathing membrane to reduce infiltration showed improvements, with a 35-36% decrease in emissions. However, increasing airtightness without mechanical ventilation raised concerns about indoor air quality. The integration of a mechanical ventilation system with heat recovery ensured a stable indoor environment by maintaining CO_2 levels below 1200 ppm, significantly improving air quality.

The hybrid photovoltaic/thermal (PV/T) system led to a 15% reduction in fuel consumption and a 38% decrease in electricity consumption, although a portion of the generated electricity was exported to the grid, slightly limiting its direct impact. The solar-assisted heat pump (SAHP) proved to be one of the most effective measures, reducing fuel consumption by 77%, though it also increased electricity use more than twofold.

Indoor Comfort and Thermal Performance

The simulations confirmed that the passive solutions effectively mitigated summer overheating while maintaining better thermal stability in winter. The maximum indoor temperature was reduced by 1.4°C with insulation and PV glazing, and an additional 0.6°C decrease was achieved with the inclusion of phase change materials (PCM). These results indicate an improvement in temperature regulation throughout the year. However, further analysis is needed to evaluate the impact of thermal inertia during spring, as increased heat retention in the envelope could lead to higher indoor temperatures during the transition between heating and non-heating periods.

Conclusions

The simulation results highlight the effectiveness of the retrofit measures in significantly reducing energy consumption and emissions while improving indoor comfort. The passive envelope improvements, particularly insulation and airtightness enhancement, had the most substantial impact. The integration of renewable energy solutions contributed to reducing reliance on fossil fuels, although their effectiveness depended on seasonal variations in solar energy availability. The study also underscores the need for further monitoring to assess the long-term effects of the renovation, particularly in addressing potential overheating during transitional seasons due to increased thermal inertia.

Table 8 - Properties of the retrofit packages and their impact on energy consumption in the Spanish demo building

		Passive			Infiltration			Active	
Renovation measure	**Orig**	**Insu**	**Insu+Wind**	**Insu+Wind+PCM**	**Memb50**	**Memb100**	**Memb100+Vent**	**PVT**	**SAHP**
Wall insulation thickness (cm)	0	5	5	5	0	0	0	0	0
Roof insulation thickness (cm)	0	5	5	5	0	0	0	0	0
Membrane thickness (cm)	0	0	0	0	2.6	2.6	2.6	0	0
U-value, walls (W/m2K)	1.69	0.37	0.37	0.37	0.67	0.67	0.67	1.69	1.69
U-value, roof (W/m2K)	1.64	0.37	0.37	0.37	0.66	0.66	0.66	1.64	1.64
U-value, windows (W/m2K)	2.8 / 5.7	2.8 / 5.7	0.6 / 2.8 / 5.7	0.6 / 2.8 / 5.7	2.8 / 5.7	2.8 / 5.7	2.8 / 5.7	2.8 / 5.7	2.8 / 5.7
PCM (cm)	0	0	0	3.2	0	0	0	0	0
Infiltration (n50, ACH)	6.7	6.7	6.7	6.7	3.4	0.11	0.11	6.7	6.7
Ventilation type	Natural	Natural	Natural	Natural	Natural	Natural	Mech, balanced	Natural	Natural
Ventilation HR (%)	0	0	0	0	0	0	75	0	0
ST roof (m2)	0	0	0	0	0	0	0	20	20
PV roof (m2)	0	0	0	0	0	0	0	20	0
PV, vert (m2)	0	0	13.2	13.2	0	0	0	0	0
Heat pump (kW)	0	0	0	0	0	0	0	0	20
Hot water tank (m3)	0	0	0	0	0	0	0	2	2
	Purchased energy use (kWh/m2)								
	Original	Passive			Infiltration			Active	
Energy type	**Orig**	**Insu**	**Insu+Wind**	**Insu+Wind+PCM**	**Memb50**	**Memb100**	**Memb100+Vent**	**PVT**	**SAHP**
Fuel tot	115.0	58.0	51.1	50.2	68.1	67.2	77.5	97.2	26.2
Elec tot	19.4	19.3	17.9	17.8	19.3	19.3	19.8	12.1	45.6
Total renewable energy	0	0	1.5	1.5	0.0	0.0	0.0	36.3	68.7
Solar/ambient heat	0	0	0	0	0	0	0	17.2	68.7
PV total	0	0	1.5	1.5	0	0	0	13.2	0
PV sold	0	0	0	0	0	0	0	5.88	0
PV self-consumption rate	0.0 %	0.0 %	100.0 %	100.0 %	0.0 %	0.0 %	0.0 %	55.3 %	0.0 %

Table 9 - Retrofit impact metrics and indoor conditions for the Spanish demo building

	Orig	**Insu**	**Insu+Wind**	**Insu+Wind+PCM**	**Memb50**	**Memb100**	**Memb100+Vent**	**PVT**	**SAHP**
Purchased energy (kWh/m2)	134	77.2	68.9	68.0	87.4	86.5	97.3	109.3	71.8
Reduction (%)		-42.5 %	-48.5 %	-49.1 %	-35.0 %	-35.7 %	-27.6 %	-22.8 %	-46.6 %
Primary energy (kWh/m2)	152.4	91.1	81.6	80.6	102.0	101.0	112.8	122.3	96.9
Reduction (%)		-40.2 %	-46.4 %	-47.1 %	-33.0 %	-33.7 %	-26.0 %	-19.7 %	-36.4 %
Emissions (kg-CO2/m2)	26.6	15.2	13.6	13.4	17.2	17.0	19.2	21.6	13.9
Reduction (%)		-42.8 %	-49.0 %	-49.7 %	-35.2 %	-35.9 %	-27.8 %	-18.6 %	-47.8 %
Indoor conditions	**Orig**	**Insu**	**Insu+Wind**	**Insu+Wind+PCM**	**Memb50**	**Memb100**	**Memb100+Vent**	**PVT**	**SAHP**
T_max (degC)	30.5	29.6	29.1	28.5	29.9	30.2	30.2	30.4	30.4
T < 18 (%)	5	0	0	0	5	0	0	5	5
T > 25 (%)	12	11	10	11	14	14	11	13	13
CO2 < 1200 (%)	41	44	45	45	36	24	100	41	41
CO2 < 1800 (%)	98	99	99	99	98	96	100	98	98

- **Spanish building performed renovation**

Based on the energy simulations conducted by AALTO University for the three houses and in alignment with the specific targets of the SUREFIT project—aiming for a 60% reduction in primary energy use and carbon emissions—several interventions were implemented, taking into account both technical feasibility and tenant requirements.

The external thermal insulation of the East, North, and West facades was carried out using prefabricated insulation panels provided by CJR. These panels consist of a layered structure with 20mm XPS, 20mm aerogel, and another 20mm XPS, achieving a U-value of 0.481 W/m²K, as determined in Deliverable 4.8. Additionally, at the request of the owners and financed by them, House 40 received an extra 8 cm layer of XPS insulation. The entire building was wrapped with a 2 cm membrane supplied by WINCO, covering both the roofs and facades to enhance airtightness and insulation.

Phase Change Material (PCM) panels were installed with specific configurations for each house: S27 panels in House 40, S29 panels in House 42, and no PCM installation in House 44, following the recommendations of PCM technicians. To complete the envelope system and ensure proper ventilation, a finishing layer of mixed wood and concrete boards was installed. While this is not a SUREFIT technology, it was necessary for the correct implementation of the insulation system.

Regarding windows, targeted replacements and upgrades were carried out. In Houses 40 and 42, the backyard doors were replaced, and PV Vacuum Glazing Windows were installed, along with the replacement of one window to accommodate the Heat Recovery Unit. Other windows were replaced at the owners' expense. In House 44, similar changes were made, but the remaining windows had already been upgraded by the owner. Window Heat Recovery Units were installed on top of selected windows, following the proposal from UNOTT, and powered by the PV Vacuum Glazing Windows. Additionally, daylight louvers were installed on three ground-floor windows in each house to optimize natural light control and reduce overheating risks.

A photovoltaic-thermal (PV-T) system by SOLIMPEKS was installed to provide electricity, domestic hot water (DHW), and heating. DHW and heating demands continue to be supplemented by the existing oil boiler. The implementation of the storage tanks varied among the houses. In House 40, a 300L storage tank was installed outside due to space constraints, with an initially planned protective shelter that was ultimately omitted due to budget limitations. House 42 followed the same installation approach as House 40, with the addition of a backup resistance for the tank, given the absence of a gas boiler. In House 44, a smaller 200L storage tank was installed indoors, also featuring a backup resistance.

Smart control systems were provided and installed by ONCONTROL to optimize energy management.

However, due to budget constraints within the consortium and the presence of multiple tenants in the Spanish pilot, the decision was made not to install the Solar-Assisted Heat Pump (SAHP) in this case

3..1 Prefabricated panels, breathing membrane and final finishes

The system was initially conceived in a theoretical framework to streamline the installation process but encountered challenges that prevented strict adherence to those estimates.

The final proposal outlined the following system and installation sequence:

Composition: Prefabricated panel, Winco membrane 2cm, Cement Bonded particle Board, secured with rafters.

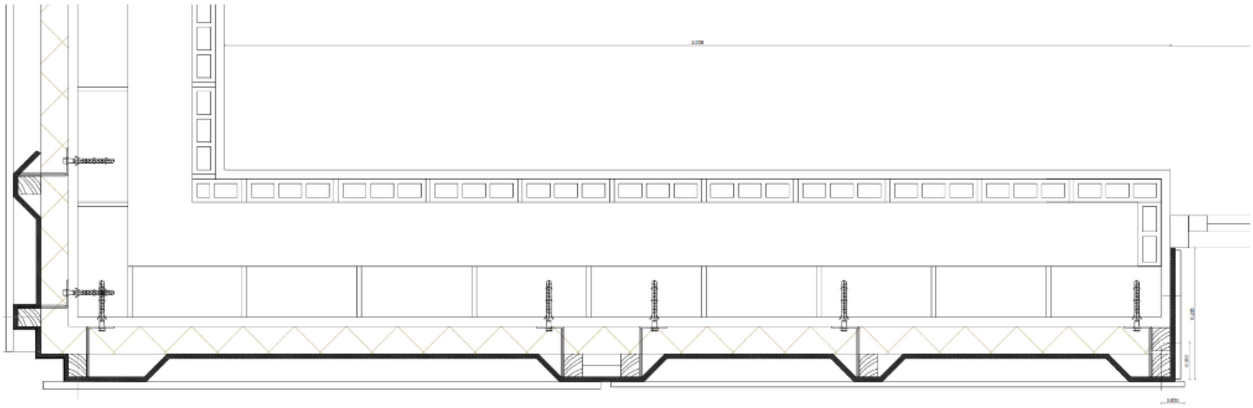


Figure 34 - Detail of the installation of the whole insulation system

Installation Sequence: Measuring and planning of final boards, marking holes on the wall, installing brackets, prefabricated panels, rafters, breathable membrane, and finally, Cement board. During this installation, we had to meticulously account for concealing existing installations and establishing connections with the new ones.

Following the setup of scaffolds, our first step was to coordinate with the PV/T installer to remove existing gas, telecommunications, and electrical installations. This process took considerable time, particularly in determining the final configuration and specifics of each system.

Figure 35 - Scaffolding and removing of gas and electricity installation

Due to the unique characteristics of the proposed system, the installation of the prefabricated panel deviated from an ETICS design to a ventilated facade approach.

A significant portion of time was dedicated to setting up brackets and battens to support the chosen finish, which involved Cement Bonded Particle Board. We engaged in an iterative process of measurement and verification to ensure precise placement of every anchor, given the boards' strict dimensional requirements.

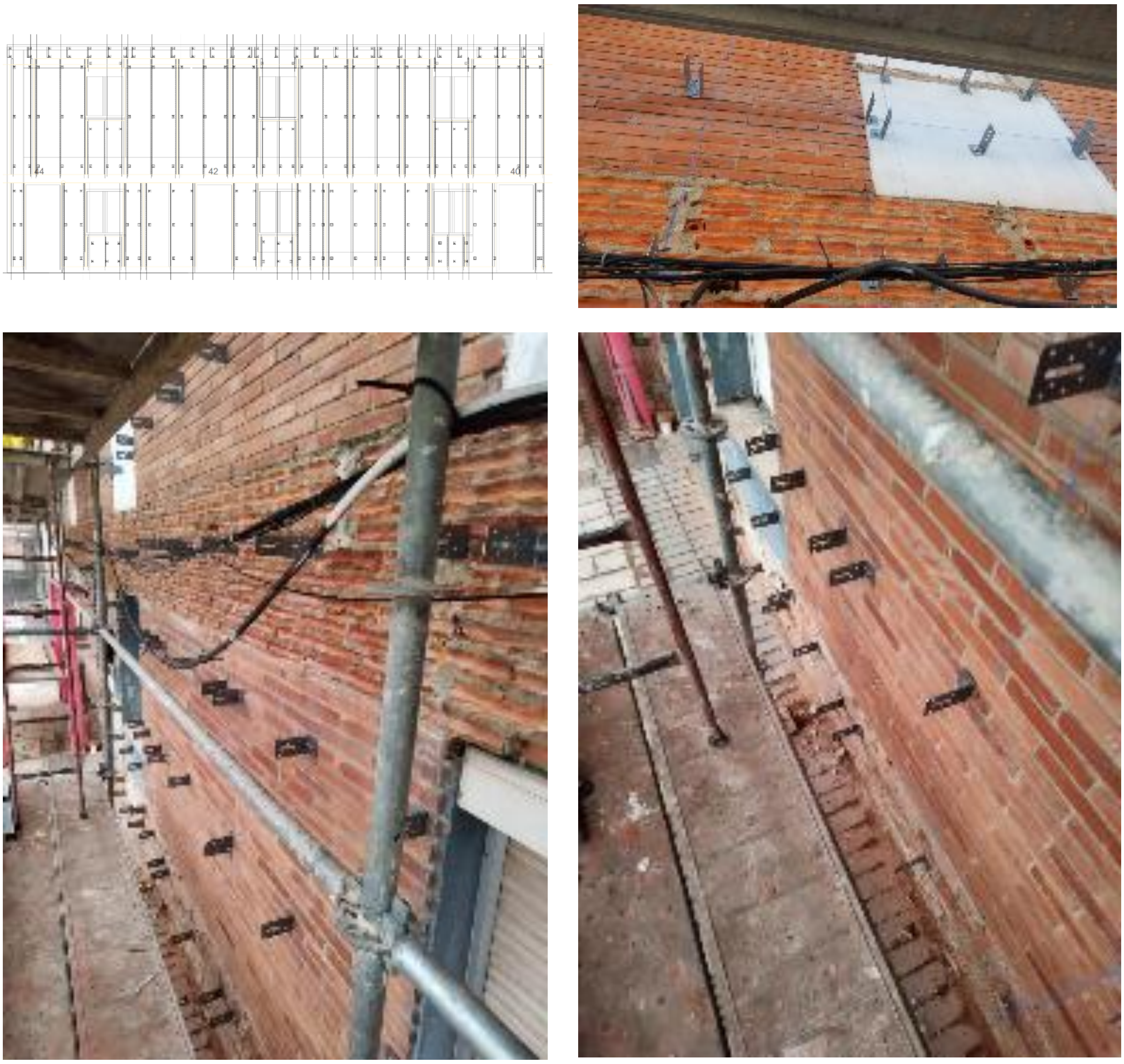


Figure 36 - Drafting and installation of anchors

The installation of the prefabricated panel required an initial training period to achieve an efficient time-installation ratio. Notably, a major focus was directed towards the meticulous finishing of doors and windows.

Figure 37 - Installation of prefabricated panel and rafters

The Winco membrane posed challenges during installation due to its 20 mm thickness, making manipulation and bending difficult. Again, the most time-consuming tasks were associated with finishing touches, especially around windows, doors, and ventilation or installation holes.

The entire process was carried out by a small team of highly skilled workers who, despite their expertise, had no prior experience with these specific technologies. This factor contributed to a delay in the overall installation timeline.

Figure 38 - Installation of the Winco rainscreen, reflective and airtightness membrane

It is important to highlight that the passive envelope SUREFIT technology was successfully installed by the end of February, although the finishes designed with Cement Bonded Particle Board were completed by mid-April.

Practically, we also encountered delays in sourcing anchors, screws, and other specialized materials required for the installation. Additionally, meticulous attention was required to ensure precise dimensions following the installation of rafters, ensuring an optimal fit for the final boards.

Figure 39 - Installation of the finishing boards

3..2 PCM Panels

The challenge arose when working in occupied houses, particularly in one instance where we had to relocate furniture to facilitate the installation process.

Moreover, due to the novelty of the product and the installer's lack of prior experience with this specific installation, we spent some time devising the most efficient approach for the job.

Nonetheless, the task itself proved relatively straightforward, with no significant complications, except for the crucial consideration of avoiding drilling into the PCM blisters. Additionally, we had to plan for the installation of lighting fixtures.

Ultimately, this technology was successfully installed by mid-January.

Figure 40 - Installation of PCM panels

3..3 PV Vacuum Glazing Window and Heat Recovery Unit (WHR)

Two main challenges were identified in this aspect. First, property owners expressed concerns regarding the integration of units into the windows due to the potential reduction of window area. This concern was particularly relevant given the small size of the existing windows and the already subdued interior lighting conditions.

To address this issue, the installation system proposed by UNOTT was adopted, positioning the units on a shelf above the windows. Simultaneously, efforts were made to develop a system to conceal all connections between the Vacuum Glazing Window and the Heat Recovery Unit.

Furthermore, the installation of the Vacuum Glazing Window required coordination with the window frame provider’s schedule. Due to their existing workload, the installation process could not commence by the end of March. Additional time was also required to determine the appropriate method for installing both the glass and wiring

The installation of this technology was completed by mid-April, in accordance with the timeline proposed by UNOTT. Initially, an automated regulated valve was considered to prevent unwanted ventilation from the exterior to the interior. However, due to the complexity of its integration, this solution was ultimately not implemented. Instead, a buffer system was designed to facilitate maintenance and ensure operational flexibility.

Additionally, challenges arose in integrating the OnControl algorithms into the window heat recovery system. The adaptation of these algorithms required adjustments to ensure compatibility with the overall system architecture, necessitating further technical refinements.

During operation, further issues were identified concerning the interaction between the board installed by OnControl in the Window Heat Recovery (WHR) system and the PV Vacuum Glazing Window. The installation included an inverter, and a battery intended to power both the WHR and the control board. However, it was observed that the system was unable to provide a stable energy supply to the board on a regular basis. As a result, it was decided to connect the WHR to the electrical grid to ensure reliable operation. The energy produced by the PV Vacuum Glazing Window is instead utilized for a secondary function, such as powering an LED light in the kitchen or any other use chosen by the homeowner.

Another challenge identified during operation is the noise generated by the system. Users have noted that the system produces a considerable level of noise, which could be a concern in residential environments. However, they acknowledge and accept this limitation as part of the implementation of an innovative technology within the framework of the project.

Figure 41 - Installation of the PV vacuum glazing window and the window heat recovery

3..4 Daylight louvers

Why did we decide for RETROLux 20 mm daylight blinds?

Daylight blinds are characterized by a highly effective louver surface up to 96% total reflectivity. Even in horizontal louver position while very good view through the high angles of incidence in summer are reflected back into the sky. This brings a very effective passive cooling effect. Thus, the blinds help to avoid overheating in summer (see appendix page 114 and 124).

In winter with lower angles of incidence more energy hits the second part of the louvers. As the second part of the louvers is redirecting the impinging rays onto the inner room ceiling, the blinds improve the daylighting. Furthermore, they achieve a solar gain in accordance with the idea of passive solar architecture.

The most appreciated advantage of the blinds is a horizontal louver position.

No major issues were detected when installing this technology

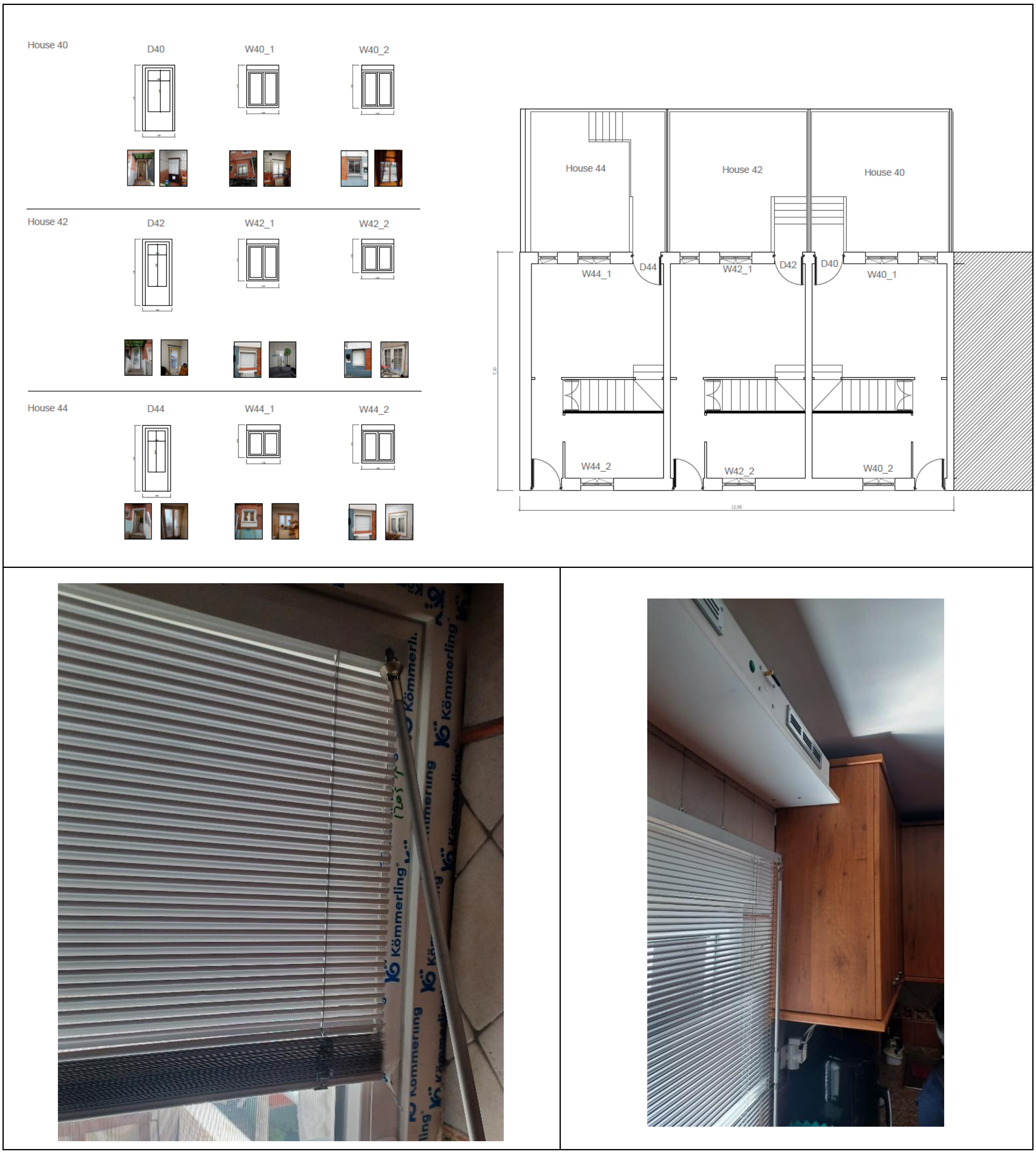


Figure 42 - Installation of the daylight louvers

3..5 PV/T Panels

The issue primarily arose from the delivery of the goods. The main materials arrived in Spain in August 2023. However, due to the inability to establish contact with the technology installer until the end of the year, it was not initially realized that some of the auxiliary materials required for the installation were missing from the first delivery.

The technology provider responded promptly and cooperatively to the request for the missing components. However, border bureaucracy and delivery times resulted in an additional delay.

To mitigate the impact of this situation, preventive measures were implemented. All preparatory work necessary for the installation was completed in advance, ensuring that the site was fully prepared while awaiting the final materials. Additionally, a review of logistical coordination processes has been undertaken to prevent similar issues in future installations.

Once the final components arrived, the installation proceeded, but several challenges emerged throughout the process. By early March, misalignment in the solar piping at House 42 was detected, requiring corrective actions to ensure compliance with the original design specifications. By mid-May, most of the installation work was completed, with the upper-level cable trays installed. However, the installation of inverters remained pending.

A major technical challenge arose on May 26, when coordination with the supplier, Msbuker, became necessary to address issues related to the inverters. Over the following months, additional operational problems were identified, requiring further adjustments. Despite continued efforts, incorrect inverter configurations persisted until late July, necessitating extended troubleshooting.

On September 16, the photovoltaic installation was officially registered with Industry, marking the transition to self-consumption. However, by September 23, additional inspections were required for pump and water heater connections. While the thermal systems were confirmed to be operational, insulation concerns were raised regarding certain inverters by mid-November.

Another significant issue was identified in House 44 due to a misunderstanding regarding the thermal storage tank specifications. The unit initially provided was too large to fit inside the house, requiring the procurement of a smaller unit. The new thermal storage tank was delivered to the headquarters on August 10, 2024, allowing for the necessary adjustments before installation.

On December 13, a faulty inverter was identified, leading to a replacement being dispatched by the supplier. The new unit arrived on January 7, 2025, with installation scheduled accordingly. While the majority of installations are now complete and fully functional, the final configuration of the inverter in House 42 remained pending.

To ensure proper system operation and maintenance, a training session with the supplier was conducted on January 30, 2025. This session provided key insights into optimizing the use of the installed technologies and addressed final configuration procedures.

At present, all thermal installations, including glycol testing and heating system adjustments, have been finalized. The photovoltaic systems are fully operational, and with the training session completed, the final inverter setup at House 42 is expected to be resolved soon.

Despite these logistical and technical challenges, significant progress has been made in the SUREFIT project. The integration of thermal and photovoltaic technologies represents a major step toward enhanced energy efficiency and sustainability. The successful coordination between installation teams and suppliers has ensured that key milestones have been met, reinforcing the project's commitment to innovation and sustainable energy solutions

Figure 43 - Installation of the PV/T panels

- **Energy savings**

For the energy consumption analysis, the focus will be placed on house 40, as it presents the most stable conditions for assessment. Several factors contribute to the decision to exclude houses 42 and 44 from the overall evaluation.

House 42 has shown a highly irregular occupancy pattern, which directly impacts energy consumption in ways that are not necessarily related to the installed efficiency measures. Additionally, the photovoltaic and thermosolar (PV/T) system installed in this dwelling remains non-operational due to an inverter malfunction, preventing any meaningful assessment of its contribution to energy savings or system efficiency. Without this key component functioning, it is not possible to compare its performance against the other two houses.

House 44, despite having a fully operational PV/T system, has undergone continuous renovation works throughout 2023 and 2024, which have likely influenced energy consumption patterns in an inconsistent manner. Construction activities, changes in heating systems, and variations in ventilation strategies introduce additional variables that make it difficult to isolate the effect of the PV/T installation from other modifications in the dwelling. Furthermore, post-May 2024 monitoring data for this house has exhibited significant inconsistencies, particularly in temperature, humidity, and air quality measurements, raising concerns about data reliability in the energy assessment as well.

House 40, in contrast, has a more stable occupancy profile, and while insulation improvements were completed in early 2024, the dwelling has maintained a consistent heating and ventilation routine. With both the photovoltaic and thermosolar components fully installed and operational since October 2024, this house provides the best conditions for a controlled analysis of energy consumption before and after the implementation of efficiency measures. For these reasons, it will be used as the primary reference for evaluating the impact of the renovations on energy performance.

Energy consumption and production figures

The processing of energy consumption data in the post-renovation phase follows the same methodology used in the pre-renovation period for **gas consumption**. As gas readings are taken quarterly, the same estimation process has been applied to distribute the data proportionally across the months, ensuring a homogeneous dataset. Domestic hot water consumption has been considered at a baseline level for two occupants, with a zero value in August, when the dwelling is unoccupied. For heating, the assumption remains unchanged, with the system assumed to be in operation from September 15 to May 1.

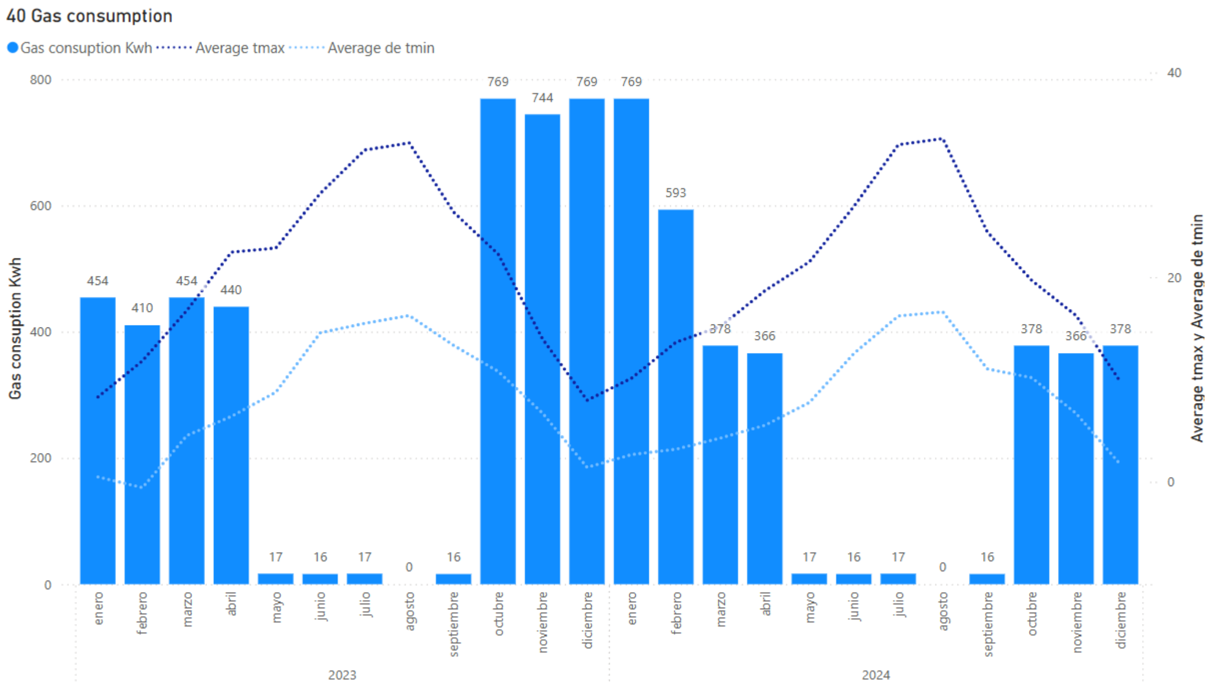


Figure 44 - Gas consumption in house 40

For electricity consumption, the data is sourced directly from utility bills. Given that billing periods do not always align with full calendar months, daily consumption values were estimated based on available data and then distributed proportionally across the respective months. This approach introduces minor variations but ensures that total annual electricity consumption figures remain accurate. By relying on actual utility data, this method provides a realistic measure of household electricity use.

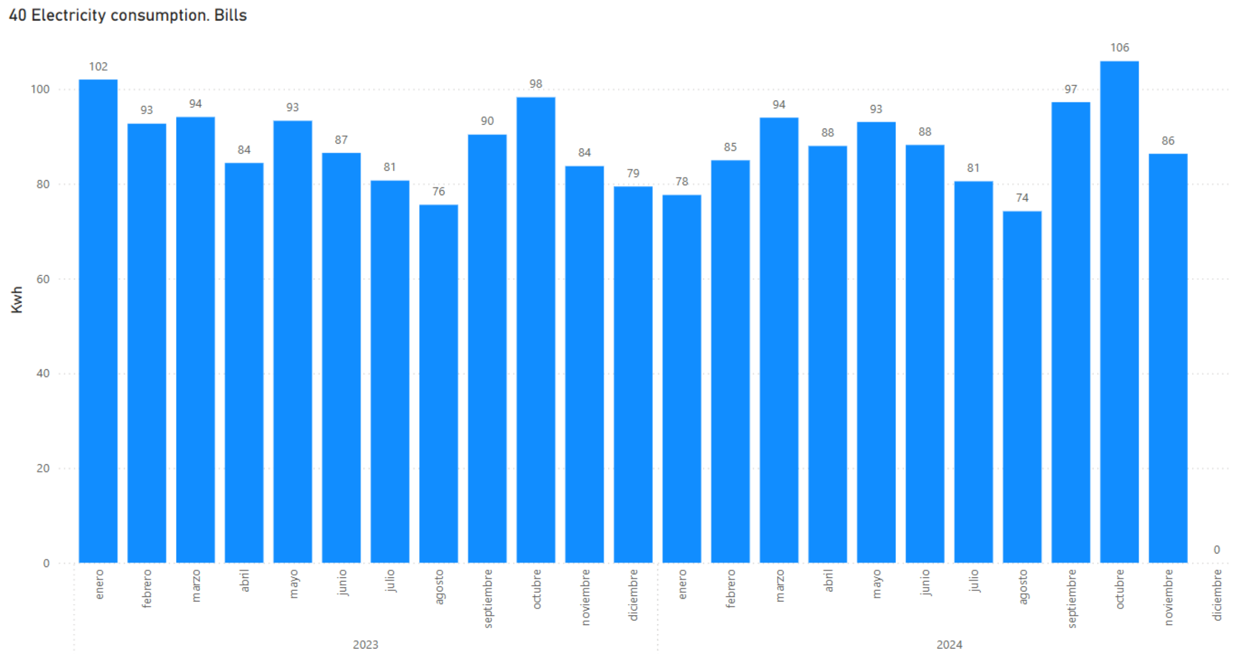


Figure 45 - Electricity consumption in house 40

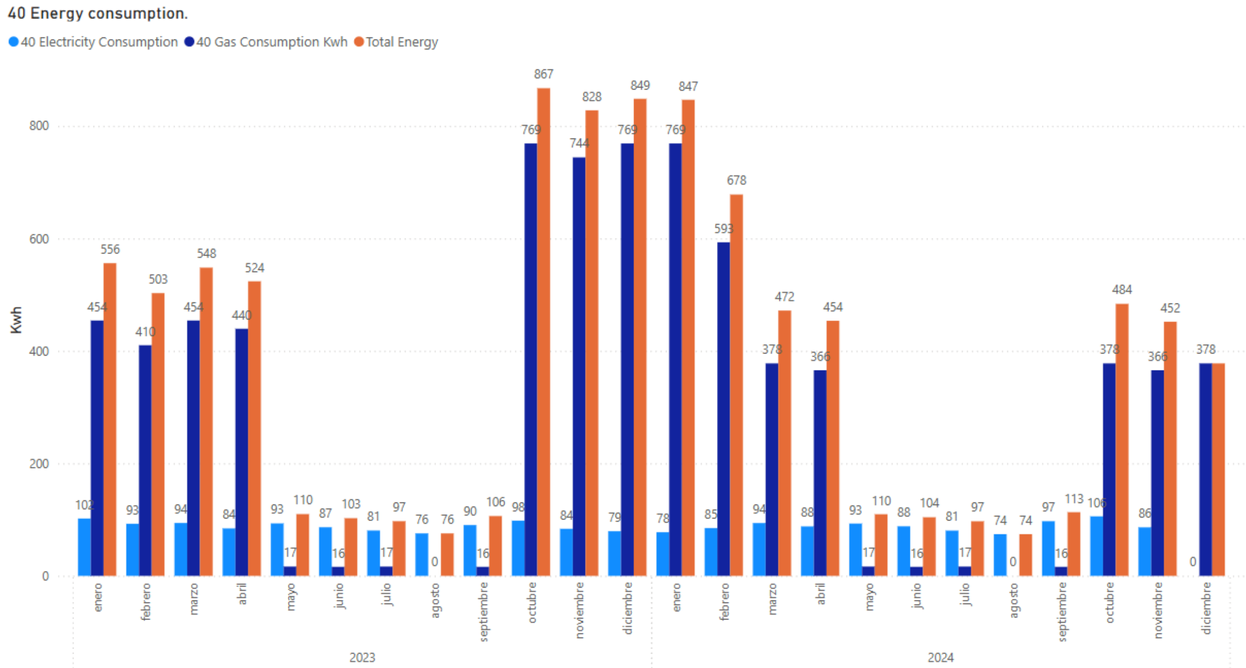


Figure 46 - Global energy consumption in house 40

A key difference in the post-renovation assessment is the estimation of **photovoltaic electricity production**, given that the PV/T system only became operational in October 2024, leaving only two months of real production data. To extrapolate photovoltaic generation for the entire year, a correlation was established between measured solar radiation levels and actual system output. This allows for a projection based on real system performance while accounting for seasonal variations.

To ensure a conservative estimate, the lowest recorded efficiency value observed during the monitoring period was used as the basis for extrapolation. Instead of assuming average or peak performance, this approach reflects a worst-case scenario, ensuring that the estimated annual photovoltaic production is not overestimated.

It is important to emphasize that, although photovoltaic electricity production for 2024 is an estimation, it is derived from real operational data. The applied methodology ensures that the projections remain grounded in observed system behaviour, while also accounting for seasonal fluctuations. This approach provides a realistic and cautious estimate of the system's annual contribution to the household's electricity consumption.

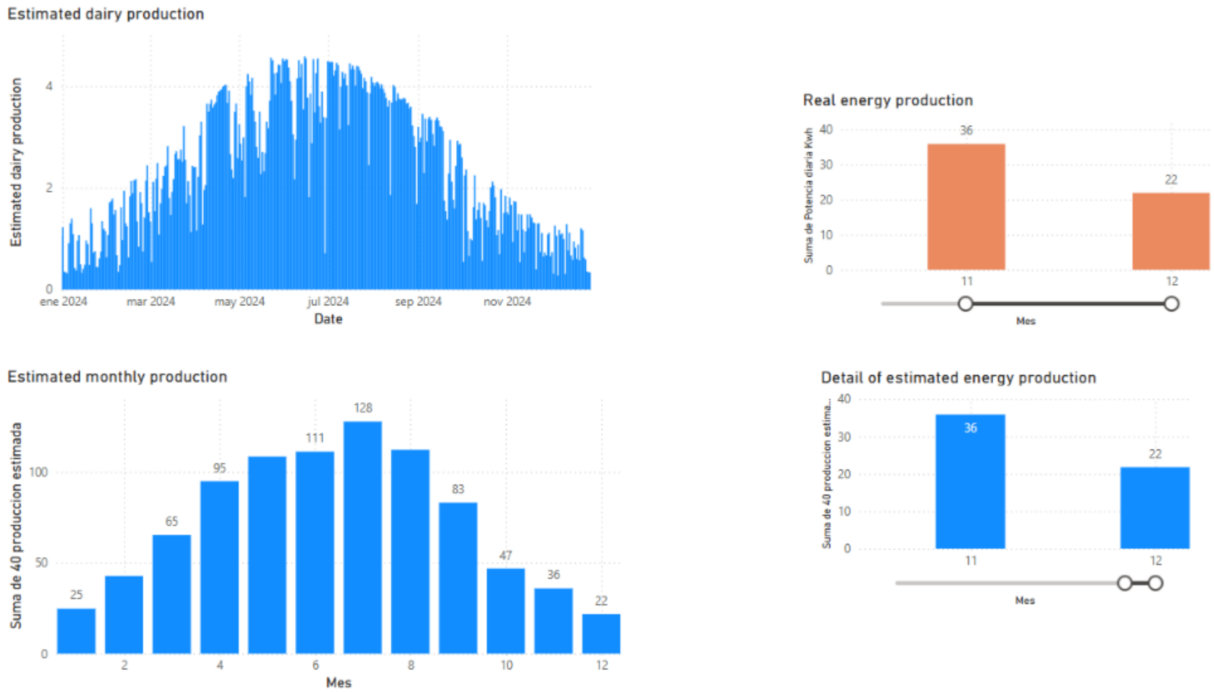


Figure 47 - PV energy estimated production

For gas consumption, a seasonal pattern is evident, with higher values recorded during the colder months when heating demand increases. The data shows a substantial reduction in gas consumption post-renovation, with annual usage dropping from approximately 3890 kWh to 2316 kWh. This reduction aligns with the improved insulation and efficiency measures implemented during the renovation process. The correlation between gas consumption and external temperature trends further confirms that heating demand has been mitigated effectively through the building envelope enhancements.

Electricity consumption, as recorded through utility bills, exhibits relatively stable values throughout the year. Monthly consumption varies between 74 kWh and 106 kWh, with no abrupt shifts post-renovation. This consistency suggests that the renovation primarily impacted heating-related consumption, with general electrical usage remaining unchanged. Given that the dwelling does not use electricity for domestic hot water, the observed stability is in line with expectations.

The photovoltaic system's electricity generation has been estimated using real production data for two months, correlating radiation values with actual energy output. A conservative approach has been applied, taking the lowest recorded efficiency value and extrapolating it to estimate the annual production. The results indicate a projected annual photovoltaic generation of 875 kWh, which significantly offsets the household’s grid electricity consumption. The applied estimation methodology ensures that the reported production values represent a worst-case scenario, reinforcing the robustness of the assessment.

The overall impact of these interventions is summarized in the final energy balance. The total primary energy demand has decreased by approximately 59.8%, from 6931 kWh/year before renovation to 2785 kWh/year post-renovation. This reduction is primarily driven by the improved thermal performance of the building and the integration of renewable energy sources. Additionally, CO_2 emissions have been reduced from 1400 kg/year to 562 kg/year, reinforcing the environmental benefits of the renovation process.

In conclusion, the renovation of house 40 has led to a significant decrease in total energy consumption, primarily through a reduction in heating demand and partial substitution of grid electricity with photovoltaic production. While minor fluctuations in energy use remain, the overall trend confirms the effectiveness of the implemented measures in achieving energy efficiency improvements.

Table 10 - CO_2 savings

	Electricity		Heating gas		Total primary energy
	Total electricity consumption ***(from the grid)*** (kWh/y)	Corresponding primary energy consumption (kWh/y)	Gasenergy consumption (kWh/y)	Corresponding primary energy consumption (kWh/y)	(kWh/y)
House	40	40	40	40	40
Pre renovation	1061,03	2652,58	3890,11	4279,13	6931,70
Post renovation	969,93	2424,83	2316,79	2548,47	4973,30
PV production	-875,00	-2187,50			
Final	94,93	237,33	2316,79	2548,47	2785,80
Reduction		**91,05%**		**40,4%**	**59,81%**

	Electricity		Heating gas		Total primary energy	Total CO_2
	Total electricity consumption ***(from the grid)*** (kWh/y)	Corresponding primary energy consumption (kWh/y)	Gasenergy consumption (kWh/y)	Corresponding primary energy consumption (kWh/y)	(kWh/y)	(kg/y)
House	40	40	40	40	40	40
Pre renovation	1061,03	2652,58	3890,11	4279,13	6931,70	1400,20
Post renovation	969,93	2424,83	2316,79	2548,47	4973,30	1004,61
PV production	-875,00	-2187,50				
Final	94,93	237,33	2316,79	2548,47	2785,80	562,73
Reduction		**91,05%**		**40,4%**	**59,81%**	**59,81%**

- **Any other result/inspection after renovation**

3..1 Post renovation thermofluxmetry

The thermofluxmetry measurements conducted before and after the renovation confirm a significant improvement in the thermal performance of the building envelope. The initial readings, taken in January 2023, revealed high heat transfer values, with a U-value averaging 1.4 W/m²K before intervention. The highest heat losses were detected at structural junctions such as window perimeters, roof-wall connections, and slab junctions, where thermal bridges were most pronounced.

After the renovation, the thermofluxmetry measurements recorded a significant decrease in the U-value, with a new average of 0.56 W/m²K, and under stable conditions, values as low as 0.45 W/m²K were observed. This reduction confirms a considerable enhancement in the thermal resistance of the walls, indicating a significant decrease in unwanted heat transfer. The most significant improvements were observed in the roof and main façade, where insulation was applied more comprehensively.

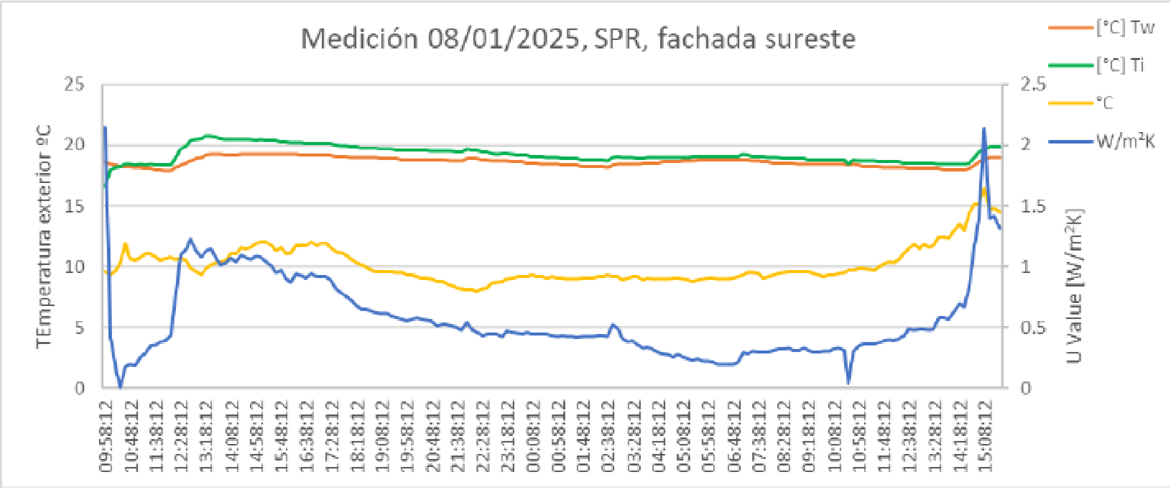


Figura 5: Resultados medición. Nota: ºC: Temperatura Exterior; Tw: Temperatura cara del paramento interior del muro; Ti: Temperatura ambiente interior: W/m²K: Valor de U.

Figure 48 - Thermofluxmetry report

Interior wall surface temperatures have also shown an increase post-renovation, with values ranging between 17.93°C and 19.27°C, compared to pre-renovation readings that fluctuated between 12.36°C and 16.51°C. This improvement reflects the enhanced heat retention capacity of the walls, reducing indoor temperature fluctuations and increasing overall comfort. Meanwhile, exterior temperature variations did not significantly impact interior temperatures post-renovation, highlighting the effectiveness of the insulation layer in mitigating external thermal influences.

Despite these improvements, some residual thermal bridges remain, particularly in areas where structural limitations constrained insulation application. However, these are considerably less pronounced than before the intervention, confirming that the renovation achieved substantial energy efficiency gains. The results of the thermofluxmetry analysis align with the findings from the thermal scans, reinforcing the conclusion that the insulation measures effectively reduced heat loss, stabilized indoor temperatures, and improved thermal comfort within the building.

3..2 Post renovation air tightness

The post-renovation airtightness assessment indicates a modest improvement in the overall air changes per hour at 50 Pa, reducing from 5.76 to 4.69, representing an 18.58% improvement. However, this reduction is not as significant as expected, given the extensive insulation and sealing work carried out. The primary factor limiting greater airtightness gains appears to be the execution of the holes made for the installation of the window heat recovery units, which have compromised the integrity of the membrane.

Further analysis suggests that infiltration issues are particularly pronounced around the newly installed frames, where leaks have been identified in the integrated louver boxes. These deficiencies highlight two potential areas for improvement: the qualification of workers responsible for installation and the design of the heat recovery units themselves. Ensuring that both aspects are addressed in future implementations will be essential to achieving a more substantial improvement in airtightness.

Additionally, the increase in relative humidity detected post-renovation suggests that while the building is now slightly more airtight, moisture control measures may need to be reassessed. This observation reinforces the need for a thorough review of the ventilation strategy to prevent unintended consequences of increased airtightness, such as excess indoor humidity accumulation.

- **Feedback from the occupants after renovation**

Table 11 - Pre and post occupancy survey of house 44

Question to the tenants. House 44	Pre-renovation	Post renovation
How would you describe the temperature inside the house during Spring?	Hot	Neutral
During Summer?	Too hot	Neutral
During Autumn?	Somehow cold	Neutral
During Winter?	Too Cold	Cold
Is this building slow or quick to heat up during Winter?	Rather Quick	Slow
Is this building slow or quick to cool down during Summer?	Rather Slow	Rather Quick
How much does noise from the various external sources annoying you?	Slightly	Slightly
In your opinion, is there any overheating issues through the windows in your house?	Definitively no	Definitively no

After the renovation, the occupant of House 44 reported significant improvements in various aspects of indoor comfort and building performance. The overall construction quality perception increased notably from a 3/10 to 8/10, reflecting a high level of satisfaction with the implemented interventions.

Thermal comfort has improved across all seasons. Before the renovation, summer was perceived as "Too Hot", and winter as "Very Cold". Post-renovation, summer temperatures are now reported as "Neutral", indicating that overheating issues have been effectively mitigated. In winter, the temperature perception has improved from "Very Cold" to "Cold", suggesting that while there is progress, further optimization may still be needed. Similarly, transitional seasons (spring and autumn) have shifted from "Hot" and "Somewhat Cold" to "Neutral", highlighting a more stable and controlled indoor environment.

Air quality has also benefited from the renovation, although some challenges remain. The perception of humidity has improved from "Humid" to "Somewhat Humid", and air freshness has shifted from "Malodorous" to "Somewhat Indoor", showing an enhancement in indoor air conditions. Ventilation has improved from "Poorly Ventilated" to "Neutral Ventilation", suggesting that the interventions have positively influenced airflow and indoor air exchange. However, scepticisms remain regarding the effectiveness of the Window Heat Recovery Units, as occupants are still awaiting a full operational assessment.

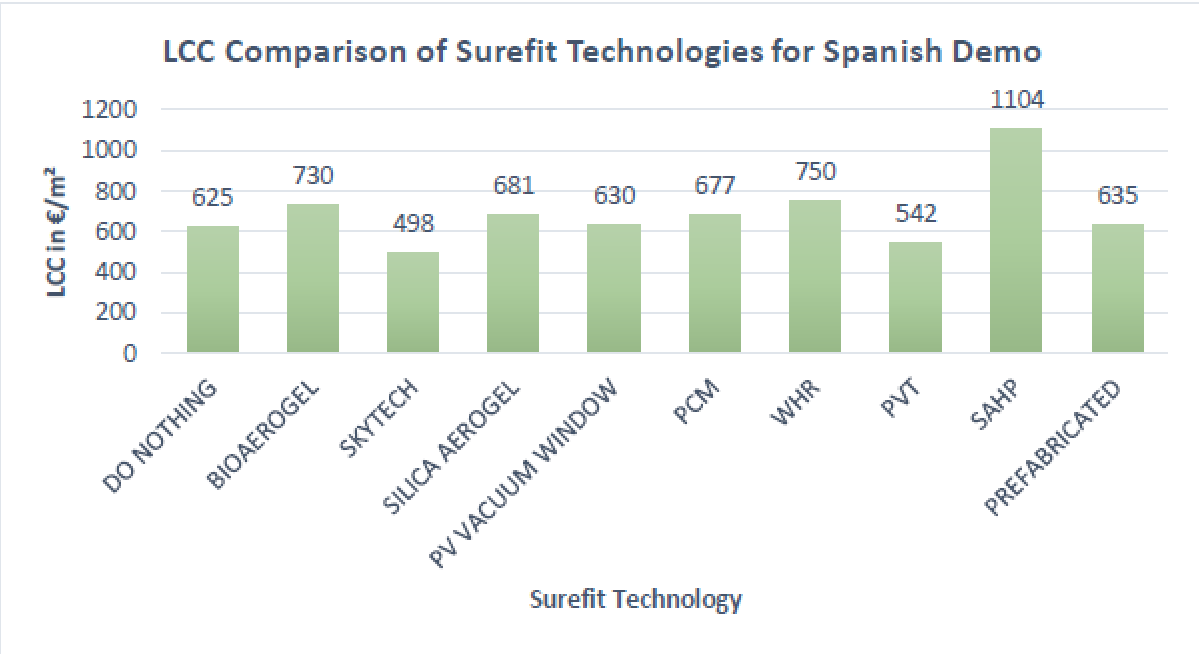
Other comfort factors, such as noise levels from traffic, have remained unchanged at a "Slightly" affected level, indicating that external noise mitigation was not a primary impact of the renovation. Satisfaction with natural and artificial lighting remains "Very Satisfactory", consistent with pre-renovation conditions. Additionally, no overheating issues were reported before or after the renovation, confirming that the improvements did not introduce unintended overheating problems.

Occupants of Houses 40 and 44 have shown strong approval of the renovation process and technologies, particularly expressing high satisfaction with the insulation improvements. They are now eagerly awaiting a full year of performance data from the PV/T system to evaluate its long-term impact. Overall, the renovation has led to substantial improvements in thermal comfort and air quality, with a few remaining aspects requiring further observation and refinement.

- **Economic evaluation**

The assessment revealed notable differences in cost-effectiveness among the implemented technologies. The Skytech insulating membrane demonstrated the most favourable financial outcome, showing the lowest life cycle cost and a relatively short payback period. Similarly, the PVT panels and prefabricated panels containing silica aerogel and XPS were found to be financially viable solutions, with competitive life cycle costs that suggested a positive return on investment over time. In contrast, the bio-aerogel insulation and the WHR system did not perform as well from an economic perspective. The bio-aerogel insulation, despite its superior thermal performance, exhibited high initial costs that were not adequately offset by long-term savings. The WHR system, while improving ventilation efficiency, led to an increase in electricity consumption, making it financially impractical within the analysed framework.

Table 12 - LCC comparison of SUREFIT technologies for Spanish demo building



The discounted payback period analysis further underscored the differences in economic performance. Among the assessed technologies, only the Skytech insulating membrane achieved a payback period of less than ten years, reinforcing its status as the most cost-effective solution for the Spanish pilot. The PVT panels, while not achieving the same shortterm financial return, exhibited strong long-term potential. The WHR system and bio-aerogel insulation, however, failed to reach a feasible payback period, as their energy savings did not compensate for their high initial costs within the study timeframe.

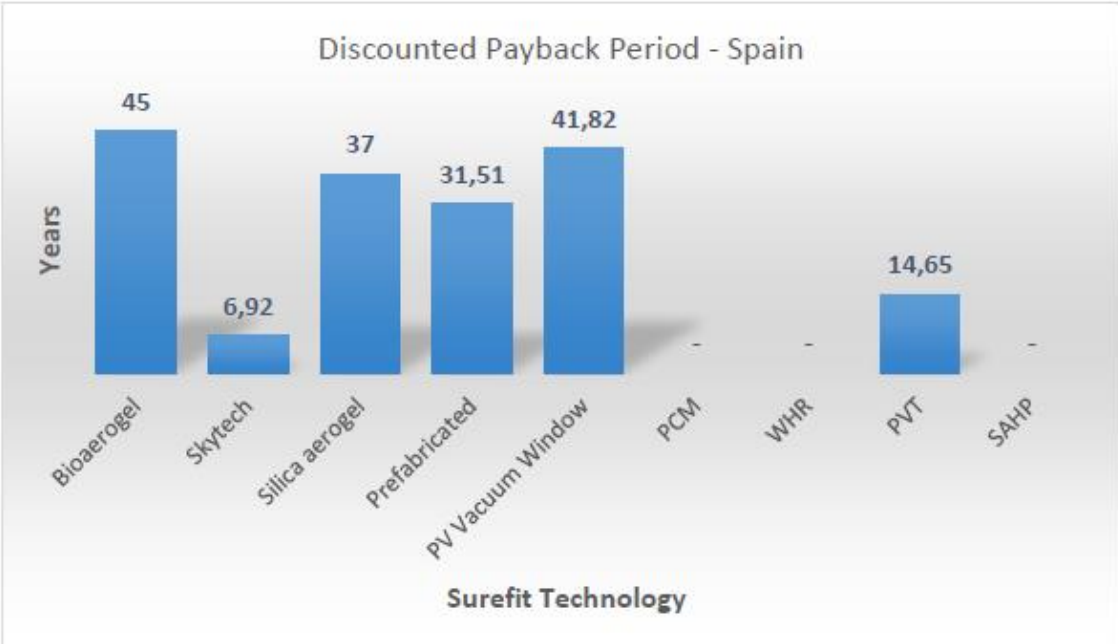


Figure 49 - Discounted payback period of the SUREFIT technologies for the Spanish building

A comparative analysis was also conducted to evaluate the competitiveness of SUREFIT technologies in relation to conventional retrofit solutions. This assessment considered traditional insulation materials, such as expanded polystyrene (EPS), as well as widely available triple-glazed PVC windows combined with standard photovoltaic panels. The results indicated that the PVT panels installed in the Spanish demonstration building performed comparably to conventional photovoltaic panels coupled with solar thermal collectors, demonstrating their potential as a competitive alternative. The PV vacuum windows, while similar in cost to conventional triple-glazed PVC windows with separate photovoltaic panels, provided additional benefits in terms of thermal performance and daylighting comfort. Among the insulation solutions, the Skytech membrane emerged as the most cost-effective, outperforming expanded polystyrene insulation in terms of both financial viability and ease of installation.

- **Overall evaluation and final conclusions**

The economic and technical evaluation of the Spanish demonstration building within the SUREFIT project highlights both significant achievements and notable challenges. The renovation measures implemented in House 40, House 42, and House 44 demonstrate improvements in thermal performance, energy efficiency, and comfort, but also reveal areas where refinements in design, execution, and system integration are needed.

The installation of external insulation and envelope improvements has effectively reduced thermal losses, as evidenced by thermographic analysis. The comparison of pre-renovation and post-renovation images confirms a clear decrease in heat leakage, particularly in previously exposed areas. The airtightness test reflects an 18.58% improvement, demonstrating that the implemented measures have enhanced the building's energy performance. However, installation-related defects, particularly leakages in window frames and perforations made for the Window Heat Recovery units, have compromised the overall airtightness. These findings suggest that installation procedures require further refinement to ensure maximum effectiveness in future projects.

The thermal flux measurements reinforce these observations, confirming improved insulation performance and a reduction in heat transfer across the building envelope. However, some thermal bridging effects persist, indicating the need for better implementation techniques to minimize heat losses at specific structural points. From an indoor comfort perspective, post-renovation conditions have shown notable improvements, particularly in winter, where temperature fluctuations have been reduced, and heat retention has improved. During summer, the implementation of Phase Change Materials has played a role in thermal regulation, particularly in bedrooms. However, current monitoring data does not yet allow a definitive conclusion regarding its full effectiveness, suggesting the need for longer-term assessment and optimization of its integration into the renovation strategy.

While the building envelope has improved, ventilation system issues have introduced new challenges. The relative humidity levels have increased post-renovation, likely due to higher airtightness combined with ventilation malfunctions. The Window Heat Recovery units have not operated as intended, primarily due to communication issues with the OnControl system, leading to inadequate air exchange. This malfunction has contributed to increased humidity levels, which could impact indoor air quality and occupant comfort if not properly addressed. Despite the technological advancements incorporated into the renovation, the assessment of CO_2 and VOC levels indicates that no significant improvement has been achieved. The ventilation system's lack of proper integration and operational failures appear to be the main contributing factors. Future projects should prioritize improved coordination between HVAC system design and installation to ensure effective air circulation and maintenance of indoor air quality.

The installation of photovoltaic panels has resulted in a notable reduction in grid electricity consumption. The energy production data highlights the influence of panel orientation on performance, with House 44—featuring a mixed east-west PV panel orientation—producing more electricity than House 40, where all panels are east-facing. This outcome suggests that strategic panel placement plays a key role in optimizing energy capture and self-consumption, an insight that could be applied in future retrofitting projects to maximize solar potential throughout the day. The total primary energy consumption of House 40 has been reduced by 59.81%, approaching the project's initial energy efficiency target. This reduction has been achieved through a combination of insulation measures, heating system improvements, and renewable energy integration. The results confirm that deep energy retrofitting strategies can lead to significant energy demand reductions but also emphasize the importance of ensuring optimal performance of all system components to achieve maximum efficiency gains.

The economic evaluation of the Spanish demonstration building has identified variations in cost-effectiveness across different SUREFIT technologies. The Skytech insulating membrane, PVT panels, and prefabricated panels incorporating silica aerogel and XPS emerged as the most cost-efficient solutions, demonstrating a positive balance between investment costs and long-term energy savings. These technologies offer competitive life cycle costs and reasonable payback periods, making them attractive options for future large-scale implementation. Conversely, bio-aerogel insulation and the Window Heat Recovery system were found to be economically unviable, primarily due to high initial costs and increased operational energy demand. The WHR system, in particular, resulted in higher electricity consumption, further diminishing its financial feasibility. These findings suggest that technologies requiring additional energy input should be carefully assessed within the broader context of energy pricing and system integration to ensure they contribute to overall cost savings rather than additional expenses.

Beyond economic considerations, several technical challenges affected the performance of the Spanish demonstration project. House 40 provided the most stable post-renovation conditions, making it the primary reference for evaluating the effectiveness of the retrofit measures. In contrast, House 42 and House 44 presented challenges that complicated data analysis. The malfunctioning of the PV system in House 42 prevented a complete assessment of its energy performance, while ongoing refurbishments in House 44 introduced inconsistencies in the collected data. These challenges highlight the need for improved quality control measures and more robust installation procedures to avoid performance setbacks in similar projects.

Another critical issue was the size discrepancy of the thermal storage tank in House 44, which required ordering a smaller replacement unit. This miscalculation resulted in delays and additional costs, emphasizing the importance of precise planning and communication between project stakeholders to prevent such errors. Future retrofit initiatives should incorporate stricter pre-installation assessments to ensure that all components are appropriately dimensioned and compatible with the available space. The malfunctioning of the OnControl system in the WHR units further underscores the necessity of seamless system integration. The communication failures between the control board and the PV Vacuum Glazing Windows contributed to ventilation inefficiencies, impacting indoor air quality. These findings highlight the importance of rigorous pre-commissioning and testing protocols before system deployment to avoid operational setbacks.

Additionally, the level of noise produced by certain installed systems posed a challenge for users. While occupants acknowledged the innovative nature of the technologies, the acoustic impact remains a concern that should be addressed in future iterations of the renovation package.

The renovation of the Spanish demonstration building within the SUREFIT project has delivered substantial improvements in energy efficiency and indoor comfort, particularly in terms of thermal regulation, primary energy consumption reduction, and overall building envelope performance. However, several technical and economic challenges have been identified that require attention in future retrofit initiatives. The results indicate that airtightness and insulation strategies have successfully reduced heat losses, yet installation flaws and system malfunctions have compromised overall performance. Ventilation system integration emerged as a critical issue, affecting indoor air quality and humidity levels, underscoring the need for more reliable mechanical ventilation solutions.

From an economic perspective, passive insulation solutions, such as the Skytech membrane and prefabricated aerogel panels, have proven to be the most financially viable, while active systems requiring additional electricity demand have faced greater financial and operational challenges. This suggests that future projects should prioritize passive energy efficiency measures before integrating more complex mechanical systems.

The installation process itself remains a key area for improvement, with evidence suggesting that better coordination between design, procurement, and execution teams could prevent installation-related inefficiencies. Future projects should incorporate enhanced pre-installation planning, rigorous quality control protocols, and improved training for installers to ensure optimal performance of all installed technologies.

While the Spanish demonstration building has achieved significant energy savings, its full potential has not yet been realized due to implementation setbacks. Addressing these challenges will be crucial for ensuring that future large-scale retrofitting initiatives maximize their effectiveness, delivering both environmental and economic benefits in the transition toward more sustainable and energy-efficient residential buildings.

4 Greek case study

The Greek demonstration case is corresponding to a small apartment situated on the first floor of a three-storey building built in 1981 and located in the city of Peristeri, Attica. The orientation of the two main facades is north south (*Figure 2*). The building and the apartment are attached with two other buildings on the east and west sides.

Figure 50 -The main (front) and backside façade of the building – the renovated apartment is indicated inside the yellow rectangle

The dimensions of the building are approximately 8m long and 15m wide. It accommodates two small spaces on the ground floor of 45m^2 and 25m^2 that used to be shops, one family apartment (4 persons) of approximately 90m^2 on the first floor and another apartment (2 persons) of approximately 90m^2 on the second floor. Each apartment has a living room, three bedrooms, kitchen and bathroom. The building is constructed with concrete pillars and the walls are made of bricks of six hollows and dimensions of 19x9x6cm, using an installation of single brick - polystyrene layer - single brick that offers thermal insulation. The roof has 8cm coating of cement mortar for waterproofing.

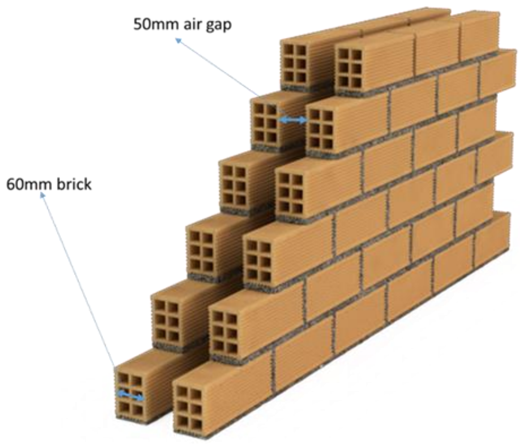


Figure 51 - Construction layers of the existing walls of the Greek demo building

The building has single glazed aluminium frame windows and big sliding sash windows of 8mm glass. Sliding sash external blinds are used for the shading of the windows and of the balcony doors, along with awnings attached to the exterior walls of the building.

Heating is supplied through diesel boiler and during summer the cooling is provided by air conditioners. The Domestic Hot Water (DHW) is supplied by low pressure water system from a triple-energy boiler that is flexible to work also with a solar collector and electricity.

SUREFIT renovation was applied only to the apartment of the first floor, as only the owner of this apartment was positive in applying the innovative SUREFIT technologies.

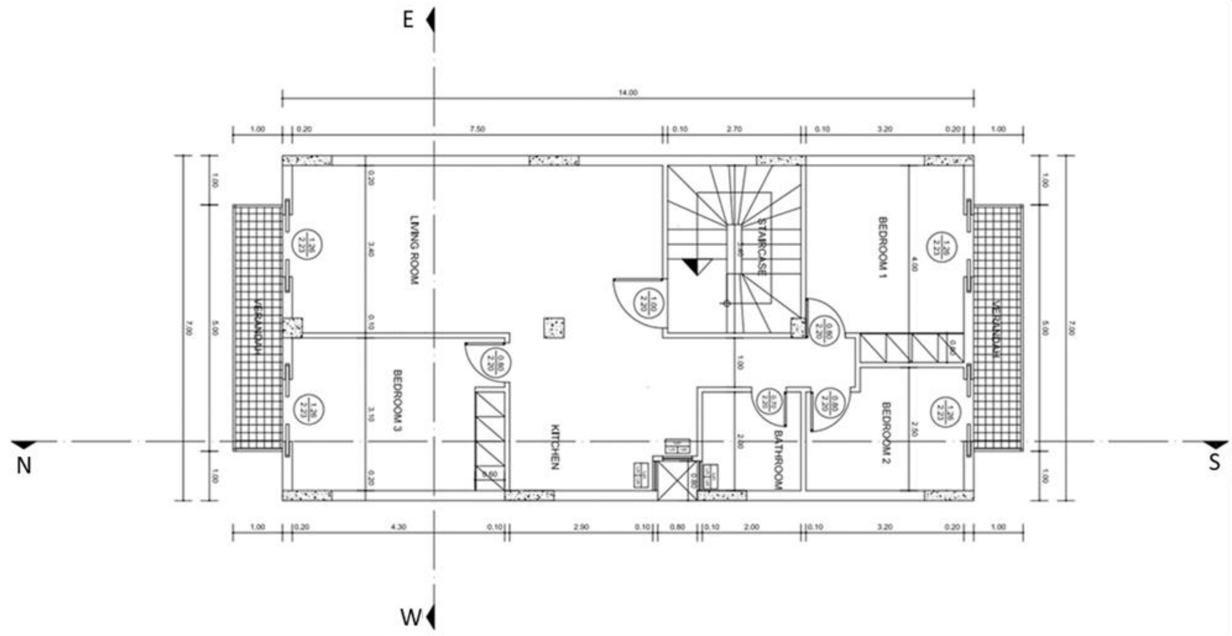


Figure 52 - Floor plan of the Greek demo case – first floor apartment

- **Greek building needs**

Based on the onsite inspections, the owners' requirements, the monitoring activities and the thermography and air tightness tests, the needs of the building were established along with the targets of the renovation:

1. The window openings of the apartment demonstrated significant losses through their frame;
2. The apartment's envelope seemed to also present energy losses especially through the floor which is adjacent to the unheated ground floor of the building;
3. There was a great use of the radiators during the winter and of the air-conditioners during the summer;
4. Noise coming from external and internal sources was also mentioned from the tenants;
5. The solar collector for the DHW of the apartment was old and needed replacement.

Figure 53 - Old window frame and the old diesel boiler

Figure 54 - The ceiling of the ground floor with which the demonstration apartment is in contact

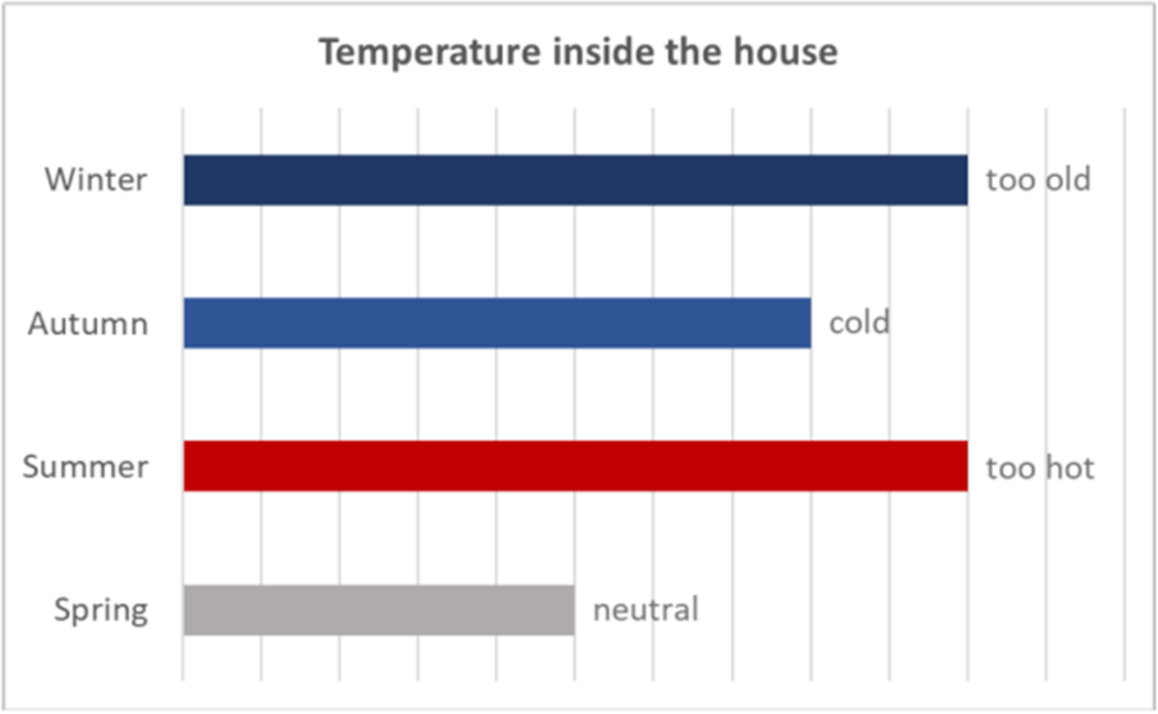


Figure 55 - Answers of the tenants regarding their thermal comfort inside the house

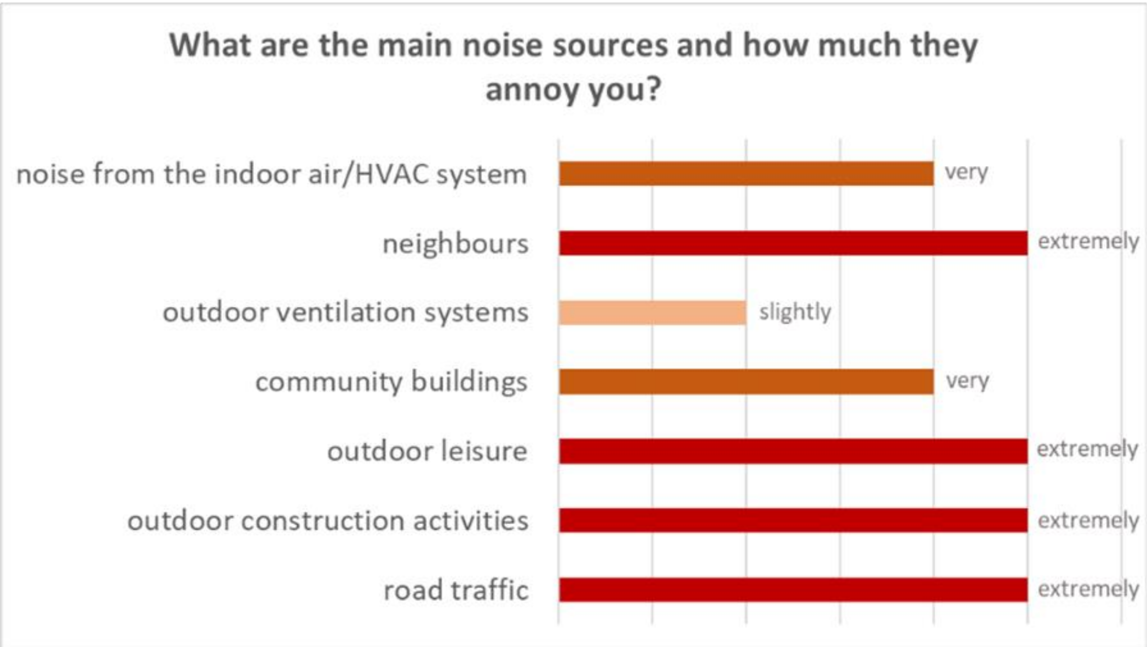


Figure 56 - Answers of the tenants regarding their acoustic comfort inside the house

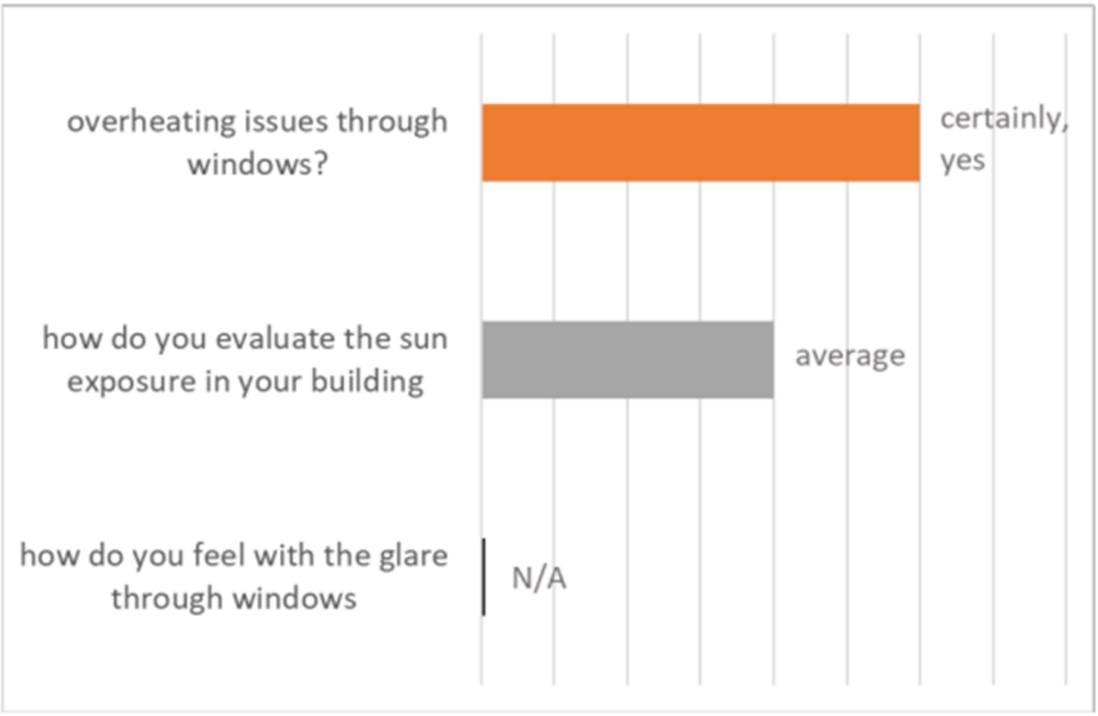


Figure 57 - Sun exposure, overheating and glare through the windows of the Greek apartment according to the tenants' opinion

The results of the air leakage test indicated that all frames had strong inflows on all of their sides. At a pressure of 50Pa, 6.27 uncontrolled ACH (air changes per hour) were recorded which is a quite high number of losses throughout the building envelope. This results in inefficiency of the heating and cooling system of the apartment, which basically explains, why the radiators and the air-conditioners were in great use during winter and summer accordingly.

In addition, during the onsite inspections, it was observed that the balcony doors had cracks on their frame which were locally and rudely repaired by the use of wooden pieces. Moreover, the owner and tenant of the apartment, has mentioned that the awnings are always rolled down, a fact that protects the house from overheating during summer, but also prevents the sun's light and heat from entering inside the apartment during winter, thus increasing the use of the heating and lighting systems.

- **Greek building energy simulation results**

By taking into account the aforementioned needs of the building and of the owner, it was decided to externally insulate the northern and southern sides of the apartment, which are not adjacent to other buildings, as well as to also insulate the floor of the apartment. Because of the fact that the owner did not want to conduct any works inside the living spaces, internal insulation of the components was abandoned.

Moreover, it was decided the replacement of all the aluminium windows and balcony doors with new PVC ones with low e glazing and PV vacuum glazing where possible, so as to enhance the thermal and acoustic comfort of the inhabitants.

The final selection of the renovation measures was also based on the different energy simulations that the AALTO University executed in the framework of the SUREFIT project's activities. These energy simulations took into account the existing state of the building and of the apartment, the geometry and its orientation, the specific characteristics and parameters of the SUREFIT technologies, as well as the targets that were set by the SUREFIT project in order to reduce CO_2 emissions and energy consumption (e.g. achieve primary energy savings by 60%, reduction of greenhouse gas emissions by 60% etc.).

AALTO had simulated variable combinations of measures and of renovation packages, some of which succeeded the 60% reduction in greenhouse gas emissions and in the primary energy reduction. The selection of the technologies that would be finally installed in the Greek demo case was the result of the simulations, of the technical restrictions that could appear during the renovation and of the owner's needs and requirements. The following interventions were chosen to be implemented:

- External thermal insulation at the North and South façade walls with the **prefabricated insulation panel** manufactured by CJR. The prefabricated insulation panel for the Greek case consists of 30mm PU + 20mm aerogel + 20mm XPS. The U-value of the thermal insulation panel is 0.36W/m^{2}K.
- Insulation of the ceiling of the ground floor with the **Skytech Pro XL breathable membrane** manufactured by WINCO.
- Replacement of the existing balcony doors and windows with energy efficient commercial systems: it was not possible for UNNOT to fabricate **PV vacuum glazing units** to cover the needs of the whole apartment, especially due to the large glazing that the balcony doors required. Therefore, it was decided to install the PV vacuum glazing system only in one double balcony door and the rest glass panes and shutters were purchased from the market. All new systems have a PVC frame, external aluminium role and windows net.
- **PV – Thermal (PVT) system** manufactured by SOLIMPEKS for the production of electricity, DHW and space heating (space heating will be supplemented by the existing oil boiler too, as the PVT can contribute only with a small percentage in the space heating needs).
- **Smart Control systems** were provided and installed by AMS.

Table 13 - Parameters and areas of the technologies implemented in the Greek demo

Selected SUREFIT technologies	Installation area	Parameters
Winco breathable membrane	Ceiling of the workshop	2.6cm
Prefabricated panels which integrate silica aerogel	Southern and northern facades of the 1st apartment floor (external)	Silica: 2cm (combined with PU and XPS)
PV vacuum windows	1 balcony door @ the South facade	N/A
PV/T panels for the production of electricity, DHW and space heating (space heating will be supplemented by the existing oil boiler)	Roof	6 panels (PowerTherm), each panel size: 1.67m*1.005m
Smart controls	In monitoring areas	

Table 14 - Characteristics and installation areas of the new windows installed at the demo apartment

Selected retrofit technologies	Installation area	Parameters
PVC windows of double glazing with low E coating and of 12mm air gap between the panes	North facade	U-value: 1.9 W/m^{2}K, g_w: 0.48
PVC windows of double glazing with low E coating and of 12mm air gap between the panes	Kitchen, bathroom	U-value: 2.2 W/m^{2}K, g_w: 0.48

The simulation results that led the design team to conclude on these interventions are indicated in the excel table below.

Table 15 - The simulations results when the final combination of measures was applied to the Greek demo

Apartment building, Athens, Greece			
Property	Original	Final combination (ceiling insulation, 100% airtigtness improvement)	Final combination (ceiling insulation, 50% airtightness improvement)
Thickness of silica aerogel insulation panel (cm)	-	4	4
Thermal conductivity of silica aerogel insulation (W/mK	-	0.015	0.015
Thickness of Winco breath membrane (cm)	-	2.6	2.6
Thermal conductivity of Winco breath membrane (W/m	-	0.029	0.029
U-value, external walls (W/m2K)	0.96	0.22	0.22
Thickness of Winco breath membrane (cm)	-	2.6	2.6
Thermal conductivity of Winco breath membrane (W/m	-	0.029	0.029
U-value, ceiling of workshop (W/m2K)	3.60	0.85	0.85
U-value, windows (W/m2K)	5.9	0.6/1.9/2.2	0.6/1.9/2.2
Area, Vacuum glazing window (m2)	0	5.62	5.62
Infiltration (ACH, n50)	6.7	0.07	3.4
PV-T panels (m2)	0	10.07	10.07
Hot water tank (m3)	0.4	0.8	0.8
Purchased energy use (kWh/m2/year)			
	Original	Final combination (ceiling insulation, 100% airtigtness improvement)	Final combination (ceiling insulation, 50% airtightness improvement)
Oil heating total	105.6	38.3	39.8
Space heating & DHW	105.6	38.3	39.8
Electricity total	15.3	6.6	6.6
Equip + Light	10.4	4.2	4.2
HVAC aux	0.3	0	0
Space cooling	4.6	2.4	2.4
Solar energy total		24.4	24.4
PV self-consumption		8.5	8.6
PV sold		15.9	15.8
PV self-consumption rate		35%	35%
	Original	Final combination (ceiling insulation, 100% airtigtness improvement)	Final combination (ceiling insulation, 50% airtightness improvement)
Purchased energy (kWh/m2)	120.9	44.9	46.4
Reduction (%)	-	63%	62%
Primary energy (kWh/m2)	143.5	53.9	55.6
Reduction (%)	-	62%	61%
CO2 Emissions (kg/m2)	36.6	13.9	14.3
Reduction (%)	-	62%	61%

- **Greek building performed renovation**

The renovation that took place in the Greek demonstration case was including the following activities:

- Insulation of the ceiling in the workshop area of the ground-floor of the building (by the use of the Skytech breathable membrane 90m^2).

- Insulation of the northern and southern facades of the first floor's apartment (external insulation by the use of the prefabricated panels mentioned above in an area of 30.7m^2).

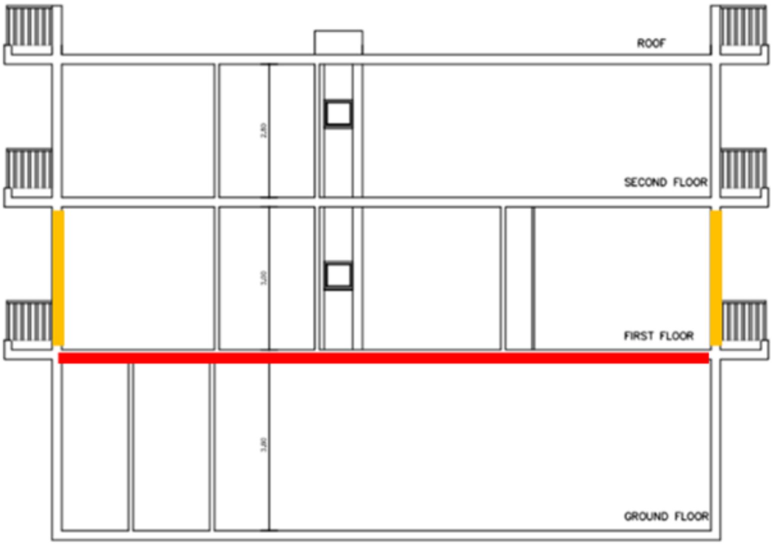


Figure 58 - Yellow areas indicate the surfaces where external insulation was applied and red surface indicates the area where the breathable membrane was applied

- PV vacuum window was applied in one balcony door at the south façade (see picture below).
- Commercial double glazed PVC windows were used to replace the remaining windows and balcony doors of the first-floor apartment.

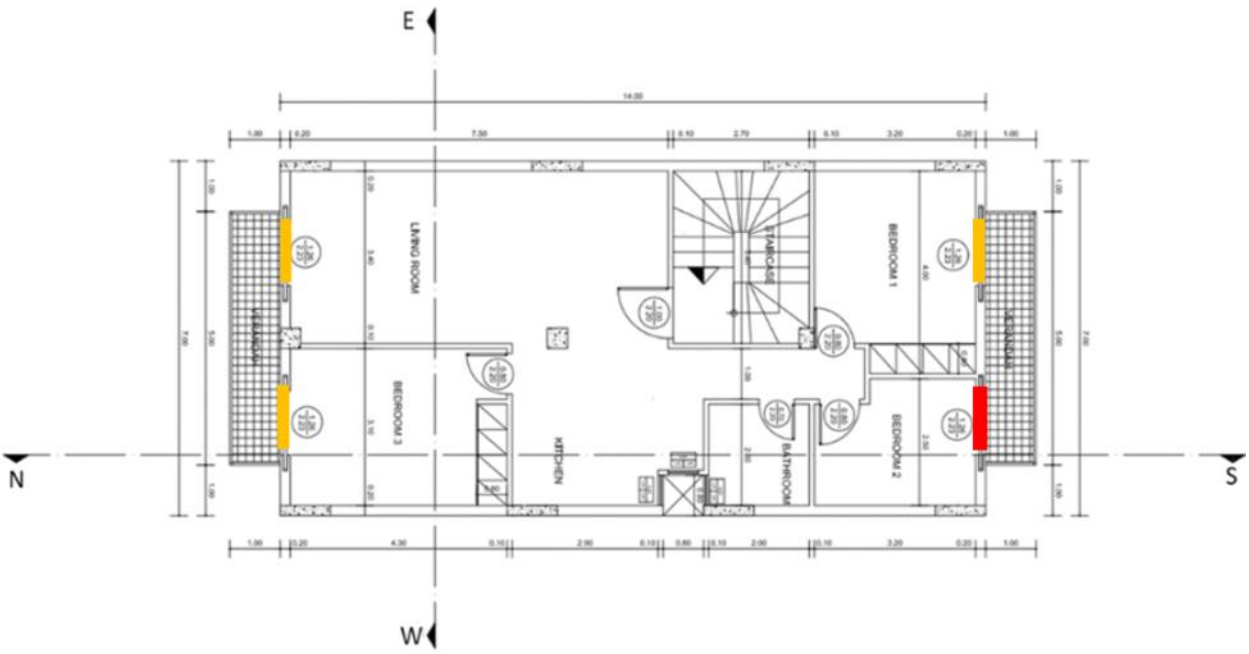


Figure 59 - The floor plan of the demo apartment – with red colour is showcased the window that will be replaced by PV vacuum glazing

- PVT system was installed in the roof of the building to provide electricity, DHW and space heating.

4..1 Installation of PVT system

The PVT system was designed to cover the needs of an 88m^{2}apartment and by taking into account that the electricity produced and the provided DHW should meet the needs of 4 persons. The system was sized so as to also provide some hours of space heating in the apartment. For that, the internal needed temperature was assumed to be around 20^{o}C, the hours of heating were estimated to be around 3-4 hours /day from November till March, whereas the water temperature of the radiators was set to be around 60^{o}C.

First, the installation of the tank for the storage of the heated water took place, by completing the required demolition works at the ground floor of the building where the mechanical systems of the building were situated.

Figure 60 - Demolition of the wall on the ground floor where the water tank would be installed

Then, the installation of the tank and of the auxiliary systems took place along with the required piping and wiring for the connection of the devices and components.

Figure 61 - Installation of the water tank and of the related auxiliary equipment

Figure 62 - Installation of piping and wiring of the PVT system

Finally, the Photovoltaic panels were installed at the roof of the building by the use of the appropriate mounting systems. The whole installation process has pretty much followed the steps and guidelines of a conventional photovoltaic roof system installation.

Figure 63 - Installation of the mounting system and of the photovoltaic panels of the PVT system

4..2 Installation of Prefabricated Insulation panels

The prefabricated panel produced by CJR in order to incorporate the silica aerogel, was manufactured according to the technical requirements and regulations applied on the Greek demo case. It was demanded to have a U value of 0.36W/m^{2}K and a thickness of 7cm, so that the final U value of the apartment's wall could reach the 0.22W/m^{2}K (AALTO calculations).

The prefabricated panels were applied upon the existing walls by following the installation steps of an ETICS installation. The pieces were cut on the required sizes/dimensions and then were attached with the appropriate insulation glue upon the walls. Then, the panels were secured upon the walls by the use of PVC anchors and at the end a fiberglass net was used to cover all the insulated surfaces and to strengthen them. The mesh was attached by the aid of insulation glue. The final surface was coated by 2 layers of insulation glue and a layer of plaster at the colour of the building's facades.

Figure 64 - Steps for attaching the prefabricated insulation panels at the existing walls (cutting, gluing, attaching to the wall, securing with plastic anchors)

Figure 65 - Installation of the fiberglass mesh, applying the glue coatings, smoothening the surfaces, applying the final paint

4..3 Installation of Skytech breathable membrane

Based on the energy simulation conducted by AALTO, the insulation of the ceiling of the ground floor with the SKYTECH membrane by WINCO will increase the energy performance of the apartment of the 1^{st} floor; therefore, $120m^2$ of the SKYTECH Pro XL membrane of 2.6cm thickness were prepared and sent by WINCO to AMS.

The SKYTECH membrane can be used as an external rainscreen to existing facades or as a roof underlay acting as a protective layer. In the case of the Greek demo, it was not used for any of those features but as a breathable membrane that can improve thermal insulation, acoustic insulation/comfort and enhance the airtightness of the renovated apartment.

As is indicated in the following pictures, the ground floor had already installed a false ceiling as it was used as a workshop-office space. The first step was to remove the false ceiling (*Figure 18*) and then create a new framed construction (like that of a false ceiling) which would be utilised for the integration of the membrane (*Figure 19*).

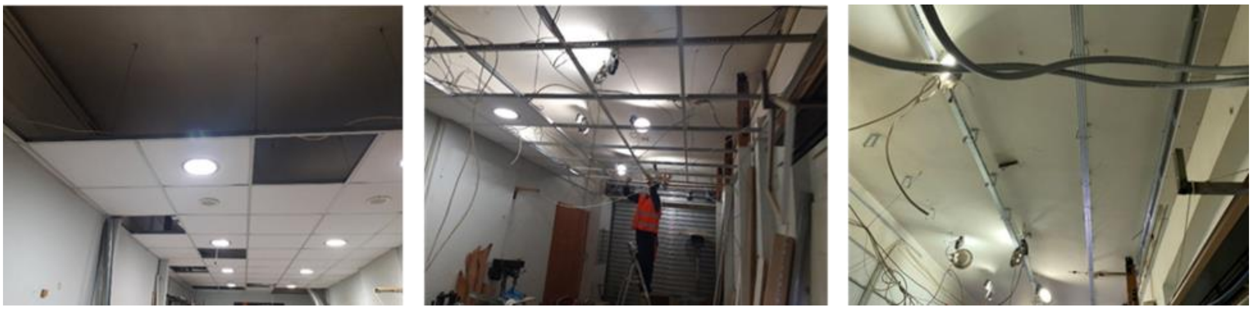


Figure 66 - Deconstruction of the old false ceiling of the ground floor

Figure 67 - Preparing the WINCO membrane and the new ceiling frame for the installation of the membrane

After the installation of the membrane, new false ceiling panels should be applied to cover and protect the breathable membrane (*Figure 20*).

Figure 68 - Installation of false ceiling panels

4..4 Installation of PV vacuum window

As was already described above, the PV vacuum glazing was only applied to one balcony door of the apartment due to the low production capacity of UNNOT laboratory.

The windows and balcony doors of the house were replaced by new double, low E and PVC framed windows and in one of the balcony doors of the south façade, the glazing of the PVC framed door was replaced by the PV vacuum glazing. Moreover, new roller shutters were installed for enhancing the thermal behaviour of the openings.

After the attachment of the PV vacuum glazing inside the PVC frame door, the wiring of the PV film was connected to the auxiliary devices so as to be able to use the produced electricity.

Figure 69 - Removal of old window and balcony doors and installation of new ones

Figure 70 - The PV vacuum glazing installed inside the aforementioned balcony PVC door and the auxiliary devices

- **Energy savings**

The energy savings were calculated by taking into account the monitoring data recorded before and after the renovation, as well as by considering the oil and electricity bills of the owner, which were communicated to AMS for the pre-renovation state of the building.

Table 16 - Reduction in final and primary energy consumption of the Greek demo building

	Electricity		Heating oil		Total primary energy (kWh/y)
	Total electricity consumption (***from the grid***) (kWh/y)	Corresponding primary energy consumption (kWh/y)	Oil energy consumption (kWh/y)	Corresponding primary energy consumption (kWh/y)	
Pre renovation	5,645.56	10,105.55	4,911.28	5,402.41	15,507.96
Post renovation	2,475.40	4,430.97	2,357.40	2,593.14	7,024.11
Reduction	-	**56.15%**	-	**52%**	**54.7%**

- **CO_2 savings**

Table 17 - Reduction in the CO_2 emissions of the Greek demo case as monitored by the monitoring devices before and after the renovation and as calculated by the energy simulations.

	Electricity		Heating Oil		Total CO_2 real (kg CO_2/yr)	Total CO_2 calculated by simulations (kg CO_2/yr)
	Electricity Consumption (kWh/yr)	CO_2 emitted per electricity unit (kg CO_2/yr)	Oil energy consumption (kWh/yr)	CO_2 emitted per oil unit (kg CO_2/yr)		
Pre renovation	5645.56	3229	4911.28	1297	**4526**	3221
Post renovation	2475.4	1416	2357.4	622	**2038**	1258
Reduction	--	56.15%	--	52.04%	**54.9%**	60.9%

- **Any other result/inspection after renovation**

Air tightness test:

After the renovation the performance of the apartment proved better during the air leakage tests. The results in the following table indicate this enhanced performance.

	Air changes per hour at 50Pa	Index of losses comments	Heating/cooling efficiency comments
Pre renovation	6.27	Particularly high index of losses from the entire building shells.	This results in the ineffectiveness of heating or cooling system of the apartment.
Post renovation	2.2	Satisfactory index of losses from the entire building shell.	This increases the efficiency of the heating/cooling system of the apartment and confirms the quality of construction interventions.
Improvement	65%	-	-

Figure 23 - Air leakage results before and after the renovation.

Thermography Inspection:

The thermography inspection was not possible to be executed after the renovation (at least till the day that this deliverable is written), due to the non-availability of the owner and to the weather conditions. Moreover, the awnings of the openings could not be rolled up, so as to have a clear view of the external side of the façade, because the awning mechanism was broken.

In order to have a successful thermography inspection in the specific apartment, the ideal situation would be to externally inspect the façade areas of the whole building and especially those where the prefabricated insulation panels were installed. In this way, the proper installation of the insulation panels could be checked, as well as the effectiveness of this insulation. For having a successful IR inspection, a cooperation with the homeowner is needed; if the scan is going to be internal, then furniture should be moved away from the walls; if the scan is going to take place externally, then awnings or other obstacles that block IR camera's view to the façade should be also moved away or rolled up. Due to the mechanical problem of the awnings, the inspection could not be successfully fulfilled.

- **Feedback from the occupants after renovation**

After the completion of the renovation some questionnaires were answered from the tenants of the apartment and the results are indicated below, along with the corresponding answers before the renovation. At the same time, verbal feedback was asked from the owner of the apartment regarding his experience inside the house after the renovation. He stated that their thermal comfort was ameliorated a lot after the renovation, as well as their acoustic comfort. The main surprise for the owner comes from the insulation of the ground floor' s ceiling, which is translated into a better thermal behaviour of the floor slab (higher temperature at the foot level) and less noise coming from the ground floor activities.

Table 18 - Questionnaire answers regarding the comfort conditions of the apartment before and after the renovation.

Question to the tenants	Pre-renovation	Post renovation
How would you describe the temperature inside the house during Spring?	Neutral	Neutral
During Summer?	Too hot	Neutral
During Autumn?	Cold	Neutral
During Winter?	Cold	Hot
Is this building slow or quick to heat up during Winter?	Slow	Quick
Is this building slow or quick to cool down during Summer?	Slow	Quick
How much does noise from the various external sources annoying you?	Extremely/very much	Slightly
In your opinion, is there any overheating issues through the windows in your house?	Definitively yes	Certainly no

- **Economic evaluation**

In order to evaluate the economic viability of the SUREFIT technologies, some Life Cycle Cost (LCC) and Payback Period calculations were executed based on the costs of materials and components provided by the manufacturers of the technologies. All the technologies were evaluated for their economic profit in each demo case, so as to be able to recognise which SUREFIT technology is the most cost efficient and competitive to market available ones.

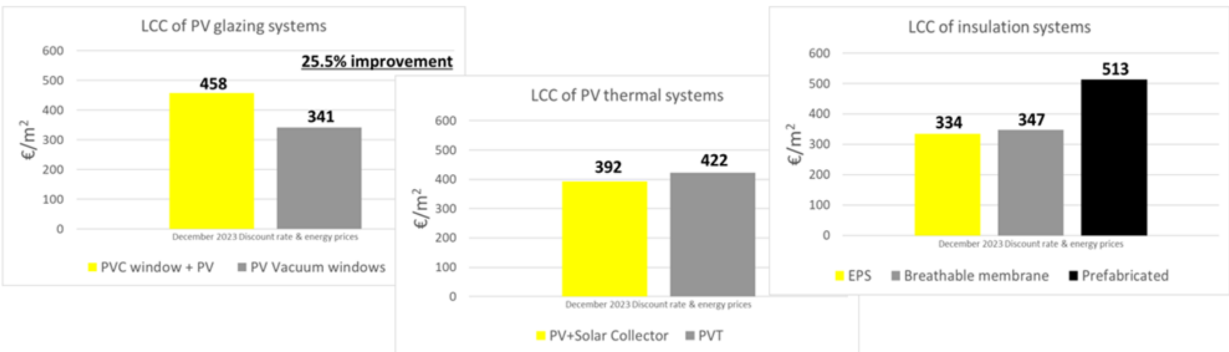


Figure 71 - Economic comparison of a SUREFIT technology applied in the Greek demo with a similar conventional one

In the diagrams above is indicated a comparison between the SUREFIT technologies that were installed in the Greek demo case and some similar conventional solutions already available in the market. It is observed that the SUREFIT technologies can compete in terms of costs the conventional ones. However, in most cases it is observed that the SUREFIT technologies are a bit more expensive, especially due to the fact that these products have been produced in a laboratory and not in an industrial production line and also because of the small amount of the products/pieces delivered.

The same results were also observed when the LCC calculation was repeated for the combination of all the interventions applied on the Greek demo, when compared with the corresponding package of conventional solutions. The LCC of the conventional solutions is lower than that of the SUREFIT ones, but the numbers are comparable, and the difference is not very big. Therefore, there is a good potential in the Greek market for these technologies to be launched, especially when they will be industrialised and their initial price decreases.

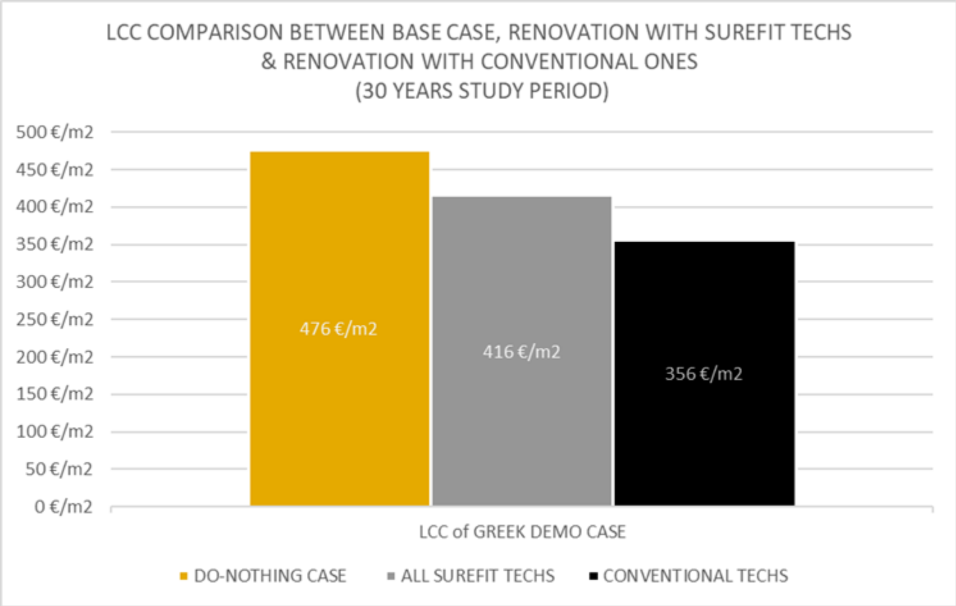


Figure 72 - Comparison of LCC indicators between the do-nothing case of the building (existing state), its renovation with SUREFIT technologies and its renovation with similar conventional ones

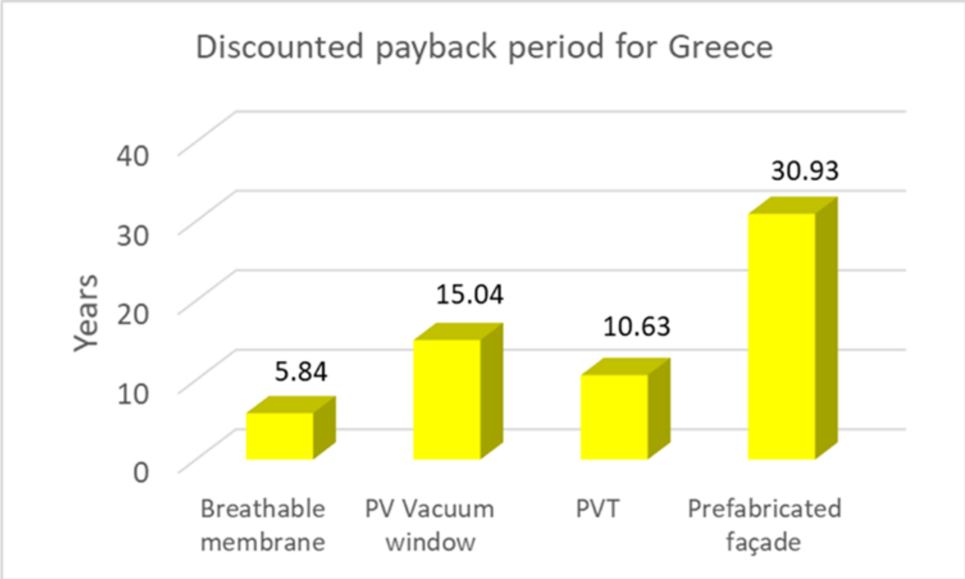


Figure 73 - The discounted payback period of the technologies applied in the Greek demo case

- **Overall evaluation and final conclusions**

The implementation of the renovation measures was completed successfully in the Greek demo case, by providing an enhanced and comfortable indoor environment to the tenants of the apartment. The thermal and acoustic comfort of the tenants was ameliorated a lot, whereas the consumptions for electricity and oil were reduced. The owner of the apartment stated that he is pleased with the result and especially with the elimination of the noise coming from the ground floor, as well as with the use of the smart controls, that allows him to program and control his heating and cooling system remotely.

In terms of achieving the targets of the SUREFIT project, the renovation of the Greek case succeeded a 55% reduction of total primary energy and CO_2 emissions and a 65% improvement of the apartment's air tightness. Additionally, the installation of the PVT system succeeded to provide a 42% of the electricity needs of the house.

The most cost-efficient measure proved to be the breathable membrane, as it combines the thermal and acoustic insulation result along with a short payback period of around 5 years.

The rest of the renovation measures showcase a longer payback period and higher costs. However, this can be improved in the near future, and if the products are industrialised (cost will drop then).

5 Portuguese case study

The Portuguese pilot building, constructed in 1970, is a two-story residential structure with a total area of 130 m². Located in Carvoeira, within the Municipality of Mafra, this building represents a typical example of mid-20th-century construction. Its façade consists of stone and two layers of plaster, reflecting traditional construction practices of the time.

The building's windows are single glazed with wooden frames, contributing to significant energy inefficiencies. Due to insufficient insulation, the house experiences frequent water infiltration, dampness, and elevated humidity levels. Natural ventilation is employed, but the original design does not adequately support proper air circulation or maintain good indoor air quality. Heating during winter is provided by a 2-kW electric radiator, which is insufficient for maintaining consistent thermal comfort.

Figure 74 - Portuguese demo case

- **Portuguese building needs and building energy simulation results**

5..1 Intermittent heating

The Portuguese demo building was simulated so that all rooms were heated, though the resident reported only heating a single room. In this case, space heating became the biggest individual source of energy consumption, as shown in Table 16. Thermal insulation of external walls and roof was the most effective at reducing space heating consumption. Solar energy utilized through the PV/T system or solar-assisted heat pump had no effect on space heating, as they were only utilized for DHW production. PV glazing was not important in any way, due to the very small window area on the side of the building facing the sun.

Table 19 - Properties of the retrofit packages and their impact on energy consumption in the Portuguese demo building, using intermittent heating

Property	Reference case (intermittent heating)	Passive			Infiltration			Active	
		Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
U-value, external walls (W/m2K)	2.40	0.57	0.57	0.57	0.76	0.76	0.76	2.40	2.40
U-value, roof (W/m2K)	3.80	0.62	0.62	0.62	0.86	0.86	0.86	3.80	3.80
U-value, windows (W/m2K)	5.1	5.1	0.6/5.1	0.6/5.1	5.1	5.1	5.1	5.1	5.1
Area, PV vacuum window (m2)	0	0	1.1	1.1	0	0	0	0	0
PCM (cm)	0	0	0	3.2	0	0	0	0	0
Infiltration (ACH, n50)	6.7	6.7	6.7	6.7	3.4	0.15	0.15	6.7	6.7
Window HR efficiency (%)	0	0	0	0	0	0	76	0	0
Solar thermal collector (m2)	0	0	0	0	0	0	0	24	6.8
PV panels (m2)	0	0	0	0	0	0	0	24	0
SAHP capacity (kW)	0	0	0	0	0	0	0	0	11
Hot water tank (m3)	0	0	0	0	0	0	0	1.4	0.42
Purchased energy use (kWh/m2/year)									
		Passive			Infiltration			Active	
	Reference case (intermittent heating)	Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
Oil heating total	18.3	18.3	18.3	18.3	18.3	18.3	18.3	4.5	3.7
DHW	18.3	18.3	18.3	18.3	18.3	18.3	18.3	0	0
Backup heating	0	0	0	0	0	0	0	4.5	3.7
Electricity total	97.1	49.5	49.2	48.7	55.3	54.3	66.8	88.5	102
Equip + Light	13.2	13.2	13.1	13.1	13.2	13.2	13.2	5.5	13.2
HVAC aux	0	0	0	0	0	0	2.2	0	0
Space heating	83.9	36.3	36.1	35.6	42.1	41.1	51.4	83	84
Backup heating	0	0	0	0	0	0	0	0	0
Heat pump	0	0	0	0	0	0	0	0	4.8
Solar energy total			0.2	0.2				49.6	
PV self-consumption			0.2	0.2				8.7	
PV sold			0	0				40.9	
PV self-consumption rate			100 %	100 %				18 %	

Table 17 shows the reduction in purchased energy, primary energy and CO2 emissions. It also shows the indoor conditions before and after retrofitting. The energy and emission metrics are very strongly correlated. For example, the impact of the passive package on purchased energy, primary energy and CO2 emissions is very similar at 41 to 44% reduction. The addition of PV glazing or PCM has basically no impact on energy consumption, as the thermal insulation of the walls and roof provide the biggest part of the savings.

Similarly, the breathing membrane reduces all the key performance indicators by 36 to 39%. The small difference between the Membrane 50% and Membrane 100% cases indicate that the major factor is the thermal insulation provided by the upgrade, not the improved air tightness. Adding the window heat recovery system increases energy consumption and emissions, as it increases the airflows in the building. However, it provides improved air quality into the house. In the original condition, the CO2 content of the air was not acceptable (above 1800 ppm) for 27% of the time. When the air tightness was increased using the 50% effective membrane, the unacceptable air increased to 38% and with the 100% effective membrane, the air was bad 66% of the time. The added ventilation provided by the window heat recovery system ensured that the CO2 content of the air was less than 1200 ppm all the time, indicating high quality air.

Table 20 - Retrofit impact metrics and indoor conditions for the Portuguese demo building, using intermittent heating

		Passive			Infiltration			Active	
	Reference case (intermittent heating)	Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
Purchased energy (kWh/m2)	115.4	67.8	67.5	67	73.6	72.6	85.1	93	105.7
Reduction (%)	-	-41 %	-42 %	-42 %	-36 %	-37 %	-26 %	-19 %	-8 %
Primary energy (kWh/m2)	163.0	92.1	91.6	90.9	100.7	99.2	117.8	136.4	155.7
Reduction (%)	-	-44 %	-44 %	-44 %	-38 %	-39 %	-28 %	-16 %	-4 %
CO2 Emissions (kg/m2)	28.3	16.3	16.2	16.1	17.7	17.5	20.6	23.3	26.6
Reduction (%)	-	-43 %	-43 %	-43 %	-37 %	-38 %	-27 %	-18 %	-6 %
		Passive			Infiltration			Active	
	Reference case (intermittent heating)	Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
Indoor conditions									
T<20 (%)	49.0	33.5	33.6	33.9	36.7	36.9	42.9	49.2	49.1
T>25 (%)	7.1	2.7	2.2	0.0	3.8	3.9	2.0	7.0	7.1
T_max (degC)	27.9	26.3	26.2	25.7	26.5	26.5	26.8	27.9	27.9
CO2 < 1200 (%)	34.2	38.5	39.0	42.2	23.6	16.3	100.0	34.2	34.1
CO2 < 1800 (%)	72.5	75.5	75.7	76.2	61.6	33.6	100.0	72.3	72.4

5..2 Continuous heating

Results of the Portuguese demo building retrofit in the case of continuous heating, are shown in Table 18. The retrofit measures were the same as in the intermittent case. The difference comes from the much higher space heating energy demand of the reference scenario (198 kWh/m^2 vs. 84 kWh/m^2 in the intermittent case). The key figures are shown in Table 19. The impact on purchased energy, primary energy and CO2 emissions is now even higher. The passive package reduces all of them by almost two thirds. The insulating membrane has almost as big an impact with a 58 to 60% reduction.

Because the house uses direct electric radiators for space heating, the hydronic PV/T and SAHP systems can only serve the DHW demands. Thus, their impact is limited. PV/T reduced emissions by 14% and SAHP by only 3%. To fully benefit from these systems, the building should be equipped with water-based radiators for distributing heat gained from heat pumps or solar collectors.

Under continuous heating, even the heating temperature setpoint was met at all times, even before retrofitting. The 7% of time that the building was overheating, was reduced to 2.2% using thermal insulation and PV glazing and finally down to 0 when PCM was included. Like in the intermittent case, the breathing membrane reduced air quality, but the mechanical ventilation system (window HR) guaranteed fresh air.

Table 21 - Properties of the retrofit packages and their impact on energy consumption in the Portuguese demo building, using continuous heating

Property	Reference case (continuous heating)	Passive			Infiltration			Active	
		Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
U-value, external walls (W/m2K)	2.40	0.57	0.57	0.57	0.76	0.76	0.76	2.40	2.40
U-value, roof (W/m2K)	3.80	0.62	0.62	0.62	0.86	0.86	0.86	3.80	3.80
U-value, windows (W/m2K)	5.1	5.1	0.6/5.1	0.6/5.1	5.1	5.1	5.1	5.1	5.1
Area, PV vacuum window (m2)	0	0	1.1	1.1	0	0	0	0	0
PCM (cm)	0	0	0	3.2	0	0	0	0	0
Infiltration (ACH, n50)	6.7	6.7	6.7	6.7	3.4	0.15	0.15	6.7	6.7
Window HR efficiency (%)	0	0	0	0	0	0	76	0	0
Solar thermal collector (m2)	0	0	0	0	0	0	0	24	6.8
PV panels (m2)	0	0	0	0	0	0	0	24	0
SAHP capacity (kW)	0	0	0	0	0	0	0	0	11
Hot water tank (m3)	0	0	0	0	0	0	0	1.4	0.42
Purchased energy use (kWh/m2/year)									
		Passive			Infiltration			Active	
	Reference case (continuous heating)	Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
Oil heating total	18.3	18.3	18.3	18.3	18.3	18.3	18.4	4.5	3.7
DHW	18.3	18.3	18.3	18.3	18.3	18.3	18.4	0	0
Backup heating	0	0	0	0	0	0	0	4.5	3.7
Electricity total	210.8	66.6	65.9	65.9	77.2	75.1	98	189.8	215.8
Equip + Light	13.2	13.2	13.1	13.1	13.2	13.2	13.2	7.6	13.2
HVAC aux	0	0	0	0	0	0	2.2	0	0
Space heating	197.6	53.4	52.8	52.8	64	61.9	82.6	182.2	197.8
Heat pump	0	0	0	0	0	0	0	0	4.8
Solar energy total			0.2	0.2				49.6	
PV self-consumption			0.2	0.2				21.1	
PV sold			0	0				28.5	
PV self-consumption rate			100 %	100 %				43 %	

Table 22 - Retrofit impact metrics and indoor conditions for the Portuguese demo building, using continuous heating

	Reference case (continuous heating)	Passive			Infiltration			Active	
		Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
Purchased energy (kWh/m2)	229.1	84.9	84.2	84.2	95.5	93.4	116.4	194.3	219.5
Reduction (%)	-	-63 %	-63 %	-63 %	-58 %	-59 %	-49 %	-15 %	-4 %
Primary energy (kWh/m2)	332.4	117.5	116.5	116.5	133.3	130.2	164.4	287.3	325.2
Reduction (%)	-	-65 %	-65 %	-65 %	-60 %	-61 %	-51 %	-14 %	-2 %
CO2 Emissions (kg/m2)	57.1	20.6	20.4	20.4	23.3	22.7	28.5	48.9	55.4
Reduction (%)	-	-64 %	-64 %	-64 %	-59 %	-60 %	-50 %	-14 %	-3 %
		Passive			Infiltration			Active	
	Reference case (continuous heating)	Insulation	Insulation + Windows	Insulation + Windows + PCM	Membrane 50%	Membrane 100%	Window HR system	PV/T system	SAHP
Indoor conditions									
T<20 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T>25 (%)	7.1	2.7	2.2	0.0	3.8	3.9	2.0	7.0	7.1
T_max (degC)	27.9	26.3	26.2	25.7	26.5	26.5	26.8	27.9	27.9
CO2 < 1200 (%)	35.5	39.5	40.0	43.2	24.3	16.3	100.0	35.4	35.4
CO2 < 1800 (%)	73.3	75.8	76.2	76.9	61.8	32.6	100.0	73.3	73.2

In the case of the Portuguese demonstration building, the most effective retrofit package was the **Passive** package, which included thermal insulation of the walls and roof with bio-aerogel and the installation of low-energy windows with integrated PV. This package was responsible for a significant reduction in CO_2 emissions, especially in the continuous heating scenario.

- **Emission Reductions:** The Portuguese building with continuous heating was the only case that achieved a reduction of over **60%** in CO_2 emissions using just a single retrofit package (the Passive package).
- **Impact of PCM:** The role of PCM (Phase Change Material) was relatively small compared to thermal insulation.
- **Combination of Packages:** Although the Passive package was the most effective on its own, the optimal combination of different retrofit packages (such as Infiltration, PVT, and SAHP) could provide additional benefits, potentially reaching the 60% reduction target in all demonstration buildings.

Intervention Restrictions:

Unfortunately, due to the building's heritage, historical, and architectural value, it was not possible to make significant changes to the facade or interior (such as ceilings and walls). The preservation of the original structure limited interventions to mechanical technologies that would not compromise the building's integrity.

This summary highlights the effectiveness of the Passive package in Portugal, especially in the continuous heating scenario, and explains the intervention restrictions due to the building's heritage value. Only mechanical technologies were used to ensure the preservation of the original architecture while maintaining energy efficiency.

5..3 Installation of technologies

Portuguese building performed renovation. The project implemented innovative solutions to increase energy efficiency and enhance occupant comfort. The installed technologies were:

- **PV Vacuum Glazing:** Vacuum glazing that improves thermal insulation, reducing heat loss through windows. The integration of photovoltaic cells enables electricity generation, contributing to sustainability.

Figure 75 - PV Vacuum Glazing - Portuguese demo case

- **Window Heat Recovery:** A system that recovers heat from exhaust air to preheat incoming fresh air, reducing heating energy demand and increasing HVAC system efficiency.

Figure 76 - Window Heat Recovery - Portuguese demo case

- **Daylight Louvers:** Adjustable devices that maximize natural light entry, reducing the need for artificial lighting and improving internal lighting quality.

Figure 77 - Daylight Louvers - Portuguese demo case

- **Smart Controls:** Advanced control systems that automatically manage heating, cooling, and ventilation. These systems adjust parameters based on environmental and occupancy data, optimizing energy consumption and providing greater comfort.

Figure 78 - Smart Controls - Portuguese demo case

- **Solar-Assisted Heat Pump:** Hybrid heat pumps that combine traditional technology with thermodynamic panels, reducing conventional energy consumption and promoting a sustainable heating solution.

Figure 79 - Solar-Assisted Heat Pump - Portuguese demo case

- **Energy savings**

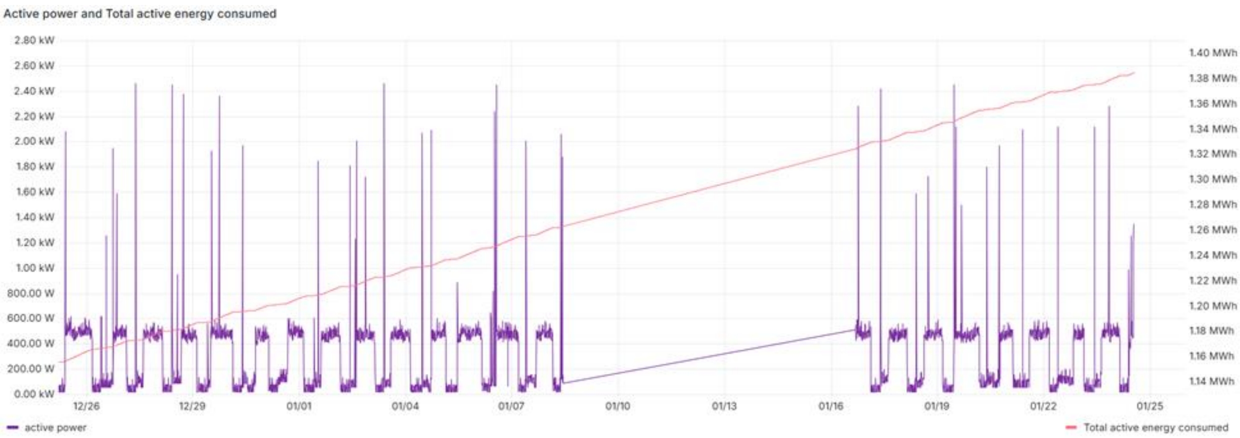


Figure 80 - Energy Consumed Before Renovation

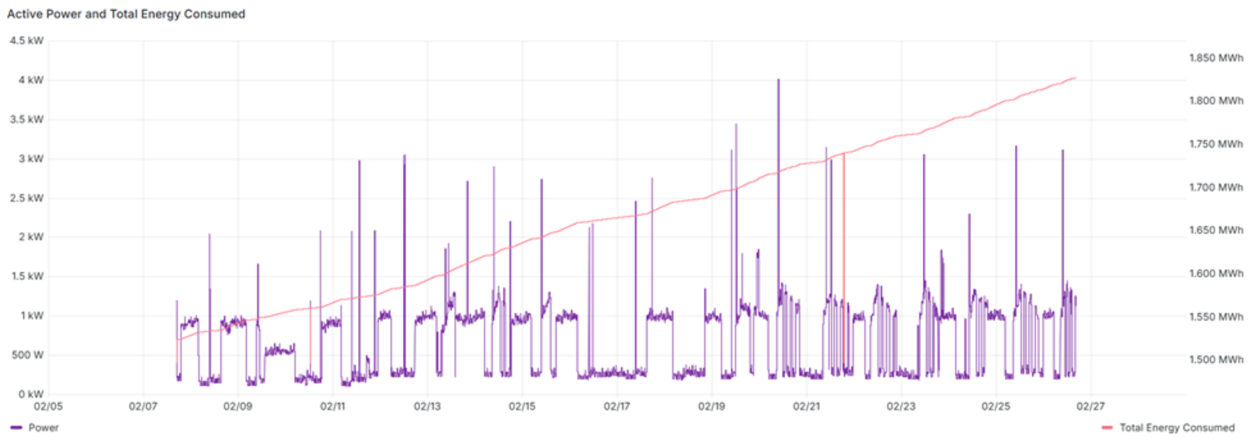


Figure 81 - Energy Consumption After Renovation

The implementation of the heat pump has led to an increase in electricity consumption but has also brought significant benefits by reducing the need for gas. In Portugal, gas prices have risen sharply, with a gas bottle now costing twice as much as in Spain. This situation highlights the importance of seeking more efficient and sustainable alternatives for water heating and climate control.

Beyond the economic impact, using gas at home poses health and safety risks. Gas water heaters, if not properly installed and maintained, can release carbon monoxide (CO), a toxic, colourless, and odourless gas that can accumulate indoors. Inhaling this gas can cause severe poisoning and, in extreme cases, be fatal. Poor ventilation or faulty equipment increases the risk of CO build-up, making gas appliances a potential hazard.

By switching to a heat pump, the need for gas combustion is eliminated, significantly reducing the risk of carbon monoxide exposure. Additionally, heat pumps offer greater energy efficiency and contribute to lowering carbon footprints, making them a safer and more sustainable choice.

Given the current rise in gas prices and the associated risks, transitioning to electric solutions such as heat pumps is a strategic decision that benefits both household finances and overall safety while promoting environmental sustainability.

- **CO_2 savings**

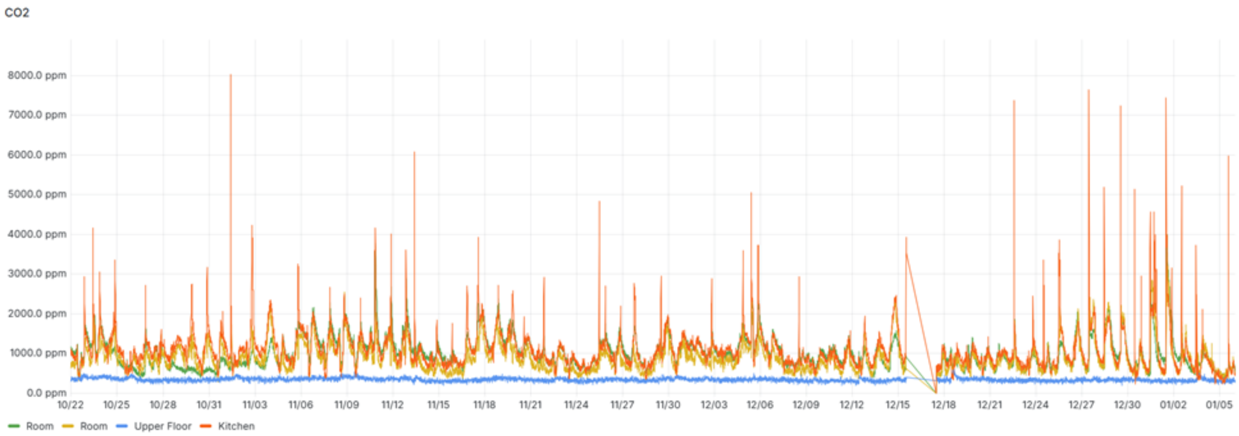


Figure 82 - CO_2 Before Renovation

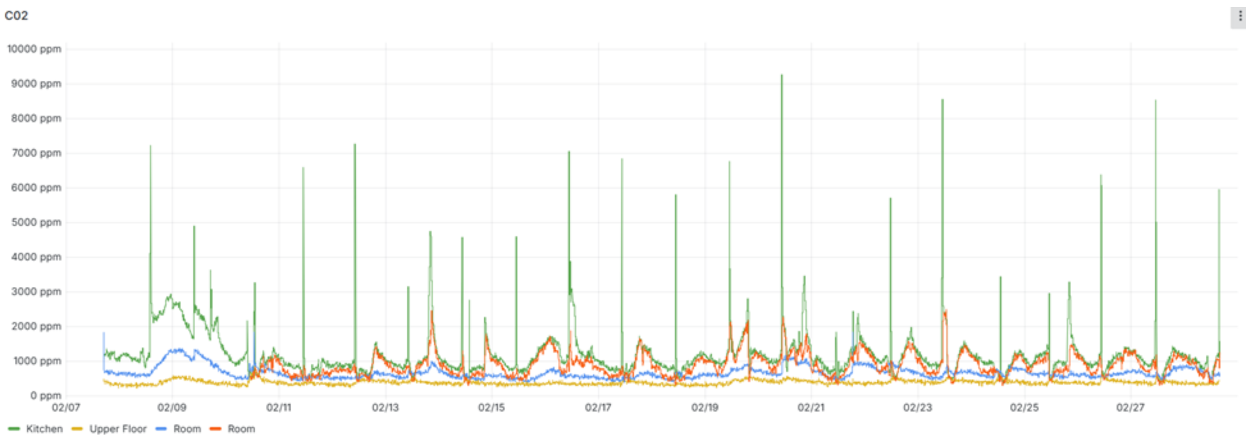


Figure 83 - CO_2 After Renovation

Before Renovation

CO_2 Levels

CO2 levels were consistently high, ranging between 2000 ppm and 10000 ppm, indicating inadequate ventilation and the accumulation of indoor pollutants.

Significant spikes were recorded, particularly in the kitchen, where gas stove usage contributed to increased CO_2 concentrations.

The upper floor, lacking ventilation or heat recovery systems, also experienced high levels, especially when occupied.

Kitchen

The kitchen recorded the highest CO_2 concentrations due to the frequent use of gas stoves and insufficient ventilation.

As the occupant spent a significant amount of time in the kitchen, prolonged exposure to elevated CO_2 levels could negatively impact health and well-being.

Upper Floor

In the absence of mechanical ventilation or heat recovery systems, air stagnation was prevalent on the upper floor, particularly when the space was in use.

The sporadic use of the room did not compensate for the inadequate air exchange, resulting in persistently high CO_2 levels.

After Renovation

CO_2 Levels

A significant reduction in CO_2 levels was observed throughout the house, with most areas rarely exceeding 2000 ppm.

Improved ventilation and the introduction of heat recovery systems substantially enhanced indoor air quality.

Kitchen

The kitchen remains the area with the highest CO_2 levels due to gas cooking and frequent occupancy.

However, even in this space, CO_2 levels have decreased compared to pre-renovation figures, attributed to a more efficient ventilation system.

Upper Floor

The installation of a window-mounted heat recovery system on the upper floor resulted in a substantial improvement in air quality.

Due to the infrequent use of this space, CO_2 levels remained consistently low, creating a healthier and more comfortable environment.

Visual and Final Conclusions

Overall Improvement

The renovation led to a significant enhancement in indoor air quality, reflected in the reduction of CO_2 levels across all areas of the house.

The implementation of an optimised ventilation system and technologies such as heat recovery played a key role in achieving this outcome.

Kitchen

Despite the improvement in ventilation, the kitchen remains the area with the highest CO_2 levels due to gas usage and frequent occupancy.

Further measures, such as installing a more efficient extraction system or replacing the gas stove with an induction hob, should be considered to optimise air quality in this space.

Upper Floor

With the introduction of a heat recovery system, the upper floor has become an area with consistently low CO_2 levels.

The low occupancy rate also contributed to maintaining high air quality, ensuring a healthier and more balanced indoor environment.

- **Any other result/inspection after renovation**

Following the implementation of new technologies and the replacement of window frames and glazing, there was a notable improvement in the thermal comfort of the dwelling. The ingress of cold air and infiltrations were significantly reduced. With the installation of the heat pump on the radiators, it was also possible to increase the indoor temperature, providing a significant benefit for the residents.

- **Feedback from the occupants after renovation**

PV Vacuum Glazing: An interesting technology but of little use due to its small surface area.

Window Heat Recovery: This system was widely praised for reducing the need for additional heating, contributing to a more comfortable indoor environment, especially in cold periods. It allows automatic CO_2 level control using Smart Controls.

Daylight Louvers: Optimized natural light entry and reduced artificial lighting use during the day. However, they are currently located in a rarely used room.

Smart Controls: While the automated systems proved efficient, both the occupant and owner initially struggled with the interface. They requested improvements in design and usability to facilitate daily use. This request was promptly addressed by OnControl.

Solar-Assisted Heat Pump: The hybrid performance of the system showed a reduction in conventional energy consumption without depending on direct sunlight. However, this technology received the most complaints: noise, vibration, and system complexity caused inconvenience not only to CJR but also to the owner and occupant.

- **Economic evaluation**

This building has the particularity that it is heated exclusively by electric heaters and therefore any reductions succeeded in energy consumption will concern the electrical energy. As electricity is related with higher primary energy conversion factors for almost all countries (compared to oil or natural gas) and is related to higher purchase prices, this is also translated to also higher expenses for the building.

In this demonstration building, it was decided to also test the prefabricated panel (the one produced for the Spanish case) for its economic performance, as it was observed that the insulating measures were performing better from an economic point of view.

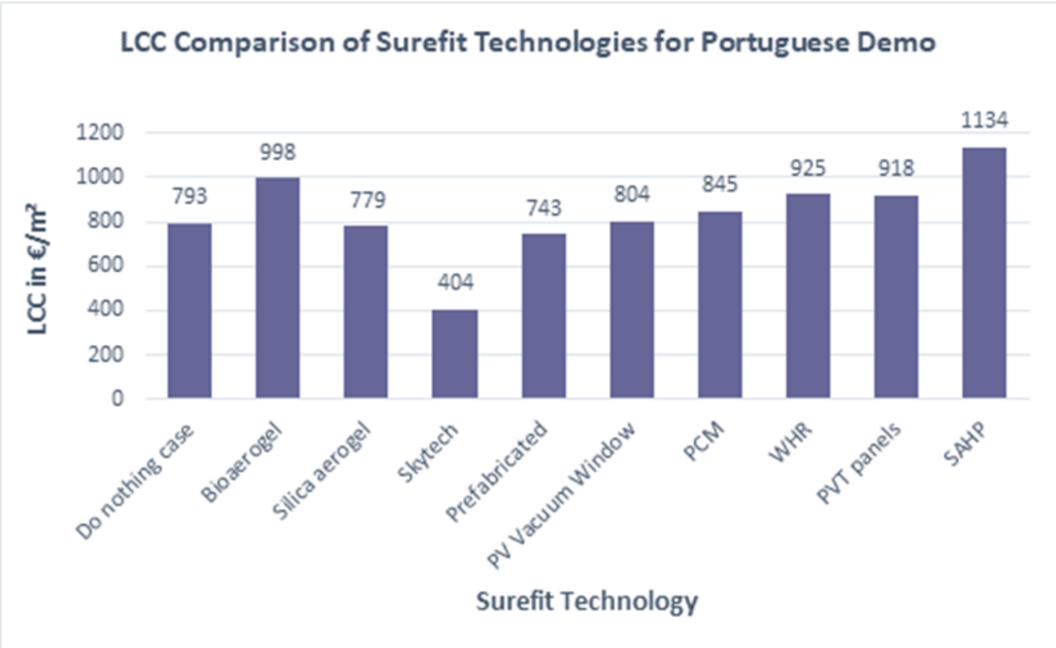


Figure 84 - LCC comparison of SUREFIT Technologies for the Portuguese demo building

Silica aerogel, Skytech membrane and prefabricated panels have lower LCC value than the “do nothing” case, however, the most cost-efficient technology is again Skytech membrane. All the other technologies are presented as non-cost effective. Therefore, only the passive technologies (insulation) seem to be effective on this demo building.

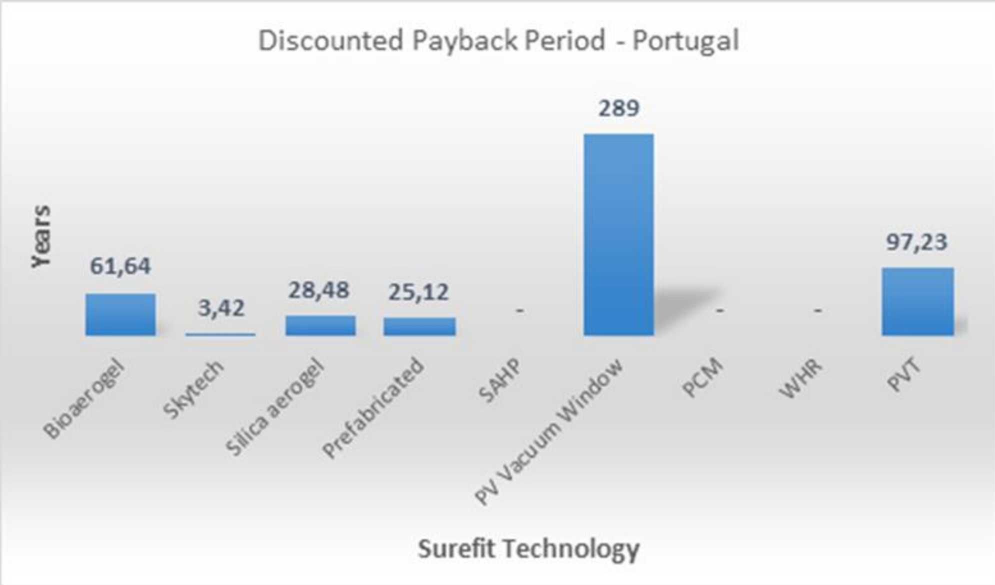


Figure 85 - Discounted Payback Period for the Portuguese demo building

From the diagram above, it is again concluded that Payback Period as an indicator cannot reveal the effectiveness of a measure. That is why it is preferred to use it in combination with other economic indicators. The only technology that pays off within the limit of 10 years is the Skytech membrane. The two measures that follow are silica aerogel and the prefabricated panel, but their payback period exceeds 10 years. The obvious reason for that is that even though these three insulating technologies produce almost the same energy savings and thus economic savings, their investment cost is much greater than that of the breathable membrane.

As a conclusion from the LCC study of all the four demos, in the following map, a prioritization of the most cost-efficient technologies for each demonstration building is depicted.

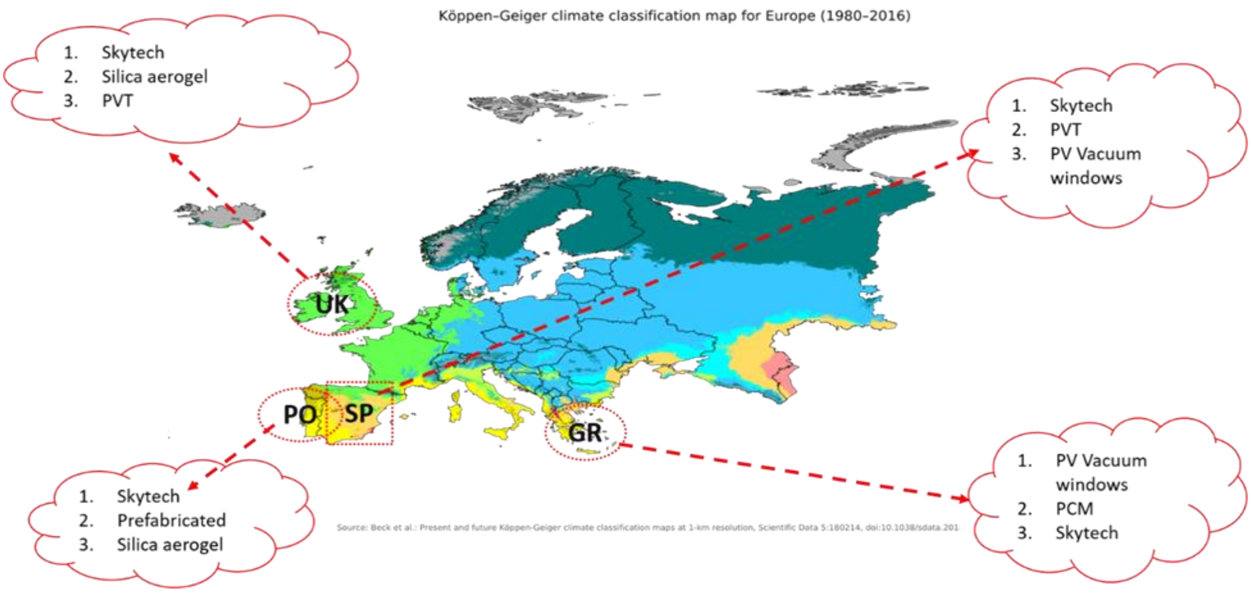


Figure 86 - Prioritization of SUREFIT technologies for each demonstration country

- **Overall evaluation and final conclusions**

The experience with installed technologies in Portugal demonstrated positive results and identified areas for improvement:

Technology Effectiveness:

The implemented solutions achieved the proposed objectives, significantly reducing energy consumption and enhancing occupant comfort.

Positive Impacts:

- **Energy Cost Reduction:** Heat recovery and smart systems contributed to lower energy bills.
- **Improved Thermal Comfort:** The integrated systems provided a more stable and pleasant indoor environment.
- **Environmental Sustainability:** The use of renewable sources and consumption optimization reinforced sustainability commitments.

Negative Impacts and Challenges:

- **System Complexity:** Some devices, especially the heat pump, required an adaptation and training period.
- **Specialized Maintenance:** Regular maintenance is necessary to ensure continuous equipment performance, potentially leading to additional costs.
- **Performance Fluctuations:** Under unfavourable weather conditions, such as cloudy days, certain systems showed variable performance, highlighting the need for operational adjustments, particularly PV Vacuum Glazing and Daylight Louvers, which depend on sunlight.

Recommendations:

- **Interface Improvements:** Simplify smart system interaction to make them more intuitive and accessible.
- **Continuous Training:** Provide training sessions to help occupants maximize system functionalities.
- **Preventive Maintenance:** Implement a regular maintenance plan to ensure equipment efficiency and durability.
- **Operational Adjustments:** Refine system parameters, especially under low sunlight conditions, to guarantee consistent performance.
- **Heat Pump Adjustments:** Simplify the system, make it more compact, and reduce vibrations and noise to enhance home integration. Otherwise, it may struggle to gain user acceptance.

This report serves as an assessment of the achieved results and as a basis for future implementations and improvements. Overall, the acquired experience reinforces the feasibility of integrated projects combining energy efficiency and environmental comfort, contributing to the promotion of sustainable practices in Portugal.

6 Finnish case study

The Finnish demo building is shown in *Figure 5.1*. It's a rental apartment building in Helsinki, owned by the municipality. There are four residential storeys and a basement area, which contains garages, storage rooms and a common sauna section. Each apartment has two bedrooms, a living room, a bathroom, and a kitchen with a dining area. The apartments are connected to the central hallway.

The building underwent a conventional energy renovation between 2022-23. During this renovation, a hybrid heating system comprising ground source heat pumps and district heating was installed. This replaced the old fully district heating -based system. PV panels were installed on the roofs to improve the share of renewables in energy use. The airtightness of the building was improved by replacing the window and door seals and by improving the balcony wall insulation, bringing the infiltration rate under 50 Pa pressure difference from 3 ACH down to 1.5 ACH. The original mechanical exhaust ventilation system without heat recovery was replaced with balanced mechanical ventilation equipped with heat recovery.

Figure 87 - Finnish apartment building

During and after the conventional renovation, technologies from the SUREFIT project were installed into one pilot apartment. The original idea was to have two technologies (air vapour barrier, louvers) in the apartment but due to miscommunication between the contractors of the conventional renovation, the air vapour barrier could not be installed. The louvers were installed in two batches: onto bedroom and living room windows in March 2023 and onto balcony windows in October 2023. *Figure 5.2* shows the floor plan of the pilot apartment and the placement of the window louvers.

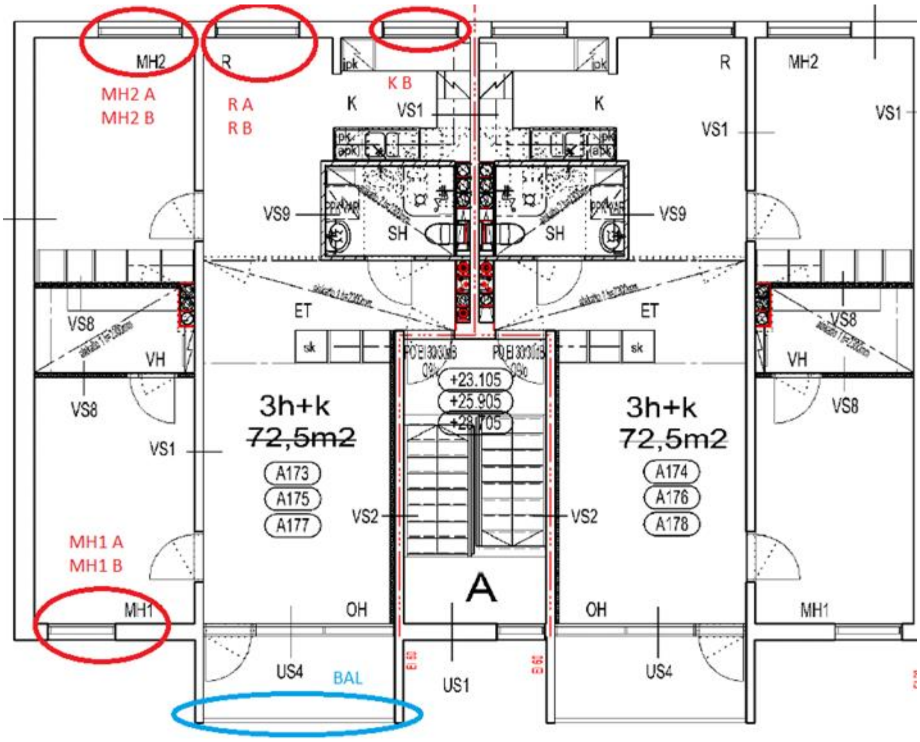


Figure 88 - Floor plan of the Finnish pilot apartment (the left one) including positions for the louvers. The kitchen window (K B) had no louver installed as it is a tiny one.

Table 23 - Building and Technologies

No	Key Exploitable result	Building Description	Main owner	Technologies installed
1	Portugal			
4	Greece			
5	UK		**UNOTT**	
6	Spain			
7	Finland	**Apartment building, one pilot apartment fitted with the technologies**	**AALTO**	**Louvers (Köster)**

- **Finnish building needs**

The Finnish demo building was changed in the beginning of the project and the new one was undergoing a conventional energy renovation. For this reason, the building owner restricted the available technologies to be installed to two (air vapour barrier, daylight louvers). Due to miscommunication of a subcontractor of the conventional renovation, the vapour barrier was later also removed from the list, making the air tightness measurements before the renovation redundant.

The occupants of the pilot apartment were very disinterested in the project throughout its course and gathering comments and feedback from them was next to impossible. We were only able to get input from them once but that was at a later stage when the daylight louvers were being installed.

- **Finnish building energy simulation results**

Due to the building owner's decisions, the simulations for the Finnish demo building were carried with a combination of conventional renovation measures and SUREFIT technologies. The results can be seen in *table 5.2* below. The final renovation was carried according to the values in the table.

Table 24 - Technology selection for the Finnish demo

Selected retrofit technology	**Installation area**	**Parameters**
EPS insulation and light gravel	**Roof**	**10 cm + 90 cm**
Mineral wool insulation	**All balcony walls**	**15 cm**
Winco vapour barrier	**One balcony wall**	**N/A**
Pipe insulation	**Heat distribution piping**	**2 cm**
Centralized mechanical balanced ventilation with heat recovery	**Roof**	**73% HR efficiency**
Daylighting louvers	**One apartment:** **3 windows and the balcony**	**10 m^2**
Bi-facial PV panels	**Roof**	**140 m^2, 25° tilt**
Ground source heat pump	**Basement**	**35 kW heating capacity**
Hot water storage tank	**Basement**	**2 m^3**

- **Finnish building performed renovation**

6..1 Installation of daylight louvers

The louvers were installed in two batches as the balcony louvers were of a different design and not yet available during the first installation visit. This first visit was done in March 2023 and during it two-bedroom windows (north-, south-facing) and the dining room window (north-facing) were equipped with KOST's louvers. The installation was quite straightforward and not that different from the installation of conventional daylight louvers. The main difference was that the operating mechanism was sturdier than in the conventional ones and had to be left between the double glazing of the window. *Figure 5.3* shows the installed louvers in one of the bedrooms.

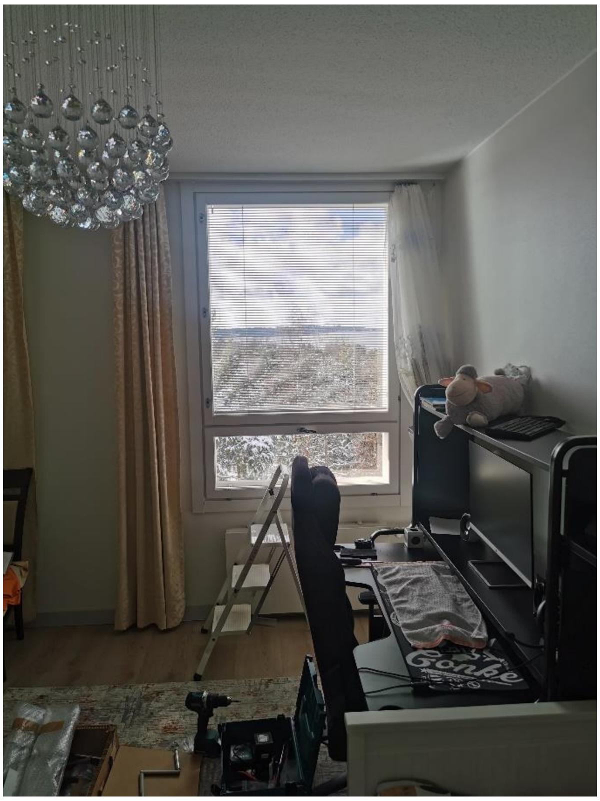


Figure 89 - Installed louvers in a bedroom

In October 2024, the balcony louvers arrived and were put in place to finish the installations at the Finnish demo building. The installation was again easy; first the support rails of the louver packs were bolted onto the concrete slab in the ceiling and then the louvers were snapped onto the rails. In *Figure 5.4* one louver pack has been installed and the reflection pattern of the sunlight can be seen. The yellow tint in the upper windows was introduced during the conventional renovation and its function was unknown to us, other than that it might disturb the operation of the SUREFIT louvers.

Figure 90 - Balcony louver pack and its light reflection pattern

- **Energy savings**

Why did we decide for RETROLux 20 mm daylight blinds?

Daylight blinds are characterized by a highly effective louver surface up to 96% total reflectivity. Even in horizontal louver position while very good view through the high angles of incidence in summer are reflected back into the sky. This brings a very effective passive cooling effect. Thus, the blinds help to avoid overheating in summer (see appendix page 80-86).

In winter with lower angles of incidence more energy hits the second part of the louvers. As the second part of the louvers is redirecting the impinging rays onto the inner room ceiling, the blinds improve the daylighting. Furthermore, they achieve a solar gain in accordance with the idea of passive solar architecture.

The most appreciated advantage of the blinds is a horizontal louver position.

The louvers could have some energy saving potential in the summertime in spaces equipped with mechanical cooling. The Finnish pilot building, however, did not have this so the louvers have no effect in its energy consumption.

- **Feedback from the occupants after renovation**

We managed to get feedback from the occupants only once, via an interview during the first installation visit. They were happy with the design of the louvers and their performance but concerned about the cumbersome operation due to the need to open the inner window every time you want to adjust the louver position. Unfortunately, we could not get a follow-up answer to this later as it would have been interesting to hear if their concern was realized or not.

- **Economic evaluation**

The daylight louvers did not bring any economical savings as the building was not mechanically cooled.

- **Overall evaluation and final conclusions**

The overall evaluation of the technology based on the appearance of the louvers and a controlled performance test conducted at Aalto offices was positive. It is an entirely passive technology which improves the user satisfaction via glare reduction and passive cooling in the summertime, and by bringing extra daylight inside during winters. The investment cost – mainly due to small scale production and case-based individual design of the louvers – is currently rather high but could be brought down with mass production and a more generalized approach with the design principles.

Conclusions

Five buildings in five countries were selected to analyse the latest strategies for energy efficient refurbishment and to improve the quality of life of the occupants.

All properties were individually analysed by an international team to identify their weaknesses. Technologies adapted to the climate and building fabric were identified to reduce energy consumption and improve comfort. The aim was to develop innovative strategies in the interaction of different technical measures in relation to the variable outdoor temperatures throughout the year and the different building cultures.

Aalto supported the decision-making process by determining heat transfer coefficients through energy consumption simulations. This particularly concerned the insulation measures.

The technology strategy for each building was developed by a team of scientists, engineers and architects from Finland, the UK, Germany, Spain, Portugal, Greece and Turkey, with input from technology suppliers and manufacturers.

The individual buildings were planned by the local teams, but with regular feedback from the international team. Regular e-meetings were held to share knowledge and information, as well as various face-to-face meetings in the UK, Finland, Greece and Portugal. The project managers met at an early stage at an international conference in Turkey.

Cooperation between the teams has developed into a successful concept. Different energy-saving strategies were developed for the individual properties in the different countries.

The Finland project was an apartment block in which the latest daylight redirection technology was installed in the existing box-type double windows on one floor.

In the UK, various technological approaches using heat pumps, heat pipes and vacuum insulation were utilised, as well as innovative windows in combination with ventilation measures.

In Spain, Portugal and Greece, very extensive refurbishment measures were carried out, in particular using thermal insulation and new windows as well as hybrid solar measures with water heat storage tanks.

Final assessment

The observation period was too short to arrive at a conclusive long-term economic assessment. It is therefore suggested that a follow-up evaluation be carried out after 5 years. In particular, the maintenance costs and susceptibility to repair of the active measures should be observed and economically assessed.

A new user survey should also be carried out in order to monitor energy consumption over several winter and summer periods and to assess the improvements in comfort from a long-term perspective.

It is also important to observe how users deal with the new technologies, whether they are operated correctly and whether maintenance cycles are actually adhered to.

It is already clear that passive measures relating to the building envelope - be it windows, thermal insulation measures or airtightness - are the most effective in reducing energy consumption and offer the best return on investment.

This realisation had already been proven in colder climates. What is new, however, as was discovered during the project in Greece, is that the same measures are also effective in warmer climates in the summer in order to reduce the need for refrigeration and air conditioning technology.

In order to monitor the active components, it is recommended that a permanent recording of consumption values be introduced in the future, which will offer the user the possibility of optimising the adjustment of the equipment in changing climates, e.g. for the winter and summer periods, which place contrasting demands on the function.