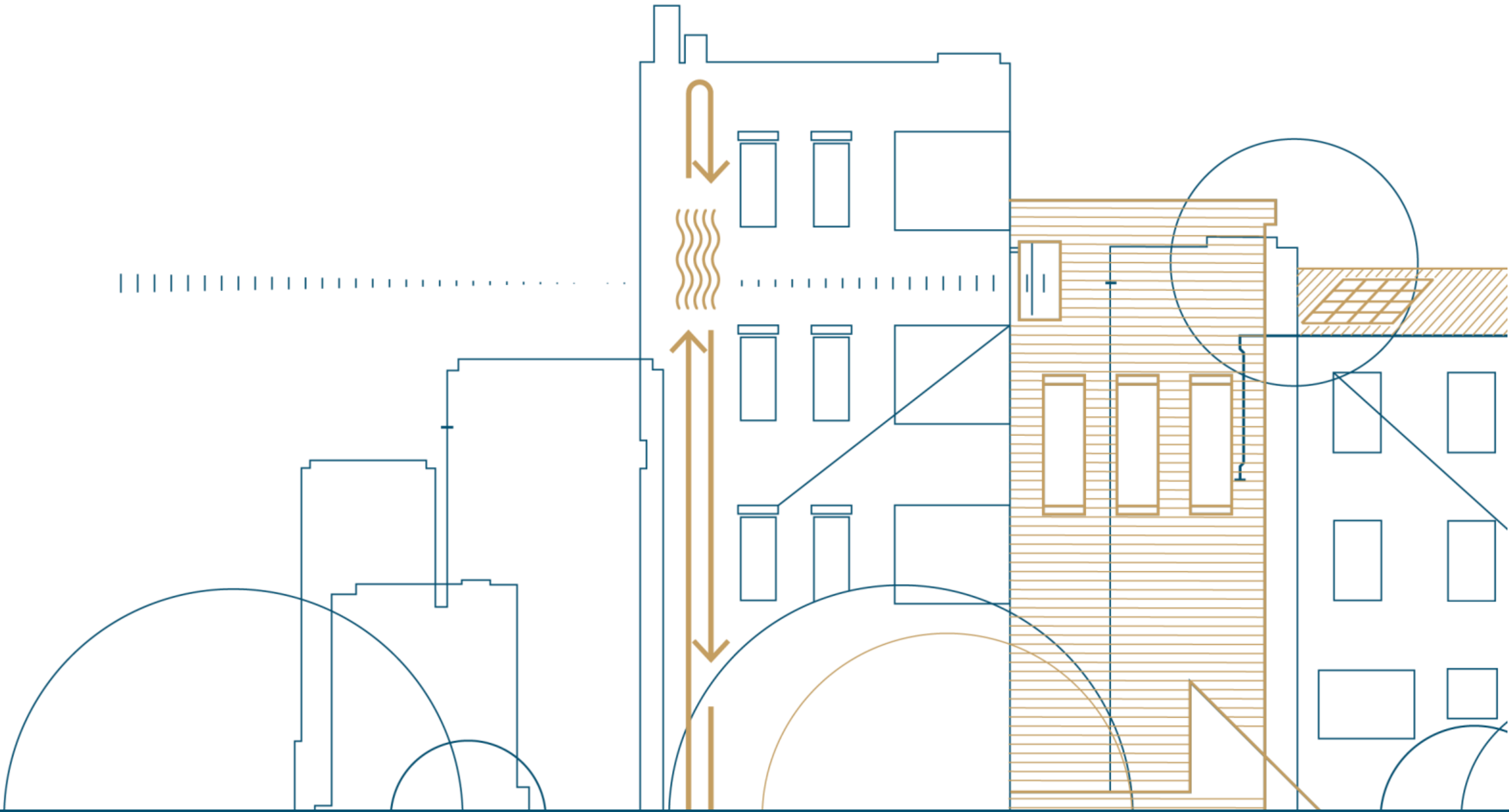
REHOUSE



D3.3

Definition of the long-term performance tests of the components of the RPs

Co-funded by the European Union

DUE DATE OF DELIVERABLE: 31.12.2023
ACTUAL SUBMISSION DATE: 28.12.2023

Project Acronym	REHOUSE
Project Title	Renovation packagEs for HOlistic improvement of EU's bUildingS Efficiency, maximizing RES generation and cost-effectiveness
Project Duration	1 October 2022 – 30 September 2026 (48 months)
GA Number	101079951

Work Package	WP3 – MEASUREMENT, EVALUATION & LEARNING METHODOLOGY, IMPACT ASSESSMENT AND PLATFORMS SPECIFICATIONS
Associated Task	Task 3.3: Methods for long-term performance assessment
Deliverable Lead Partner	AMS
Contributors	AMS, CARTIF, PSYCTO, RENEL,NTUA, RINA-C, TERA, StT, KFLEX, SUPSI, RI, PW, SUNAGE, CEA, TWR, WOODS, NBK, PLAT, ENEA, UNIBAS, ARCA, DUTH, FCHURCH
Author(s)	Maria Pappa (AMS), Constantinos Tsoutis (AMS), Sofia Papadopoulou (AMS), Pantelis Bakalis (PSYCTO), Apostolos Gkountas (PSYCTO), Evangelia Rigati (RENEL), Vicky Kotoula (RENEL), Cosimo Tafuro (RI), Fabio Parolini (SUPSI), Matteo Porta (RINA-C), Cristina Vaccarella (RINA-C), Monica Misceo (ENEA), Vincenza Luprano (ENEA), Giuseppe Santarsiero (UNIBAS), Gennaro Di Tella (ARCA), Armando De Santis (ARCA), Vincenzo De Devitii (ARCA), Eleonora Pedone (PW), Andrea Cavallaro (TERA), Mateusz Imiela (K-FLEX), Stefan Cichosz (K-FLEX), Paula Serrano Curiel (CARTIF), Julia Mª Vicente Gómez (CARTIF), Christian Orgiazzi (CEA), Fabrice Claudon (CEA), Juliette Helluin (TWR), Zoltan Pasztory (WOODS), Horvath Brigitta (PLATAN), Ioannis Atsonios (NTUA), Takács Kinga (FCHURCH), Gábor Mondovics (FCHURCH), Alex Ferrario (SUNAGE), Igor Perevozchikov (NBK), Pantelis Botsaris (DUTH), Adamantios Papatsounis (DUTH)
Reviewer(s)	NBK (Aurélien Henon), CERTH (Ioannis Labropoulos), CARTIF (Javier Antolín Gutiérrez)
Dissemination Level	Public (PU)
Type	Report
Version	Rehouse_Deliverable D3.3 (AMS)__FINAL_Last REVIEW
Status	Final Version

This Project is co-funded by the European Union under the EU Programme Horizon-CL5-2021-D4-02-02 under Grant Agreement Number: 101079951. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the CINEA can be held responsible for them.

This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under track number (SUNAGE: Contribution to the participation in the project: "REHOUSE", SBFI No. 22.00345. SUPSI: Contribution to the participation in the project: "REHOUSE", SBFI No. 22.00326).

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI

DOCUMENT HISTORY

VERSION	DATE	DESCRIPTION	AUTHOR(S)
Rehouse_Deliverable D3.3_DRAFT_V1	05/10/2023	First version prepared by AMS	AMS
Rehouse_Deliverable D3.3_DRAFT_V2	10/10/2023	Second version prepared by AMS and send to the involved partners	AMS
Rehouse_Deliverable D3.3_DRAFT_V2_PSYCTO	30/10/2023	PSYCTO's contribution for RP#1	PSYCTO
Rehouse_Deliverable D3.3_DRAFT_V2_RENEL-_updated	28/11/2023	RENEL's contribution for RP#2	RENEL
Rehouse_Deliverable D3.3_DRAFT_V2_RENEL-_demoITA	23/11/2023	Contribution for RP#4	RINA-C, KFLEX, StT, TERA, SUNAGE
Rehouse_Deliverable D3#5_RI+SUPSI SUNAGE +PW_F.V._Rev.RI	14/12/2023	Contribution for RP#5	RI, SUPSI, SUNAGE, PW
Rehouse_Deliverable D3.3_DRAFT_French_RP#6 CEA	21/11/2023	Contribution for RP#6	CEA, TECHNIWOOD
REHOUSE_D3#7-8 (WOODS)_REVISED	14/12/2023	Contribution for RP#7 and RP#8	WOODS
D3.3_NBK_contribution	23/11/2023	Specific information about the French context in what concerns technical experimentation assessment	NBK
Rehouse_Deliverable D3.3_DRAFT_V2_CAR	21/11/2023	Contribution related to legislation and testing methods	CARTIF
Rehouse_Deliverable D3.3_DRAFT_V2_NTUA	07/12/2023	Contribution related to legislation and testing methods/ Also simulation methods for RP#3	NTUA

VERSION	DATE	DESCRIPTION	AUTHOR(S)
Rehouse_Deliverable D3.3__FINAL_AMS	15/12/2023	Final version of the document sent for first review	AMS
Rehouse_Deliverable D3.3__FINAL_AMS-Reviewer_CERTH	20/12/2023	Review and comments from CERTH	CERTH
Rehouse_Deliverable D3.3__FINAL_AMS_AH	20/12/2023	Review and comments from NBK	NBK
Rehouse_Deliverable D3.3__FINAL_AMS_CAR	20/12/2023	First review and comments from CARTIF	CARTIF
Rehouse_Deliverable D3.3 (AMS)__FINAL_Last REVIEW	22/12/2023	Finalised version after incorporating all the suggestions of the reviewers	AMS

EXECUTIVE SUMMARY

This deliverable describes and plans the needed procedures that will lead to the intermediate demonstration at TRL6 of the REHOUSE Renovation Packages through long-term performance testing, along with all the activities proposed in order to evaluate the properties of their materials, components and systems.

Deliverable 3.3 and Task 3.3 of *WP3 "MEASUREMENT, EVALUATION AND LEARNING METHODOLOGY, IMPACT ASSESSMENT AND PLATFORMS SPECIFICATIONS"* are directly related to Deliverable 2.4 and Task 2.4 of *WP2 "RENOVATION PACKAGES DESIGN, SPECIFICATION & DIGITALISATION (TRL6 DEMONSTRATION)"*, where all the testing activities, simulations and measurements will be carried out to certify that the renovation packages can operate in relevant environment (TRL6).

Throughout the different chapters of this deliverable is possible to find a brief description of the Renovation Packages (RPs) and their components (Detailed specifications and characteristics of the Renovation Packages/technologies are included in Deliverable 2.2 *"Detailed specification of the renovation packages"*), the methodology and actions carried out to fulfil Task 3.3, a brief overview of the legislative situation in the European Union related to testing procedures in buildings and their components, in addition to listing and describing some existing testing techniques and methods that are commonly used and therefore potentially used as part of the REHOUSE project.

The most relevant part of this report is the selection and definition of the methods and testing procedures that will be executed for each Renovation Package to prove their transition from their current TRL (4/5) to TRL6. The procedures that will be followed for most of the RPs include a pre-assembly phase of testing, a prototype phase and a post-assembly phase. The detailed methods and the results of the application of these testing procedures to the Renovations Packages will be presented in Deliverable 2.4 *"Report of the long-term performance tests of the components of the RPs"* of WP2.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACRONYM	DESCRIPTION
ADBE	Adaptable/Dynamic Building Envelope
BIPV	Building Integrated PhotoVoltaic
COP	Coefficient of Performance
CPR	Construction Products Regulation
D	Deliverable
DHW	Domestic Hot Water
EC	European Commission
EU	European Union
HP	Heat Pump
HVAC	Heating, Ventilation & Air Conditioning
IR	Infrared Radiation
IWS	Intelligent Window System
ML	Machine Learning
MPC	Model Predictive Control
MPF	Multi-Purpose Facade
MPPT	Maximum Power Point Tracking
NZEB	Nearly Zero Energy Building
PCM	Phase Change Materials
PLC	Programmable Logic Controller
PV	PhotoVoltaic
RP	Renovation Package
TES	Thermal Energy Storage
TRL	Technology Readiness Level
WP	Work package
WT	Work task

1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE DOCUMENT

The purpose of this document is to reveal and describe the methods and tests that will be executed by the Renovation Package leaders/providers and their involved partners, in order to:

- Calculate the performance and efficiency of the components and of the renovation packages as a whole, to estimate their durability and service life.
- Simulate different components and versions of the final products, so as to make optimizations in the design or the materials of the technologies.
- Test and assess the performance of the components or the RPs as a whole, in terms of thermal properties, seismic resistance, mechanical behaviour, fire resistance, moisture resistance, etc.
- Introduce innovative techniques or methods to execute the above-mentioned evaluations/assessments.

The final aim of this Task and of this Deliverable is to propose and define a methodology for each RP that will be then followed in Task 2.4 *"Performance assessment for TRL6 demonstration"* of *WP2 "Renovation Packages Design, Specification & Digitalisation (TRL6 Demonstration)*", to ensure that the final products which will be installed in the demo sites, will reach their projected design life. Simultaneously, the tests and methods that will be used for this purpose should prove the safety and durability of the RPs and should certify that they can operate at TRL6 environment.

1.2 CONTRIBUTIONS OF PARTNERS

Task 3.3 is mainly supported by all the Renovation Package Leaders and the partners that are involved in each RP technology. In addition, assistance is needed by the research field partners which support the Renovation Package leaders in completing the testing or simulation procedures. The table below shows the related partners. However, background of other partners may be needed in special cases or for specific RPs.

PARTICIPANT SHORT NAME	CONTRIBUTIONS
RP Leaders and involved partners: PSYCTO, RENEL, AMS, RINA-C,TERA, KFLEX, StT, RI, PW, CEA, TWR, WOODS, PLAT, SUNAGE	Input related to the renovation packages and the tests and methods that will be applied in Task2.4 of WP2, to assess the performance of the renovation packages/technologies.
Research partners: NTUA, CARTIF, SUPSI, CEA, NBK	Supporting actions and assistance in the design of methodologies for each renovation package, input related to the renovation packages. In some cases, description of tests/simulations that will be executed in Task2.4.

PARTICIPANT SHORT NAME	CONTRIBUTIONS
DEMO SITE Leaders: DUTH, FCHURCH, ENEA/ARCA, CEA	Assistance provided to the RP leaders, regarding the Demo Site's specific requirements, required tests, any certifications needed, other studies, etc.

Table 1: Task 3.3 involved partners and their contributions

1.3 RELATION TO OTHER ACTIVITIES IN THE PROJECT

This Task is directly related to *Task 2.4 "Performance assessment for TRL6 demonstration"* of *WP2 "Renovation Packages Design, Specification & Digitalisation (TRL6 Demonstration)"*, during which the upgrade and tests of the eight (8) renovation packages will be carried out to certify that the technologies integrated can operate in relevant environment (TRL6).

Another task that is also closely related to Task and Deliverable 3.3 is *Task 2.2 "Detailed specification of the Renovation Packages"* of WP2, where the renovation packages describe the detailed specifications for all their components and materials. Both tasks have been progressing in parallel as a way to be able to identify the specific details of the RPs in terms of components, materials, etc. being the basis for the definition of the specific testing methods here indicated.

ACTIVITY (DELIVERABLE NUMBER)	DESCRIPTION
T2.4/D2.4	Report of the long-term performance tests of the components of the RPs
T2.2/D2.2	Detailed specification of 8 renovation packages and their components

Table 2: Related to D3.3 and Task 3.3 Deliverables

In order to achieve the TRL6 advance in Task 2.4 (where the deployment of the testing procedures will take place), in Task 3.3 we need to define the methods and methodologies that will be followed in order to accomplish the tests.

The methodology established and followed for each RP, depend on the current TRL of each RP (TRL4/5) and on the technical characteristics and components of each RP.

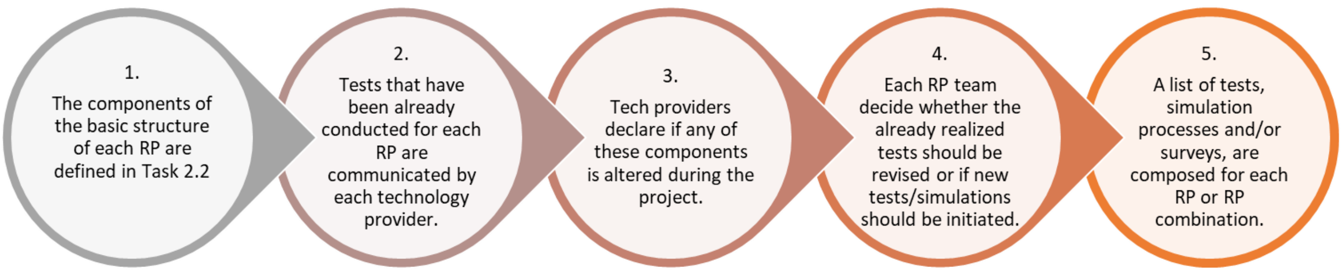


Figure 1: Main phases of Task 3.3 to select and define the RP's specific assessment methodologies

2 GENERAL DESCRIPTION OF RENOVATION PACKAGES & OF THEIR COMPONENTS

2.1 RENOVATION PACKAGE #1: MULTI-SOURCE HEAT PUMP

It is a novel multi-source heat pump designed and manufactured by PSYCTOTHERM (PSYCTO) suitable for combined exploitation of different local renewable sources, such as solar energy, geothermal energy, ambient air and thermal energy from storage systems, in order to provide space heating and cooling, and domestic hot water. The heat pump may achieve an improved COP compared to conventional heat pump systems, reaching up to 4.5, as it will be able to operate based on a control strategy that will select the heat source or a combination of these, which may lead to the most efficient system performance.

The system's energy management strategies involve optimization algorithms that take into account all the system components, allowing the activation of demand-response and the exploitation of the full value of smart appliances and smart charging of electric vehicles. The optimization can consider various possibilities for the overreaching goal such as self-consumption minimization, cost minimization or CO_2 emissions minimization. To address this, a high- and low-level optimization scheme will be developed, taking into consideration various decision variables such as the right moments to charge the space heating or the DHW buffer, and which of the sources should be used on the evaporator side (air, ground or solar). At every moment the rule-based control makes a decision based on the current state and the requirements for the next time step.

The main innovations of the heat pump system are the following:

- Multi-source operation of the heat pump, combining many natural heat sources;
- Use of thermal energy storage systems as heat source for the heat pump operation;
- Energy management and control system of the heat pump, resulting to more efficient and reliable operation;
- Selection of HFO refrigerant, allowing the use of the heat pump in the future according to F-Gas regulation;
- Integration of thermal solar panels with heat pumps leading to a higher temperature operation of the heat pump.

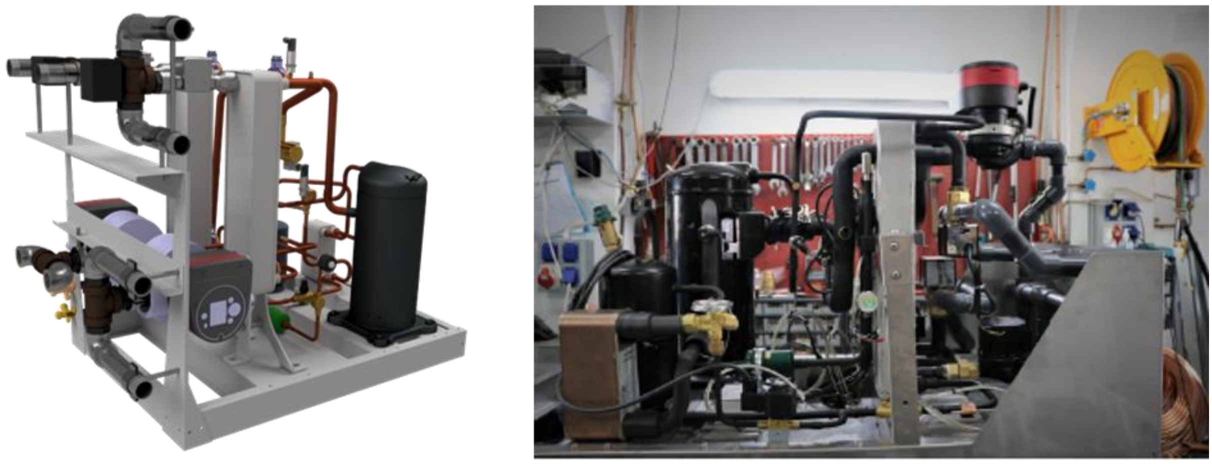


Figure 2: View of a designed multi-source heat pump with the main components

2.2 RENOVATION PACKAGE #2: ADAPTABLE/DYNAMIC BUILDING ENVELOPE (ADBE)

The ADBE prototype forms a structural ecosystem based on modern construction standards and flexible specifications. It is an aluminium-glass façade which comprises prefabricated and multi - functional panels, mounted on an aluminium structure on the building's wall. Due to its modular design, it enables its installation to each and every building's architectural design, both in residential and non-residential buildings, offering multiple additional functionalities to the existing building envelope. With the curtain wall, the construction is done on the outer side of the existing building, which enables a refurbishment under operation of the building without any technical incidents. The aluminium-based profile ensures stability, solidity, and lightness as well as mounting flexibility. Moreover, due to the adopted modular façade construction design the positioning of off-the-shelf PV solar panels, batteries and HVAC units can be adjusted accordingly, depending on the building's orientation, structural design and illumination needs. The main advantages of such solution are:

- Modular design with fully prefabricated units in various sizes: enabling fully customized fabrication, according to each building's façade topology;
- Easy installation: no need for extensive and expensive renovation actions;
- Integration of multiple off-the-shelf solutions: including modern (e.g. bio-based) insulation materials, aluminium structure (recyclable material), PV solar panels, electric batteries, HVAC units, etc;
- Integration of sensors and actuators for the full control and monitoring of the installed equipment.

An indicative ADBE system is illustrated in Figure 3.

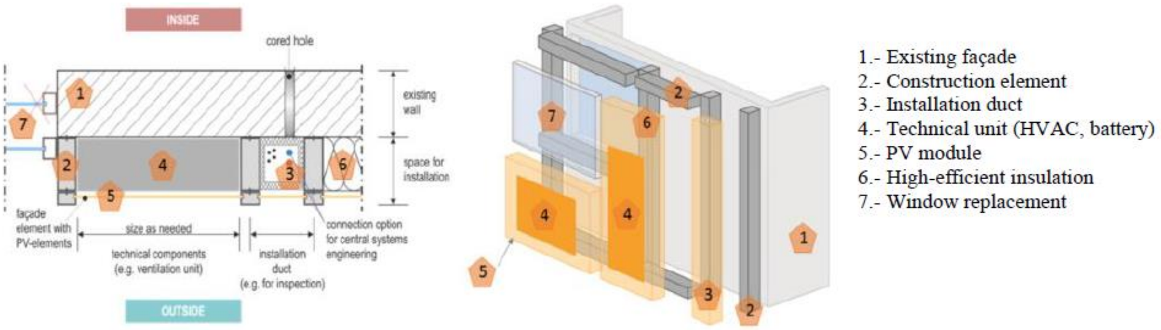


Figure 3: Indicative ADBE components and technical drawing

2.3 RENOVATION PACKAGE #3: SMARTWALL

SmartWall is a multi-functional wall system that can combine several technologies including:

- Fully-prefabricated panels with eco-friendly insulation.
- A slim type fan coil for heating and cooling.
- A mechanical ventilation system with HEPA, active carbon or other types of filter.
- Commercial PV panels with energy storage.
- Automated control system (AMScope).
- High-performance windows with smart blinds control for improved visual comfort.
- An active fire certified system to protect the vulnerable to fire components.

It is a versatile and flexible prefabricated façade system with the ability to be installed on the external or internal side of the building. Figure 4 illustrates its three basic components, which are the following:

a) Frame.
b) Insulation material.
c) Finishing layers.

Figure 4: Basic Components of SmartWall Systems

Depending on the application and the project's requirements, the materials used for the frame, the insulation and the finishing layers can be altered or adapted to the specific needs of the building. Moreover, the extra components that will be integrated in the SmartWall can also be differentiated according the corresponding demands of each project.

For the purposes of the REHOUSE project the SmartWall version that was designed after considering the requirements of the Greek demonstration building, is the one indicated in the following figure:

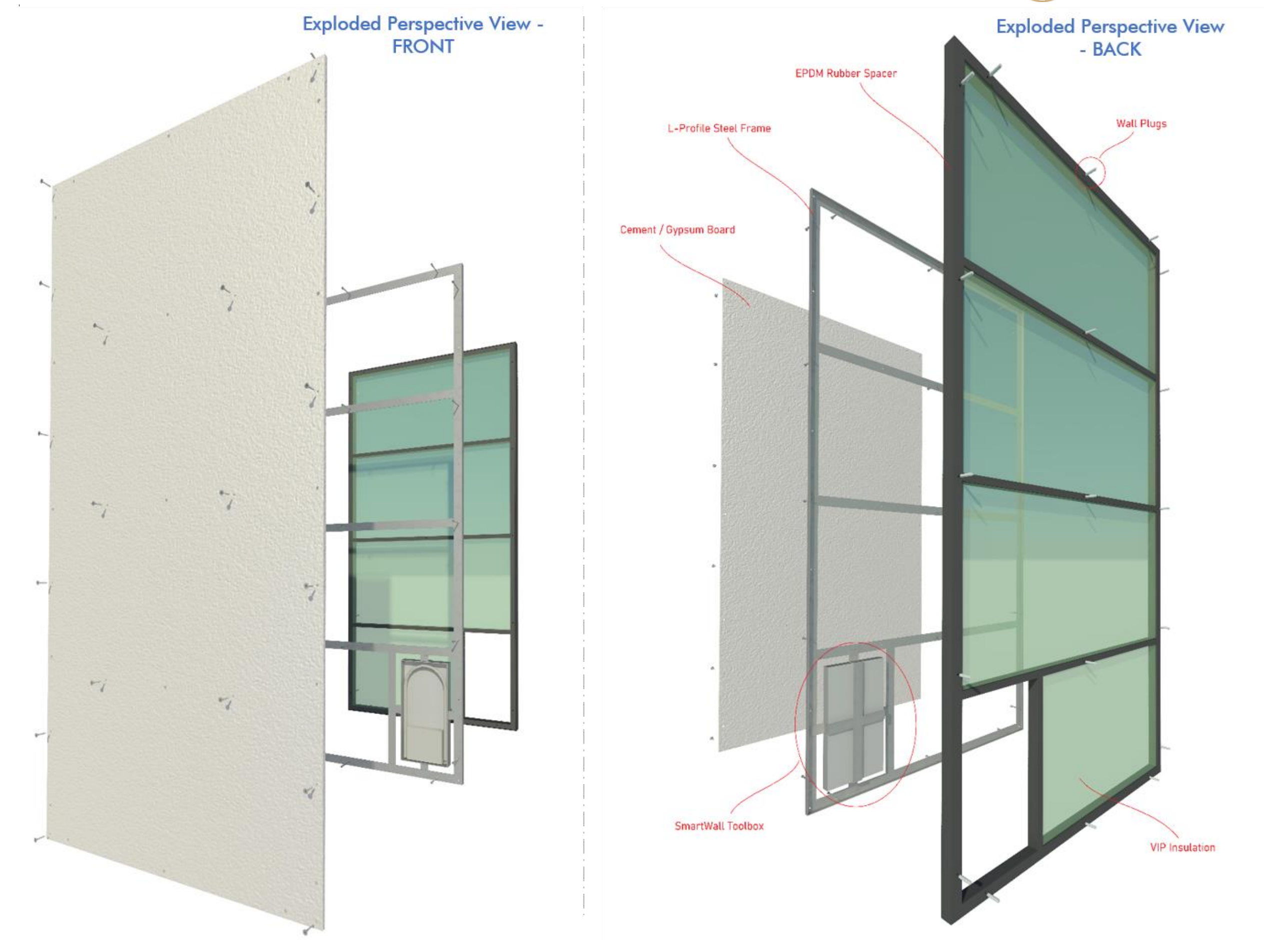


Figure 5: REHOUSE SmartWall version

The frame of this specific SmartWall will be made of steel but a lighter type of steel will be used (an L-shaped profile) and it will be protected by an insulating material to confront any potential thermal bridges. The insulation material will be under investigation and testing in Task 2.4. The finishing board of this SmartWall panel will be a cement board as the panels will be installed on the external side of the building (a gypsum board is usually utilized when the SmartWall is installed internally).

2.4 RENOVATION PACKAGE #4: CENTRALIZED HOLISTIC H&C RENOVATION KIT

RP#4 consists of a holistic renovation kit for centralized heating and cooling. It is designed based on a commercial reversible air to water heat pump fed by onsite Building Integrated PV (BIPV) and coupled with a stratified bio-based PCM *Thermal Energy Storage* (**TES**) tank developed by partners StT, K-FLEX, RINA-C and SUNAGE. In particular, the components that reveal this technological solution are then governed by a dedicated smart control system defined by StT and RINA-C, that exploits the use of smart rubber technology, introduced into the project by K-FLEX in the distribution pipes and which is then integrated into an overall open source and interoperable energy monitoring platform managed by TERA.

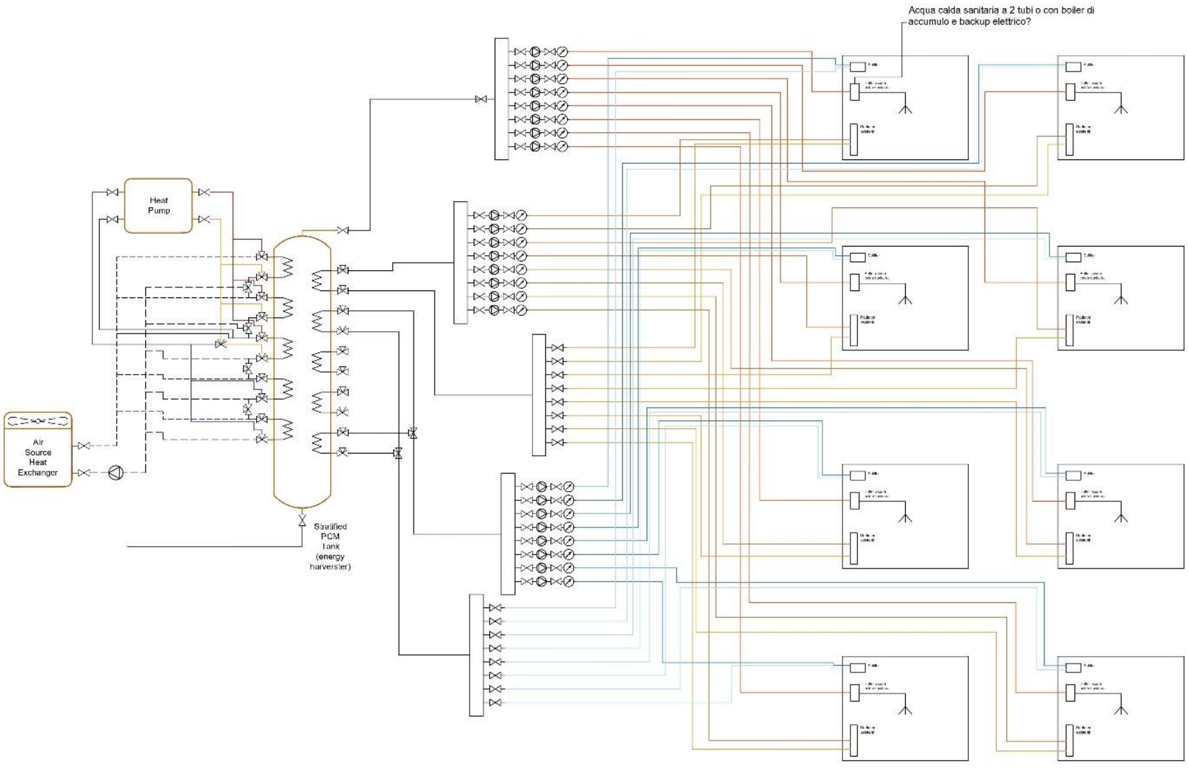


Figure 6: RP#4 Schematic Diagram

The reversible HP and bio-based layered PCM TES are the heart of the renovation kit. In reference to the innovative TES system, the latter combines latent energy storage (PCM) and thermal stratification in a single concept defined by a simple tank filled with several layers of PCM with different temperatures of change of phase temperature. This allows for forced stratification within the tank, adding the benefits of increased PCM-specific storage capacity. TERA will develop the optimized control system that will be based on the mutual interaction of *Model Predictive Control* (**MPC**) and *Machine Learning* (**ML**) techniques that will reside in the open-source monitoring and management framework. MPC and ML will be implemented to determine in each operational phase the best temperature level according to available source temperatures and those sink temperatures required to cover the space heating, space cooling and domestic hot water (**DHW**) needs. Moreover, such control will integrate continuous information of the distribution temperatures provided by a cutting-edge monitoring solution based on a PCM rubber embedded into the pipes' insulation.

Additionally, the smart rubber technology proposed by K-flex, is an insulating material enriched with the addition of bio-based waxes that exhibits the properties of phase change materials (**PCMs**), and its performance is based on detecting the change in electrical resistance of the material with increasing temperature. The PCM waxes are designed to amplify the signal at well-defined points - the points of exothermic melting of the waxes. As the temperature increases, a change in the wax's state of aggregation occurs, accompanied by the release of heat. Thus, a higher energy gain results in a more intense change in the electrical resistance of the material. Materials prepared in this way are tested in terms of: the appropriate wax content, the properties of the material produced, and their ageing characteristics under different conditions. Thus, providing a comprehensive picture of the properties of smart rubber. The final step is to optimise the sensory properties of the material – correctly reading the recorded signal and attributing changes to the ambient temperature.

For the correct function of the system is very important the knowledge of the state of charge of the different layers of PCMs. This information will drive the optimization algorithm developed to increase the use of renewable energies, reduce or recover waste heat and optimize the use of the heat pump. The development and test of innovative PCM charge sensors, embedded in the tank, is a very important part of the storage system itself.

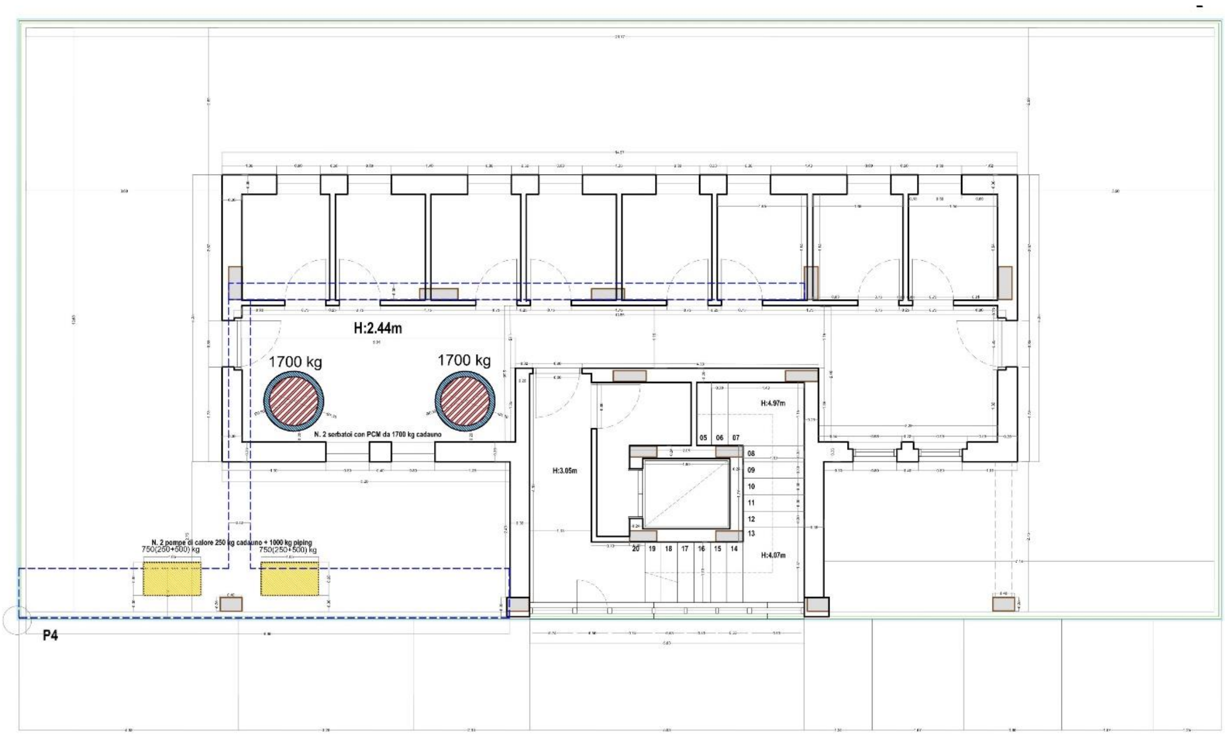


Figure 7: RP#4 component Layout

2.5 RENOVATION PACKAGE #5: MULTIPURPOSE FACADE WITH BIO-BASED INSULATION & BIPV

This innovative renovation package presents a cutting-edge prefabricated façade system that seamlessly incorporates a sustainable bio-based insulation material, hemp. It ensures not only enhanced thermal performance but also a reduced environmental footprint. The system goes beyond traditional renovations by seamlessly integrating easy-to-install Building Integrated Photovoltaic (BIPV) panels. These PV panels harness solar energy to contribute to the building's power needs. The multipurpose facade is fixed on an exoskeleton structure, engineered to provide robust support for each individual component. Using a holistic approach not only the installation process is streamlined but also ensures the long-term durability and efficiency of the renovated structure, marking a significant leap towards sustainable and energy-efficient building solutions.

The figure below, illustrates the components of the ***MPF*** (**M**ulti **P**urpose **F**acade) which are the following:

1. Thermal sound-absorbing - Hemp panel Multidensity - *PW*
2. Substructure - *RI*
3. BIPV - *SUNAGE*
4. Facing - RI
5. Window Casing - RI

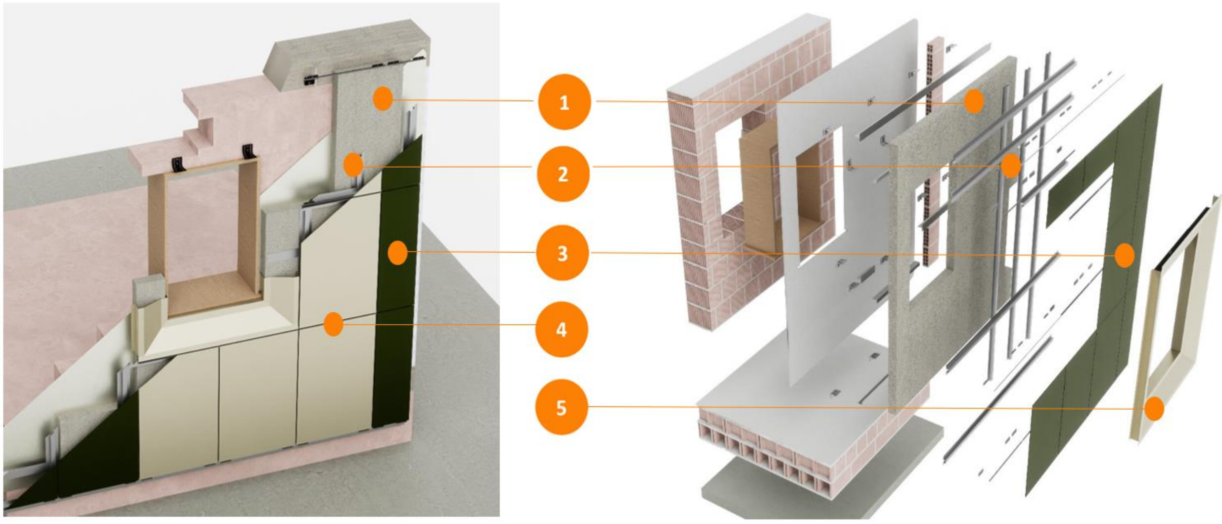


Figure 8: MPF Components

Sub-Structure is designed to be anchored to the existing building and engineered to support, coupling and interlocking of the panel types foreseen by the project, such as:

1) Thermal sound-absorbing panels: characterized by a hemp-based panels - multidensity biocanapanel, manufactured by Pedone Working, this panel offers exceptional thermal and sound absorption properties. This panel is made by different hemp density (fibre + wood). Such characteristic improves the mechanical and fire resistance of the panel.
2) The pre-wired BIPV suncol puzzle panel by SUNAGE, is built by high efficiency coloured glass-glass modules featuring with an anti-glaring finish. These PV modules come equipped with a smart mechanical fixing system, facilitating swift on-site assembly and maintenance, ensuring both efficiency and ease of installation.
3) The external facing is composed of either a durable fibre cement slab, known as Equitone, or an Aluminium Sandwich panel, both providing a protective barrier against atmospheric agents.

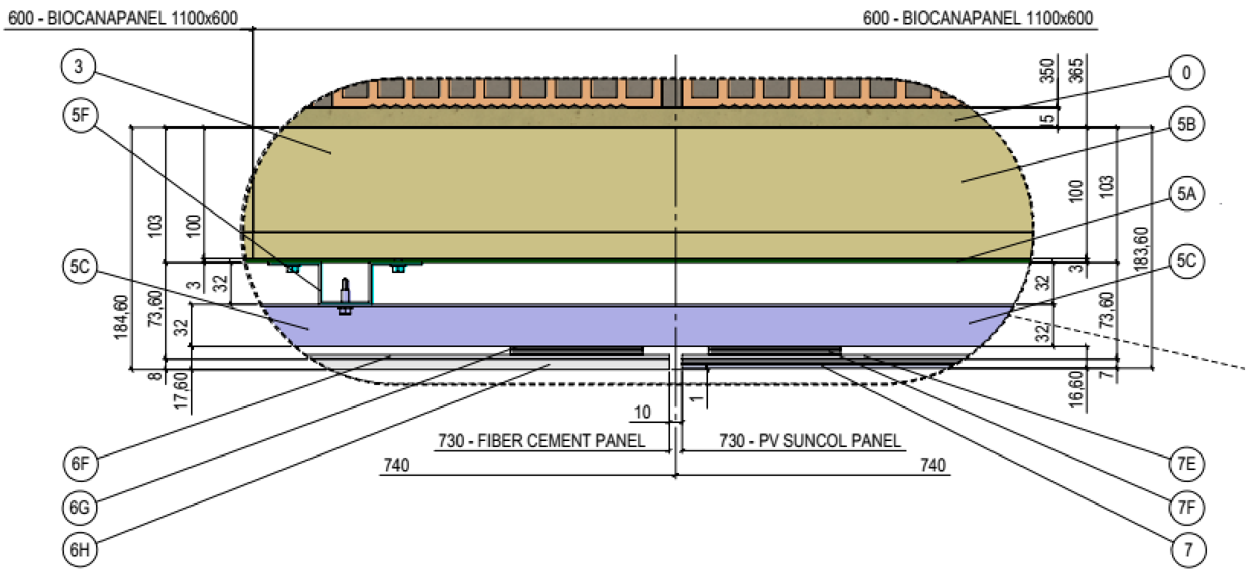


Figure 9: MPF Stratigraphy

2.6 RENOVATION PACKAGE #6: PANOREN

PANOREN is a multi-functional envelope solution built on the basis of an existing commercial insulation panel Panobloc® that will be combined with additional components and design aspects providing new functionalities for an optimized integrated façade system.

PANOREN will integrate in one single package a commercial insulation solution based on recycled wood material – Panobloc®, a second-life PV facing slab for energy production and protection against rain conditions, design adaptations for an industrialised construction process and architectural elements inside the core insulation panel that will integrate the required ducts for the ventilation system.

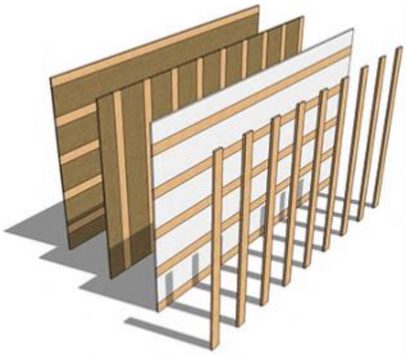


Figure 10: Detail of Panobloc®

More specifically the following innovations will be incorporated to the insulation complex Panobloc®:

- Biosourced materials.
- Second life solar panels for cladding and roofing.
- Optimization of the structure to increase the thermal insulation.
- Integration and control of roller shutter.
- Ventilation duct integration (double flow mechanical ventilation).
- Improve the sustainability of the structure (moisture transfers).

Moreover, the following optimization on the industrialization process and implementation costs reduction will be developed:

- Diagnosis of the existing: improve and make reliable the robotization and automation (drones) of the measurement of the existing building and the evaluation of the air tightness and the acoustics of the existing building.
- Improvement in the method of lifting panels.
- Improvement in the method of fastenings panels.

2.7 RENOVATION PACKAGE #7: ACTIVATED CELLULOSE THERMAL INSULATION MADE OF WOOD WASTE

RP#7 consists of a hard insulation material panel of wood waste without adding any adhesive or bonding materials (activated cellulose made of saw dust), thus making it a 100% chemical-free material.

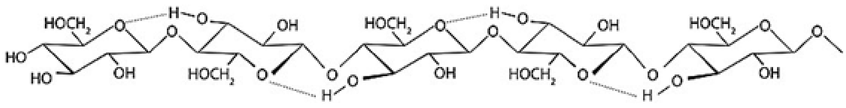


Figure 11: The cellulose chain with hydrogen bridges

Figure 12: The activated cellulose insulation has a high compression strength

The final product of this developed insulation material is simple in appearance, no technical or active parts are built in, and no moving elements and/or digital or electronical components are integrated inside it. Originally, the activated cellulose is a simple passive insulation material. The novelty is in the environmental friendliness, namely it was made of waste materials from a natural based origin and no adhesive was added for the primary bonding of the insulation material.

Taking into consideration the above-mentioned facts and that the insulation is a passive element of the building, the properties of the insulation material can only be tested.

2.8 RENOVATION PACKAGE #8: INTELLIGENT WINDOW SYSTEM

It is a modular low-cost Intelligent Window System (IWS) that can be easily adapted to the outer skin of new or existing windows and incorporates smart management of solar gains thanks to the embedment of smart sensors and the intelligent algorithm built in.

Intelligent Windows System is an active part of the building with electronic parts and also with mechanical parts. According to the sensor's provided data the microcontroller decides to open or close the shifting window glass. Consequently, this regular moving will wear down some parts of the IWS which have to be predicted and of course checked over time.

Figure 13: Intelligent Window System moving engine and moving parts

In Figure 13 above, the moving engine and the moving parts of the prototype are indicated. The chain elements will be changed to metal parts in the demo building windows.

Short term measurement will be performed for the thermal transmittance of the whole window structure, including the existing window and the IWS together. The former simulations predicted significant reduction of heat loss in winter. This test will be done after the fixing of the IWS and will be restricted to the temporary part of the monitoring period. It is not foreseen that these values could be changed in long term period that is why it is not planned to run tests later on.

Other parts of the IWS are weatherproof, no sense to be checked also later.

The chance of possible error in preliminary tested electric controller is very low and, it does not depend on the time.

The part that can be checked is the integrated battery, as at this stage it is not known the final version of the electric system of the building. But in case there is a higher capacity battery in the cellar, then it can substitute the local battery on every IWS. The central battery has much higher efficiency and by so, less specific environmental damage.

3 METHODOLOGY, REFERENCE LEGISLATION AND COMMONLY USED METHODS AND PROCESSES

This section presents the methodology followed in the REHOUSE project to select the testing methods to be deployed in each RP, some reference legislation related with testing procedures at EU level and a preliminary list of some of the most usable testing methods and processes.

3.1 METHODOLOGY FOLLOWED FOR THE TESTING PROCEDURES SELECTION FOR EACH RP

The methodology that each Renovation Package leader followed in order to identify and select the adequate testing procedures/methods to be deployed through Task 2.4 "*Performance assessment for TRL6 demonstration*" was based as a first step , and through a combined work between Task 2.2 "*Detailed specification of the renovation packages*" and Task 3.3 "*Methods for long-term performance assessment*", in the collection of all relevant information through an excel file prepared for this purpose (see Table 3 below). For the creation of this excel it was also considered the work done in Task 2.1 "*Taxonomy of Renovation Packages*", where the data models of the RPs were established, along with the needs of Task 2.2.

In this excel file all the specific components of each Renovation Package were defined and declared (Task 2.2) along with the need for tests or simulations for each component or for the RP as a whole (Task 3.3). The selection of the testing methods took into account the current Technology Readiness Level (TRL) of the Renovation Package, the regulations and related legislation of each country and the necessity to optimize the renovation packages to the best possible final product.

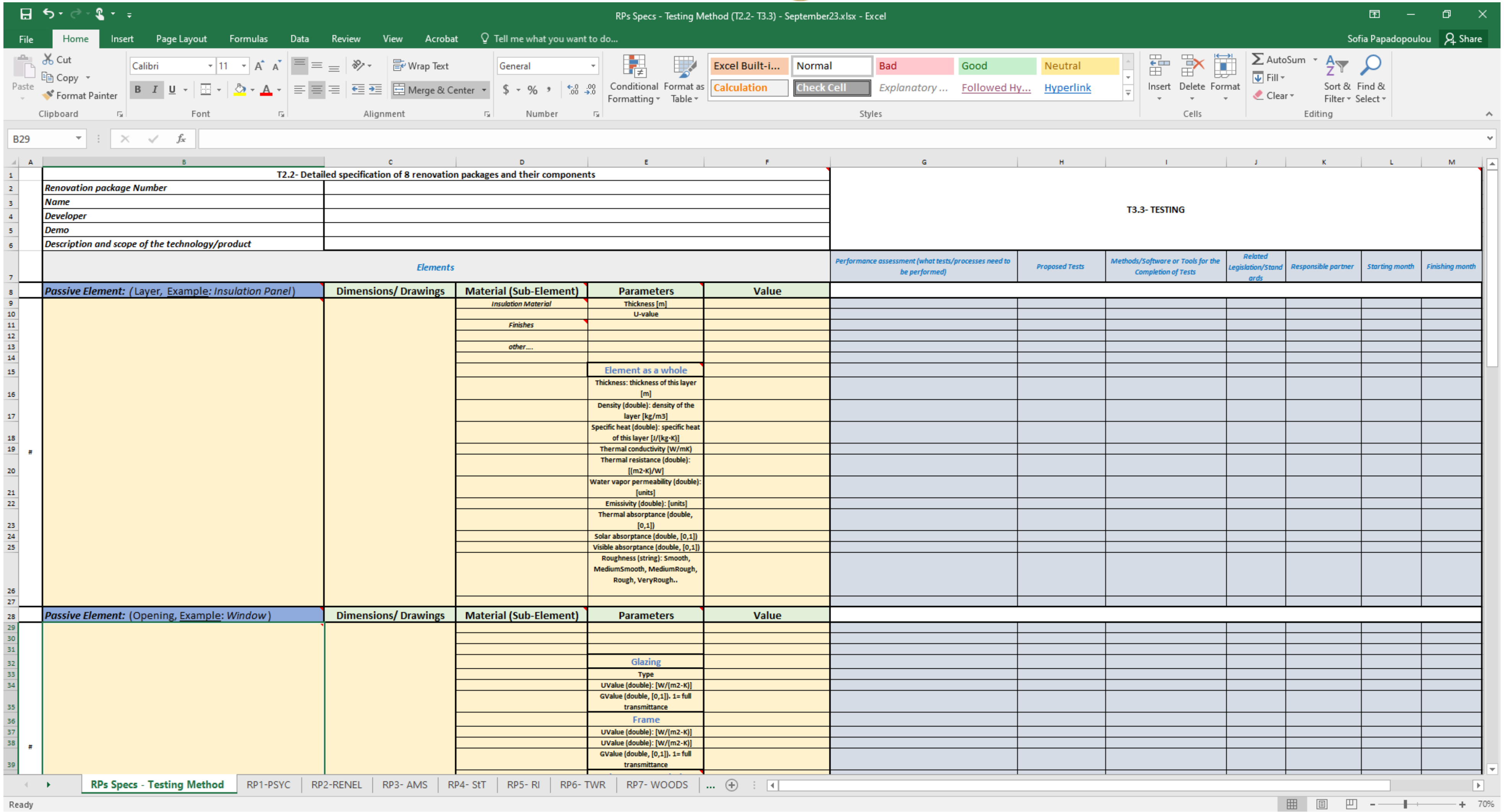
Three kinds of processes were considered for performance testing of the RPs:

1) Tests carried out before the completion and assembly of the RPs to test or prove the compatibility of the different components/materials.
2) Tests or calculations dictated by the national or European building regulations.
3) Tests carried out after the assembly of the RPs and before their installation at the demo sites – in the produced prototypes – for quality assurance purposes.

The procedures that the RP leaders are going to follow and deploy for the assessment of the performance of their products, were presented and discussed, along with the possibility or the necessity to produce any prototypes/samples before the final installation of the Renovation Packages on the demonstration buildings. It is mentioned in Task 2.4 that all the related tests should be performed to the prototypes prior to their installation at the demo sites (in industrial environment – to prove TRL6 accomplishment and demonstrate the technology in relevant environment).

Therefore, the following RPs, will also be developing a prototype version before their final installation on-site, so as to be tested and validated for their properties:

a) Multi-source heat pump (the prototype manufactured for the demo site will be tested prior to its installation) – RP#1
b) SmartWall – RP#3
c) Multipurpose prefab facade with bio-based insulation and BIPV – RP#5
d) Panoren – RP#6
e) Activated cellulose thermal insulation made of wood waste sample – RP#7
f) Intelligent Window System – RP#8



T2.2- Detailed specification of 8 renovation packages and their components					T3.3- TESTING
Renovation package Number					
Name					
Developer					
Demo					
Description and scope of the technology/product					
Elements					*Performance assessment (what tests/processes need to be performed)* / *Proposed Tests* / *Methods/Software or Tools for the Completion of Tests* / *Related Legislation/Standards* / *Responsible partner* / *Starting month* / *Finishing month*
Passive Element: (*Layer*, *Example: Insulation Panel*)	Dimensions/ Drawings	Material (Sub-Element)	Parameters	Value	
		Insulation Material	Thickness [m]		
			U-value		
		Finishes			
		other....			
			Element as a whole		
			Thickness: thickness of this layer [m]		
			Density (double): density of the layer [kg/m3]		
			Specific heat (double): specific heat of this layer [J/(kg-K)]		
			Thermal conductivity (W/mK)		
			Thermal resistance (double): [(m2-K)/W]		
			Water vapor permeability (double): [units]		
			Emissivity (double): [units]		
			Thermal absorptance (double, [0,1])		
			Solar absorptance (double, [0,1])		
			Visible absorptance (double, [0,1])		
			Roughness (string): Smooth, MediumSmooth, MediumRough, Rough, VeryRough..		
Passive Element: (*Opening*, *Example: Window*)	Dimensions/ Drawings	Material (Sub-Element)	Parameters	Value	
			Glazing		
			Type		
			UValue (double): [W/(m2-K)]		
			GValue (double, [0,1]). 1= full transmittance		
			Frame		
			UValue (double): [W/(m2-K)]		
			UValue (double): [W/(m2-K)]		
			GValue (double, [0,1]). 1= full transmittance		

Table 3: Screenshot from the Excel sheet created for the purposes of collecting data for Tasks 2.2 and 3.3

3.2 EUROPEAN BUILDING LEGISLATION RELATED TO TESTING PROCEDURES STANDARDS

European legislation defines the essential requirements that goods must meet when they are placed on the market and the European standardisation bodies are assigned with the task to draw up the corresponding technical specifications. The free circulation of products and services is now facilitated by the EU-wide implementation of common European technical standards for structural design: The Eurocodes.

The EN Eurocodes are specifying how structural design should be conducted within the European Union and are expected to contribute to the establishment and functioning of the internal market for construction products and engineering services by eliminating the disparities that hinder their free circulation within the Community. Further, they are meant to lead to more uniform levels of safety in construction in Europe.

The Eurocodes apply to structural design of buildings and other civil engineering works including:

- Geotechnical aspects.
- Structural fire design.
- Situations including earthquakes, execution and temporary structures.

The Eurocodes series is made up by ten European Standards[1]:

- Eurocode 0: Basis of structural design (EN1990)
- Eurocode 1: Actions on structures (EN1991)
- Eurocode 2: Design of concrete structures (EN1992)
- Eurocode 3: Design of steel structures (EN1993)
- Eurocode 4: Design of composite steel and concrete structures (EN1994)
- Eurocode 5: Design of timber structures (EN1995)
- Eurocode 6: Design of masonry structures (EN1996)
- Eurocode 7: Geotechnical design (EN1997)
- Eurocode 8: Design of structures for earthquake resistance (EN1998)
- Eurocode 9: Design of aluminium structures (EN1999)

The following European Regulations and Directives are related to the EN Eurocodes:

- Construction Products Regulation;
- Public Procurement Directive;
- Services Directive;
- Directive on the provision of information in the field of technical standards and regulations.

The one most related to the buildings and their materials, is the Construction Products Regulation which also gives guidance related to the performance assessment of the construction products.

Construction Products Regulation (CPR): The Construction Products Directive of 1989 (CPD 89/106/EEC) was one of the first directives from the EU Commission to create a common framework for the regulations on buildings and construction products. It has been replaced by the Construction Products Regulation (CPR) and is legally binding throughout the EU. The objective of the Construction Products Regulation is to achieve the proper functioning of the internal market for construction products by establishing harmonised rules on how to express their

[1] https://eurocodes.jrc.ec.europa.eu/en-eurocodes/eurocodes-family

performance and procedures for the CE marking of construction products.

The major key points of the CPR are:

- To set out the conditions for the marketing of construction products.
- To set out methods and criteria for assessing and expressing the performance of construction products.
- To set up a common technical language through harmonized technical specifications, harmonized standards and harmonized testing methods.

EU countries, on the other hand, are responsible for fire safety, mechanical resistance and stability, environmental, energy and other requirements applicable to construction works.

Although the Eurocodes are the same across the EU member states, for matters related to safety and economy or for aspects of geographic or climatic nature, national adaptation is allowed if therein explicitly foreseen. In some cases, the National standards may override the European ones and thus, in these cases caution should be paid when aiming at a specific national market.

The European Standardisation system related to construction is a comprehensive system of design standards that comprises the EN Eurocodes, along with material and product standards, as well as execution and test standards.

Below are presented some of the standards, policies or methods that are followed at European level for the main safety issues related to the buildings:

Earthquake resistance: The first European standard for seismic design was first published in 2000 as Eurocode 8 (also denoted by EN 1998): “Design of structures for earthquake resistance”. It covers common structures and, although its provisions are of general validity, special structures, such as nuclear power plants, large dams or offshore structures are beyond its scope.

The objectives of seismic design in accordance with Eurocode 8 are explicitly stated. Its purpose is to ensure that in the event of earthquakes:

- Human lives are protected;
- Damage is limited; and
- Structures important for civil protection remain operational.

Except for this standard, each country depending on the seismicity of their region, has established its own national regulations taking into account the already available European, national and international anti-seismic regulations, the seismicity zone they belong into and the magnitude and frequency of the already occurred earthquakes.

Protection against noise: At European level, the noise policy relates to environmental noise. EU does not have yet a policy on noise in buildings, e.g. neighbour noise is not included in the EU Noise Policy. Concerning national noise policies, they relate typically to the EU policy and thus in general to environmental noise only. Environmental noise is regulated at EU level at the source of the noise, with legislation on issues such as harmonized noise limits for motor vehicles, outdoor equipment and other noise-generating products.

Fire protection and testing: Not all the European countries have fire safety regulations and each country follows different regulations, despite the fact that fire safety in the built environment remains a major societal issue. The Eurocodes address the structural fire design, making possible the application of fire safety engineering approach, but providing still no data to perform advanced modelling[2]. First, the start of a fire should be prevented; thus, the construction products that are used in the built environment should prevent the start and expansion of a fire. Construction products which might be exposed to an initiating fire are subject to **"**reaction to fire**"** performance requirements.

Until recently EU countries had different methods for testing and classifying the Reaction to Fire performance of construction materials. This, made comparison of the resulting data extremely difficult, with manufacturers required to carry out different tests in order to sell their products in a particular country. The implementation of a single classification system across the EU member states has introduced a common method for comparing the Reaction to Fire performance of construction products.

The classification criteria and test methods used to assess the performance of products covered by the CPR in terms of their reaction to fire are EN 13501-1: "Fire classification of construction products and building elements". For insulation products intended to be used in wall and ceiling constructions, there are seven Reaction to Fire classification levels available – A1, A2, B, C, D, E and F, where A1 corresponds to non-combustible products and F to easily flammable ones.

Additional criteria provide information on a product's tendency to produce smoke and flaming droplets or particles. For combustible products, smoke release is an important consideration and is measured for Reaction to Fire classes A2 to D. There are three smoke intensity levels: s1, s2 and s3, with s3 being the worst. Burning droplets/particles can inflict skin burns and cause further spread of fire. Burning droplets/particles are measured for Reaction to Fire classes A2 to E. There are three classes of burning droplets: d0, d1 and d2, with d2 being the worst.

<table>
<tr><th>Degree of flammability</th><th>Smoke production</th><th>Droplets generation</th></tr>
<tr><td>A1: Non-combustible, no contribution to fire</td><td></td><td></td></tr>
<tr><td>A2: Limited combustibility</td><td rowspan="4">S1: Low emission rate & speed
S2: Medium emission rate & speed
S3: High emission rate & speed</td><td rowspan="5">D0: No droplets
D1: Limited generation of droplets
D2: Not classified</td></tr>
<tr><td>B: Combustible, limited contribution to fire</td></tr>
<tr><td>C: Combustible, minor contribution to fire</td></tr>
<tr><td>D: Combustible, medium contribution to fire</td></tr>
<tr><td>E: Combustible, high contribution to fire</td><td></td></tr>
<tr><td>F: Combustible, easily flammable</td><td></td><td></td></tr>
</table>

Table 4: Classification System For The Reaction To Fire Of Materials

Resistance to fire: One definition of fire resistance is "the ability of a structural element to sustain the performance of its structural duty, and resist fire for a certain period. More specifically when referring to a fire-resisting component that means that it can:

2 https://eurocodes.jrc.ec.europa.eu/news/status-and-needs-implementation-fire-safety-engineering-approach-europe

- Resist structural collapse thus maintaining its load-bearing function and/or
- Resist the pass through of smoke, flame and hot gases (integrity) and/or
- Resist heat conduction (thermal insulation properties).

In the EN 1991-1-2 the terms: load bearing function – R, Integrity – E, and Insulation – I, are mentioned. Then they are also defined in the EN 13501-2 where the classifications for resistance to fire are described together with the parts 3 and 4 for other type building components and systems. According to the EN 13501-2:

R - Loadbearing capacity is the ability of the element of construction to withstand fire exposure under specified mechanical actions, on one or more faces, for a period of time, without any loss of structural stability. The criteria that provide for assessment of imminent collapse will vary as a function of the type of loadbearing element (columns, walls, floors, roofs).

E - Integrity is the ability of the element of construction that has a separating function, to withstand fire exposure on one side only, without the transmission of fire to the unexposed side as a result of the passage of flames or hot gases. They may cause ignition either of the unexposed surface or of any material adjacent to that surface.

I - Thermal insulation is the ability of the element of construction to withstand fire exposure on one side only, without the transmission of fire as a result of significant transfer of heat from the exposed side to the unexposed side. The element shall also provide a barrier to heat, sufficient to protect people near to it.

The most relevant test standards are EN 1363, EN 1364, EN 1365 and EN 1366.

The results are expressed as the number of minutes all three aspects resist the effects of a fire, so an element fulfilling all of these criteria for 30 minutes would be classified as REI 30. The classifications for resistance to fire are described in EN 13501-2, 3 and 4.

Finally, another issue that was recently dealt by the EU was the energy performance of the buildings and how they could be improved towards a decarbonized building stock. The Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) are the EU's main legislative frameworks promoting the improvement of the energy performance of buildings within the EU.

The Energy Performance of Buildings Directive (EPBD): The EPBD is the main legal instrument in the European Union for improving energy performance in buildings. It provides for a comprehensive and integrated approach towards improving the efficient use of energy in both new and existing buildings, residential as well as commercial. The EPBD regulates both ‘passive’ measures for the building design and envelope, as well as the ‘active systems’, such as for heating, cooling, ventilation and lighting. The EPBD mentions specifically that the energy performance of buildings should be calculated based on a methodology, which may be differentiated at national and regional level. However, that methodology should take into account existing European standards.

In the pursuit of European sustainability policies and the enhancement of energy efficiency in buildings, the integration of renewable sources stands out as a key solution. Particularly for buildings, the incorporation of Building Integrated Photovoltaics (BIPV) emerges as a promising avenue.

Given their classification as construction products, these BIPV solutions must not only adhere to the stipulations outlined in the Construction Products Regulation (CPR) but also comply with relevant electrotechnical requirements delineated in the Low Voltage Directive (LVD)

(2014/35/EU). Operating at the European level, the voluntary standard EN 50583, currently undergoing revision, serves as the dedicated standard for these products. This standard specifically addresses photovoltaic (PV) modules used as construction products, homing in on properties crucial to meeting the essential requirements outlined in the European Construction Products Regulation CPR 305/2011. This comprehensive approach ensures that BIPV solutions contribute not only to sustainability objectives but also align with the stringent quality and safety standards mandated by European regulations.

3.3 COMMONLY USED EXISTING TESTING METHODS

Modelling by the aid of simulation software, is a useful technique which, along with the experiments can assist in the optimization of processes, products and devices in a quicker and more efficient way than running experimental methods or testing prototypes alone. However, many times this modelling should be combined or complemented by tests or on-site measurements and experiments. In some cases, modelling may not be possible and thus it is necessary to proceed with the testing.

In this chapter, a list of available software solutions and techniques that can be used for the evaluation of the performance of different systems, technologies or products is presented along with the tests that can or should be conducted in order the products to comply with the relevant European or national regulations. It is important to remark that it is not possible to describe all the existing methods and tools meaning that the focus is only on those that are more related to the buildings or to the building products/elements developed as part of REHOUSE project.

Simulation software tools

Thermal Performance Simulation software:

Comsol Multiphysics is a simulation software than can simulate designs, devices and processes in all fields of engineering and scientific research, such as fluid module, heat conduction module, and structural mechanics module, by building a model for understanding, designing and optimizing products or devices. Based on the finite element method, the software realizes the numerical calculation of each physical field and multiple physical fields, in which equations and mathematical models have been defined and validated, in order to provide the user a valid mathematical description of the examined phenomenon. Comsol software can be used for the simulation of heat transfer phenomenon in complex geometries of RPs in order to assess their thermal performance with high accuracy including all incorporated thermal bridges. The thermal transmittance (U-value) of the RPs can be calculated ensuring the compliance with the national regulations.

Structural Analysis Simulation software:

ANSYS engineering simulation software is used to simulate computer models of structures, electronics, or machine components for analysing the strength, elasticity, toughness, temperature distribution and other attributes in order to determine how a product or structure will function with different specifications, without building test products or conducting crash tests. The ANSYS software can simulate and analyse movement, fatigue, temperature distribution, fluid flow and other effects over time. For example, it can simulate durability and strength of a bridge after years of traffic.

SolidWorks on the other hand is another tool that is commonly used in the industry to design, model and manufacture products. It is a solid modeler, which utilizes a parametric feature-based approach to create 3D CAD models.

Building Energy Simulation software:

TRNSYS (pronounced 'tran-sis') is an extremely flexible graphically based software environment used to simulate the behaviour of transient building systems. It has been commercially available since 1975 and it was primarily used in the fields of renewable energy engineering. The TRNSYS model simulates the performance of the entire energy system by breaking it down to its individual components. Its main applications include: solar systems, low energy buildings and HVAC systems, cogeneration, etc. Its libraries offer a wide variety of useful components, whilst the dynamic energy analysis is capable of accurately simulating transient HVAC system's behaviour.

Apart of TRNSYS software is relevant to list also other available Building Energy simulation software that exist in the market such as Design Builder (the most established and advanced user interface to Energy+), OpenStudio (software tool developed by the United Stated Department of Energy -DOE- to support the whole building energy modelling and using also as basis Energy+) and TERMUS (BIM modelling software for dynamic building simulations and analysis with Energy+).

Building Energy Simulation software (as the ones indicated above) can be used to simulate energy systems and isolated components of the RPs and the complete demo buildings (integrating all their systems) before and after the implementation of RPs aiming to quantify their potential upgrade of the building energy performance and to ensure the NZEB status, based on national regulations.

Fire Testing and Resistance to Fire methods

EN 13501-1 defines a standardized procedure for the classification of reaction to fire for all construction products, including products incorporated within building elements. The following 5 EN/ISO test methods are included in the EN 13501-1:

EN 13823	**Reaction to fire tests for building products** — Building products excluding floorings exposed to the thermal attack by a single burning item.
EN ISO 1182	**Reaction to fire tests for building products** — Non-combustibility test.
EN ISO 1716	**Reaction to fire tests for building products** — Determination of the gross heat of combustion (calorific value).
EN ISO 9239-1	**Reaction to fire tests for floorings** — Part 1: Determination of the burning behaviour using a radiant heat source.
EN ISO 11925-2	**Reaction to fire tests** — Ignitability of building products subjected to direct impingement of flame — Part 2: Single-flame source test.

Table 5: Test method/standards involved in EN 13501-1[3]

[3] https://www.motistech.com/solution/en-13501-1

Reaction to Fire tests

A reaction to fire test assesses how easily a product can be ignited and contribute to fire growth. It relates mostly to the early stages of a fire development and is arguably mostly relevant to those products directly exposed to the fire source i.e. wall linings, ceiling linings and external wall surfaces. It is also relevant for assessing the performance of construction products during construction or during building maintenance, e.g. welding of the building elements. Some of the most related tests are the following:

Non-combustibility test (*Compliance: EN ISO 1182)*:

The test specimen in φ 45mm by 50mm height is inserted into a stabilized furnace at 750 degrees, and the temperature of the furnace, surface, and centre of the specimen will be measured. In the meantime, the flaming time, and mass loss of the specimen are measured during the test.

Figure 14: Non-combustibility test

Single Burning Item (SBI) (*Compliance: EN 13823)*:

Two specimens (1.5m×0.5m and 1.5m×0.5m) are placed in the corner of the trolley and the trolley is positioned underneath the exhaust system. The sample is exposed to a propane-fuelled sandbox ignition source (30.7kW). The duration of the test is 20 minutes and during this period the combustion gases are collected by the exhaust hood and duct, and the calorimeter system will sample gases and calculate the heat release (THR600), smoke production (TSP600s), the fire growth rate FIGRA 0.2MJ, and the smoke growth rate SMOGRA results. In the meantime, the specimen reaction to fire behaviour is visible by the side observation window. The criteria for the "reaction to fire" classification, according to the EN 13501-1: 2019 standard "Fire classification of construction products and building elements – Part 1: Classification using data from reaction to fire tests", are presented in the Table 6.

Figure 15: SBI test

PARAMETER	A2/B	C	D	E	S1	S2	S3	D0	D1	D2
FIGRA	<120	<250	<750	>750	-	-	-	-	-	-
THR600s	<7.5	<15	>15	>15	-	-	-	-	-	-
SMOGRA	-	-	-	-	<30	<180	>180	-	-	-
TSP	-	-	-	-	<50	<200	>200	-	-	-
d < 10s	-	-	-	-	-	-	-	0	>0	>0
d > 10s	-	-	-	-	-	-	-	0	0	>0

Table 6: EN 13501-1 classification criteria

Single-Flame Source Test (*Compliance: EN ISO 11925-2)*:

A specimen is mounted vertically and exposed to a small flame (20mm height), the ignition time (after the small flame removal), flame spread height, and presence of droplet/particles is recorded during the single-flame source test.

Figure 16: Single-flame source test

Seismic regulations complying and testing

As already mentioned, the European regulation that deals with the seismic resistance of structures is Eurocode 8; however, each country depending on its specific geological or climatic conditions can and should introduce any additional directives or regulations for ensuring the safety and durability of the structures. Moreover, the seismic performance of different components can be assessed either with theoretical methods like structural analysis software, or with experimental methods and tests.

Several different experimental techniques can be used to test the response of structures and soil or rock slopes to verify their seismic behaviour. One of these is the use of an earthquake shaking table which can simulate a wide range of ground motions including reproductions of recorded earthquakes time-histories. The mechanical stresses of earthquakes are reproduced by using a test table with high low-frequency and multiaxial displacement requirements. Test specimens are fixed to the platform and shaken, often to the point of failure . Using video records and data from transducers, it is possible to interpret the dynamic behaviour of the specimen.

Figure 17: Earhtquake shaking table with specimen

IR Thermography

Infrared Radiation (IR) thermography is the science of measuring and mapping surface temperatures and is considered as a non-destructive method to assess the performance of different materials or components like insulation, air-conditioning units, cabling, piping etc. With the use of infrared and thermal testing, the detection of the possible defects is based on temperature patterns (thermal anomalies, hot and cold spots etc.) and is conducted by translating the temperature differences between the different elements or components into logical conclusions. There are several applications of IR thermography. It can be used in leak detection, composition changes or cracks in concrete structures, in electrical equipment or circuits to locate hot spots and crucial areas, in assessing insulating materials performance, etc.

However, the conditions under which the thermography inspection can take place, may vary depending on the application and different parameters may be needed to be considered, so as to have the desired results. For example, environmental conditions play an important role on outdoor thermographic inspections (wind speed, rain etc.), whereas if there are no temperature variations on the surface of the inspected area, then the inspection cannot be effective.

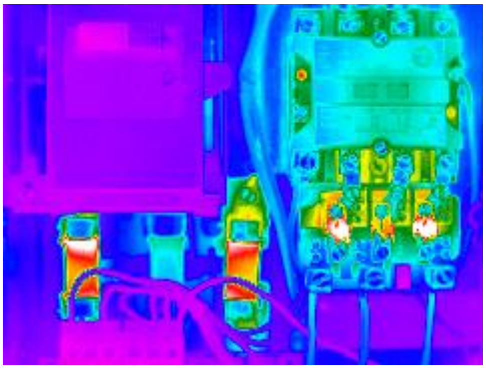


Figure 18: IR thermography of electrical equipment

Other methods and/or non-destructive techniques

In the next chapters and depending on the tests that will be conducted for each component or Renovation Package, other techniques, methods or tests will be described along with their related standards.

4 METHODS & TESTING PROCESSES PROPOSED FOR EACH RP

In this section the methods and the testing procedures that the Renovation Package leaders will execute during Task 2.4, in order to secure the long-term performance of the components of their technologies (TRL6 accomplishment), are described. As part of this TRL6 advance, innovative testing methods/methodologies are proposed, like structural analysis simulations, sampling-based techniques, non-destructive testing techniques, fire resistance, aging testing techniques etc., in order to evaluate how materials, perform under simulated service conditions and to ensure they will reach their projected design life.

4.1 RP#1: MULTI-SOURCE HEAT PUMP

The main aim of the heat pump testing is to verify its reliability and evaluate the operational flexibility. Especially the latter is critical in the pilot system, when adjusting the heat source temperature over a large range, or shifting from air-source operation to water-source coming from the other heat sources (solar panels or geothermal field). These tests are also important for debugging the control algorithms of the vapour compression heat pump and fixing the safety measures of the unit (e.g. in case of refrigerant loss, frost formation at the air-fan, or overheating). There is measuring equipment for measurements that are collected at the water and air side inlet/outlet temperature, and flow rates at the evaporator and condenser, the (indoor) ambient temperature, and the total power consumption.

Moreover, various temperature and pressure sensors will be installed at the inlet and outlet of the unit's main components and piping to perform the unit condition monitoring and control the unit's operation. The measurements are collected and recorded by the unit's PLC with a sampling rate defined by the user.

To perform the test at the premises of PSYCTO, before the unit will be installed at DUTH, the hot side of the heat pump will be connected with a natural gas boiler that will provide suitable heat, while the cold side of the heat pump will be connected to a water tank and an air-source dry-cooler for chilling the water. Using the PLC unit, the unit can switch between the water-cooled and air-cooled evaporator, depending on the heat source availability. The PLC will record the main properties measured during testing.

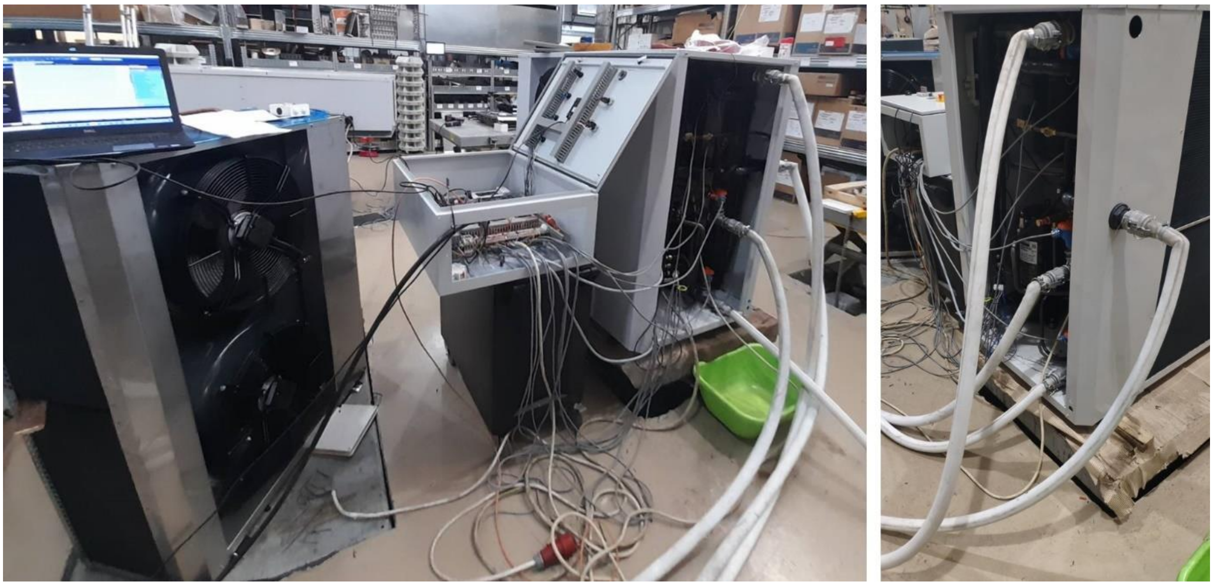


Figure 19: Testing of heat pumps at the test lab of PSYCTO

Figure 20: The pumping system of the testing facility

4.2 RP#2: ADAPTABLE/DYNAMIC BUILDING ENVELOPE

The ADBE system is a modular design that consists of various components, all commercially available in the market. The relevant technical datasheets and certifications can be found by the manufacturing companies and ensure their compliance with the European and National standards. All components will arrive at RENEL’s facilities, where proper tests will be conducted to ensure that they operate appropriately.

Firstly, visual inspection will be carried out upon arrival of the equipment to observe any possible defects of the elements. Each component will then be thermally tested via thermography inspections to measure their surface temperatures and ensure their optimal operation. Additionally, various measurements will be made after the assembly of the different modules to test the voltage, current, resistance, etc. of the proposed solution. The ADBE system will then be transported to the demo site and will be ready for installation at the building. New measurements will be conducted after the installation of the system to the pilot site.

The same tests and/or measurements will take place for both the equipment that will be installed in Greece and in Hungary.

In the following figures the components that will be installed in the Greek demo site building are displayed. More specifically, the PV glass units are fully customized depending on the project’s requirements and they are compatible with European and national standards. In the framework of the REHOUSE project the dimensions of each module will be 1.6 m x 1.6 m, consisting of different layers with a total thickness of 18.24 mm. The thickness of the front and rear tempered glasses is 6 mm each and the float glass layer between them is 3.2 mm thick. The encapsulant polyvinyl butyral (PVB) foils are 1.52 mm and the cell type is amorphous silicon (a-Si).

Figure 21: The a-Si PV panels and their technical specifications

The number of aluminium frames for the PV glass that will be mounted on the building’s envelope are 32, whereas the number of hooks and wall brackets necessary for the installation of the aluminium frames will be 128 for each particular type of component. All parts of the structure are commercially available and comply with the European and National Standards.

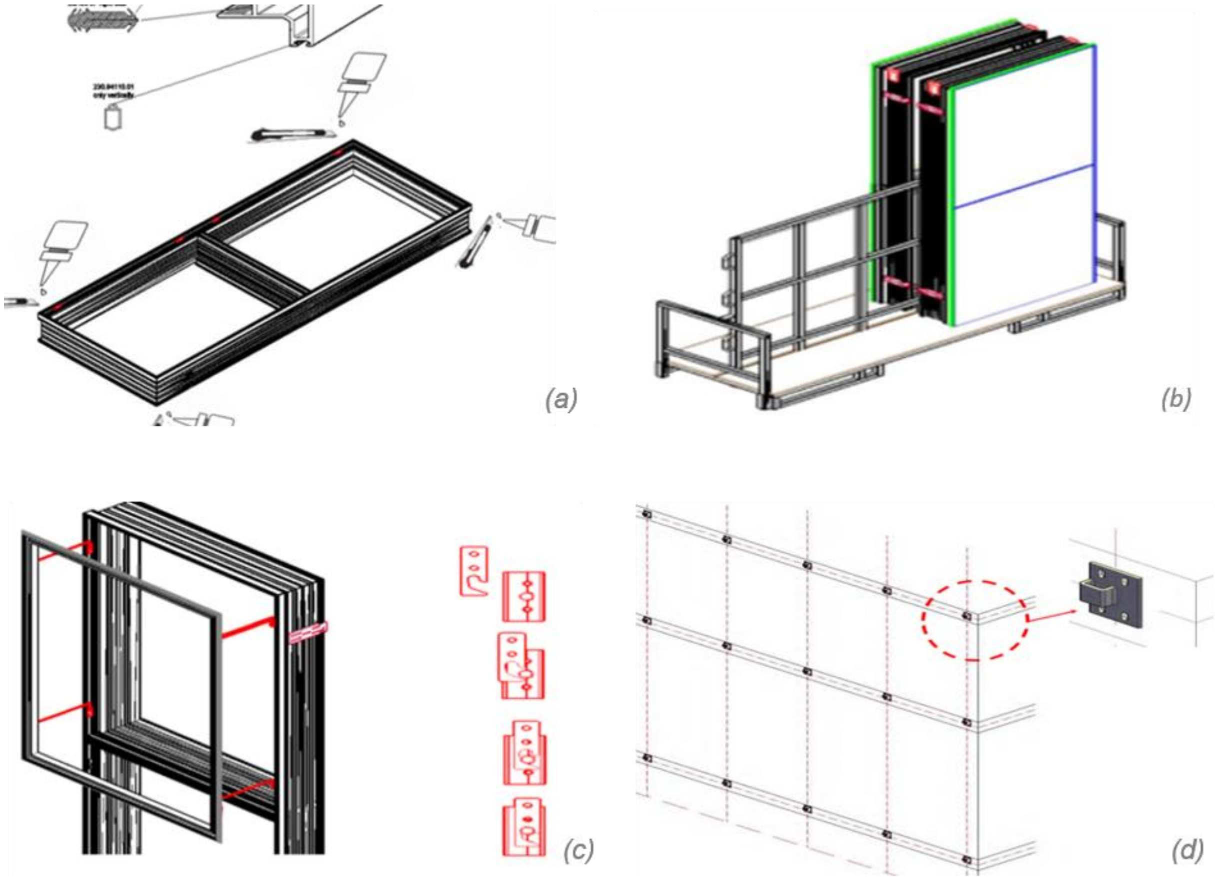


Figure 22: Aluminium structure that will be mounted on the external wall, (a) Aluminium frame for engulfing the PV glass, (b) Aluminium frames to be mounted in the building's envelope and assemble the PV glass facade, (c) Aluminium hooks and (d) Aluminium wall brackets

For the energy conversion and battery charger the Multiplus Inverter/Charger 24/3000/70, manufactured by Victron Energy, will be installed. In order to ensure that the maximum efficiency is achieved, the BlueSolar Charge Controller MPPT 150/35 by Victron Energy will be installed to track the maximum power point, as shown in Figure 24. These components are available in the market and are accompanied by their certifications.

Figure 23: The Multiplus Inverter/Charger 24/3000/70

Figure 24: Solar Charge Controller MPPT 150/35

The energy produced by the photovoltaics will be stored to batteries and the remote monitoring and control of the system will be possible. The selected energy storage system within the REHOUSE project is illustrated in Figure 25. The size of the batteries depends on the consumptions of the end users that will be indicated by the Greek demo site. The storage component is available in the market and is manufactured by Victron Energy company. All the required certifications are given by the manufacturer for the specific product.

Figure 25: The proposed GEL OPzV 2V cell battery

4.3 RP#3: SMARTWALL

SmartWall is a prefabricated façade panel which is made of many different components. The majority of these components are commercially available and thus are accompanied by their certificates and datasheets. Therefore, for those components, no testing is needed as they are compatible and comply with the European and National regulations. In the figure below the specific components of the SmartWall panels that will be installed in the Greek demo building are indicated.

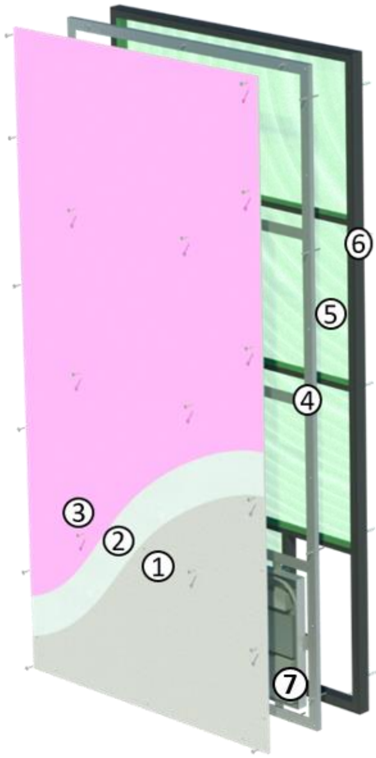


Figure 26: Layers of the SmartWall

The SmartWall panel of the Greek demo building will be consisted of:

1. Two layers of anti-bacterial, self-cleaning, self-healing AMS's multifunctional coating enhanced with PCMs
2. Intumescent paint (commercial paint)
3. Cement board Aquapanel Knauf 12.5mm (commercially available)
4. Steel L Profile 50 x 25 x 3 mm (commercially available)
5. Insulation material (commercially available)
6. Thermal break (commercially available)
7. Toolbox – AMScope

From these components, only the AMS's multi-functional coatings and the toolbox are not commercial. The AMS's multi-functional coatings will be tested during Task 2.4 "*Performance assessment for TRL6 demonstration*" regarding the following:

A) Self-cleaning performance by the water contact angle test (according to ISO 27448-1).
B) Anti-fungal performance by the assessment of resistance to fungal growth (according to BS 3900:1989 Part G6).
C) Spectral reflectance (ASTM E903 - 96 & ASTM G173).
D) Adhesion to the substrate by the cross-cut test (according to ISO 240 – Paints and varnishes).

As far as the toolbox is concerned, this is constructed by a metallic box consisting of different components, so as to enclose the electrical elements of the SmartWall and of the accompanying technologies. The main component of the toolbox is the AMS Control Panel System (AMScope) which will be inside the box and is consisted of various electronic components combined together to a board in order to perform certain control actions (more information is provided in *Deliverable 2.2 “Detailed specifications of the renovation packages”*).

Figure 27: AMScope and Toolbox

A prototype of this toolbox will be also constructed and a series of inspections and tests will be realized:

1) Visual inspections for external defects;
2) Mechanical tests: Ensure toolbox casing is firmly secured on frame, ensure toolbox cover is secured on the box, etc.;
3) Low voltage electrical tests;
4) Operational test;
5) IR thermography inspection may be also used.

Apart from the above-mentioned items, all the other elements of the SmartWall are commercial, thus no separate testing is needed for them. However, the combination of all these components together, should be assessed so as to prove the smooth operation of the system as a whole, and its durability in time.

An existing prototype on which the REHOUSE SmartWall system was based, was already tested at lab-scale for its seismic resistance and fire behaviour, in previous EU funded projects. As the basic structure of the SmartWall will not change (it will only become lighter) in relation to the already tested prototype, there is no need to repeat the seismic test, and only a structural analysis is enough to fulfil the requirements of the national regulations.

Regarding the fire performance, some tests will be conducted to assess the performance of materials that are not categorized as class A (A1, A2) regarding their reaction to fire. It is generally foreseen to use fire resistant materials and to coat the components with appropriate intumescent paints to ameliorate their fire behaviour.

More specifically the fire performance of SmartWall will be assessed by “reaction to fire” tests following the EN 13823 standard, also known as Single Burning Item (SBI) test. The results of the test will be used for the fire classification of the SmartWall based on EN 13501-1.

During the first part of the test procedure, an auxiliary burner is ignited in order to calculate precisely the fire power level and smoke production of the burner itself. After that, the auxiliary burner is turned off and the main burner is ignited. The following equations are used for the calculation of the fire growth rate (FIGRA), the total heat release, 600 s after the fire test initiation (THR_{600s}), the smoke growth rate (SMOGRA) and the total smoke production, 600 s after the fire test initiation (TSP600s):

$$FIGRA = 1000 \times max\left(\frac{HRR_{av}(t)}{t}\right)$$

$$THR_{600s} = \frac{\sum_{0}^{600}\left(max\left[HRR(t),0\right]\right)}{1000}$$

$$SMOGRA = 10000 \times max\left(\frac{SPR_{av}(t)}{t}\right)$$

$$TSP_{600s} = \sum_{0}^{600}\left(max\left[SPR(t),0\right]\right)$$

where HRR is the heat release rate and SPR is the smoke production rate.

Different designs were produced during the design phase of the project, which examined different versions of the SmartWall with varying insulation materials and a lighter steel frame that would perform better in terms of structural stability.

During REHOUSE, new eco-friendly materials will be also examined in terms of thermal performance, in theoretical and experimental levels defining different alternatives cases of SmartWall. Firstly, the thermal performance analysis of all SmartWall cases will be carried out following the ISO 10211:2017[4], which is a steady state approach aiming to calculate the equivalent thermal transmittance (U-value) or equivalent thermal resistance (R-value) taking into account all incorporated thermal bridges. The analysis is based on the blank type of SmartWall, which does not contain window, PV panel or other components. The presence of the metal structure creates non-negligible thermal bridges. The equivalent U-value, U_{eq}, taking into account the impact of thermal bridges is calculated by the equation:

$$U_{eq} = U_{clear} + \frac{\sum_{k}(\Psi_k \cdot l_k)}{A} + \frac{\sum_{n}\chi_n}{A}$$

where U_{clear} is the thermal transmittance without the effect of thermal bridges, calculated according to ISO 6946[5] standard, Ψ_k expressed in [W/(m·K)] is the linear thermal transmittance of the linear thermal bridges, l_k [m] is the length over which the Ψ_k value applies, χ_n expressed in [W/K] is the point thermal transmittance of the point thermal bridges and A [m^2] is the total surface of the SmartWall module.

The U_{clear} is calculated based on the ISO 6946 and the thermal properties of the incorporated materials:

[4] ISO 10211:2017, Thermal bridges in building construction - Heat flows and surface temperatures - Detailed calculation

[5] ISO 6946:2017, Building components and building elements. Thermal resistance and thermal transmittance - Calculation methods

$$U_{clear} = \frac{1}{R_{si} + \sum_{i=1}^{N} \frac{d_i}{k_i} + R_{se}}$$

where d_i is the thickness of layer i, k_i is the thermal conductivity of the material of layer i, N is the number of layers, R_i and R_e are the internal and external surface thermal resistances, respectively. Typical values for the surface thermal resistances of a wall are 0.13 (m^2K)/W for the internal surface and 0.04 (m^2K)/W for the external surface, according to ISO 6946 standard.

For the calculation of the equivalent thermal transmittance/resistance of the SmartWall, it is simulated by means of the commercial CFD package COMSOL, under steady state indoor and outdoor environmental conditions.

The total heat flow, Q, that passes through the whole surface of simulated RP, $A_{SmartWall}$, is obtained by simulation results. Hence, the equivalent U-value, U_{eq}, is calculated by the following equation:

$$U_{eq,SmartWall} = \frac{Q}{A_{SmartWall}(T_{in} - T_{out})}$$

where T_{in} and T_{out} are the indoor and outdoor temperatures.

The final design of SmartWall is optimized taking into account, among others, the thermal performance (utilizing U_{eq}) and the limitations that are required by the Greek demo (maximum thickness of SmartWall).

Secondly, three (3) prototypes will be produced in order to:

i) Check the compatibility of different insulating materials with the other SmartWall components.
ii) Test different insulating materials for eliminating the potential thermal bridges.
iii) Resolve assembly and/or anchoring issues.
iv) Evaluate their mechanical properties.
v) Check some technical details related to the cabling, the control box dimensions etc.

As a conclusion, the processes that will be performed during Task 2.4 in order to assess the performance of the SmartWall and of its components are the following:

- Thermal performance analysis:
    - U-value, thermal bridging, material selection.
    - Software: COMSOL
- Energy performance of SmartWall at building level:
    - NZEB criteria, PV production, input for LCA.
    - Software: TRNSYS
- Fire test with new materials:
    - Reaction to fire test - SBI
- Performance of AMS coatings:
    - Contact angle (self-cleaning).
    - IR Reflectance.
    - Anti-moulding.
    - Self-healing.
- Hygrothermal performance analysis (if it is needed – it will be decided during Task 2.4):

  - Growth of condensation.
  - Software: WUFI
- Construction of 3 prototypes:
  - Visual inspections.
  - Mechanical properties tests.
  - Low voltage tests.
  - Anchoring techniques validation.
  - IR thermography inspections.

4.4 RP#4: CENTRALIZED HOLISTIC H&C RENOVATION KIT

The centralized holistic renovation kit for centralized heating and cooling of RP4 consists of several components, which require the definition of a proper testing methodology to validate the customized MPC logic and to assure the correct working conditions of each component. Moreover, the expected performances of the core part of this renovation kit (namely, the reversible HP and the bio-based stratified PCM TES) strictly depend on a consistent number of real parameters (e.g. external temperature, PV generation, users-side hot temperature, users-side cold temperature, grid exchange, electrochemical storage state of charge).

To consider all these possible configurations, the testing process will be conducted by means of virtual models. The chosen modelling environment where these components will be developed and tested is Matlab/Simulink. Firstly, within this framework, a detailed physical representation of each component will be set up according to the real ones. Meanwhile, the MPC logic will be developed by means of Python programming language and the Pyomo optimization package: this choice is considered the most suitable for the purposes of the RP and for further applications, since Python is an open-source language which, eventually, permits to upload the MPC algorithm on a real control system for real management purposes. The aforementioned algorithm will be developed as a complete management system for the whole renovation kit, taking into account multiple working modes for the reversible HP (e.g. heating in winter mode, heating + DHW in winter mode, cooling in summer mode, cooling + DHW in summer mode), several combinations of the available generation assets (e.g. BIPV, HP grid-fed) and different conditions required for the TES system (e.g. temperature levels depending on users' demand). Finally, the Python control logic will be integrated into the Simulink model to test, improve and validate the resulting performances of the virtual model.

TERA IoT Edge Computer – The heart of the monitoring and control system

Performance testing on Tera Embedded Device consists of running different testing scenarios that end users would have on a 5000-point db of Bacnet points and measure the performance of the IoT edge device.

The testing architecture setup at TERA lab consists of:

- **HW**: TERA IoT Edge Device (ARM Cortex A7 dual core @1GHz processor; 1 GB DDR3 RAM; 8 GB onboard Flash eMMC);
- **SW**: Fin Framework version 5.0.6 branded as TERA version (JVM RAM allocation 512 MB).
- **Db specs**: 5000 data Bacnet points, 40% history capacity, X BACnet connectors, X Modbus IP connectors, default bline logic, default jobs, cloud connected.

- **Performance Markers**: CPU Usage, RAM consumption, Flash space used.
- **User Acceptance Criteria**: Java heap size allocation: max 70%; CPU usage: under 70%; Disk space: under 90%; reasonable lag in navigation and loading time.

Main applications tested are listed below and results from the tests will be described in *Deliverable 2.4 "Report of the long-term performance tests of the components of the RPs"*.

- Jobs (multiple sessions).
- Alarms.
- Graphics.
- History.
- Schedules.
- bLine logic.

Additionally, smart rubber being developed by K-flex is being empirically tested using the following analytical techniques:

- Fourier-transform infrared spectroscopy (**FT-IR**; spectral range: 4000-400 cm^{-1}, 20 scans per measurement, resolution: 4 cm^{-1}; chemical structure investigation and checking the possible decomposition of compounds);
- Thermogravimetric analysis (**TGA**; 25-800°C, heating rate: 15°C/min, nitrogen atmosphere, flow rate: 50 mL/min; thermal stability assessment);
- Differential scanning calorimetry (**DSC**; 25-200°C, heating rate: 15°C/min, nitrogen atmosphere, flow rate: 50 mL/min; detection of phase transitions and determination of associated thermal effect);
- Tensile tests (establishing mechanical performance: elongation at break, tensile strength);
- Determination of electrical resistance (recording changes in resistance with temperature change - testing the sensory capabilities of the material);
- And accelerated ageing tests under different conditions (thermo-oxidative, in a humidified atmosphere RH=90%; testing the performance of the intelligent rubber during use under different conditions).

Based on the techniques mentioned above, the optimum amount of wax that can be used, characterisation of the properties of the material produced, and checking the possibility of changes in the properties over time under different conditions of use are being determined.

Steel Tech Stratified PCMs Heat Storage Tank

The Stratified PCMs Heat Storage Tank represent the core innovation from the heating and cooling plant and it is necessary to test its relevant compliance with the already existing standards and laws.

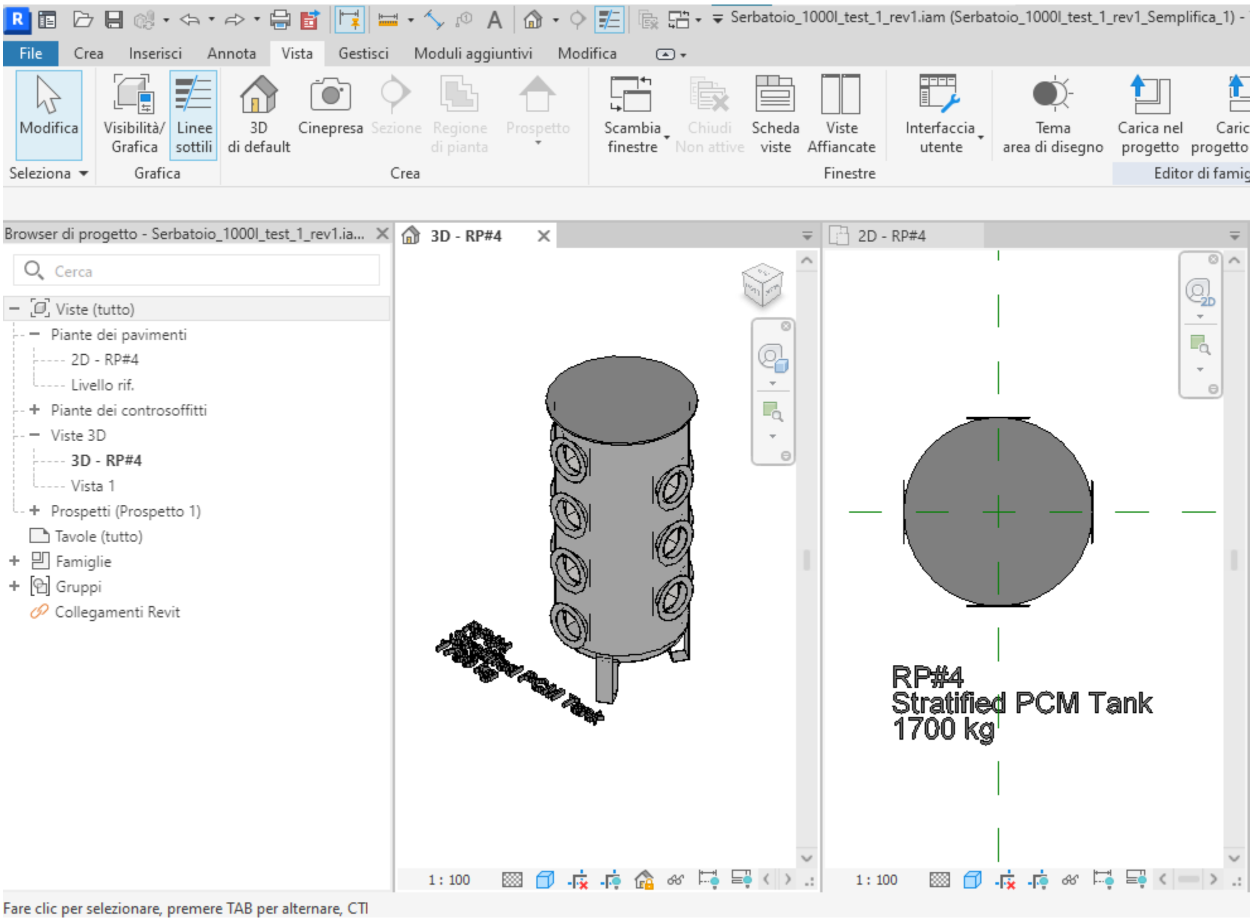


Figure 28 - RP#4 Stratified PCM Tank

The current standards and laws for pressured hot water tanks are:

Standard	Description – Title
EN 12897	Water supply - Specification for indirectly heated unvented (closed) storage water heaters.
P.E.D. Directive 2014/68/EU	Pressure Equipment Directive (PED).
Decr. Lgs. 93/2000	Italian law for the actuation of PED Directive
DM 174 06.04.06	Regulation concerning materials and objects that can be used in fixed systems for the collection, treatment, supply and distribution of water intended for human consumption

Table 7: Standards and laws involved for pressurized tank for hot water storage[6]Tests mandatory by standards and laws:

[6] https://www.motistech.com/solution/en-13501-1

Tests mandatory by standards and laws:

Test Type	Standard	Test target	Notes
Tank pressure resistance test	EN 12897 (4.3.1)	Maximum test pressure 2 times the nominal maximum pressure.	-
Primary heating exchangers pressure resistance test	EN 12897 (4.3.2)	Maximum test pressure 2 times the nominal maximum pressure.	-
Durability test	EN 12897 (4.3.3)	20.000 cycles at 1,2 maximum pressure	-
Effective volume test	EN 12897 (6.2.2)	Actual tank volume	**Not directly applicable** since the storage system is not based on the water content. It will be done for “empty” tank (not filled by PCMs)
Hot water volume	EN 12897 (6.2.4)	See 6.2.4	**Not directly applicable** This test will be done with PCMs and the procedure of the standard will be adapted to the new working condition.
Primary heat exchanger power	EN 12897 (6.2.5)	See 6.2.5	-
Thermal dispersion	EN 12897 (6.2.8)	See 6.2.8	**Not directly applicable** This test will be done without PCMs inside the tank
Temperature control system test	EN 12897 (6.2.10)	-	-
Pressure drop in heat exchanger	EN 12897 (6.2.11)	-	-

Table 8: Mandatory tests for tank

These mandatory tests will be done mainly with tank not filled by PCM materials, see the notes for more details.

Furthermore, the following not standardized tests will be done to assess the combination of the tank with the PCM storage capacity:

Test Type	Standard	Test target	Notes
Heat capacity test	Not applicable	-	Test procedure will be defined internally

Test Type	Standard	Test target	Notes
Internal heat exchange coefficient of PCMs	Not applicable	-	Test procedure will be defined internally
Over and under temperature stress test	Not applicable	No damages at PCMs and PCMs enclosures	Test procedure will be defined internally. Test on scaled tank

Table 9: Tests to assess the combination of tank with the PCMs

Not standardized tests will be done also to assess the encapsulation solution, before applying it to the whole tank.

Test Type	Standard	Test target	Notes
Heat exchange test of encapsulated PCMs	Not applicable	Define the characterization curve for heat exchange coefficient at different DT	Test procedure will be defined internally
Cycling test of heat capacity of encapsulated PCMs	Not applicable	Define the heat capacity decay	Test procedure will be defined internally
Pressure test	Not applicable (as reference EN 12897 - 4.3.1)	Define the resistance of encapsulation method to the pressure	Test procedure will be defined internally
Over and under temperature stress test	Not applicable	No damages at PCMs and PCMs enclosures	Test procedure will be defined internally. Test on single encapsulated PCM
Durability test	Not applicable (as reference EN 12897 - 4.3.3)	No damages at PCMs and PCMs enclosures	Test procedure will be defined internally. Test on single encapsulated PCM

Table 10: Tests for the encapsulation solution assessment

Also, for the innovative charge sensor, not standardized tests will be performed to assess the sensor performance and resistance:

Test Type	Standard	Test target	Notes
Laboratory test for sensor characterization	Not applicable	Define the characterization curve of the sensor	Test procedure will be defined internally
Cycling test for repeatability	Not applicable	Define the reputability of the measurement	Test procedure will be defined internally
Pressure test	Not applicable (as reference EN 12897 - 4.3.1)	Define the resistance of the sensor to the pressure	Test procedure will be defined internally
Over and under temperature stress test	Not applicable	No damages at sensor	Test procedure will be defined internally.

Test Type	Standard	Test target	Notes
Durability test under normal working condition	Not applicable (as reference EN 12897 - 4.3.3)	No damages at sensor or decay in measurement (precision/accuracy)	Test procedure will be defined internally.

Table 11: Test that will be performed for the charge sensor

4.5 RP#5: MULTIPURPOSE FAÇADE SYSTEM WITH BIO-BASED INSULATION & BIPV

The Multi-Purpose Façade represents a sophisticated system comprising prefabricated panels seamlessly integrated with a modular substructure affixed to the walls of an existing building. This synergy results in a comprehensive thermo-sound-absorbing and photovoltaic coating, collectively embodying a multi-purpose façade that significantly influences the building's design and architecture.

Some of these constituent components are readily available in the commercial market, each accompanied by pertinent certificates and datasheets. Consequently, no additional testing is required for these components, as they are inherently compatible and compliant with both European and National regulations.

The prototype and laboratory tests that will be conducted on the MPF panels will validate their performance and adherence to stringent quality standards. This integrated approach not only ensures the reliability and efficiency of the multifunctional facade, but also underlines its seamless integration into the regulatory framework, making it a sustainable and compliant solution for the design and construction of buildings, which contributes to energy efficiency and reduces consumption even of existing buildings.

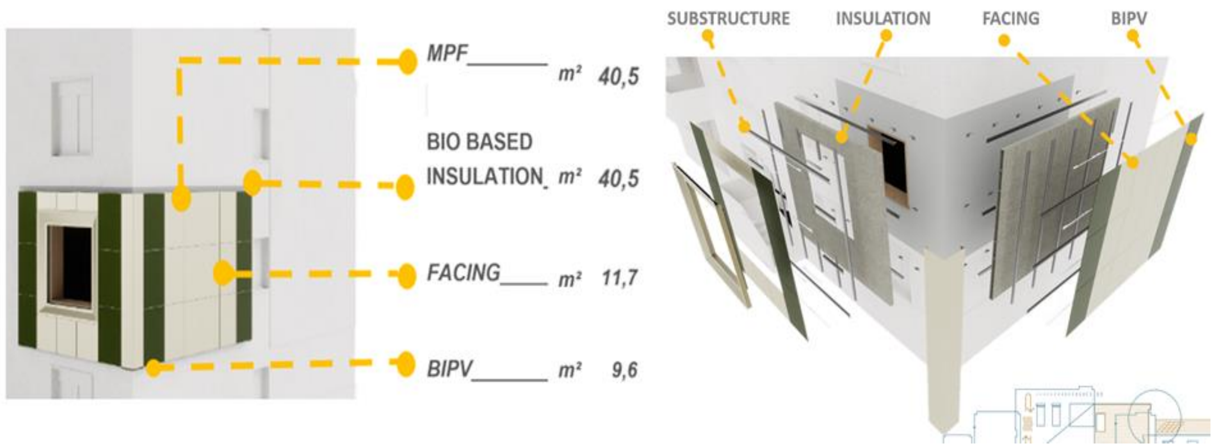


Figure 29: Prototype specification

4.5.1 PRE-ASSEMBLY TESTING OF RPS COMPONENTS/ MATERIALS TO VERIFY COMPATIBILITY

Substructure:

The structural components will be subjected to Finite Elements Method FEM analysis.

In particular, a first attempt analysis was conducted on the structure to be used as a tester for the project of the entire demonstrator on the Margherita di Savoia (BT) site.

The analysis will be conducted on the load-bearing structure, considering panels as a significant load (insulation, photovoltaic and rainproof finish).

More information will be provided in *Deliverable 2.4 "Report of the long-term performance tests of the components of the RPs*".

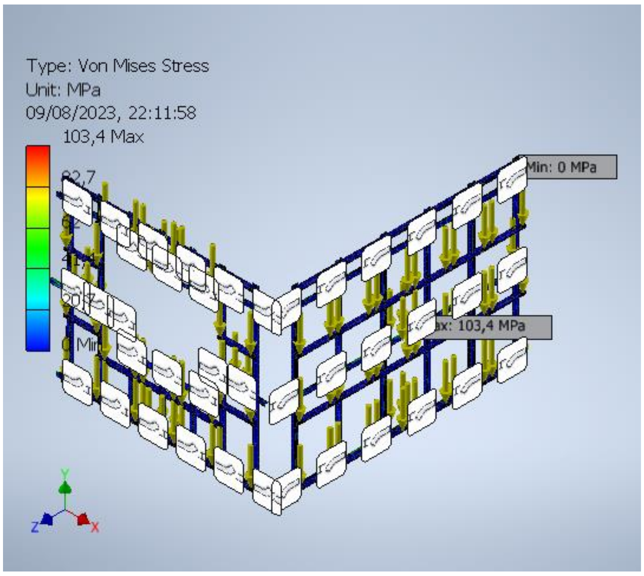


Figure 30: Static loads preliminary analysis

Photovoltaic modules must meet both electrical requirements and those required by the Construction Products Regulations. As containing photovoltaic parts, they must meet international standards IEC 61215 and IEC 61730. These standards respectively establish requirements for qualification of the design of terrestrial photovoltaic modules suitable for long-term operation in outdoor climates and basic construction requirements for photovoltaic (PV) modules to ensure safe electrical and mechanical operation, and the second part lists the tests that a PV module must meet for safety qualification.

As part of the project, testing procedures will be carried out to ensure that the individual BIPV product could comply with the required TRL and ensure performance and reliability levels.

Electrical characterization tests will be conducted for performance evaluation through the following sequence:

- VISUAL INSPECTION

  Non-destructive evaluation method through thoroughly examining an object or structure using the naked eye or optical instruments. The primary goal is to identify any visible defects, irregularities, or anomalies, such as cracks, corrosion, wear, or other physical imperfections.

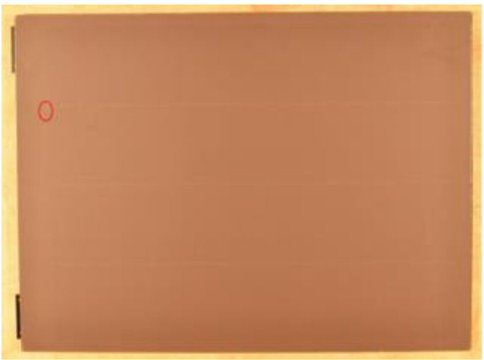
 

Figure 31: PV module – FRONT and BACK sides

- ELECTRICAL PERFORMANCE

  Testing method for the electrical performance of terrestrial photovoltaic (PV) modules. The electric performance criteria outlined in IEC 61215 include several key parameters:

  - Maximum Power (Pmax).
  - Open-Circuit Voltage (Voc).
  - Short-Circuit Current (Isc).
  - Voltage at Maximum Power (Vmpp).
  - Current at Maximum Power (Impp).
  - Fill Factor (FF).

  Compliance with the standards outlined in IEC 61215 ensures that photovoltaic modules meet specific performance and safety criteria.

- ELECTROLUMINESCENCE

  Electroluminescence (EL) is a diagnostic technique used to inspect photovoltaic (PV) modules to assess their structural and electrical integrity. It is a valuable tool in the inspection and quality control of PV modules, enabling the early detection of defects and contributing to the overall reliability and performance of solar energy systems.

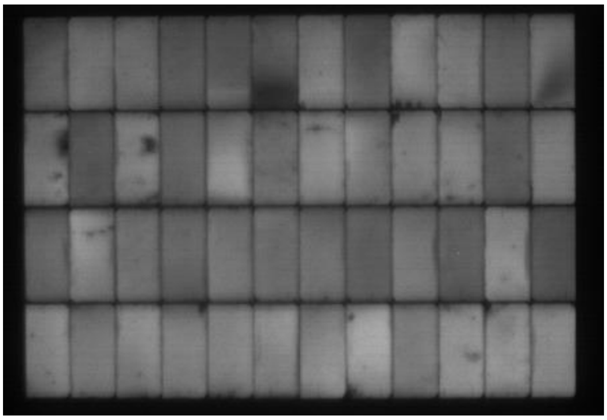


Figure 32: PV module – electroluminescence image

- SPECTRAL RESPONSIVITY

  Spectral responsivity is a measure of how effectively a photovoltaic (PV) device, such as a solar cell or module, responds to different wavelengths of light across the solar spectrum.

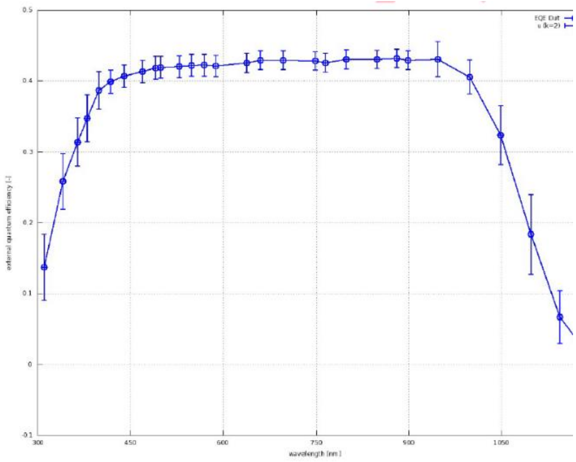


Figure 33: PV module – Spectral responsivity curve

4.5.2 COMPLIANCE TESTING AND CALCULATIONS DERIVED FROM NATIONAL AND EUROPEAN BUILDING REGULATIONS

Specific evaluations derived from international, European, and national standards will be undertaken to assess and validate the safety and reliability of the components. It is crucial to note that the products are currently in the Technology Readiness Level (TRL) phase, where certification tests are not applicable. Instead, tests will focus on demonstrating the product's suitability for installation in a real-world testing environment, corresponding to TRL6.

As part of these evaluations, on the BIPV products, the Wet Leakage Current Test will be conducted to ensure that the Building Integrated Photovoltaic (BIPV) module does not pose any electrocution hazards. This test is instrumental in verifying the insulation integrity of the module under wet operating conditions, guaranteeing its safety and reliability in practical applications.

The primary objective of the Wet Leakage Current Test (MQT 15) in adherence to IEC 61215 is to assess the module's insulation performance under wet operating conditions. The test aims to ensure that the ingress of moisture, stemming from sources such as rain, fog, dew, or melted snow, is prevented from entering the active components of the module's circuitry. This evaluation is crucial to mitigating potential issues such as corrosion, earth faults, or safety hazards that may arise due to moisture intrusion.

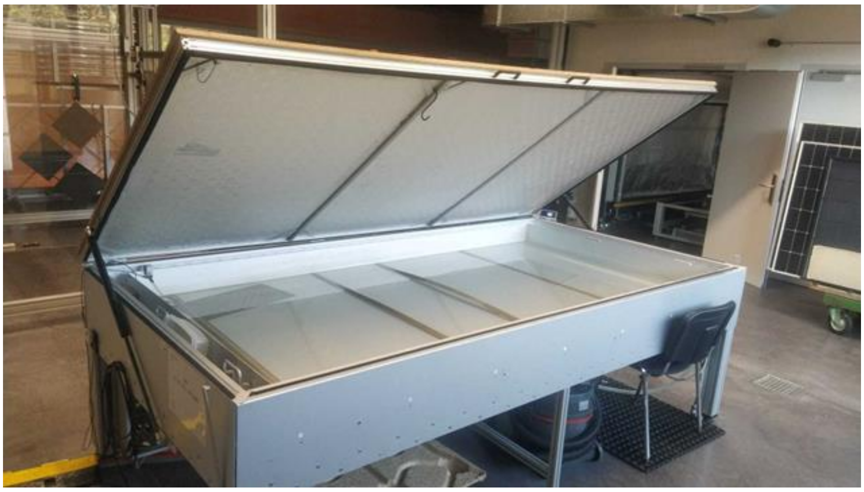


Figure 34: Wet leakage test - equipment

Hail tests will also be carried out on the BIPV module to assess its impact resistance during special events.

The Hail Test (MQT 17), conducted in accordance with IEC 61215, serves the fundamental purpose of evaluating the resilience of photovoltaic (PV) modules to hail impact. This test is essential to ensure the durability and structural integrity of the modules when subjected to hailstorms, a critical consideration for their reliable performance in diverse environmental conditions.

The Hail Test establishes specific performance criteria based on the size and impact velocity of the simulated hailstones. The PV module is expected to withstand the hail impact without exhibiting structural damage that could compromise its functionality or safety.

While testing according to European standards is not required for BIPV modules in the facade, the Swiss VKF standard will be applied. This standard involves testing the impact at a 45-degree angle, imposing more severe conditions than modules placed in the facade.

Figure 35: Hail resistance test – Equipment and module detail

As far as the hemp panels are concerned, the following tests will be conducted:

Reaction to Fire: The Single Burning Item test (SBI) will be conducted in accordance with EN 13823. The Single Burning Item (SBI), is a method of test for determining the reaction to fire behaviour of building products when exposed to the thermal attack by a single burning item (a sand-box burner supplied with propane). The specimen is mounted on a trolley that is positioned in a frame beneath an exhaust system. The reaction of the specimen to the burner is monitored instrumentally and visually (more information was mentioned also in other chapters of this deliverable). This test is important in order to verify the fire resistance of panels.

Figure 36: SBI test – Flames propagation

Water Repellency: Spray Test is a test on the hemp panel. This test is used to determine the depth of penetration of water under pressure. This test is regulated for other types of materials by the Italian standard UNI EN 12390-8 (June 2002) based on the international standard ISO (DIS) 7031 and similar to the standard DIN 1048, part 5 (1991). A cubic, cylindrical or prismatic specimen with a side length or a diameter of not less than 150 mm shall be used. The test apparatus involves the application of water at a pressure of 500 kpa for 72 hours. This test is used to study the behaviour of the facade panel simulating the driving rain. This methodology is experimental on this material.

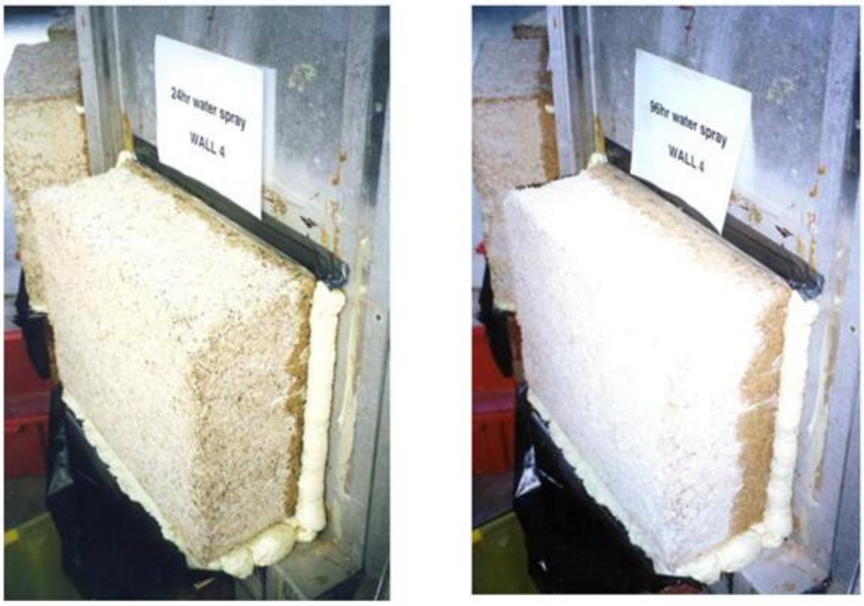


Figure 37: Spray test

In the next figure, the summary of the tests already conducted, as well as the upcoming assessments for the individual components of the multipurpose façade is indicated. Some of the already executed tests were realized to prove the transition of the Renovation Package from TRL4 to TRL5 environment.

At completion of prototype, TESTS are foreseen.

BIPV TEST: *The TRL advance has to include testing on the single component and testing on the integrated façade system (large-scale prototype tested according to EU standards). Here, the preliminary tests are reported in order to demonstrate the characterization and reliability of the BIPV component. Other tests on the facade system will be reported in the RP#5 activity.*

- *Visual inspection*
- *Performance at STC*
- *Maximum power Determination*
- *Spectral responsivity*
- *Electroluminescence*
- *Wet Leakage*
- *Mechanical load test (serviceability and ultimate limit state)*
- *Hail test (serviceability and ultimate limit state)*

Tests will be carried out according to IEC and VKF standards.

FIXING and SUPPORT STRUCTURE:

- *Visual inspection*
- *Tear load test of wall fixing system*
- *Shear load test of wall fixing system*
- *Tear load test of supporting sub structure*
- *Shear load test of supporting sub structure*
- *Wet Leakage*

Tests will be carried out according to IEC standards.

HEMP PANELS TEST:

The TRL advance has to include testing on the single component and testing on the integrated façade system (large-scale prototype tested according to EU standards). Here, the laboratory tests are reported in order to demonstrate the characterization and reliability of the hemp panels. Other tests on the facade system will be reported in the RP#5 activity.

- *Visual inspection*
- *Reaction to fire*
- *Sound absorption*
- *Water vapor diffusion resistance*
- *Compressive stress at 10% deformation*
- *Water Repellency: Spray Test*

Tests will be carried out according to IEC standards.

Figure 38: Summary of tests and assessment for the components of the multipurpose facade

4.5.3 QUALITY ASSURANCE TESTS CONDUCTED ON ASSEMBLED RPS PROTOTYPES - POST-ASSEMBLY AND PRE-INSTALLATION AT DEMO SITES

To validate compliance with reliability and safety standards at TRL7 for the Margherita di Savoia demonstration building, comprehensive tests will be conducted on the multipurpose facade once all components are assembled. The primary safety assessments will involve mechanical tests and a fire reaction test for the entire facade assembly.

Also, the insulation thermal test will be applied to demonstrate the performance level reached by the envelope.

One critical evaluation is the Static Mechanical Load Test (MQT 16), designed to ascertain the module's capacity to endure a predetermined static load. The minimum design load, specific to the site's construction, standards, codes, probability of occurrence, design assumptions, and location/climate, will determine the test load. This calculation involves multiplying the design load by the safety factor γm, set at a minimum of ≥ 1.5.

Test Load = γm × Design Load

As outlined in this document, the minimum design load stands at 1,600 Pa, resulting in a required test load of 2,400 Pa. Throughout the design development, load criteria will be defined based on the installation conditions. The Static Mechanical Load Test mimics the effects of typical environmental loads, such as wind or snow on PV modules, ensuring the system's robustness against external forces.

Figure 39: Mechanical load test – Equipment

The evaluation of mechanically fastened exterior wall cladding kits will refer to the European Assessment Document (EAD) for guidance on impact tests. The EAD outlines the test procedure and specifies the use of impactors.

For the impact tests, hard body impacts will be conducted using a steel ball weighing either 0.5 kg or 1.0 kg, dropped from varying heights based on the desired impact class. This type of impact scenario replicates instances like vandalism involving stone-throwing.

Additionally, small soft body impacts will be performed with a 3.0 kg soft ball from different heights, reflecting specific impact categories (e.g., resembling impacts from a hand). Larger soft body impacts will be simulated using a spherical bag weighing 50.0 kg, mimicking the impact of a human body.

This building facade impact test is paramount for assessing the structural resilience and safety of components, especially for Building Integrated Photovoltaic (BIPV) modules integrated into facades. These modules face exposure to diverse environmental elements and potential impacts.

The primary goal of impact testing is to confirm that facade components, including BIPV modules, can withstand impact forces without compromising structural integrity, electrical performance, or safety hazards. This is imperative for ensuring the sustained reliability of BIPV installations and the safety of occupants.

However, it is crucial to consider the location of facade elements and their accessibility when determining the required impact category, adding an additional layer of precision to the assessment process.

Figure 40: Impact test – Hard and large soft body impacts

To assess the new innovative facade system, a fire test will be conducted on the fully assembled system in accordance with EN 13501. Specifically, the SBI test will be implemented to determine the fire reaction of the system. While the building is not designated for fire department activities, conducting this test is essential for safety considerations and to obtain a comprehensive evaluation of the system's fire response.

Figure 41:SBI test – Complete facade system

In the next figure is indicated the summary of the tests that will be conducted for the assembled components of the multipurpose façade:

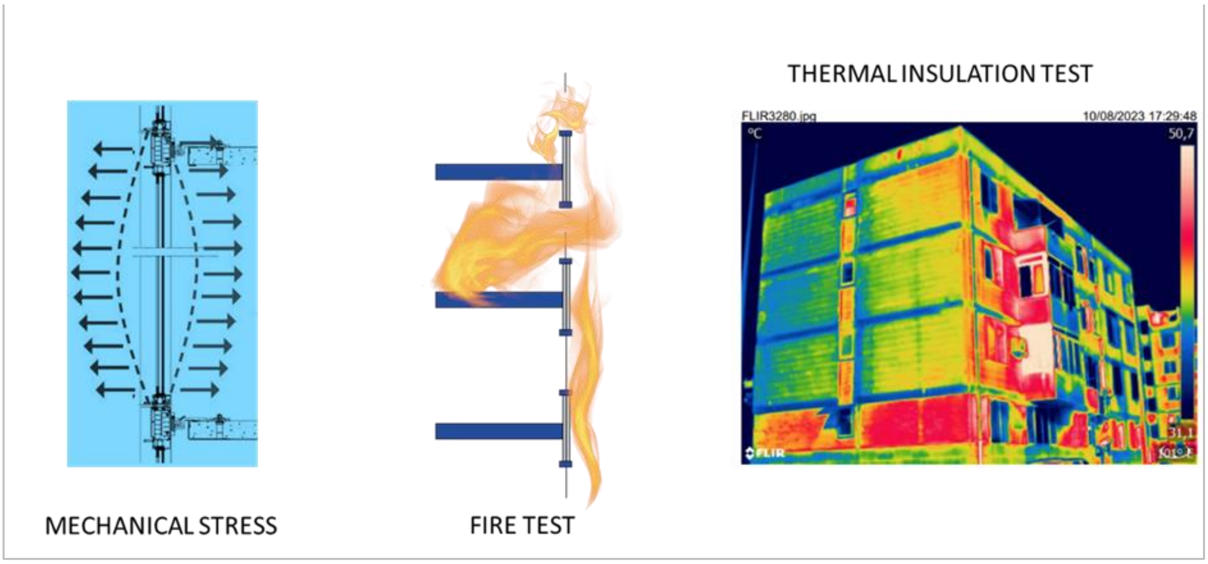


Figure 42: Tests/assessments that will be performed after the assembly of the multipurpose facade

4.6 RP#6: PANOREN

PanoRen builds on an insulation solution already available in the market Panobloc® which has already reached certification[7] from the French CCFAT[8], the commission in charge of technical approvals.

The above certification concerns the application of the Panobloc on metallic or concrete structure and is justified by forty experimental tests[9]: air tightness, water permeability, wind resistance, mechanical, acoustic, fire, thermal and hygrothermal tests.

Further developments of the PanoRen, in particular the integration of the flow controlled mechanical ventilation and the PV façade integration will require to be tested at CEA-INES facilities through the installation and characterization of prototypes on the FACT building façades.

The prototype will be installed on the West and North façade of the FACT experimental building and will integrate different testing activities:

- Singular points: window, French window with balcony and a wall angle;
- Roller shutter's integration alimented by a photovoltaic module;
- Double flow controlled mechanical ventilation integration:
    - Architectural elements inside the core insulation panel in order to integrate the ventilation system's ducts;
    - Air inlet, outlet and connection with the duct inside the panel;
    - Air tightness test following a similar methodology as the Blower door test;
    - Thermal efficiency: temperature difference between the outlet of the double flow and the outlet in the room;
- Photovoltaic module integration (facade)
    - Assembly, fixing issues;

[7] Technical approval number 2.1/14-1636_V2
[8] See more about the CCFAT in the Following link (in French): https://www.ccfat.fr/la-ccfat/missions-et-activites/
[9] The list of the different tests is available in the ANNEX 6.1

  - Cabling and duct integration;
- Moisture transfer:
  - Study of hygrothermal risks in wood-frame and bio-based insulation;
  - Study of the effect of a damaged initial wall on the moisture in the PanoRen;
- Air-tightness;
- PV module heating:
  - A temperature sensor will be installed under the module and sensors will measure the air gap temperature between the PV module and the wall;
- Innovative fastening system:
  - Reduction in the number of fasteners;
  - Elimination of horizontal gaps between panels;
  - Reduction of stresses transmitted to floor slabs;

RP#6 integrates also a second-life PV installation. The certification procedure for second-life PV module will be the following:

- The module used will be a commercial PV module that has been certified, that works, and with no technical modifications that makes them incompatible with their use. If the maintenance has to be done on constitutive elements of the PV module, components will have the same requirements as the initial components.
- The selection will be done for PV modules (less than 10 years) knowing the reasons why the modules have been removed. All modules that are concerned by serial defects that are irreparable will not be selected. Four tests, described below, are planned to certify the second-life PV module.
  - All the PV modules will be tested following the standard IEC 61730. This test consists of an electrical diagnosis in a wet environment. The module is immersed, excepted cable connections. A voltage is applied to the output connectors, then increased to the module's maximum voltage (or 500 V) and applied for a period of 2 minutes. The expected results is an insulation resistance higher than 40 $M\Omega.m^2$.
  - Visual inspection following the standard IEC 61215. An illumination of minimum 1000 lux is applied on the module in order to proceed to the visual inspection. If the module present defects that will cause future degradation, for example cracks or corrosion, it will be rejected.
  - Performance test following the IEC 61215 and IEC 60904. This test will attest the module's electrical performance under standard test conditions (STC).
  - Electroluminescence test based on the standard IEC 60904-1-13. This test will allow to detect defaults on the different PV cells of the module.

All these tests are expected for new PV module by the standard IEC 61215.

4.7 RP#7: ACTIVATED CELLULOSE THERMAL INSULATION MADE OF WOOD WASTE

Before building in this insulation material to the demonstration site, it will be tested for its mechanical and thermodynamic properties in relation also to its water and fire resistance performance.

In our case the insulation will be used on the façade, and consequently the compression strength is not a crucial factor especially because the insulation will not be in the front of the façade, but behind a siding material, thus no compression stress will be appeared on the incorporated insulation panels.

The most important property of a thermal insulation material is the thermal conductivity. This will be measured before the installation of the material to the demo site and in a sample form, but the question is: will the thermal conductivity change over the time? No or not exactly relevant information can be found in the literature, however it is an important information that the built-in insulation can meet the requirements after decades. On the other hand, the consequent question is: will the energy consumption of the building change because of the latent change of thermal conductivity of insulation materials? Technically it will be more practical to place an insulation in fully similar conditions, and measure thermal conductivity regularly.

In preliminary assumptions it is possible some degradation of the fibres and fibre connections which can result in a smaller number of bonding inside the panel. It is not known whether it increases or decreases thermal conductivity. In the frame of the long term testing it will be important and interesting to be checked.

Of course, before installing the insulation, enough and reliable information concerning its resistance in humidity and water intrusion must be provided. This will be measured before and seems to have no sense to be tested later.

For fire resistance, tests will be performed prior the installation, to classify the insulation material. But since no changes are expected over the time, especially because of the fire-retardant component, no degradation or leaching is predicted.

Therefore, the only long-term test that will be executed is the measurement of thermal conductivity (λ) over the time. This will be measured by the hot plate method. This method uses the steady state condition, where the cold side is set to 5ºC and the hot plate to 15ºC. The driven force of the thermal flux is this 10-degree Celsius temperature difference. In the first step the sample has to reach the steady state condition when no further temperature changes occur inside and also on the surface of the specimen. The measurement starts only if the sample temperature is in steady state condition. Measurement usually lasts 100 minutes, and every minute the equipment logs the actual data and calculates the thermal conductivity. The final results come from the average of the hundred measured data. This method is time consuming, but one of the most reliable methods.

The hot plate thermal conductivity measuring device has a side insulation for providing the one-dimensional heat flux on the area of the heat flux meter.

For getting the most reliable data regarding the changes in thermal conductivity of the activated cellulose insulation, it would be better to use the same method and if possible, the same equipment with the same settings.

To perform thermal conductivity measurements, it will be needed to have a sample with the same exposure as that of the integrated on the existing wall, insulation. For this reason, a sample part will be placed under the façade, so as to be able to be removed for measurements from time to time. The best solution would be to measure every year and log the data for having a trend of changes.

The samples should be placed behind the siding of the façade to be protected from UV radiation, which could degrade the material structure. In this positioning the sample will be in the same weather conditions as the built in (integrated) insulation.

Before measurement, the samples have to be conditioned in normal climate (20ºC and relative humidity of 65%) for three weeks to eliminate the moisture effect. The more wet is the sample, the higher is its thermal conductivity. Actually, it is not the time that is important but the constant weight of the samples.

4.8 RP#8: INTELLIGENT WINDOWS SYSTEM

As can be seen in Figure 43 a life size model prototype of the Intelligent Window System (IWS) was built for running tests before finalizing the structures, the mechanics and the control unit. These tests showed some problems in the controller algorithm and also showed the weak points of the mechanics. According to this several improvements were identified, e.g. the plastic moving elements needed to be changed to aluminium, the controller program was improved, etc.

Figure 43: IWS life size prototype with the electric engine

The Intelligent Window System does not need a long-term test, because no changes are foreseen in the effectivity of the thermal resistance. The most important are the safety aspects such as the ant-crushing mechanism, or in case the fire alarm is activated to consider that the IWS should automatically be opened.

The active system contains moving parts such as the electric engine connected to the gear and moving parts, and these parts can be worn. This wear effect or damage due to use, must be checked regularly once installed in the demo building to collect the relevant information concerning the life cycle of these parts.

The IWS was designed to be able to change these moving elements easily, so the maintenance should be a simple action. In addition, the design of the façade will be prepared in such a way that the engine and the gear (see the picture above) will be accessible to be able to maintenance or change if necessary.

As it is mentioned in Chapter 2.8 of this deliverable, the moving parts were designed to have as long life as possible, but it is not known how the possible contamination and the different operational external conditions will affect the moving elements of the system. Of course, if the moving force is higher, then the worn effect will be faster.

Beside the mechanics, the control system was also checked in order to analyse in detail how the system switch the mechanics for close or open the IWS automatically. It was identified that the energy consumption of the controller was higher than expected, that is why the electric engineer and IT professional of WOODSPRING redesigned the electronics reducing the consumption from 50 mW to 10 mW. This aspect is important from the aspect of battery size or the consumed energy amount. The new electric circuit is more reliable and with a higher technical level.

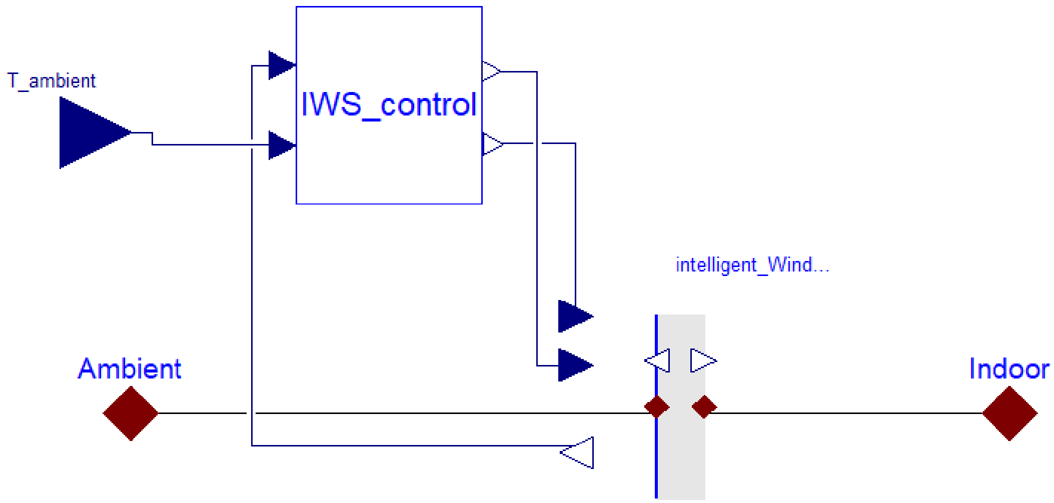


Figure 44: IWS control diagram

5 CONCLUSION

In this deliverable the eight Renovation Packages that will be installed in the four demo sites of the REHOUSE Project, were presented along with the testing or other procedures that will be followed in order to prove their TRL6 transition and demonstration in Task 2.4 of WP2.

Since all the RPs are currently in the Technology Readiness Level (TRL) phase, certification tests are not applicable and no certifications are needed to install these products at the demo sites. However, as was described in this document, many of the materials or components that will be used or will be integrated inside the Renovation Packages are commercial products and thus, already certified. For some cases, the testing procedures that will follow in Task 2.4 could lead to specific certifications. Apart from that, some testing processes and their resulting certifications (if any) could help raise the acceptance of new and innovative technologies from the building owners, but also from their insurance companies too.

As it was mentioned in this deliverable, most of the Renovation Package leaders will construct prototypes or samples which will be tested and assessed for their performance before the installation of the final products to the buildings. The prototypes that will be produced will be:

a) Multi-source heat pump (the prototype manufactured for the demo site will be tested prior to its installation) – RP#1
b) SmartWall – RP#3
c) Multipurpose prefab facade with bio-based insulation and BIPV – RP#5
d) Panoren – RP#6
e) Activated cellulose thermal insulation made of wood waste sample – RP#7
f) Intelligent Window System (prototype already built) – RP#8

The main methods and techniques that will be used for the assessment of each RP can be concluded below:

- For RP#1: Measurements will be conducted at the water and air side inlet/outlet temperature, and flow rates at the evaporator and condenser, the (indoor) ambient temperature, and the total power consumption. Moreover, various temperature and pressure sensors will be installed at the inlet and outlet of the unit's main components and piping to perform the unit condition monitoring and control the unit's operation. The measurements will be collected and recorded by the unit's PLC with a sampling rate defined by the user. This will be realised before the installation of the heat pump unit at the demo site.
- For RP#2: Visual inspection will be carried out upon arrival of the RP components to their premises, to observe any possible defects of the elements. Each component will then be thermally tested via thermography inspections to measure its surface temperatures and ensure its optimal operation. Additionally, various measurements will be made after the assembly of the different modules to test the voltage, current, resistance, etc. of the proposed solution.
- For RP#3: The procedures that will be executed are a thermal performance analysis, an energy performance analysis of SmartWall at building level, fire test with the new materials, testing for evaluating the performance of AMS's coatings and the construction of 3 prototypes which will be used to evaluate the mechanical properties, investigate anchoring issues, inspect the thermal performance, etc.
- For RP#4: The testing process will be conducted by means of virtual models. The chosen

modelling environment where the RP's components will be developed and tested is Matlab/Simulink. Within this framework, a detailed physical representation of each component will be set up according to the real ones. Tests will be also conducted for the heat storage tank, the encapsulation solution and the charge sensor.

- For RP#5: Tests will be performed on the components of the RP before their assembly (pre-assembly evaluation procedure) and tests will be also executed after the assembly of the whole RP to ensure the reliable operation of the technology before its installation to the demo site. The tests that will be performed after the assembly of the RP involve, fire test, mechanical test and thermal insulation test (IR).
- For RP#6: A prototype will be constructed and will be installed in a mock-up for evaluating its performance. In addition, different tests will be executed for the second-life PV modules, in order to be certified and comply with the related standards and requirements.
- For RP#7: Long-term measurements of the thermal conductivity (λ) of the activated cellulose thermal insulation will be realised over time.
- For RP#8: A prototype was built for running tests before their integration into the building. These tests showed some potential improvements to the IWS system in terms of mechanics and control. The moving parts of the IWS should be checked regularly once installed in the demo building.

Obviously, as each Renovation Package is different and consists of various components, the methods that will prove their reliability, safety and operation at TRL6 relevant environment will be different for each one of them. In addition, other RPs are simple and involve only one material like e.g. RP#7 activated cellulose insulation and others are complex and consist of many elements or technologies, like RP#3 and RP#5. However, all of them must prove their safe operation in TRL6 environment during Task 2.4.

6 ANNEX

6.1 SPECIFIC TESTS ALREADY CONDUCTED FOR THE AVAILABLE IN THE MARKET "PANOBLOC" (UPON WHICH RP#6 IS BASED):

Extract from the French CCFAT technical approval number 2.1/14-1636_V2 that certified the existing Panobloc® solution : list of the forty experimental tests : air tightness, water permeability, wind resistance, mechanical, acoustic, fire, thermal and hygrothermal tests

Essais AEV et mécaniques:

- Essais de perméabilité à l'air, de l'étanchéité à l'eau et de la résistance à la charge due au vent (AEV) ; Rapports FCBA N°404/11/355/961 du 09 Janvier 2012 et FCBA N°404/12/78/120 du 1er Mars 2012.

- Essais de résistance aux chocs de sécurité intérieur avec impact de corps mou ; Rapport FCBA N°403/11/1121/2 du 10 Avril 2012.

- Essais de résistance mécanique des systèmes d'assemblage UNIBLOC®RIDEAU, Rapport FCBA N°403/11/1121/1 du 10 Avril 2012.

- Essais de délamination et de cisaillement des plans de collage selon les méthodologies des normes NF EN 391 et NF EN 392 ; Rapport FCBA N°403/11/962 du 30 Mars 2012.

- Essais de comportement en situation accidentelle de séisme, Rapport CSTB N° EEM 12 26037932 du 29 mai 2012.

- Essais de flexion 4 points ; Rapport FCBA N°403/12/831/1 du 15 novembre 2012.

- Rapport d'étude – Validation sismique du procédé « PANOBLOC » avec une épaisseur de plis de 50 mm - rapport CSTB n° DEIS/FACET-17-465

Essais acoustiques:

- Mesures d'indice d'affaiblissement acoustique aux bruits aériens ; Rapports CSTB N°AC12-26042734 du 21 février 2013, CSTB N° AC13-26042962 du 21 février 2013 et CSTB N° AC13-26043932 du 4 septembre 2013.

- Mesures d'isolement latéral aux bruits aériens ; Rapports CSTB N°26043932 du 7 octobre 2013.

Résistance au feu :

- Essais de tenue au feu selon NF EN 1364-1 ; Rapport CSTB N° RS11-139 du 16 Février 2012.

- Essais de transfert thermique selon NF EN 1364-1 ; Rapports EFECTIS N° 13-F-089 du 19 juillet 2013 et EFECTIS N° 13-F-090 du 19 juillet 2013.

Sécurité incendie:

- Appréciation de laboratoire ; Avis CSTB n° AL14-146 version 2.

Performances thermiques :

- Evaluation des coefficients de transmission surfacique (Up) de parois verticales ; Rapport FCBA N°2011.512.0328 du 24 novembre 2011.

- Evaluation des ponts thermiques linéiques et ponctuels ; Rapport FCBA N°2012.469.1144 du 23 Mai 2012 et FCBA N°2012.467.0261 du 17 septembre 2012.

- Validation des performances thermiques ; Rapport CSTB n° DIR/HTO 2014-210 – 14-066 du 23 octobre 2014.

- Validation des performances thermiques ; Rapport CSTB n° DIR/HTO 2017-074 – 17-027 du 26 juin 2017.

Comportement hygrométrique:

- Etude des risques de dégradations liées à l'humidité ; Rapport CRITTBOIS N°2012-619 du 28 novembre 2012.