SUREFIT

SUstainable solutions for affordable REtroFIT of domestic buildings

Call: H2020-LC-SC3-2018-2019-2020

Topic: LC-SC3-EE-1-2018-2019-2020

Type of action: IA

Grant Agreement number	**894511**
Project acronym **Project full title**	**SUREFIT** **SU**stainable solutions for affordable **RE**tro**FIT** of domestic buildings
Due date of deliverable	**31/08/2024**
Lead beneficiary	**ISQ**
Other authors	**All partners contributed**

WP7 - Deliverable D 7.2

Handbook of guidelines and best practices for installation and operation of the technologies and retrofitting of domestic buildings

Dissemination Level

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

Document History

Version	Date	Authors	Description
1	24/09/2021	ISQ	Creation of the document
2	29/09/2021	ISQ	First draft for partners
3	17/02/2023	ISQ	Second draft
4	16/08/2024	All Partners	Contribution from partners
5	31/08/2024	ISQ	Final version for Coordinator

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No **894511**.

Contents

1 Introduction - Importance of residential buildings retrofitting 7

1.1 CONTEXT 7

1.2 SUREFIT METHODOLOGY 7

1.3 HANDBOOK OF GUIDELINES AND BEST PRACTICES 8

1.3.1 Understand the concept of retrofit and its phases 8
1.3.2 Who needs this guide? 9
1.3.3 How to use the guide 9

2 Assessment 10

2.1 ASSESSMENT STEPS 10

2.2 ENERGY PERFORMANCE ASSESSMENT 11

Energy management 11
Data collection 11

2.3 ENERGY CONSERVATION MEASURES 12

2.4 TRADITIONAL TECHNOLOGIES 13

2.5 SUREFIT INNOVATIVE TECHNOLOGIES 14

2.5.1 Resume 14
2.5.2 Passive technologies 15
2.5.2.1 A – (Bio) Aerogel insulation 15
2.5.2.2 B - Insulating breathable membrane 16
2.5.2.3 C- Phase changing materials panel 17
2.5.2.4 D -Prefabricated panels 19
E - Lighting – Daylighting Louvers 20
2.5.3 Active technologies 21
2.5.3.1 F - Photovoltaic vacuum glazing window (PV-VG) 21
2.5.3.2 G- Direct Expansion Solar Assisted Heat Pump (DX SAHP) 23
2.5.3.3 H - Evaporative cooler 25
2.5.3.4 I - Ground Source Heat Pump (TP GSHP) 27
2.5.3.5 J - Photovoltaic Thermal System (PV/T) 28
2.5.3.6 K - Window Heat Recovery System (WHR) 28
2.5.3.7 L - Smart controls 29

3 Decision-making 31

3.1 Decision-Making Framework 31

3.1.1 Renovation Scope 31
3.1.2 Criteria for decision-making 32
3.1.2.1 Financial aspects 32
3.1.2.2 Environmental aspects 33
3.1.2.3 Social aspects 34
3.1.3 Decision support tool 34
3.1.3.1 Identify and evaluate ECM alternatives. 35
3.1.3.2 Decide on the best alternative 36

4 Implementation 37

4.1 Planning the implementation 37

4.1.1 Develop a timeline 37
4.1.2 Obtain necessary permits 37

4.1.3 Hire services/products/professionals 38
4.2 Installation of technologies: best practices 39
4.2.1 Passive technologies 39
4.2.1.1 A – (Bio)-Aerogel insulation 39
4.2.1.2 B - Insulating breathable membrane 39
4.2.1.3 C - Phase changing materials panel (PCM Panel – ThinIce®) 39
4.2.1.4 D - Prefabricated Panels 39
4.2.1.5 E - Lighting - Daylight Louvers 40
4.2.2 Active technologies 40
4.2.2.1 F - Photovoltaic vacuum glazing window (PV-VG) 40
4.2.2.2 G - Direct Expansion Solar Assisted Heat Pump (DX SAHP) 40
4.2.2.3 H - Evaporative cooler 40
4.2.2.4 I - Ground Source Heat Pump (TP GSHP) 41
4.2.2.5 J - Photovoltaic Thermal System (PV/T) 41
4.2.2.6 K - Window Heat Recovery System (WHR) 41
4.2.2.7 L - Smart controls 42
5 Use phase (Operation & maintenance) 43
5.1 OPERATION 43
5.1.1 Passive Technologies 43
5.1.1.1 A - Bio-aerogel insulation 43
5.1.1.2 B - Insulating breathable membrane 43
5.1.1.3 C - Phase changing materials panel (PCM Panel – ThinIce®) 43
5.1.1.4 D - Prefabricated Panels 44
5.1.1.5 E - Lighting - Daylight Louvers 44
5.1.2 Active Technologies 45
5.1.2.1 F - Photovoltaic vacuum glazing window (PV-VG) 45
5.1.2.2 G - Direct Expansion Solar Assisted Heat Pump (DX SAHP) 45
5.1.2.3 H - Evaporative cooler 45
5.1.2.4 I - Ground Source Heat Pump (TP GSHP) 45
5.1.2.5 J - Photovoltaic Thermal System (PV/T) 45
5.1.2.6 K - Window Heat Recovery System (WHR) 45
5.1.2.7 L - Smart controls 45
5.2 MAINTENANCE 46
5.2.1 Passive technologies 46
5.2.1.1 A – (Bio) Aerogel insulation 46
5.2.1.2 B - Insulating breathable membrane 46
5.2.1.3 C-Phase changing materials panel (PCM Panel – ThinIce®) 46
5.2.1.4 D-Prefabricated Panels 47
5.2.1.5 E-Lighting - Daylight Louvers 47
5.2.2 Active technologies 47
5.2.2.1 F-Photovoltaic vacuum glazing window (PV-VG) 47
5.2.2.2 G-Direct Expansion Solar Assisted Heat Pump (DX SAHP) 47
5.2.2.3 H - Evaporative cooler 48
5.2.2.4 I - Ground Source Heat Pump (TP GSHP) 48
5.2.2.5 J - Photovoltaic Thermal System (PV/T) 48
5.2.2.6 K - Window Heat Recovery System (WHR) 48
5.2.2.7 L - Smart controls 49
6 Verification (Evaluation and Optimization) 50
6.1 Periodic energy assessments 50
6.1.1 Evaluation of energy targets achieved 51

6.1.2 Evaluation of occupants' comfort improvement 51

7 References...52

Publishable summary

The objective of this deliverable is to outline the methodology and strategy used during SUREFIT project's findings as well as give guidance for each stage of the process. This methodology provides a comprehensive and systematic approach to planning and retrofitting domestic buildings.

The domestic building retrofit journey is the process of improving the energy efficiency and sustainability of a residential home through energy conservation measures. It is a multi-stage and comprehensive process that starts with an initial assessment and ends with project completion.

The SURe^{3}FIT Approach:
The five-phase approach is shown in 5 steps, guiding homeowners through the entire retrofitting process:
1. Assessment and Planning: Evaluating the current energy performance and identifying potential areas for improvement. Includes an analysis of available energy conservation measures, and descriptions of the SUREFIT developed technologies.
2. Decision-Making: Selecting the most suitable retrofitting solutions based on technical feasibility and economic considerations. The guide presents the SURe^{3}FIT operational tool, designed to integrate economic and environmental criteria while also anticipating benefits that extend to the social aspects of sustainability.
3. Implementation: Developing a detailed plan, acquiring necessary permits, and executing the chosen retrofitting measures. The guide describes the implementation guidelines for the SUREFIT developed technologies.
4. Use: Learning to operate the installed measures and following a maintenance plan for optimal performance. The guide describes the usage guidelines for the SUREFIT developed technologies.
5. Verification: Evaluating the effectiveness of the implemented retrofitting measures.

1 Introduction - Importance of residential buildings retrofitting

1.1 CONTEXT

Buildings account around 40% of the European Union's energy consumption and 36% of its greenhouse gas emissions. Most of the citizens' energy consumption, 80%, is dedicated to heating, cooling, and domestic hot water.

In addition, at present around 35% of buildings in the European Union are over 50 years old and almost 75% of the building stock is inefficient. However, only 1% is renovated each year.

EU's Energy Performance of Buildings directive sets the goal for Europe to achieve a zero-emission, fully decarbonised building stock by 2050. This requires the development and application of technological solutions, and renewable, more efficient, and less polluting energy systems for our homes to decrease emissions, save energy, tackle energy poverty, facilitate renovation, improve quality of life, and generate jobs and growth.

Between 85% to 95% of the EU's buildings are expected to still be standing in 2050. So, retrofitting residential buildings is at the forefront of these efforts.

1.2 SUREFIT METHODOLOGY

The SUREFIT methodology offers a systematic framework for retrofitting residential buildings, aimed at enhancing energy efficiency, reducing emissions, and ensuring financial viability and occupant comfort. It supports stakeholders, including building owners and municipalities, in making informed decisions that balance cost-effectiveness with sustainability. This methodology helps transition buildings towards nearly zero-energy status (nZEBs), in line with EU energy targets.

Key aspects include:

- **Comprehensive Information**: Ensuring stakeholders have all necessary details for assessment and planning.
- **Cost-Effective Strategies**: Highlighting affordable and effective retrofitting measures.
- **Empowered Decision-Making**: Supporting confident decision processes.
- **Implementation Guidance**: Covering the entire retrofitting process.
- **Maintenance and Verification**: Emphasizing ongoing maintenance and performance verification for zero emissions.

Divided into five phases—assessment & planning, decision-making, implementation, use, and verification — this methodology includes best practices for using SUREFIT-developed technologies and tools to reduce energy consumption and increase renewable energy use. It integrates seamlessly with the guidelines and best practices detailed in Section 1.3 of the Handbook, ensuring effective installation and operation of innovative retrofitting technologies in domestic buildings.

1.3 HANDBOOK OF GUIDELINES AND BEST PRACTICES

1.3.1 Understand the concept of retrofit and its phases

The residential building retrofit journey is the process of improving the energy efficiency and sustainability of a residential home through retrofitting measures. It is a multi-stage and comprehensive process that starts with an initial assessment and ends with project completion.

The **first stage** in the retrofit journey is the initial assessment, which includes a detailed evaluation of the home's energy performance and sustainability. This assessment may involve energy audits, building inspections, and analysis of energy bills and other relevant data. This stage aim is to identify areas of inefficiency and opportunities for improvement. Along with the assessment comes project planning. Once the objectives for retrofitting are defined, and in line with energy efficiency and sustainability targets, the retrofitting measures are identified and designed to address the areas of inefficiency identified. The planning may involve selecting technical retrofitting measures concerning: i) insulation and building envelope (e.g. windows); ii) HVAC systems; iii) renewable energy integration; iv) water heating and usage, and the possible combinations between them.

The **second** phase is decision-making. The aim of this stage is to develop a comprehensive plan that maximizes energy efficiency and sustainability while minimizing costs. In other words, it aims at providing a systematic approach for homeowners to make informed decisions, prioritizing actions, and allocating resources efficiently.

The **third stage** is the implementation phase, where retrofitting measures are implemented. This may comprise obtaining necessary permits, but mostly it involves construction and installation of technologies, e.g., the installation of insulation, window replacement, heating systems updates, and other retrofitting measures identified in the planning step. The aim of this stage is to ensure that the retrofitting measures are effectively and efficiently implemented.

The **fourth stage** is the use phase, in which the user of the retrofitted home learns how to operate of the measures installed as well as how to follow and apply the maintenance plan.

The **final stage** is the verification phase, which assesses the effectiveness of the retrofitting measures. This may include conducting energy audits, analysing energy bills, and other relevant data (similarly to what may be performed in the assessment phase, but now in a post-retrofit scenario). The aim of this stage is to determine the energy efficiency and sustainability gains made possible by the retrofitting measures, as well as to identify any areas for further improvement.

The retrofit journey is a complex process that requires careful planning, design, and implementation. It is important to work with experienced professionals who can guide homeowners through each stage of the process and ensure that retrofitting measures are implemented effectively and efficiently. Following the retrofit journey allows homeowners to improve the energy efficiency and sustainability of their homes, reducing energy bills, and contributing to a more sustainable future.

1.3.2 Who needs this guide?

This *"Handbook of guidelines and best practice for installation and operation of the technologies and retrofitting of domestic buildings"* is a valuable resource for two key audiences:

- **Homeowners:** This guide is intended for those who own residential buildings and are interested in improving their comfort, reducing energy bills, and minimizing their environmental impact. It empowers users to navigate the residential building retrofit process effectively. It provides insights into the different stages involved, the technologies available for upgrades, and the potential benefits that can be expected.
- **Technicians:** This handbook is also intended for professionals specializing in the planning, installation, or maintenance of residential building retrofits. It offers a comprehensive resource, delving into best practices for various technologies, ensuring high-quality and efficient upgrades that meet homeowner expectations.

1.3.3 How to use the guide

This guide empowers homeowners and technicians with the information needed to achieve a successful zero-emissions residential building retrofit. It follows a multi-stage methodology specifically designed for this purpose.

For Homeowners:

- <u>Navigate the Retrofit Journey:</u> The guide outlines the five crucial phases of a retrofit – assessment, decision-making, implementation, use, and verification. This equips the homeowner to understand the process and make informed choices throughout.
- <u>Maximize Benefits:</u> Learn about innovative SUREFIT Project technologies that reduce heat loss, energy consumption, and environmental impact, while increasing the reliance on renewable energy sources.

For Technicians:

- <u>Deliver High-Quality Retrofits:</u> The guide provides a comprehensive best practice manual for installing and operating SUREFIT technologies. This ensures the delivery of efficient upgrades that meet homeowner expectations.

Structure and Tools:

The guide and methodology are organized into the five essential phases mentioned above. To support the retrofit project, the SUREFIT-developed tool offers all the necessary calculations and simulations. This tool, along with relevant reference databases, is presented within this document for easy access.

2 Assessment

2.1 ASSESSMENT STEPS

Section 2 outlines the key steps involved in assessment of residential building retrofits within the SUREFIT project. A successful retrofitting project hinges on a thorough initial assessment that establishes a baseline for energy performance and identifies areas for improvement.

Carrying out an initial energy assessment is the first essential step to start retrofitting a building. Based on collected data this assessment will provide measurable results to evaluate the energy performance and status of the present building and then enable energy saving measures to be identified and estimated. Building energy audits and certificates serve as valuable tools in guiding renovation decisions and improving overall energy performance. By identifying areas of energy wastage and suggesting energy-efficient upgrades, these measures can significantly contribute to cost savings, environmental sustainability, and occupant well-being.

Energy audits are systematic examinations of a building's energy consumption patterns, the efficiency of its systems, and potential areas for energy conservation. They serve as a diagnostic tool to identify inefficiencies and offer tailored solutions for optimization. Several reasons why energy audits are crucial in the renovation process:

- Identification of Energy Wastage: Energy audits carefully examine how much energy a building uses and where it's being wasted. This helps identify problems like poor insulation, inefficient heating and cooling systems, and old appliances that consume too much energy.
- Tailored Improvements: By understanding a building's specific energy use, audits can recommend targeted upgrades to address the identified problems. This ensures that the renovation focuses on the areas that will save the most energy.
- Informed Decision-Making: With data from energy audits, building owners can make informed choices about renovations. They can prioritize cost-effective improvements that will lead to significant energy savings over time.

The initial assessment process typically involves the following steps:

Step 1: Initial Assessment

An initial assessment, conducted prior to a detailed energy audit, should examine the building's energy consumption, condition, and occupant behaviour. This preliminary evaluation helps identify potential areas of concern and establish objectives for the subsequent, more in-depth audit.

Step 2: Data Collection

Before an energy audit, a detailed data collection process is required. This includes gathering information on the building's energy use (utility bills) and the efficiency of its heating, cooling, ventilation (HVAC) systems, insulation, windows, doors, lighting, and appliances. Additionally, the building's layout and any structural or design features impacting energy performance are documented.

Step 3: On-Site Inspection

An on-site inspection further assesses the building's condition. This focuses on the building envelope (walls, roof, windows) and HVAC systems, looking for air leaks, poor insulation, or inefficient equipment. Specialized tools like thermal imaging cameras may be used to detect hidden energy losses.

2.2 ENERGY PERFORMANCE ASSESSMENT

A complete picture of a building's energy efficiency goes beyond just identifying areas for improvement. This section explores how the building's energy performance is assessed through various metrics.

- **Energy Use:** Measured through on-site measurements or energy bills, this metric reflects the building's annual energy needs for heating, cooling, ventilation, hot water, and lighting.
- **Building Envelope Quality:** The quality of the building envelope (walls, roof, windows) significantly impacts energy performance. U-value measurements and thermographic testing will be conducted to assess thermal insulation and identify areas of heat loss.
- **Indoor Environmental Quality:** Occupant health and comfort are crucial considerations. Temperature, humidity, air exchange rate, and presence of contaminants will be measured and compared to established standards to ensure a healthy and comfortable living environment.

By considering these factors, we gain a comprehensive understanding of the building's overall energy efficiency and can develop targeted improvements for a successful retrofit project.

Energy management

The energy manager is a professional specialised in building energy consumption. They carry out detailed energy audits or hire a specialized company to do it. With the support of this guide and the tool, the building owner can perform a preliminary audit themselves. However, for meticulously assessed measures and accurate saving estimates, consulting specialized professionals is recommended.

Data collection

The energy performance of a property is calculated based on several factors, including the building's envelope (walls, roof, windows, etc.), the use of renewable energy sources (like solar panels), ventilation systems, the efficiency and type of fuels used for heating and hot water, lighting, and how it's used. Besides this general information, it's also important to understand the indoor air quality and the comfort levels of the occupants.

Therefore, one of the key tasks of the energy audit is data collection. Information sources will include technical documents, surveys conducted on-site and with occupants, and measurements.

Measurements

Measurements are needed to gather information about the building's energy use, its envelope (walls, roof, windows), and how well its systems work. This information might not be found in existing documents. Even if documents and surveys provide some data, measurements are done to check their accuracy. Since most buildings don't have equipment that constantly monitors energy use, these on-site measurements become essential. In some cases, specific tests, like blower door tests that measure air leaks, are the only way to get precise information.

Occupants' survey

The usage building systems, especially HVAC (heating, ventilation, and air conditioning), depends on factors like climate, the culture of the occupants, and their socioeconomic resources. Occupant surveys help gather information not only about how often these systems are used but also about comfort levels in summer and winter.

2.3 ENERGY CONSERVATION MEASURES

The core of a successful residential building renovation project lies in the implementation of energy-saving measures. These measures aim to optimize energy usage, reduce operational costs, and enhance overall sustainability. Here's an overview of some key options:

- <u>Building Envelope:</u> Upgrading the building envelope signifies enhancing the insulation levels of walls, roofs, and floors to minimize heat transfer. Additionally, replacing outdated windows and doors with energy-efficient models featuring advanced glazing technologies and effective weather sealing contributes significantly to improved thermal performance.
- <u>HVAC Systems:</u> Modernizing the heating, ventilation, and air conditioning (HVAC) systems by transitioning to high-efficiency units fosters significant energy savings. Options such as heat pumps, geothermal systems, and condensing boilers offer improved efficiencies while maintaining occupant comfort levels. Programmable thermostats further optimize energy use by allowing for precise control of indoor temperatures based on occupancy patterns.
- <u>Lighting:</u> Replacing traditional incandescent or fluorescent bulbs with energy-efficient light-emitting diode (LED) lighting offers a multi-faceted benefit. LED lighting not only significantly reduces energy consumption but also boasts longer lifespans and generates less heat, contributing to both energy and cost savings.
- <u>Renewable Energy Integration:</u> The integration of solar photovoltaic (PV) panels on rooftops or other suitable locations allows buildings to generate clean electricity from sunlight. This reduces reliance on grid power and lowers utility bills for occupants. Geothermal heat pump systems leverage the stable temperature of the earth to provide efficient and environmentally friendly heating and cooling solutions.
- <u>Building Automation and Controls:</u> Implementing smart home systems enables centralized control of lighting, HVAC, and other appliances. These systems can adapt to occupancy patterns, automatically adjusting energy use for optimized performance.

- Passive Design Strategies: Incorporating passive design strategies such as natural ventilation and daylighting contributes to a more sustainable building. Natural ventilation utilizes strategic placement of windows and vents to maximize airflow and minimize the need for mechanical cooling. Daylighting strategies focus on maximizing access to natural light through well-placed windows and skylights, reducing reliance on artificial lighting during daylight hours.

2.4 TRADITIONAL TECHNOLOGIES

Before exploring the innovative technologies utilized within the SUREFIT project, it's valuable to establish a foundation in traditional energy-efficiency measures. These well-established practices offer a cost-effective starting point for improving a building's energy performance.

Here's an overview of some key traditional approaches:

- **Building Envelope Improvements:**
    - Enhanced Insulation: Upgrading building envelope insulation in walls, roofs, and floors minimizes heat transfer. This reduces reliance on heating and cooling systems for maintaining comfortable indoor temperatures.
    - Window and Door Replacements: Replacing old, drafty windows and doors with energy-efficient models featuring advanced glazing and weather sealing significantly improves thermal performance.
- **HVAC System Upgrades:**
    - Efficiency-Focused Replacements: Replacing outdated heating, ventilation, and air conditioning (HVAC) systems with modern, high-efficiency units can lead to substantial energy savings. Consider options like heat pumps, boilers with improved efficiencies, and ventilation systems with heat recovery capabilities.
    - Programmable Thermostats: Installing programmable thermostats allows for precise control of indoor temperatures based on occupancy patterns. This optimizes energy use by automatically adjusting heating or cooling during unoccupied periods.
- **Lighting Retrofits:**
    - LED Replacements: Swapping traditional incandescent or fluorescent bulbs with energy-efficient light-emitting diode (LED) lighting offers significant benefits. LED bulbs consume less energy, boast longer lifespans, and generate less heat, contributing to both energy and cost savings.

This established set of approaches lays the groundwork for the innovative SUREFIT technologies explored in the following section.

2.5 SUREFIT INNOVATIVE TECHNOLOGIES

2.5.1 Resume

The SUREFIT project incorporates a comprehensive range of innovative technologies designed to optimize energy efficiency and enhance building performance. These technologies address various aspects of a building's energy use, categorized as either passive or active:

- **Passive Technologies:** These leverage natural processes and require minimal external power to function.
- **Active Technologies:** These involve mechanical systems that utilize energy to provide heating, cooling, ventilation, or electricity generation.

The following table provides a detailed breakdown of the SUREFIT technologies, categorized by type, specific technology, its function, and the primary location of its application within the building envelope.

Table 1 - SUREFIT innovative technologies synthesis

Type	Technologies		What	Where
Passive	Aerogel Insulation	-	-	Walls Ceiling
	Insulating Breathable Membrane	-	Thermal insulation	Walls Roof
	Phase Changing Materials Panel	PCM	Heating Cooling	Floors Ceiling
	Prefabricated panels	-	-	External walls
	Daylight Louvers	-	Lighting	Windows
Active	PV Vacuum Glazing Windows	PV-VG	Thermal insulation	Windows
	Direct Expansion Solar Assisted Heat Pump	DX SAHP	Heating Cooling Domestic Hot Water	Rooftop / External walls (panel) Pump / cylinder (interior)
	Evaporative cooler			
	Ground Source Heat Pump	TP GSHP	Heating	Ground
	Photovoltaic Thermal System	PV/T	Electricity Heating	Rooftop
	Window Heat Recovery System	WHR	Ventilation	Windows
Other	Smart Controls	-	-	Inside

2.5.2 Passive technologies

2.5.2.1 A – (Bio) Aerogel insulation

Aerogels are a synthetic, porous, extremely ultralight material. They are a type of gel where the liquid part has been replaced by gas. Aerogels are introduced in blankets which incorporate particles in ultra-thin, flexible nonwovens. They can be attached internally and externally to the building walls and roof, guided by wooden rafters/frames. The aerogel technologies to be exploited in the boundaries of SUREFIT are the innovative bio-aerogels and the commercial silica-aerogels.

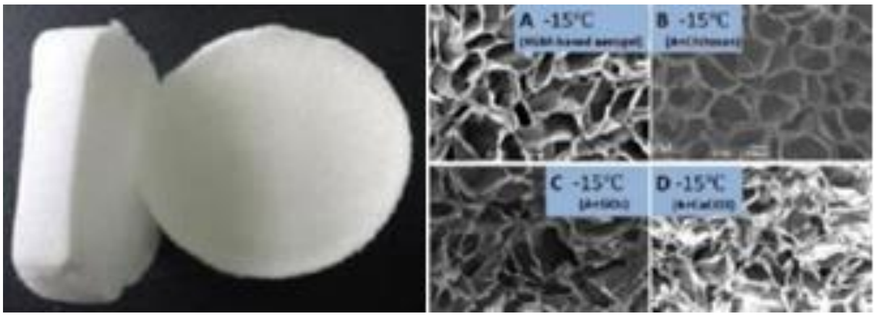


Figure 1 – Bio-aerogel insulation and structure

The SUREFIT project utilizes **bio-aerogel** insulation technology developed by UNOTT. These bio-aerogels are composed of konjac glucomannan (KGM) and starch, representing a sustainable material solution. Their raw materials are derived from natural, agricultural waste products such as wheat straw, minimizing their environmental footprint. The manufacturing process, specifically freeze-drying, contributes to these positive environmental attributes while also yielding bio-aerogels with excellent thermal insulation and favourable mechanical properties.

Bio-aerogels offer a multitude of advantageous characteristics, including high surface area, superior thermal and acoustic insulation properties, low density and thermal conductivity, high porosity, flame and humidity resistance, and a low refractive index and dielectric constant. However, a current challenge associated with bio-aerogels is their relatively high manufacturing cost, which may limit their widespread adoption. This cost can be attributed to the technology's current stage of development. As the market for bio-aerogels matures, production costs are expected to decrease, leading to a more favourable price point. Market analysts predict a compound annual growth rate (CAGR) of 30.8% to 31% for the aerogel market between 2017 and 2023, suggesting a promising future for this technology.

Table 2 - Bio-aerogel Insulation specifications

Properties	Value	Unit
Materials	konjac glucomannan (KGM)/starch	-
Density	43	kg/m^3

Thermal conductivity	0.037	W/(mK)
Specific heat capacity	2260	J/(kgK)
Moisture permeability	65	GNs/kgm
Overall product thermal	0.024	W/(mK)
Safety	Non-toxicity and biodegradable	-
Lifespan	30	years
Cost - purchase	69.8	€/m^2

Silica-aerogel insulation

Silica aerogel is the pioneering type of aerogel and remains the most prevalent option commercially. Silica, the oxide of silicon (SiO2), is a key component, known for its glassy properties and excellent insulating capabilities. These aerogels boast highly porous structures and exceptional lightness, with air comprising up to 95% of their volume. The production process involves sol-gel processing of molecular precursors, followed by supercritical drying of assembled gels. This supercritical drying step eliminates capillary forces, allowing for the preservation of the aerogel's remarkable porosity.

Silica's low thermal conductivity makes it a highly effective insulator. The material solidifies in three-dimensional clusters, occupying only about 3% of the total volume. The remaining 97% consists of air trapped within nanopores. While silica aerogels offer superior insulation, it's important to acknowledge their production process can have environmental drawbacks. Additionally, the incorporation phase may generate and emit hydrophobic dust, requiring careful handling considerations.

2.5.2.2 B - Insulating breathable membrane

The SUREFIT project utilizes a breathable membrane developed by WINCO to achieve a closed building envelope. This innovative membrane enhances wind resistance (airtightness), effectively prevents thermal bridges, and reflects up to 95% of radiant heat, contributing to improved indoor comfort during summer months.

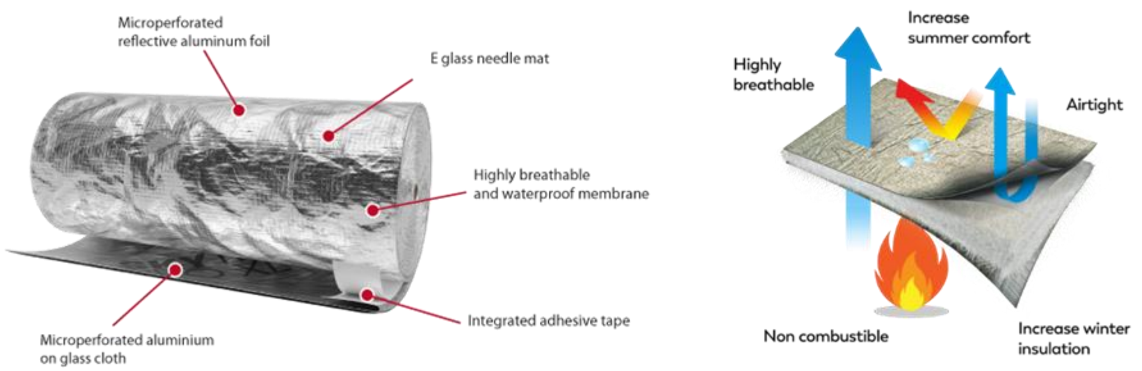


Figure 2- Skytech Pro XL membrane

The incorporation of the insulating membrane also facilitates better control of internal building conditions, as the need for active heating and cooling systems is reduced. Additionally, the membrane provides a 16 dB noise reduction benefit. Installation of the breathable membrane requires rafters and wood sheathing.

Table 3 - Insulation breathable membrane specifications

Properties	Value	Unit
Thermal conductivity	0.029	W/(mK)
Density	96.15	Kg/m^3
Sound reduction	-16	dB
Available thickness	6, 13, 26	mm
Airtightness	0.16 – 0.18	m^3/hm^2
Thermal resistance	1.50, 1.70, 2.20	m^{2}K/W
Water vapor resistance	0.022, 0.041, 0.080	m
Vapor resistance	0.11, 0.20, 0.40	MNs/g
Life span	30	years
Cost - purchase	10.80	€/m^2

2.5.2.3 C- Phase changing materials panel

Positive phase change materials (PCM) are mixtures of two or more chemicals which, when mixed in a particular ratio, have a freezing / melting point above water freezing temperature of 0°C and they therefore offer a thermal energy storage facility between **+4°C (39º**F) and **+117 °C (242º**F).

The working principle of Phase Change Materials is connected to their heat capacity and latent heat characteristics. They constantly release and absorb sufficient energy at phase transition to provide useful heat/cooling. Their constant change of physical state from solid to liquid and vice versa, occurs in fixed temperatures and the released/absorbed energy during the transition process, is greater than the sensible heat (body exchange heat-thermodynamically) of the medium.

Figure 3 - PCM Panel – ThinIce

Introducing PCMs into a building block or panel, can increase the energy storage density of material. Additionally, if integrated into the insulation, the transfer of heat to; and from, indoor environments are decreased. Thereof, PCMs are characterised by smooth temperature variations about a set value. UNNOT, together with PCM Products Ltd, have developed PCM in form of panels called ThinIce®.

Table 4 - Phase changing materials panel suitable for retrofit buildings specifications (+20°c to +30°c)

Properties	**Value**	**Unit**
Thermal conductivity	0.53 - 0.54	W/(mK)
Density	1520 - 1530	Kg/m^3
Specific thermal capacity	1.9 – 2.2	kJ/kg K
PCM phase change point	20 – 30	ºC
PCM Durability (Max Temp)	60	ºC
Lifespan	25	years
Cost - purchase	93.60	€/m^2

2.5.2.4 D -Prefabricated panels

The SUREFIT project incorporates prefabricated panels utilizing silica aerogel for enhanced building insulation with a reduced material thickness. These panels, produced by CJR, come in two variations tailored to the specific demonstration building locations:

- **Spanish Panel:** This three-layer panel combines 20 mm of XPS (extruded polystyrene) insulation with a 20 mm silica aerogel blanket, sandwiched between another 20 mm XPS layer.
- **Greek Panel:** Similar to the Spanish panel, this variation also utilizes three layers. The core consists of a 20 mm silica aerogel blanket, encased between 20 mm layers of polyurethane insulation.

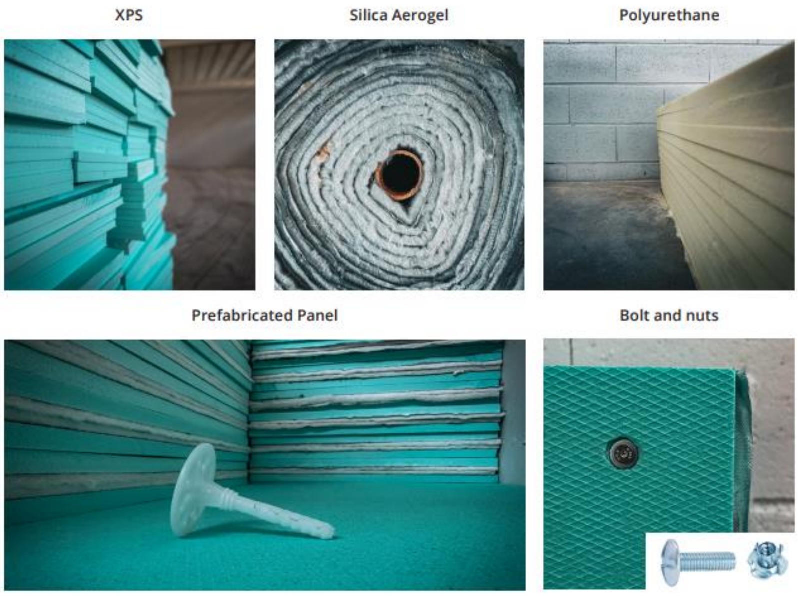


Figure 4 – Pre-fabricated panel materials and structure

Table 5 – Pre-fabricated panel thermal characteristics

	Material	Thermal conductivity (w/m.K)	Thickness (mm)	Weight (kg/m2)
Spain	Fiberglass Mesh	0,000	0,6	0,16
	XPS	0,033	20	0,63
	Silica Aerogel	0,022	20	3,74
	XPS	0,033	20	0,63
	Fiberglass Mesh	0,000	0,6	0,16
			61,20 mm	5,32 kg/m2

	Material	Thermal conductivity (w/m.K)	Thickness (mm)	Weight (kg/m2)
Greece	Fiberglass Mesh	0,000	0,6	0,16
	XPS	0,033	20	0,63
	Silica Aerogel	0,022	20	3,74
	Polyurethane	0,023	30	1,05
	Fiberglass Mesh	0,000	0,6	0,16
			71,20 mm	5,74 kg/m2

These configurations allow for the calculation of the U-value (thermal transmittance) for each panel type. The Spanish panel achieves a U-value of 0.481 W/(m²K), while the Greek panel boasts a superior U-value of 0.360 W/(m²K), indicating its exceptional thermal insulation performance.

Table 6 -Prefabricated panel specifications resume

	Spain		Greece	
Properties	**Value**	**Unit**	**Value**	**Unit**
U-value	0.481	W/(m²K)	0.360	W/(m²K)
Weight/m2	5.32	kg/m²	5.74	kg/m²
Thickness	61.20	mm	71.20	mm

E - Lighting – Daylighting Louvers

Lighting systems are a major contributor to a building's overall electricity consumption. The SUREFIT project addresses this by incorporating daylight louvers, a technology developed by Koester, to maximize the use of natural light. These louver systems offer a dual benefit: they significantly reduce reliance on electric lighting while simultaneously preventing glare issues and overheating.

The unique design of these louvers effectively redirects natural daylight deeper into a room, reaching up to 6 meters from the window. This deeper penetration of diffused light allows for a more evenly lit interior space, minimizing the need for artificial lighting. Additionally, the louvers employ a retro-reflective function that manages direct sunlight, mitigating glare and maintaining comfortable working conditions.

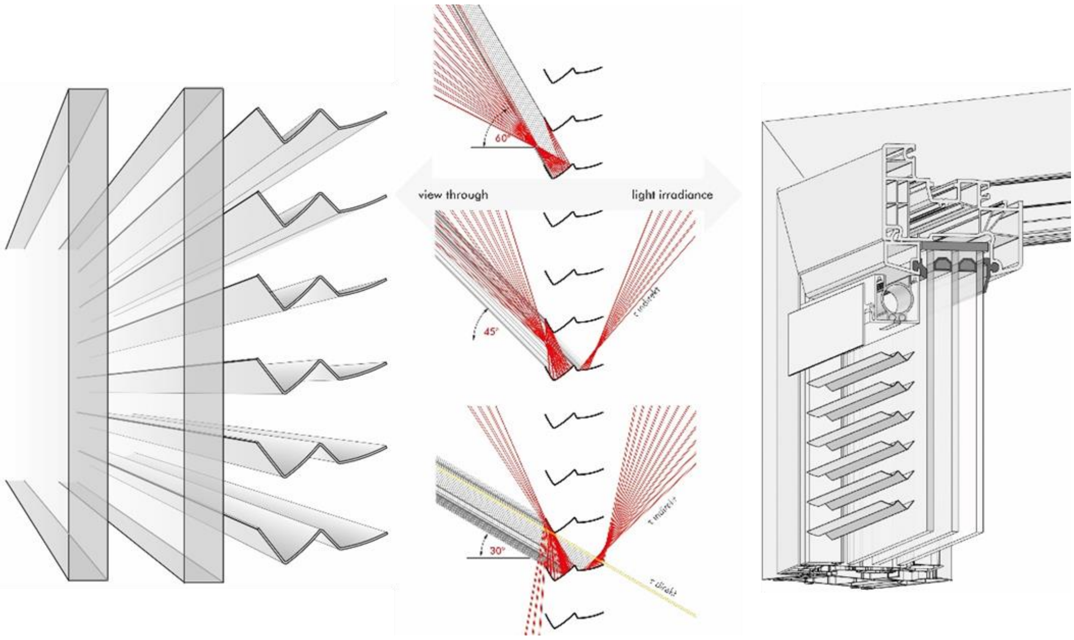


Figure 5 - daylight louvers design, light diffusion, and construction elements

2.5.3 Active technologies

2.5.3.1 F - Photovoltaic vacuum glazing window (PV-VG)

The SUREFIT project incorporates Photovoltaic Vacuum Glazing (PV-VG) windows, a technologically advanced solution offering a unique combination of superior thermal insulation and electricity generation capabilities. These windows share a similar structure to double-glazed units, but with a crucial difference: the cavity between the glass panes is evacuated, creating a vacuum instead of a gas fill. This vacuum provides significantly higher insulation levels compared to any gas filling, effectively reducing heat transfer, and improving a building's overall energy efficiency.

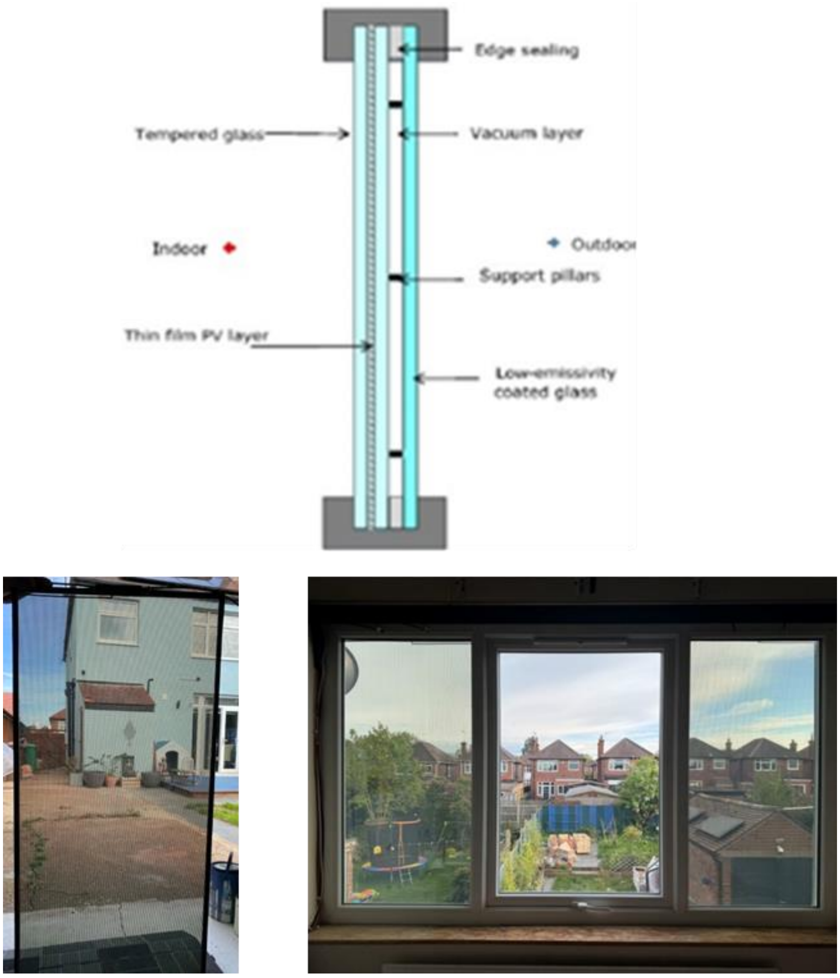


Figure 6 – PV-VG Windows structure and appearance

Adding to their exceptional thermal performance, PV-VG windows (Figure 6) also excel in acoustic insulation, offering superior sound reduction capabilities. The photovoltaic (PV) component, integrated as thin-elastic films within the window structure, facilitates electricity generation from sunlight, contributing to a building's energy production. PV-VG windows consist of three primary elements:

1. Self-cleaning coated glass for improved maintenance and aesthetics.
2. A highly evacuated cavity for exceptional thermal insulation.
3. Thin-film PV glass with an additional glass cover for durability and aesthetics.

Some of the technical properties are presented in the following Table 7.

Table 7 - Photovoltaic vacuum glazing window specifications

Properties	**Value**	**Unit**
U-value	0.6	$W/(m^2K)$
Density	241	kg/m^3

Thickness	15.1	mm
Light transmittance	50	%
Solar heat gain coefficient (SHGC)	0.39	-
Solar shading coefficient	0.45	-
Lifespan	20	years
Solar to electricity generation efficiency	4	%
Cost - purchase	Under evaluation.	€/unit

2.5.3.2 G- Direct Expansion Solar Assisted Heat Pump (DX SAHP)

The SUREFIT project incorporates a highly efficient Direct Expansion Solar Assisted Heat Pump (DX SAHP) system developed by UNNOT. This innovative technology combines the functionalities of a solar thermal collector with a heat pump, offering a versatile solution for heating, cooling, and domestic hot water needs within a building.

The DX SAHP operates on the principle of utilizing ambient air as a heat source for heating purposes. Additionally, the system incorporates photovoltaic (PV) panels to extract solar energy, further enhancing its efficiency. Notably, the cooling effect generated by the DX SAHP on the PV panels provides a secondary benefit: it improves the efficiency of the solar energy conversion process.

In essence, the DX SAHP leverages a combination of ambient air and solar energy to provide a sustainable and efficient solution for maintaining comfortable indoor temperatures and hot water needs within a building.

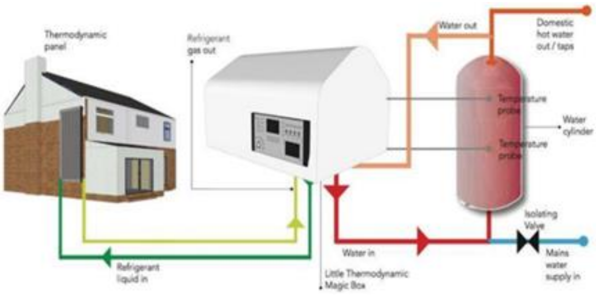


Figure 7 - Direct Expansion Solar Assisted Heat Pump Schematics

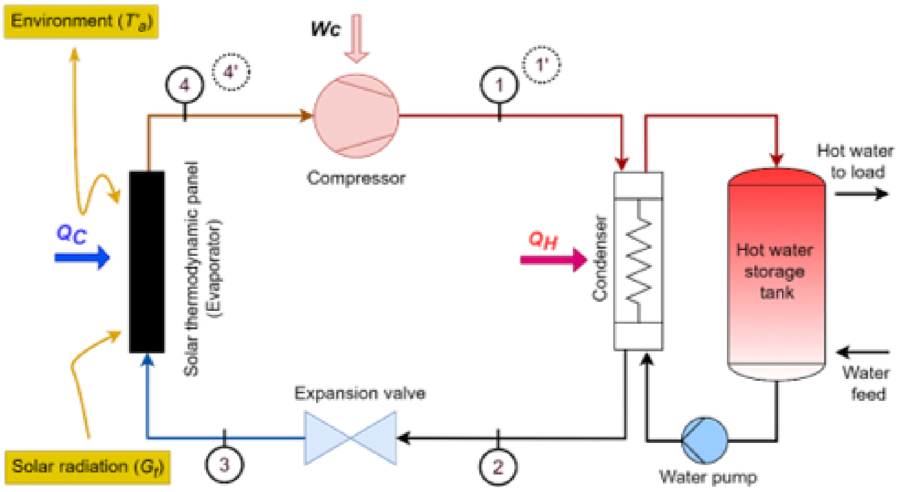


Figure 8 - Schematic of Solar Assisted Heat pump

The table below provides a detailed breakdown of the performance specifications for the Direct Expansion Solar Assisted Heat Pump (DX SAHP) system implemented within the SUREFIT project.

Table 8 - Direct Expansion Solar Assisted Heat Pump specifications

Properties	Value	Unit
System capacity	3.0	kW
	5	
	7	
	11	
Heated water output	52	L/h
	80	
	143	
	180	
Suggested water tank capacity	60-150	L
	150-260	
	200-320	
	200-420	
Delivery efficiency	98	%
	1(3)	Panels per kW

Solar thermodynamic panels required (for system capacity)	2(5)	
	3(7)	
	4(11)	
Cost - purchase	Under evaluation.	kW-€/unit
Cost - maintenance	180	€/year/unit

2.5.3.3 H - Evaporative cooler

Air-conditioning systems are significant consumers of energy, placing a strain on electricity infrastructure and contributing to greenhouse gas emissions. Evaporative cooling offers a highly energy-efficient alternative in suitable applications. Traditional dew point cooling can effectively decrease air temperature close to the dew point without increasing moisture content, maximizing the cooling capacity of dry air. However, conventional dew point cooling heat exchangers are often complex, expensive to manufacture, and unsuitable for handling large airflows.

Figure 9 – Evaporative cooler system

The SUREFIT project incorporates a novel dew point core developed by UNOTT (UK Patent: Air Conditioning, WO 2010/034994) to address these limitations (Figure 11). This innovative core utilizes a structure like evaporative cooling pads, combining the benefits of both evaporative cooling and dew point cooling while eliminating the drawbacks associated with traditional dew point systems. The core employs two key techniques:

- Special Corrugated Plates for Dew Point Cooling: These plates optimize the process of dew point cooling.
- Special Sealing Technology: This technology ensures efficient sealing within the core.

A significant advantage of this novel core is its scalability. Unlike traditional dew point heat exchangers, the SUREFIT design can be easily enlarged to handle large airflow volumes without experiencing increased pressure drops. Partners within the project have already completed the initial development of a psychrometric energy core (PEC) prototype based on this novel concept.

The table below provides a detailed breakdown of the performance specifications for the evaporative cooling system considered within the SUREFIT project.

Table 9 - Evaporative cooler system specifications

Properties	Value	Unit
System capacity	0.5	kW
	1.0	
	3.0	
	4.5	
Airflow rate	504	L/h
	1008	
	3024	
	4500	
Water consumption	4.5	L/h
	9	
	27	
	39	
Delivery efficiency	98	%
Cost - purchase	0.5 – 450	kW-€/unit
	1.0 – 675	
	3.0 – 1687	
	4.5 – 2700	
Cost - maintenance	0	€/year/unit

2.5.3.4 I - Ground Source Heat Pump (TP GSHP)

The SUREFIT project incorporates a novel Ground Source Heat Pump (GSHP) system developed by UNOTT. This innovative design utilizes a hand-held piler for heat source extraction, offering a cost-effective and easy-to-install alternative to conventional GSHPs. This approach is particularly advantageous in regions with limited drilling capabilities.

The system relies on thermal pipes, either solid rods or tubes containing a liquid like propylene glycol/water solution. The heating process involves circulating the glycol solution within the pipes to extract heat from the ground. The table below outlines the key technical properties of the SUREFIT GSHP system.

Table 10 - Ground Source Heat Pump specifications

Properties	Value	Unit
System capacity	1.3	kW
	3.0	
	6.0	
	7.0	
Heated water output	224.1	L/h
	517.2	
	1012.8	
	1344	
Suggested water tank capacity	250-300	L
	300-350	
	500-800	
	500-800	
Delivery efficiency	98	%
Life span	25	yrs
Heat pipe length required (for system capacity)	13(1.3)	meters
	30(3.0)	
	60(6.0)	
	70(7.0)	
Cost - purchase	Under evaluation.	kW-€/unit
Cost - maintenance	180	€/year/unit

2.5.3.5 J - Photovoltaic Thermal System (PV/T)

The SUREFIT project incorporates a Photovoltaic Thermal (PV/T) system developed by SOLIMPEKS. This innovative technology addresses a key challenge associated with traditional photovoltaic (PV) panels. While they generate electricity from sunlight, their efficiency degrades when they overheat. Standard commercial PV systems typically achieve an electricity conversion rate of only 10-15% of the captured solar radiation, with the remaining energy lost as heat.

The SOLIMPEKS PV/T system ingeniously captures this waste heat and utilizes it for thermal energy production. This unique design allows a single panel to generate both electricity and usable thermal energy, maximizing overall energy output. The system absorbs heat generated by the PV module to produce hot water, optimizing PV efficiency by transferring heat into water for domestic hot water (DHW) production. Additionally, a portion of the generated thermal energy can be used for space heating within the building.

The table below outlines the key technical properties of the SOLIMPEKS PV/T system.

Table 11 - Photovoltaic Thermal System specifications

Properties	**Value**	**Unit**
Dimensions	2280x 1185 x 60	mm
Gross area	2,7	m2
Weight	40	kg
Nominal power (W_p)	540	W
Short circuit current (I_{sc})	13,68	A
Open circuit voltage (V_{oe})	49,98	V
Max power voltage (V_{pm})	38,73	V
Liquid content	0,85	L
Max operating pressure	8,6	bar
Lifetime	20	Years
Cost - purchase	550	€/unit
Cost - maintenance	80	€/hour of work

2.5.3.6 K - Window Heat Recovery System (WHR)

Traditional ventilation methods often rely on opening windows, leading to significant heat loss from the living space and increased energy consumption for heating. The SUREFIT project incorporates a Waste Heat Recovery (WHR) system developed by UNNOT to address this challenge. This innovative technology boasts the potential to reduce annual energy bills by 20%.

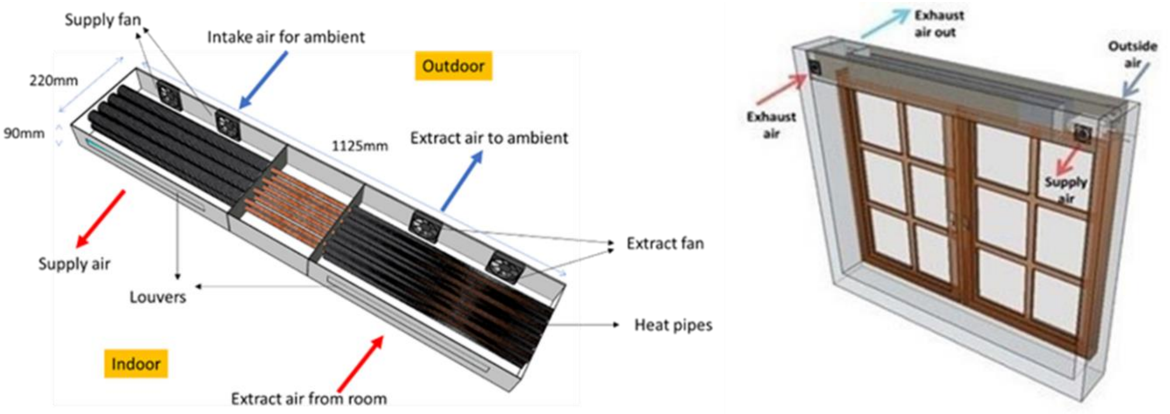


Figure 10 - Window Heat Recovery System schematics

The WHR system features compact units designed for easy installation and mounting directly onto window frames. The system operates by capturing waste heat from the room and using it to preheat incoming fresh air, resulting in significant energy savings. Evaluations indicate that the WHR system can recover over 70% of the heat required to maintain comfortable indoor temperatures.

The table below summarizes the key technical properties of the UNNOT WHR system.

Table 12 - WHR system specifications

Properties	**Value**	**Unit**
Heat recovery efficiency	>70	%
Ventilation rate	10-60	m^3/h
Max fan power	34	W
Lifespan	20	years
Cost - purchase	Under evaluation	€/unit

2.5.3.7 L - Smart controls

ONCONTROL developed a hardware and software solution to continuously monitor the atmospheric conditions inside the buildings and perform decision-making tasks to improve the occupant's safety and comfort.

The solution is composed of one coordinator device and multiple end devices that measure important data:

- Ambient (end devices spread around the building)
  - Temperature.
  - Relative Humidity.
  - Illuminance.
  - CO2, VOC, and NOX levels.

- Electrical (device installed on the switchboard)
    - Voltage.
    - Current.
    - Active power.
    - Total consumed energy.

The following images represent the installed end devices. The left one shows a switch, an energy meter, and the end device used to communicate the reading. On the right is a picture of one of the end devices installed across the multiple pilot houses (dimensions: 8.61x8.61x2.54 cm).

Figure 11 - Devices installed on the pilot houses.

The gathered data is presented in a dashboard accessible by the house owners and is used to perform control decisions. Based on the ambient data, setups and instructions to other devices can be given maintain proper levels (temperature, humidity, and gases/compounds concentrations) inside the building.

3 Decision-making

Building retrofitting encompasses making decisions regarding various stages, from choosing the building elements to be renovated, selecting alternatives for its rehabilitation, overseeing construction, operation, and use, to managing its demolition or reuse. While this process may differ between companies, evolve, and even vary within the same organisation, it is a crucial phase for the renovation journey. Effective decision-making can lead to more successful and efficient project outcomes, significantly impacting the building's life cycle.

This section presents a decision-making framework for the residential building retrofitting process, aligned with the decision-making tool developed in this project.

3.1 Decision-Making Framework

The decision-making framework depends on the previous retrofitting phases, including a thorough identification of the scope and objectives of the renovation and the definition of the criteria to be evaluated. The next steps involve selecting an appropriate method or tool to evaluate alternatives and identifying and assessing Energy Conservation Measures (ECMs). Finally, the best solutions must address the issues and goals established earlier.

3.1.1 Renovation Scope

Key considerations you shall address before initiating any retrofit scenario:

- **Project Goals:** Clearly define the primary objectives of the renovation. Are you looking to accommodate new family members, increase property value, improve living conditions, improve aesthetics, or enhance energy efficiency?
- **Scope of renovation:**
  - Radical versus targeted renovation: Decide whether to renovate the entire building or focus on specific areas.
  - Internal versus external interventions: Should it involve internal spaces, external envelope, or both?
  - System-level changes: Evaluate upgrades to building systems like heating, cooling, or ventilation.
- **Budgetary Constraints:** What is the available budget for the renovation? Assess available financial resources and explore potential funding options.
- **Building Characteristics:** Understand the building's structural, architectural, and energy performance features to identify suitable retrofitting measures later. What materials and technologies are suitable for the renovation?
- **Occupant Needs and Preferences:**

- Consider homeowners' requirements, expectations, and lifestyle to ensure the renovation aligns with their needs.
- Address how the renovation will impact the occupants. Will there be any disruptions during the process, and how can these be minimized?
- Define the desired timeline for the renovation. How long should the project take, and when should it be completed?

- **Expected future impact:** Understand the long-term implications of the renovation and align it with the goals. How will maintenance, energy consumption, and property value be affected?

3.1.2 Criteria for decision-making

Criteria selection requires alignment between stakeholders, including experts from various fields, the construction company managing the project and the building owner, while upholding sustainable development principles. This often involves balancing multiple factors and conflicting objectives.

In this context, tools and methods for multi-criteria decision-making have become popular, serving as valuable resources to address these challenges [1]. The SUREFIT project has developed a decision support tool to aid homeowners and professionals in this process, which will be addressed in section 3.1.3.

First, some key aspects for selecting alternative materials and technologies for building renovation and sustainability assessments will be highlighted. The main key performance indicators (KPIs) usually fall into three categories: economic, environmental, and social[2]. Additionally, aspects related to the construction phase, such as delivery time, technical feasibility of implementation, accessibility, and resilience, should also be addressed.

> *Note:* ***Consider Your Building's Limitations***
> *It's essential to understand what your building can and cannot handle. Some renovation ideas might not be possible due to the building's structure, age, or local regulations. Factors such as earthquakes, extreme weather, or building codes can all limit your options.*

3.1.2.1 Financial aspects

Financial factors significantly influence renovation decisions. Key considerations include:

- Initial investment costs: Assessing the upfront expenses associated with various retrofitting measures.
- Ongoing costs: Evaluating potential changes in energy bills, maintenance expenses, and other operational costs.

- Potential savings: Estimating long-term savings from reduced energy consumption, increased property value, or other benefits.
- Payback period: Calculating the time required to recoup the initial investment through energy savings or other returns.
- Financial incentives: Exploring available grants, subsidies, or tax benefits to offset costs.
- Financing options: Considering loans, mortgages, or other financing mechanisms to spread the financial burden.

One common indicator to consider is how long it will take to recover your initial investment in the renovation. This is often called the payback period. To calculate this, you can estimate the total cost of the renovation and compare it to the annual savings you'll make on your energy bills.

Simple Payback Period (SPP) = Initial Cost/ (Yearly Savings – Yearly Costs)

For instance, if your renovation saves you €200 a year on energy costs, and the renovation costs €2000, your payback period would be 10 years.

Generally, a shorter payback period is better, but it is important to consider other factors as well. More sophisticated KPIs, which require additional inputs like inflation, discount rates, and timing of savings, offer a more accurate assessment but are also more complex to calculate. This is why tools that automate these calculations and simplify the process are valuable for decision-making. You can find more details about other KPIs calculations, such as the Discounted Payback Period, in section D8.1 of this project.

3.1.2.2 Environmental aspects

The potential environmental benefits and drawbacks of different retrofitting options also play a crucial role in sustainable building retrofits. Key considerations include:

- **Energy efficiency:** Improving the building's energy performance through insulation, efficient appliances, and renewable energy integration.
- **Material sustainability:** Selecting environmentally friendly materials with low embodied energy and minimal environmental impact.
- **Waste reduction:** Minimizing waste generation during the renovation process through recycling and reuse.
- **Indoor air quality:** Enhancing indoor air quality by selecting low-emission materials and improving ventilation.
- **Climate resilience:** Adapting the building to withstand the impacts of climate change (e.g., extreme weather events).

A common approach for the sustainability analysis is to predict the expected change in environmental criteria for the retrofit scenarios and compare it with the original one. There are numerous important KPIs available for evaluating these impacts, such as:

- Heat loss coefficient.
- Energy needs.
- Renewable energy self-sufficiency ratio.
- Primary energy consumption.
- Global Warming Potential.

3.1.2.3 Social aspects

Social factors influence occupant well-being, comfort, and satisfaction. Key considerations include:

- **Occupant health and comfort:** Improving indoor air quality, thermal comfort, illuminance, and acoustic conditions.
- **Accessibility:** Ensuring the building is accessible to people with disabilities.
- **Community integration:** Considering the building's role within the community and its potential impact on social interactions.
- **Health and well-being:** Promoting physical and mental health through design features that support healthy lifestyles.
- **Social equity:** Ensuring that the renovation benefits all occupants and contributes to a more equitable living environment. Emphasizing the needs of the most vulnerable populations, particularly in alleviating energy poverty, is crucial at this stage.

By addressing these social factors, building retrofits can enhance the overall quality of life for occupants and contribute to a more inclusive and sustainable community.

3.1.3 Decision support tool

Implementing sustainability assessment tools in building retrofitting can help establish a common definition and process, requiring an explicit outline of what to evaluate. A structured and transparent process is crucial, allowing alternatives to be assessed and compared from various perspectives while maintaining enough flexibility for questioning and improving current policies [3].

Considering the objectives set for the project, the SURe^{3}FIT operational tool was designed to integrate economic and environmental criteria while also anticipating benefits that extend to the social aspects of sustainability (Figure 12).

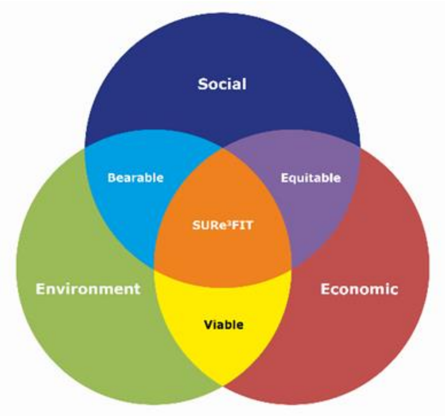


Figure 12 - e³ - Energy Efficiency in the Built Environment

3.1.3.1 Identify and evaluate ECM alternatives.

The SURe³FIT tool is a modular Microsoft Excel application that enables both the analysis and selection of individual solutions for building retrofitting (e.g., replacing a single window with a double one) and the evaluation of multiple combined measures. This comprehensive approach allows for a more integrated assessment of the building, improving the decision-making process and ensuring that the final recommendations are more cost-effective and optimal.

It considers interactions between various building elements, such as:

- Windows.
- Walls.
- Roofs.
- Floors.
- Domestic hot water, heating, and cooling systems.
- Simple solar systems.

This tool provides valuable assistance by:

- Assessing building characteristics and energy performance for both baseline and retrofit scenarios.
- Evaluating the potential impact of different retrofitting measures.
- Comparing costs and benefits of the various individual and combined identified options.

In addition, the SURe³FIT tool is flexible and offers two main possibilities for assessing Energy Conservation Measures (ECMs):

- Option I: Simulate Energy Data via the SURe³FIT Tool (recommended for users with limited data).
- Option II: Manually Input External Energy Data (bypassing the "Energy Performance Simulation" module).

Note: ***Simulate Appropriate Building Solutions***

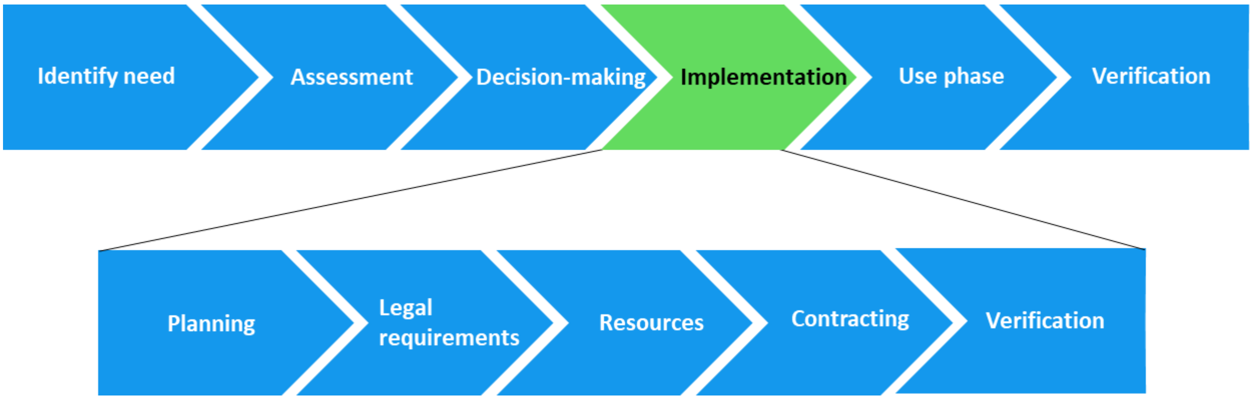
Remember to consider the building's limitations and the feasibility of the solutions you wish to analyse, such as technical constraints and regulatory requirements. Only simulate measures in the platform that are coherent with your specific analysis scenario.

3.1.3.2 Decide on the best alternative

To determine the best alternative for building rehabilitation, the SURe³FIT tool introduces several enhancements to the cost-optimality methodology defined by Delegated Regulation 244/2012 and EN 15459 [4] [5]. Notably, it incorporates a life-cycle approach, aligning with the latest goals and guidelines set forth by the new Energy Performance of Buildings Directive [6]. Additionally, the tool facilitates the comparison of solutions through various financial parameters, such as Return on Investment (ROI) and Adjusted Payback Period (APP), in addition to the Net Present Value (NPV) KPI.

The detailed step-by-step process for using the tool and obtaining the results, as well as information on the structure, settings overview, output descriptions, and more, is available in Deliverable 7.3 of this project.

4 Implementation



4.1 Planning the implementation

Once you have established a budget – explored the financial incentives & options- and selected the ECMs selection, it's time to plan the renovation process.

It may involve: i) developing a timeline for the retrofitting project (include a start date, estimated completion date, and milestones along the way); ii) obtaining permits (some ECMs may require permits from local or state authorities – check these before beginning work to avoid delays or fines); iii) hire services/products/professionals (depending on the complexity of the retrofitting project, you will likely need to hire professionals to install new technologies and upgrades)

4.1.1 Develop a timeline

Create a detailed project timeline outlining start and end dates, as well as key milestones for each renovation phase. Some key phases that might need to be taken into consideration:

- Planning of the implementation: Feasibility studies, design, permits, material sourcing.
- Preparation of the building: Site setup, equipment mobilization, utility disconnections.
- Execution of the defined works: Insulation, window replacement, HVAC upgrades, electrical works, or others.
- Completion and final checks: System testing, final inspections.

A good practice is to consider potential delays on the several phases and allocate buffer time.

4.1.2 Obtain necessary permits

Research local building codes and regulations, determine necessary permits based on your renovation's scope, and apply for them in advance to prevent delays. Navigating the permit process can be complex. To ensure your renovation complies with regulations, follow these steps:

- **Understand local requirements:** Research EU directives, national building codes, and local regulations relevant to your project. Consider factors like climate, building age, and intended use.

- **Determine permit needs:** Assess which permits are necessary based on the scope of your renovation.
- **Seek professional advice:** Consult with architects, engineers, or legal experts to ensure compliance.
- **Prioritize energy efficiency:** Adhere to energy efficiency standards and consider obtaining an energy performance certificate if required.
- **Address health and safety:** Implement safety measures for workers and occupants.
- **Consider accessibility:** Make your building inclusive by following accessibility guidelines.
- **Preserve heritage:** If applicable, obtain necessary approvals for renovating historic buildings.

Note: ***Administrative process within SUREFIT***

As part of the SUREFIT project's Spanish pilot, securing city council approval was essential before installing the new technologies. To streamline this process, we proactively engaged with the Valladolid City Council's Urbanistic Licensing Department for early project review. While navigating this process, we identified and fulfilled unexpected tax obligations not included in the initial budget. Ultimately, the permit application was submitted without encountering significant obstacles.

4.1.3 Hire services/products/professionals

Depending on the scope of work, you may need to hire contractors, installers, or consultants to handle specific tasks. This could include professionals skilled in insulation, plumbing, electrical work, or other specialized areas.

4.2 Installation of technologies: best practices

Within the next sections the Installation of the SUREFIT technologies is briefly presented. A full description of the Technology-Specific Guidelines can be found at the end of this document.

4.2.1 Passive technologies

4.2.1.1 A – (Bio)-Aerogel insulation

Bio-aerogel insulation is typically delivered in panels or rolls. Due to its weight, it's recommended to use appropriate lifting equipment and personal protective gear, such as a dust mask and eye protection. The installation area should be clean and dry.

Bio-aerogel panels or rolls are mechanically fixed to the substrate using suitable fasteners. Care should be taken to avoid damaging the material during cutting and installation. For optimal performance, ensure tight fitting between panels and address any potential air leakage points.

Like bio-aerogel, **silica-aerogel** insulation is typically delivered in panels or rolls and requires appropriate handling and protective gear. The installation process involves securing the material to the substrate using mechanical fixings. Careful attention should be paid to ensure proper fit and prevent thermal bridging.

4.2.1.2 B - Insulating breathable membrane

The Skytech Pro XL membrane is primarily designed for external façade applications, requiring a ventilated air gap for optimal performance. However, it can also be used as interior insulation.

To install the membrane, a frame is typically constructed. The membrane is then placed on the frame, ensuring proper tension and alignment.

4.2.1.3 C - Phase changing materials panel (PCM Panel – ThinIce®)

ThinIce® panels are typically integrated into underfloor heating systems or installed as ceiling panels. For underfloor applications, the panels are placed within the heating system's structure. When used in ceilings, they are installed above standard ceiling tiles. Proper installation is crucial for optimal performance and heat transfer.

4.2.1.4 D - Prefabricated Panels

Prefabricated panels offer an efficient and effective method for improving building insulation and thermal performance. These panels typically consist of an insulation core sandwiched between outer layers for protection and aesthetics.

Prefabricated panels are designed for quick and easy installation. The specific process may vary depending on the panel type and building design. Generally, the panels are attached to the building's exterior using appropriate fasteners and adhesives. Proper installation ensures optimal thermal performance and weatherproofing.

4.2.1.5 E - Lighting - Daylight Louvers

The blinds are installed either behind the window or on the window wing. Preferably the blinds are installed in a glazing bead installation. The blinds can be motorized or controlled by hand crank.

4.2.2 Active technologies

4.2.2.1 F - Photovoltaic vacuum glazing window (PV-VG)

Handling PV-VG units requires care due to their glass components. Use appropriate protective gear and handling techniques to prevent damage. Proper installation involves careful placement within a flat frame, using suitable bedding materials, and avoiding excessive pressure on the glass.

4.2.2.2 G - Direct Expansion Solar Assisted Heat Pump (DX SAHP)

Proper installation of a DX SAHP is crucial for its efficient operation and longevity. Key considerations include:

- **Site selection:** Choose a location with appropriate clearances for maintenance and avoid areas exposed to hazardous materials or extreme weather conditions.
- **Level foundation:** Install the unit on a flat, level surface to ensure proper drainage and stability.
- **Electrical connections:** Adhere to electrical codes and regulations, providing adequate power supply and grounding.
- **Plumbing connections:** Use appropriate materials and fittings, ensuring proper insulation and water flow.
- **Ventilation:** Allow sufficient airflow around the unit for optimal performance.

4.2.2.3 H - Evaporative cooler

Proper installation of an evaporative cooler is essential for optimal performance and efficiency. Key considerations include:

- **Location:** Choose a suitable location with adequate airflow and access for maintenance.
- **Levelling:** Ensure the cooler is level to prevent uneven water distribution.

- **Water supply:** Connect the cooler to a reliable water supply and install a drain for excess water.
- **Electrical connections:** Adhere to electrical codes and regulations for safe and proper installation.
- **Ductwork:** If applicable, connect the cooler to ductwork for efficient air distribution.

4.2.2.4 I - Ground Source Heat Pump (TP GSHP)

GSHP systems involve the installation of ground heat exchangers and the heat pump unit itself.

Ground heat exchangers: Typically, vertical ground loops are used due to their cost-effectiveness. These loops consist of pipes buried in the ground to absorb or release heat. Proper depth and spacing are crucial for efficient heat transfer.

Heat pump unit: The heat pump unit is installed indoors, connected to the ground loops and the building's heating and cooling system. Adequate space and proper ventilation should be provided for the unit.

4.2.2.5 J - Photovoltaic Thermal System (PV/T)

Installing a PV/T system requires careful planning and adherence to safety guidelines. Key considerations include:

- Site assessment: Evaluate the roof's structural integrity, orientation, and tilt to determine suitability for PV/T installation.
- Component handling: Exercise caution when handling the system's components due to their weight and potential for damage.
- Electrical safety: Ensure compliance with electrical regulations and proper grounding to prevent electric shock hazards.
- Roof mounting: Securely mount the PV/T panels to the roof using appropriate hardware and following manufacturer's guidelines.
- Plumbing connections: Connect the thermal loop to the building's heating or cooling system.
- Electrical connections: Connect the PV modules to the inverter and electrical grid.

4.2.2.6 K - Window Heat Recovery System (WHR)

The WHR unit is designed for relatively easy installation. Key steps include:

- Site preparation: Determine the optimal location for the unit, considering factors like airflow and accessibility.

- Wall installation: Prepare the wall opening using the provided template and install the wall housing component.
- Electrical connections: Connect the unit to the power supply according to the provided instructions.
- Ducting: Connect the ventilation ducts to the unit, ensuring proper airflow and sealing.

4.2.2.7 L - Smart controls

The end devices to be installed on the different parts of the building are powered by three AAA batteries, estimated to last over 1 year. When the batteries are replaced, the device automatically reconnects to the networks and transmits the acquired data. They shall be installed in a place representative of the environment to measure (Figure 13).

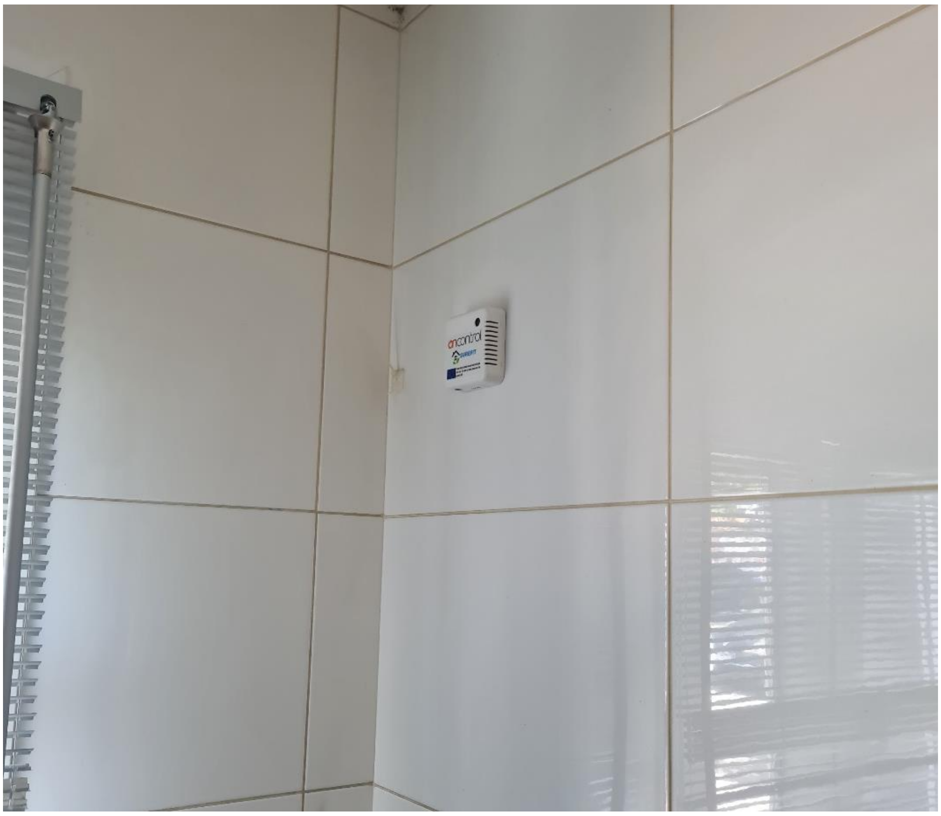
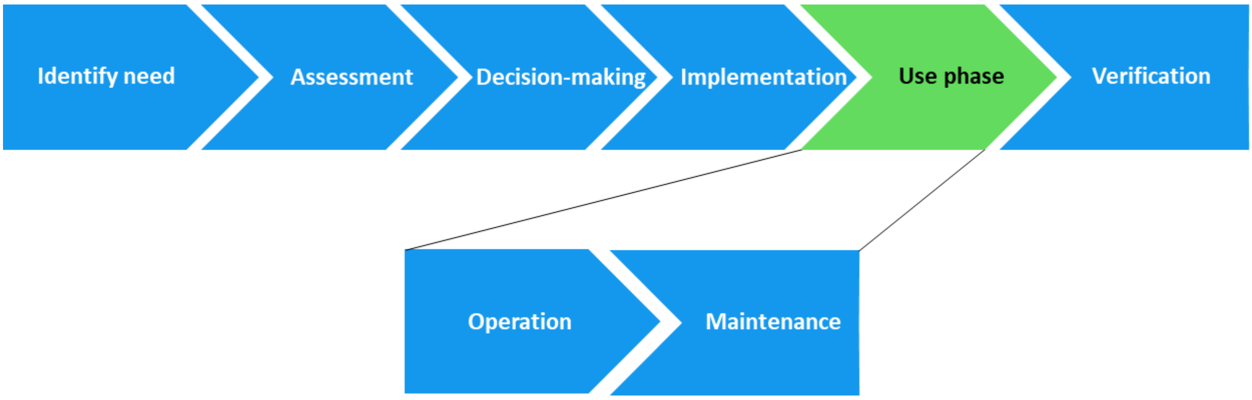


Figure 13 - Example of a good placement of the end device.

5 Use phase (Operation & maintenance)



As part of the process of home retrofitting, homeowners need to learn how to operate new technologies installed during the retrofitting project. This requires reading and understanding the user manual for each technology.

User manuals provide detailed instructions on how to use a particular technology, including safety guidelines, troubleshooting tips, and maintenance requirements.

Within the next sections the Operation & Maintenance of the SUREFIT technologies are briefly presented. A full description of the Technology-Specific Guidelines can be found at the end of this document.

5.1 OPERATION

5.1.1 Passive Technologies

5.1.1.1 A - Bio-aerogel insulation

Bio-aerogel insulation acts as a thermal barrier, reducing heat transfer through walls, roofs, or floors. Its hydrophobic properties help prevent moisture absorption, minimizing the risk of mould and mildew growth.

Silica-aerogel insulation functions as a thermal barrier, effectively reducing heat transfer. Its low thermal conductivity helps maintain indoor comfort and energy efficiency.

5.1.1.2 B - Insulating breathable membrane

When used as a façade component, the membrane's breathability allows moisture vapor to escape while preventing rainwater ingress. This creates a ventilated air gap that enhances insulation performance.

As interior insulation, the membrane provides thermal resistance, reducing heat transfer and improving energy efficiency.

5.1.1.3 C - Phase changing materials panel (PCM Panel – ThinIce®)

ThinIce® panels utilize phase change material (PCM) technology to store and release thermal energy. During the day, the PCM absorbs excess heat, preventing overheating. At night, the stored heat is released, providing a comfortable environment without relying on additional heating systems.

5.1.1.4 D - Prefabricated Panels

Once installed, prefabricated panels act as a thermal barrier, reducing heat transfer and improving energy efficiency. The insulation core prevents heat loss in winter and heat gain in summer, contributing to a comfortable indoor environment.

5.1.1.5 E - Lighting - Daylight Louvers

The task of the retro-louvers is to protect the interior from overheating and at the same to illuminate the room with natural daylight. In order to achieve those tasks, the louvers are designed bifocal: The V-shape part of the louvers is oriented to outside and retro-reflects the sun back into the sky (Fc-value for high angles of incidence in summer approx. 0.3). The light shelf which is oriented to the interior takes care of the daylight illumination in room depths. Even though the blinds are mirrored on the surface, they are glare free due to the special reflection contours.

As opposed to standard blinds, the innovative RETROLux blinds should not be closed during high angles of incidence. They have their best efficiency in open, horizontal position. Only for very low angles of incidence, the blinds can be closed by tilting the louvers. By hand crank the blinds can be wrapped. For wrapping the shining upper side of the louvers should always be turned inside. The daylight louvers are almost maintenance free. After 5-10 years it is suggested to use a brush to take of the dust. After 15-20 years, the blinds can be dipped into an ultrasonic bath to remove the dust from the surface. There are ultrasonic machines for blinds available. It is also possible to remove the dust by taking the blinds of the window, putting them on a table and cleaning the single louvers with a cloth and bio ethanol.

5.1.2 Active Technologies

5.1.2.1 F - Photovoltaic vacuum glazing window (PV-VG)

PV-VG windows generate electricity through integrated photovoltaic cells while providing insulation and daylighting benefits. The vacuum between the glass panes enhances thermal performance and reduces energy consumption.

5.1.2.2 G - Direct Expansion Solar Assisted Heat Pump (DX SAHP)

A DX SAHP harnesses solar energy to enhance the efficiency of a heat pump system. Solar panels capture sunlight and transfer heat to the heat pump's refrigerant, improving its performance. The system provides both heating and cooling functions, depending on the climate and user needs.

5.1.2.3 H - Evaporative cooler

Evaporative coolers work by passing air through a wetted filter pad. As the water evaporates, it cools the air, reducing indoor temperature. These coolers are most effective in dry climates where humidity levels are low.

5.1.2.4 I - Ground Source Heat Pump (TP GSHP)

GSHP systems utilize the ground as a heat source or sink. The heat pump extracts heat from the ground in winter and transfers it to the building. In summer, the process is reversed, with heat from the building transferred to the ground. This efficient system reduces reliance on traditional heating and cooling methods.

5.1.2.5 J - Photovoltaic Thermal System (PV/T)

PV/T systems generate both electricity and heat. The photovoltaic cells convert sunlight into electricity, while the thermal component collects solar heat for water heating or space heating applications. The system's performance is influenced by factors such as solar radiation, panel orientation, and weather conditions.

5.1.2.6 K - Window Heat Recovery System (WHR)

The WHR unit operates by exchanging heat between incoming and outgoing air streams. The system's fans draw in fresh air while expelling stale air, recovering heat in the process. The recovered heat is then transferred to incoming fresh air, improving indoor comfort and energy efficiency.

5.1.2.7 L - Smart controls

The end devices work without making noise or emitting light to not disturb the occupants. The data is transmitted wirelessly, and the fans' speed is controlled automatically. Nevertheless, the owners can access a web interface, where they can manually regulate the fans' behaviour, if desired.

5.2 MAINTENANCE

5.2.1 Passive technologies

Note: ***Passive systems /Healthy Building Envelope***

The building envelope acts as a protective barrier, regulating temperature, air quality, and moisture levels within your home. Regular inspection and maintenance of its components—roof, walls, windows, and doors—are crucial for preserving energy efficiency, comfort, and structural integrity. Prioritize routine checks, cleaning, and repairs to identify and address issues promptly. Pay close attention to areas prone to damage, such as roof flashings, wall corners, and window seals. Consider the impact of local climate conditions and implement specific maintenance practices accordingly. By investing in proper building envelope care, you can extend the lifespan of your home, reduce energy consumption, and create a healthier living environment.

5.2.1.1 A – (Bio) Aerogel insulation

Bio-aerogel insulation generally requires minimal maintenance. Regular inspections for signs of damage or deterioration are recommended. If necessary, minor repairs can be conducted by replacing damaged sections. The specific maintenance requirements may vary depending on the installation location and environmental conditions. The aerogel insulation has a life expectancy of 40+ years.

Silica-aerogel insulation generally requires minimal maintenance. Regular inspections for signs of damage are recommended. Due to its hydrophobic properties, it is resistant to moisture and mould growth. However, it's essential to maintain proper ventilation in the building to prevent condensation and potential damage to the insulation. The silica-aerogel insulation has a life expectancy of 40+ years.

5.2.1.2 B - Insulating breathable membrane

Regular inspection of the membrane is recommended to identify any potential damage or deterioration. If necessary, minor repairs can be conducted by replacing damaged sections. Proper ventilation should be maintained to ensure the membrane's optimal performance.

5.2.1.3 C-Phase changing materials panel (PCM Panel – ThinIce®)

ThinIce® panels generally require minimal maintenance. Regular inspections for signs of damage or deterioration are recommended. If necessary, damaged panels can be replaced. Proper ventilation should be maintained to prevent moisture build-up. The life expectancy of these panels is upwards of 25 years.

5.2.1.4 D-Prefabricated Panels

Prefabricated panels require minimal maintenance. Regular visual inspections should be conducted to check for any signs of damage, such as cracks or delamination. If issues are identified, repairs should be carried out promptly to maintain the panel's performance.

5.2.1.5 E-Lighting - Daylight Louvers

The life expectance is minimum 30 years for the louvers and spare parts. Wear parts are lifting cords and eventually the ladder cords. One should check each year whether those parts show wear and tear. In case of tear, they can be replaced by any sunshade specialist.

5.2.2 Active technologies

Note: ***Active systems***

Active thermal systems, such as heating, ventilation, and air conditioning (HVAC) systems, rely on mechanical equipment to regulate indoor temperature and air quality. To maintain optimal performance and efficiency, schedule regular professional maintenance, including filter cleaning, coil inspections, and system calibration. Consistently clean or replace air filters to improve airflow and reduce energy consumption. Optimize system efficiency by programming your thermostat to suit your lifestyle and consider upgrading to newer, high-efficiency models when feasible. Develop a comprehensive maintenance plan, including regular inspections of both active and passive system components, and keep detailed records for future reference. Consult HVAC professionals for complex repairs or system upgrades.

5.2.2.1 F-Photovoltaic vacuum glazing window (PV-VG)

Regular cleaning of the glass surface is essential to maintain optimal performance and appearance. Avoid using harsh chemicals or abrasive materials. Inspect the window frame and seals for any signs of damage and address issues promptly to prevent water ingress. The PV-VG system has a life expectancy of 30-years.

5.2.2.2 G-Direct Expansion Solar Assisted Heat Pump (DX SAHP)

Regular maintenance is essential for the DX SAHP's optimal performance and longevity. Key maintenance tasks include:

- Visual inspections: Regularly check for any signs of damage, leaks, or abnormal operation.
- Cleaning: Clean the unit's condenser and evaporator coils to remove dirt and debris.
- Filter maintenance: Replace or clean air filters as needed to ensure proper airflow.
- Refrigerant levels: Monitor refrigerant levels and address any leaks promptly.
- Electrical connections: Inspect electrical components for any signs of wear or damage.

The DX-SAHP has a life expectancy of 20-years.

5.2.2.3 H - Evaporative cooler

Regular maintenance is crucial for the efficient operation and longevity of an evaporative cooler:

- Cleaning: Regularly clean the filter pads, water tank, and exterior of the unit to prevent buildup of dirt and minerals.
- Water quality: Use clean water to avoid mineral deposits and algae growth.
- Drainage: Ensure proper drainage to prevent water leaks and damage.
- Electrical components: Inspect electrical connections and components for any signs of wear or damage.

The Evaporative cooler has a life expectancy of 20-years.

5.2.2.4 I - Ground Source Heat Pump (TP GSHP)

The same as DX SAHP maintenance guide, i.e., regular maintenance is essential for optimal GSHP performance and longevity:

- System inspections: Conduct periodic inspections to check for leaks, corrosion, or other issues.
- Filter cleaning: Clean or replace air filters as needed to maintain efficient airflow.
- Refrigerant levels: Monitor refrigerant levels and address any leaks promptly.
- Ground loop monitoring: Monitor ground loop fluid levels and quality to prevent system degradation.

The TP GSHP has a life expectancy of 20-years.

5.2.2.5 J - Photovoltaic Thermal System (PV/T)

Regular maintenance is essential for optimal performance and longevity of the PV/T system:

- Visual inspections: Check for signs of damage, leaks, or debris buildup on the panels.
- Cleaning: Clean the panels regularly to remove dirt and optimize energy production.
- Electrical connections: Inspect electrical components for any loose connections or damage.
- Thermal loop maintenance: Check the thermal loop for leaks or blockages.
- Performance monitoring: Monitor the system's performance to identify any issues or degradation.

5.2.2.6 K - Window Heat Recovery System (WHR)

Regular maintenance is essential for optimal performance and longevity:

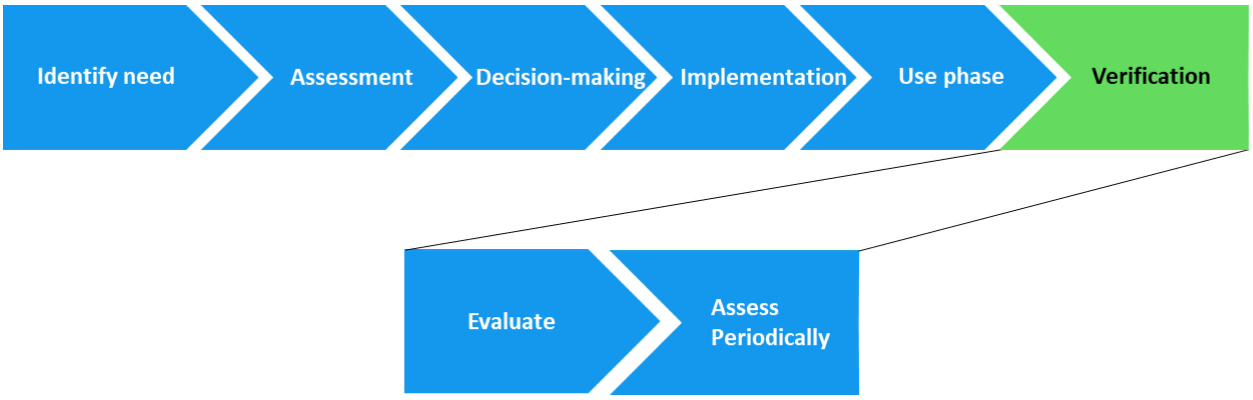
- Filter cleaning: Clean the filters regularly to prevent airflow restrictions and maintain efficiency.
- Exterior inspection: Inspect the unit's exterior for any signs of damage or wear.
- Electrical components: Check electrical connections and components for any issues.

With little maintenance required and life expectancy under the right conditions, product lifespan is over 10-years+.

5.2.2.7 L - Smart controls

The installed system works autonomously, without human intervention, except for battery replacement. The estimated lifetime is between 1 and 1.5 years, relying on a power save mode in the firmware.

6 Verification (Evaluation and Optimization)



Evaluating the level of reduction in energy consumption after renovation is an important step in assessing the effectiveness of the retrofit measures applied to the residential home. The aim of retrofitting is the improvement of the energy efficiency of a building and the reduction of its energy consumption and the evaluation of the effectiveness of the energy consumption measures allows the confirmation of whether the energy consumption reduction targets were achieved or not.

It's possible that the implemented retrofit measures did not have the expected impact. In these situations, it is necessary to identify the reasons for the underperformance and implement corrective actions.

Additionally, evaluating the energy performance post-retrofit allows for the identification of additional opportunities for improvement. Even when the energy consumption reduction goals set at the beginning of the retrofit journey were met, other retrofit measures might be identified to further enhance the building's energy performance.

Finally, verifying and evaluating the energy performance after retrofit is important to create knowledge and promote the replication of the best practices. The obtained results can be used to identify the most effective retrofit measures and share best practices with other building owners.

6.1 Periodic energy assessments

Regular energy assessments are essential to properly evaluate the long-term impact of the retrofit measures. These assessments can be done at regular intervals to track changes in energy consumption patterns over time. By comparing the energy consumption data from different time periods, it is possible to identify trends and patterns of use, evaluate the durability of the installed retrofit measures, and to detect potential issues or deterioration of the results or measures taken during retrofit.

Several steps can be stablished for a structured assessment of the retrofit works:

- Define a regular interval for conducting energy assessments after the retrofit, such as annually or biannually. A consistent schedule allows for effective tracking of energy performance over time, creating a history of results that allows long term comparison.

- Gather updated energy consumption data, utility bills, and occupancy patterns to compare against pre-retrofit figures. This information provides a foundation for a meaningful assessment of the continuous impact of the measures taken.
- Compare current energy consumption with the baseline data from before the renovation. This can help to identify trends, anomalies, or deviations from the results that may require attention.

6.1.1 Evaluation of energy targets achieved

One important factor in the evaluation process is determining if the set energy goals were met. This requires comparing the real energy usage post-retrofit with the expected energy reductions. There are various aspects to consider, including the building's occupancy schedules, weather conditions, and energy costs. If the energy goals were not met, a thorough examination should be done to pinpoint the causes and possible solutions.

- Calculate the actual energy savings achieved post-renovation by subtracting the current energy consumption from the baseline consumption.
- Account for any changes in occupancy, weather conditions, or other external factors that could influence energy consumption.
- Highlight specific energy conservation measures that have yielded significant savings. Identify any measures that did not perform as expected and explore potential reasons.

6.1.2 Evaluation of occupants' comfort improvement

One of the primary objectives of retrofitting is to enhance occupants' comfort levels. Therefore, it is crucial to evaluate the impact of the retrofit measures on indoor climate conditions. This can be achieved through occupant surveys, monitoring indoor temperature and humidity levels, and assessing thermal comfort parameters. By understanding how retrofit measures affect occupants' comfort, it is possible to identify areas for improvement and optimize the building's performance.

- Engage occupants to gather feedback on their comfort levels, indoor air quality, and overall satisfaction post-retrofit.
- Evaluate survey responses to identify trends or areas of concern related to comfort, temperature, humidity, and indoor air quality.
- If survey results indicate discomfort or dissatisfaction among occupants, investigate the root causes and take corrective actions.

7 References

[1] A. N. Nielsen, R. L. Jensen, T. S. Larsen, and S. B. Nissen, “Early stage decision support for sustainable building renovation – A review,” *Building and Environment*, vol. 103, pp. 165–181, Jul. 2016, doi: 10.1016/J.BUILDENV.2016.04.009.

[2] I. Flores-Abascal *et al.*, “A novel multicriteria methodology to assess the renovation of social buildings,” *Journal of Building Engineering*, vol. 77, p. 107505, Oct. 2023, doi: 10.1016/J.JOBE.2023.107505.

[3] L. Malmgren and K. Mjörnell, “Application of a Decision Support Tool in Three Renovation Projects,” *Sustainability 2015, Vol. 7, Pages 12521-12538*, vol. 7, no. 9, pp. 12521–12538, Sep. 2015, doi: 10.3390/SU70912521.

[4] S. Tadeu, C. Rodrigues, P. Marques, and F. Freire, “Eco-efficiency to support selection of energy conservation measures for buildings: A life-cycle approach,” *Journal of Building Engineering*, vol. 61, p. 105142, Dec. 2022, doi: 10.1016/J.JOBE.2022.105142.

[5] S. Tadeu, “Operational tool for selecting energy systems for small buildings based on useful energy needs”, In: Riffat, Su,. ed., Sustainable Energy Technologies: Proceedings of the 20th International Conference on Sustainable Energy Technologies, 15th – 17th August 2023, Nottingham, UK. University of Nottingham: Buildings, Energy & Environment Research Group. Vol. 3, Pp 148-155. Available from: nottingham-repository.worktribe.com [Last access July 4, 2024].

[6] “Directive - EU - 2024/1275 - EN - EUR-Lex.” Accessed: Aug. 30, 2024. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive