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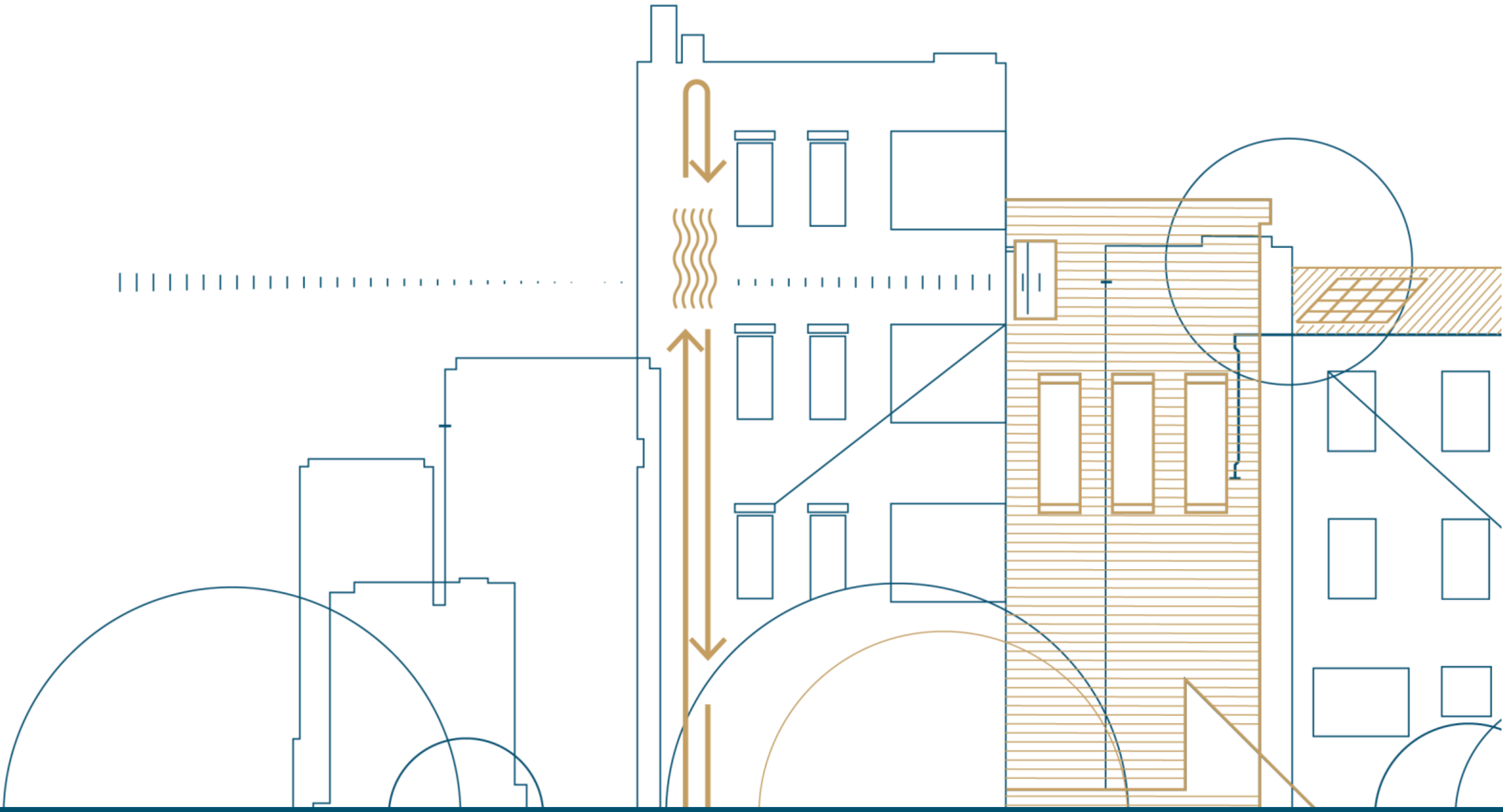
REHOUSE



D2.3

Detailed models of 8 renovation packages (BIM-based)

Co-funded by the
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Associated Task	T2.3 Modelling, Control and improvement of prefab/off-site construction of Renovation Packages
Deliverable Lead Partner	CERTH
Contributors	CERTH, PSYC, WOODS, RENEL, AMS, NTUA, RI, TWR, RINA-C, SUPSI, UNIBAS, K-FLEX, PLATAN, PW, SUNAGE, TERA, CEA, ENEA, CAR
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DOCUMENT HISTORY

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EXECUTIVE SUMMARY

D2.3 “*Detailed models of 8 renovation packages (BIM-based)”* is presented as a report showing the main results from T2.3 “*Modelling, Control and improvement of prefab/off-site construction of Renovation Packages*” within WP2 “*Renovation packages design, specification and digitalisation [TRL6 demonstration]”* in the framework of the Horizon Europe project REHOUSE. The report covers the development of the Renovation Packages (RPs) models and their preliminary analysis; the simulations/assessments of the Demo sites, and the 8 RPs Building Information Modelling (BIM) models. In addition, numerous documents were generated and included as annexes of this report containing detailed descriptions of all activities conducted within this task, serving as a comprehensive reference for the undertaken work.

The results of this task will be utilized by partners throughout the design, execution (renovation), and operation (monitoring) phases of the project. The document details the simulations conducted that will bridge the gap between the as-designed and as-built models. Additionally, it outlines the prefabrication and off-site construction strategies employed for certain components of various RPs, along with the control algorithms utilized for the active parts.

RP energy models were created for RP1, RP2, RP3, RP7, and RP8 using the INTEMA.building tool by CERTH. Within the development process in INTEMA.building, operational algorithms were crafted to effectively control the models' functioning. These control strategies aimed at enhancing energy system efficiency and minimizing thermal losses, especially for models simulating the building envelope. Notably, advanced control strategies were implemented for RP1, RP2, RP3, and RP8, whereas RP7, being a passive technology (insulation), operated without the need for a controller. Also, in RP4, a novel control strategy will be implemented to define the energy asset management approach. The overarching objective will be to minimize end-user energy consumption and environmental impact. The control algorithms for RP4 will be formulated using the Python programming language, and the resultant scripts will undergo initial testing within an environment developed in Matlab-Simulink.

Additional simulations and analyses were conducted, where necessary, for RP2, RP3, and RP5 to ensure optimal quality and project goal achievement. These efforts included surveys to identify specific needs and potential barriers, detailed measurements for RP dimensioning, and the creation of preliminary designs and mock-ups. The overarching aim was to facilitate successful prefabrication processes and minimize discrepancies between design and implementation.

Energy analyses and life cycle assessments/cost analyses (LCA/LCC) were conducted for baseline and renovation scenarios at the Greek (GR) and Hungarian (HU) demo sites. Additionally, energy analysis simulations were performed for the Italian (IT) and French (FR) demo sites, covering both baseline and renovation scenarios. Some data used may differ from the final dataset, as assumptions were made for the simulations. More accurate data will be utilized in future project deliverables.

Finally, the BIM-based models of the 8 Renovation Packages within the REHOUSE project, representing the primary focus of D2.3, were created. Each RP BIM model includes details such as the responsible partner for model creation, software used, file extension, level of development, and accompanying images. While some RP properties are outlined, comprehensive specifications for all RPs can be found in D2.2 “*Detailed specification of 8 renovation packages and their components*”. Notably, various RPs entail diverse configurations, resulting in the development of multiple BIM models.

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LIST OF ABBREVATIONS

ACRONYM	DESCRIPTION
ADBE	Adaptable/Dynamic Building Envelope
BIM	Building Information Modelling
BIPV	Building-Integrated Photovoltaics
COP	Coefficient of Performance
D	Deliverable
DHW	Domestic Hot Water
EC	European Commission
EER	Energy Efficiency Ratio
EG	Electrical Grid
FCU	Fan Coil Unit
F-Gas	Fluorinated Greenhouse Gases
H&C	Heating and Cooling
HVAC	Heating, Ventilation, and Air Conditioning
HP	Horsepower
IFC	Industry Foundation Classes
IWS	Intelligent Window System
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
PCMs	Phase-Change Material
PI	Proportional Integral
PID	Proportional Integral Derivative
PV	Photovoltaics
RP	Renovation Package
TRL	Technological Readiness Level
WP	Work Package
TES	Thermal Energy Storage
ML	Machine Learning
MPF	Multi-Purpose Façade
MPPT	Maximum Power Point Tracking

1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE DOCUMENT

D2.3 “*Detailed models of 8 renovation packages (BIM-based)”*, is presented as a report summarizing the main results obtained as part of the Task 2.3 “*Modelling, Control and improvement of prefab/off-site construction of Renovation Packages”* being the main scope of this task the development of the detailed models of the 8 Renovation Packages (BIM-based) of the REHOUSE project.

Within this task all the Renovation Packages (RPs) were modelled with a common agreed data model defined in Task 2.1 “*Taxonomy for Renovation Packages Characterisation”,* and the information provided by the RP owners of Task 2.2 “*Detailed specification of the renovation packages”* of the REHOUSE project. The development of the RP models (based on BIM and other formats) led to the process improvement of the prefabrication and/or the off-site construction strategies of some of their components. Several control algorithms of the active parts of some RPs were also implemented to facilitate upgrades in their overall system.

At the demonstration level, simulations were carried out to reduce the gap between the as-designed and as-built models. The aim of these simulations (RP and Demo level) was to ensure, to a great extent, that the final performance of the renovated buildings would meet the expectations of the design phase.

Numerous reports were generated and included as annexes of this deliverable containing detailed descriptions of all the activities carried out within Task 2.3, providing a comprehensive reference for the undertaken work.

This document is structured in 6 main chapters: Chapter 1 serves as the Introduction, providing an overview of the document's scope. Chapter 2 focuses on the developed Renovation Packages (RPs) models and their preliminary analysis while Chapter 3 presents the simulations of the demo sites, and Chapter 4 provides insights into the BIM models of the RPs. Finally, Chapter 5 offers conclusions and a recapitulation of the work undertaken in this deliverable, summarizing the key findings and contributions. In the Annexes individual modelling and simulation reports developed as part of this task are presented.

1.2 CONTRIBUTIONS OF PARTNERS

The contribution of the partners to the Task 2.3 and Deliverable 2.3 is shown in Table 1.

Table 1: Partners’ contribution to T2.3

PARTICIPANT	CONTRIBUTIONS
CERTH	Task leader, deliverable leader, selecting and coordinating the information provided by the RP owners, the demo leaders and the responsible partners for the creation of the BIM models.
CAR, AMS, RINA-C, RI, TWR	Responsible partner for the creation of the RPs BIM models.
PSYC, RENEL, AMS, NTUA,	RPs owners and partners. Responsible for the

PARTICIPANT	CONTRIBUTIONS
WOODS, StT, RINA-C, K-FLEX, SUNAGE, RI, PW, SUPSI, UNIBAS, TERA, TWR, CERTH	information provided for the RPs and the development of the RPs models and their preliminary analysis.
DUTH, WOODS, PLATAN, ENEA, UNIBAS, CEA, CERTH	Demo leaders and partners responsible for the information, inputs, and simulations/assessments of the demo sites.

1.3 RELATION TO OTHER ACTIVITIES IN THE PROJECT

Table 2: Relation of T2.3/D2.3 with other activities in the project

ACTIVITY	DESCRIPTION
T2.1 and D2.1 (Taxonomy of the RPs)	The data model defined in T2.1 was used as the base to create the BIM models.
T2.2 and D2.2 (Detailed specifications of the RPs and their components)	Data from this task were used for the creation of the BIM models.
T2.4 (Performance assessment for TLR6 demonstration) and T2.6 (Digital products repository)	The data included in D2.3 will be used to successfully complete the tasks T2.4 and T2.6.
T2.5 (Guidelines for the industrialization and use of the RPs)	The RPs models will support the creation of the RPs guidelines in T2.5.
T3.5 (Open specifications for common data repository: Digital Building Logbook)	Information can used for the development of the Digital Building Logbook
T4.1 (Deployment of IPD methodology and BIM-based DBL), T4.2 (Diagnosis), T4.3 (Design and preparation)	Assist for the development of the Demo BIM models and to successfully complete the tasks.

2 DEVELOPMENT OF RPS MODELS AND PRELIMINARY ANALYSIS

Various models were created, sharing a mutually agreed-upon dataset, and simulations for several RP were carried out by the respective responsible partners. While these models and simulations were not mandatory, it is worth noting that all RP owners except RP6 chose to participate in these activities. There was no further need to develop RP6 models, as fastenings for securing the RP6 panels were already modelled, and several panels have already been manufactured (for more details see D2.2). In the process of model development, several control algorithms for the active components of certain RPs were incorporated, and diverse strategies were explored to enhance the prefabrication and/or off-site construction processes. The goal of these models and analysis is to derive optimal final solutions.

2.1 RPS ENERGY MODELS AND CONTROL ALGORITHMS/SYSTEMS CREATION - INTEMA.BUILDING

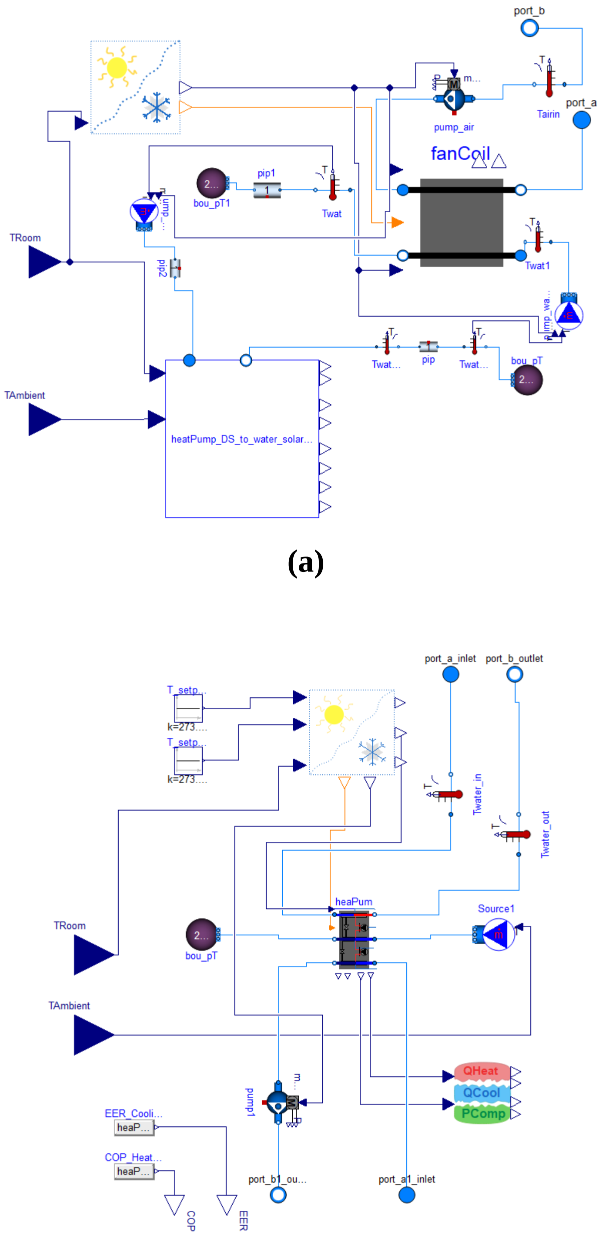
Energy models of different RPs (RP1, RP2, RP3, RP7, RP8) were developed through the INTEMA.building tool by CERTH. During the development of the models in INTEMA.building, operation algorithms, aiming at the proper control of the models' operation, have been developed. The control strategies aim to increase the efficiency of the energy systems and reduce the thermal losses in the case of models that regard the simulation of the building envelope. The development of the models is based on proper controllers (e.g. PI, PID) which are fed, for instance, with variable temperature level inputs, and guide the control unit into making the correct decisions. Specifically, it is remarkable to state that advanced control strategies have been developed for the RP1, RP2, RP3 and RP8, while the RP7 is a passive technology (insulation) that does not require a controller for its operation.

Below a summary of the models and the control algorithms/systems developed within the INTEMA.building are presented. It is important to note that the detailed reports of each of the 5 RPs can be found in the annexes of this report.

2.1.1 RP1: MULTI-SOURCE HEAT PUMP

Developed model - INTEMA.building

For the simulation of the multi-source heat pump (RP1), a detailed model is developed in Modelica language using the INTEMA.building tool. Figure 1a illustrates the configuration of the multi-source heat pump that is connected to a fan coil system that feeds the air zone with treated air. Figure 1b focuses on the model of the multi-source heat pump. The multi-source heat pump uses the ambient air, geothermal energy (geothermal field), and/or solar energy (solar thermal collectors) through the water as heat sources.



(a)

(b)

Figure 1. The developed model in Modelica, (a) Model of the multi-source heat pump in connection with the fan coil system, (b) Model of the multi-source heat pump

Control Algorithms/System

An appropriate control system has been used to control the heat source that feeds the evaporator of the heat pump during the winter period. This control allows the selection of the most efficient heat source (air or solar/geothermal) aiming to increase the COP of the heat pump. Additionally, during the cooling period, advanced control systems efficiently adjust the high pressure of the cycle to minimize the electricity consumption (or maximize the EER).

2.1.2 RP2: ADAPTABLE/DYNAMIC BUILDING ENVELOPE

Developed model - INTEMA.building

Four types of facade systems with integrated PV panels structures were developed in Modelica language and tested using the INTEMA building tool: (a) an opaque building element on which the ADBE façade with the building-integrated PV panel is attached (Figure 2), (b) an opaque building element on which the ADBE façade with the insulation element and the building-integrated PV panel is attached (Figure 3), (c) an opaque building element on which the ADBE façade with the insulation element and the building-integrated PV panel as well as a window element are attached (Figure 4), and (d) a wall and window construction on which the ADBE façade with the insulation element and the PV panel are integrated (Figure 5). The ADBE-a facade will be utilized in the Greek Demo Site in Kimmeria.

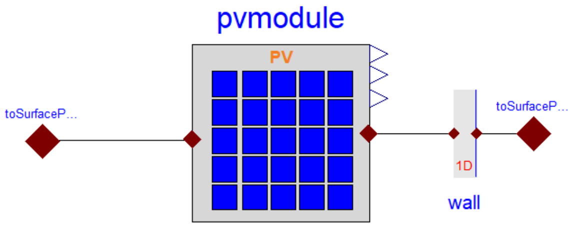


Figure 2. The developed model of the ADBE- a technology in Modelica

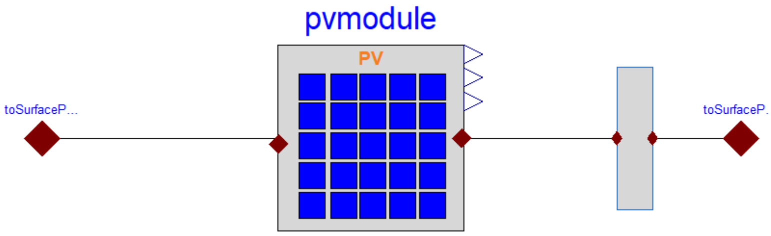


Figure 3. The developed model of the ADBE- b technology in Modelica

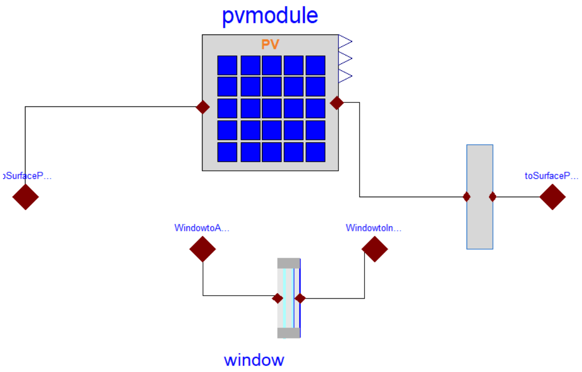


Figure 4. The developed model of the ADBE- c technology in Modelica

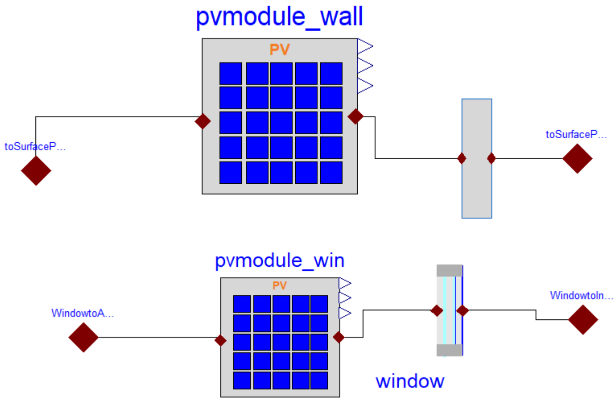


Figure 5. The developed model of the ADBE- d technology in Modelica

Control Algorithms/Systems

The RP2 includes BIPV panels which are accurately controlled to operate in the maximum power point. Therefore, there is an automatic algorithm that selects the suitable operation point (current, voltage) that maximizes the power production depending on the ambient conditions (temperature, incident solar irradiation). Practically, the model is fed with the correct weather data and automatically selects the operation strategy that can lead to the desired operating point.

2.1.3 RP3: SMARTWALL

Developed model - INTEMA.building

For the simulation of the SmartWall technology (RP3), four models were developed and tested in INTEMA.building tool using Modelica language: a) SmartWall façade that comprises of a thermal insulation element attached on a wall component (Figure 6), b) SmartWall façade that comprises of a thermal insulation element attached on a wall component and a glazing system (Figure 7), c) SmartWall façade that comprises of a thermal insulation element attached on a wall component, a glazing system, and a fan coil system (Figure 8), and d) SmartWall façade that comprises of a thermal insulation element attached on a wall component, a glazing system, a fan coil system and a mechanical ventilation system with heat recovery (Figure 9). More specifically these four models simulate a simple wall construction and a window on which the SmartWalls facade is attached as an extra construction layer. The SmartWall facade may or may not include a glazing system, a fan coil system, and a mechanical ventilation system.

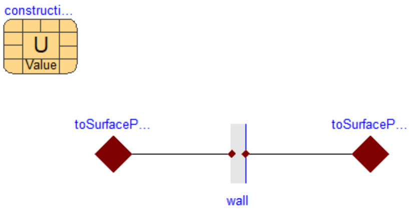


Figure 6. The developed model of the SmartWall- a technology in Modelica

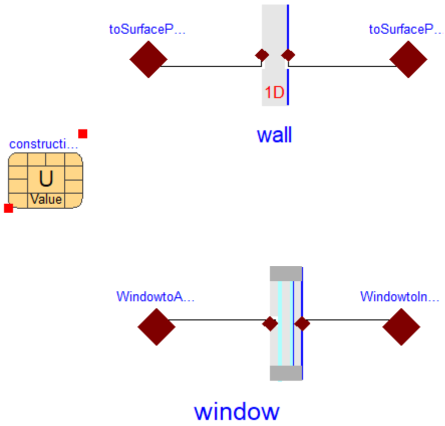


Figure 7. The developed model of the SmartWall- b technology in Modelica

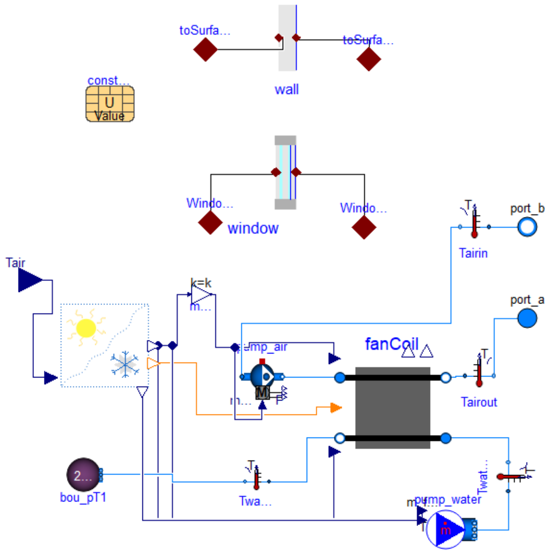


Figure 8. The developed model of the SmartWall- c technology in Modelica

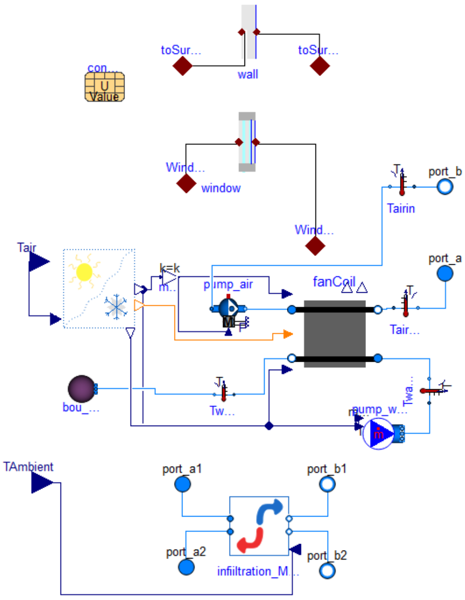


Figure 9. The developed model of the SmartWall- d technology in Modelica

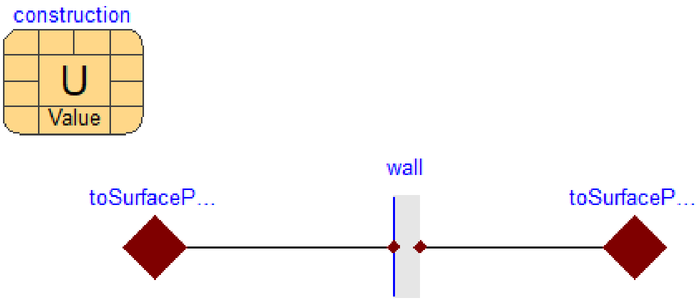
Control Algorithms/Systems

The RP3 is an active smart wall with incorporated fan coil units. For the simulation of the respected technology, proper control systems have been added to the developed model aiming to adjust the fan coil's operation based on the building's heating or cooling demand. Precisely, proper control units determine the operation of the pumps, the valves, etc. regarding the indoor temperature. If the indoor temperature is less than the winter temperature setpoint, then the fan coils operate providing heating in the space. On the other hand, if the indoor temperature is higher than the summer temperature setpoint then the fan coils provide cooling in the space.

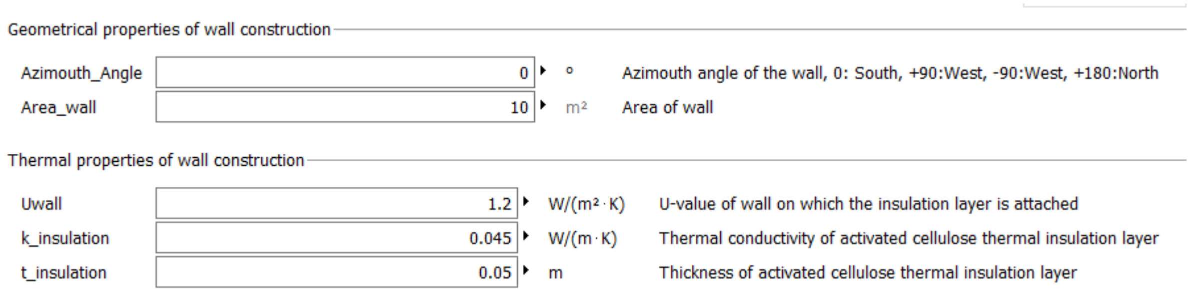
2.1.4 RP7: 100% ENVIRONMENT-FRIENDLY ACTIVATED CELLULOSE THERMAL INSULATION MADE OF WOOD WASTE

Developed model - INTEMA.building

For the simulation of the activated cellulose thermal insulation block (RP7), a model of a wall component was developed and tested in the INTEMA.building tool using Modelica language. More specifically this model simulates a simple wall construction on which the activated cellulose insulation block is attached as an extra thermal layer. Figure 10a shows the developed model in Modelica. The developed model simulates a simple wall element which is constructed of multiple thermal layers that represent a building's external wall and an external layer that represents the activated cellulose insulation block. Figure 10a and Figure 10b depict the required parameters for the simulation of the model. Firstly, the geometrical data that concern the wall's area, as well as the wall's azimuth angle are required. Secondly, the thermal transmittance value of the external wall [Uwall] on which the activated cellulose thermal insulation is attached, as well as the thermal conductivity [k_insulation] and the thickness of the insulation [t_insulation] are required.



(a)



Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimouth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	10	m²	Area of wall

Thermal properties of wall construction

Uwall	1.2	W/(m²·K)	U-value of wall on which the insulation layer is attached
k_insulation	0.045	W/(m·K)	Thermal conductivity of activated cellulose thermal insulation layer
t_insulation	0.05	m	Thickness of activated cellulose thermal insulation layer

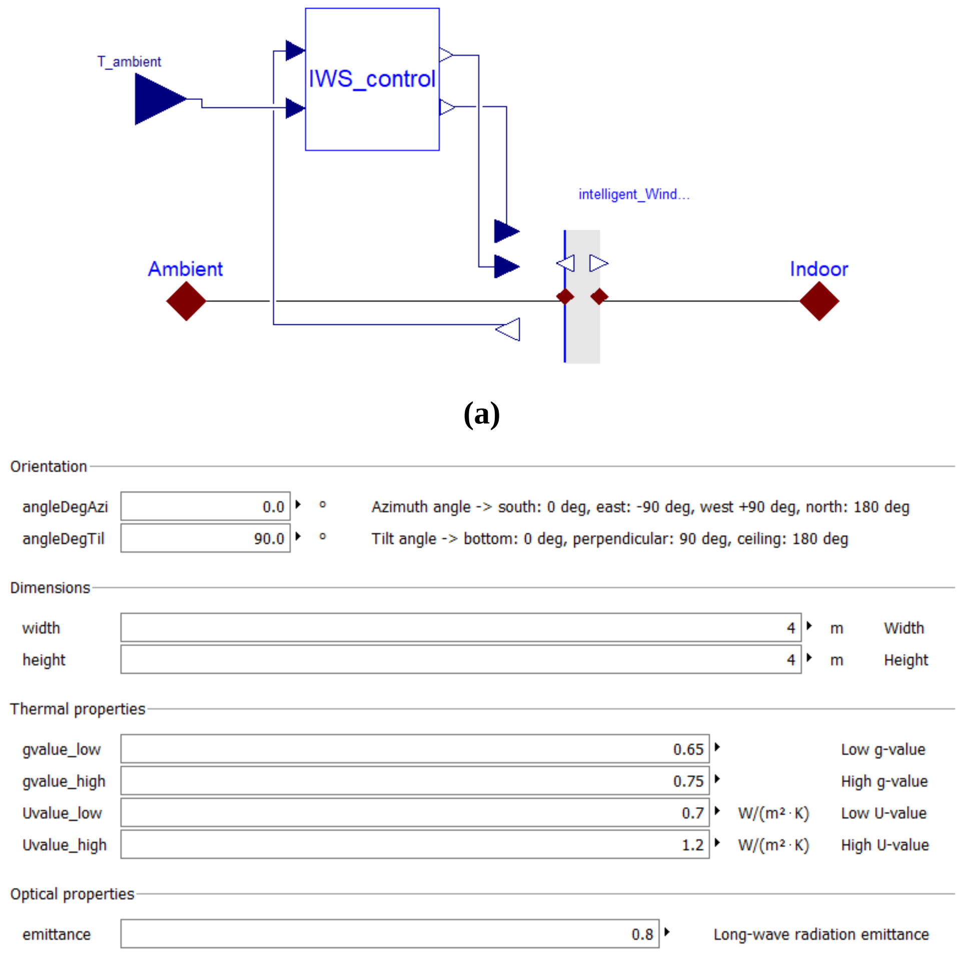
(b)

Figure 10. The developed model of the activated cellulose insulation layer, (a) Model developed in Modelica, (b) Parameters required for the simulation of the insulation technology

2.1.5 RP8: INTELLIGENT WINDOW SYSTEM

Developed model - INTEMA.building

For the simulation of the IWS technology (RP8), a model of a window with modular thermal properties was developed and tested in the INTEMA.building tool using Modelica language. More specifically this model simulates a simple window construction on which the IWS technology is attached as a window layer that reversibly switches the window's properties. Figure 11a shows the developed model in Modelica that simulates the window construction, on which the IWS is attached and whose thermal transmittance value and g-value are adjusted by a control system according to the external stimuli of the ambient temperature and the incident solar radiation. Figure 11b depicts the required parameters for the simulation of the model. Firstly, the geometrical data that concern the window's height and width, as well as the window's azimuth and tilted angle are required. Secondly, the thermal transmittance values [Uvalue_low, Uvalue_high] and g-values [gvalue_low, gvalue_high] of the window construction are required. These two values describe the state of the existing window of the building (non-activated IWS) [Uvalue_high and g_value_high] and the state when the IWS is activated [Uvalue_low and g_value_low]. The final parameter [emittance] concerns the emittance value of the window's glass.



(a)

Orientation

angleDegAzi	0.0	°	Azimuth angle -> south: 0 deg, east: -90 deg, west +90 deg, north: 180 deg
angleDegTil	90.0	°	Tilt angle -> bottom: 0 deg, perpendicular: 90 deg, ceiling: 180 deg

Dimensions

width	4	m	Width
height	4	m	Height

Thermal properties

gvalue_low	0.65		Low g-value
gvalue_high	0.75		High g-value
Uvalue_low	0.7	W/(m²·K)	Low U-value
Uvalue_high	1.2	W/(m²·K)	High U-value

Optical properties

emittance	0.8	Long-wave radiation emittance

(b)

Figure 11. The developed model of the IWS technology, (a) Model developed in Modelica, (b) Parameters required for the simulation of the window system

Control Algorithms/Systems

The RP8 concerns an intelligent window technology that is designed to reduce the thermal loads in a building. The input variables of the control system are the ambient temperature and the incident solar irradiation on the window. The developed control system evaluates if the gain of the technology's activation is positive and properly adjusts the window's operation. Practically, the control system determines if the placement of the extra window reduces the building's thermal loads by taking into consideration i) the decrease in the total U-value of the window and ii) the reduction of the total g-value. The control rules have been determined after the conduction of necessary sensitivity studies to successfully satisfy the initial goal of the reduction of the thermal loads in the building.

2.2 OTHER RP CONTROL ALGORITHMS/SYSTEMS CREATION

2.2.1 RP4: CENTRALIZED HOLISTIC H&C RENOVATION KIT

A further action that will be implemented in the renovated system is the inclusion of a new control strategy that will define the energy assets management strategy allowing to exploit of the PCM thermal energy storage in combination with the HP, the RES (i.e., the PV system that will be installed on the façades) and the energy tariffs with the aim to reduce the end user energy consumption and the environmental impact. The control algorithms will be developed using Python programming language and the resulting scripts will undergo a prior testing phase in an environment that will be developed in Matlab-Simulink.

The system will be modelled by a specific set of equations representing the optimization problem that will be included in the control algorithm. A preliminary version of these equations has been already developed and the final version will be finalized once the real capacities of each technology involved in the building demands are known.

The identified problem variables are:

- Thermal energy provided by the heat pump HP_{cond}
- Thermal energy required by the heat pump HP_{eva}
- Electrical energy required by the heat pump HP_{el}
- Electrical energy provided by the photovoltaic panels PV
- Electrical energy provided by the national grid connection EG
- Electrical energy sold to the national grid EG_{to}
- Energy entering the TES that comes from the condenser of the heat pump $TES_{to,i}$
- Energy exiting the TES that goes to the evaporator of the heat pump $TES_{from,i}$
- Energy exiting the TES section i_H that goes to the heating systems TES_{H,i_H}
- Energy provided to TES section i_C coming from the cooling systems TES_{C,i_C}
- Energy exiting the TES section i that goes to the DHW systems $TES_{DHW,i}$
- Energy stored in the batteries ELS, the amount entering ELS_{to} and the amount exiting ELS_{from}.

These variables are vectors having a length equal to the ratio between the time horizon value T_H and the assumed time step t. All these variables will be constrained based on the maximum capacities derived from the design phase for each technology.

The optimization problem includes also the following constraints:

- Heating demand balance: to fulfil the demand, the energy will be provided by one or two specific sections of the ones on which the TES is divided; this section will be set after the final design phase.
- Cooling demand balance: to fulfil the demand, the energy will be provided by one or two specific sections of the ones on which the TES is divided; this section will be set after the final design phase.
- DHW demand balance: to fulfil the demand, the energy will be provided by all the sections of the TES; the energy acquired from each section by the water flowing in the TES will be assumed to be distributed as a constant percentage that will be defined based on data acquired during the TES test phase or on StT experience.
- Electrical demand balance: it will be also considered the chance to sell to the EG the potential excess of energy generated by the PV plant.
- TES energy balance: this constraint will be duplicated for each section in which the TES will be divided.
- ELS energy balance.
- HP electrical consumption: this equation correlates the electrical energy consumption with the thermal energy produced by the HP considering the COP (evaluated based on the source temperature and the temperature of the TES section that is assumed connected to the HP condenser side).
- Maximum production from the PV plant: this calculation will be performed using the weather data derived from a forecast website (e.g., MeteoBlue), the geometrical and spatial information about the building and panels orientation, in addition to the technical characteristic of the PV panel that are useful to define the efficiency under the operating conditions.

The objective function is based on the minimization of the energy bill taking into account also the potential cost that is linked to the CO_2 emissions.

In order to carry on the control algorithms testing phase, Matlab-Simulink models of the energy system will be developed in order to provide the simulation environment. The devices that will be modelled are the HP, the PCM TES, the PV system, the EG connection and the end user (as thermal and electrical forecast demands, generated by means of statistical or ML approaches, such as Random Forest method, applied to the results of the analysis performed with Termus software by ENEA or data derived from literature, energy bills and monitoring campaign). The devices will be modelled as dynamical models using differential equations (as for TES) or simplified models using performance maps (as for HP and PV plants). Preliminary versions of the device models have been already available; however, they will be adapted based on the specific characteristics of the systems after the final design phase (e.g., PV efficiency coefficients or TES number of sections). During the operative phase, the control algorithm will be used to generate the optimal power setpoints that have to be provided by each energy device in order to fulfil the demand following the behaviour that allow to reach the objective function minimization. The test campaign will be useful to make a step towards TRL6 of RP4 testing the interconnection between the energy system and the control algorithm, in particular the proper operativity of the energy system if the power setpoints generated by the optimization code were followed.

2.3 OTHER RP MODELS CREATION AND SIMULATIONS

Other than the creation of the energy models for the RPs in INTEMA.building, as detailed above, additional simulations and analysis have taken place, where necessary, to ensure the optimal quality of the final products and the achievement of the project's goals. The implemented simulations and analysis include, among others, surveying for the specific needs and potential barriers to be encountered in each pilot, detailed measurements to facilitate the dimensioning of the RPs, preliminary designs and mock-ups. These efforts aimed to ensure a successful prefabrication process for elements slated for prefabrication, with the ultimate goal of minimizing the gap between design and implementation.

2.3.1 RP2: ADAPTABLE/DYNAMIC BUILDING ENVELOPE

For the development of the RP2 model, a thorough analysis has been conducted to create an optimal final solution. Initially, a preliminary design of the system was developed based on the evaluation of the demo building, specific needs of the end-users and limitations, as well as measurements taken at the Greek demo site. A 2D model of the proposed solution was initially designed using the AutoCAD design software tool, as illustrated in Figure 12. A 3D model of the PV façade was also designed in AutoCAD tool, to give a more realistic picture of the under-study system (Figure 13).

Figure 12: 2D design of the PV façade for the REHOUSE project in AutoCAD software

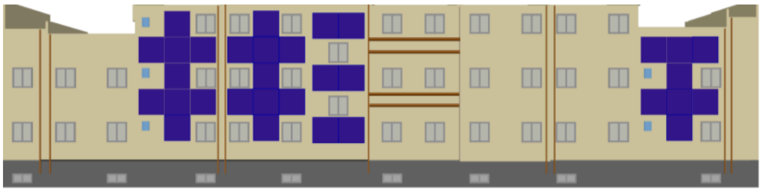


Figure 13: 3D design of the PV façade for the REHOUSE project in AutoCAD software

In order to improve the whole implementation process, special attention has been paid to prefabrication and off-site construction. More specifically, the aluminium structures will be prefabricated at the factory in an appropriate size to engulf the PV glass elements. Afterwards, they will be transported to the demo site by truck, ready for installation. The remaining equipment, i.e. the PV glass components, the batteries, the inverter and the MPPT controller will also be manufactured at the factory and will be ready for installation upon arrival at the demo site. Last but not least, detailed drawings of the building façade and electrical installations have been developed off-site in the office and will give explicit instructions for the on-site construction of the system. Especially the BIM-based data model, which will be used in the design, execution (renovation) and operation (monitoring) phase bridges the gap between the design and construction phase and ensures that the final performance of the buildings meets the expectations in the design phase. As a result, the whole process will be considerably simplified, requiring less time and on-site effort for the completion of the project. Moreover, due to the high level of prefabrication of the components, no special training of the crew is required during the construction phase of the ADBE system.

2.3.2 RP3: SMARTWALL

The current analysis describes the development of the RP3 (SmartWall) model (by NTUA) using the TRNSYS software. The SmartWall was simulated in detail including both the insulation system and the incorporated energy systems (HVAC and PVs) based on hourly transient conditions. The analysis focused on the improvement of the building energy performance due to the implementation of RP3. For this reason, even though the whole Greek demo building was simulated, the results concern the seven rooms where the RP3 is planned to be installed. Additionally, the analysis of RP3 at the renovation state excluded the impact of RP1 (heat pump) and RP2 (BIPV wall), for this reason, a commercial heat pump was assumed as the heat source of RP3, while the contribution of RP2 on the total PV production was not taken account. The main components of the RP3 model were the building materials as insulation of external walls, one fan-coil and one mechanical ventilation unit per SmartWall, one variable speed pump, a buffer tank, a PV array for each of three SmartWall panels, and the commercial heat pump. All components were dimensioned based on the examined scenario of seven rooms of the Greek demo.

The whole Greek demo building was simulated for the existing and renovated with the RP3 state. For a fair comparison of the two cases, the same assumptions regarding the boundary conditions and the operational characteristics were taken. In the renovated state (using only the RP3), the SmartWall is added externally to the existing walls offering significant thermal insulation, while seven new windows are also installed. A combination of three different SmartWall types is used for insulating the southern and northern walls of the 7 examined rooms.

The energy analysis indicated that if the boundary condition of the floor of the examined seven rooms of the ground floor was to be adjacent to the ceiling of the basement, there would be no significant need for cooling, as the basement is cooler during the summer months. However, if the boundary condition of the floor of these rooms was adiabatic, there would be significant cooling needs accounting for approximately 10% of the total energy demands for heating and cooling. Besides, the significance of the high-insulated building envelope is also revealed by the fact that the implementation of RP3 delays the start of the heating period by 15 days.

The energy results showed that the implementation of RP3 reduced the thermal transmittance (U-value) of the external walls by 65% - 79%, depending on the SmartWall type. This insulation upgrade of the external walls, along with the improvement of airtightness (reduction of infiltration rate) resulted in a reduction of energy demands for heating by 38.5%. After the implementation of the energy systems of SmartWall, the final energy consumption for heating (biomass for existing and electricity for renovated state) was reduced by 87% due to the implementation of a more efficient heat source (heat pump with COP ca. 5.0 instead of biomass boiler). Finally, the implementation of the RP3 in the seven rooms reduced primary energy consumption by 61.3%. The detailed report can be found in the annexes.

2.3.3 RP5: MULTIPURPOSE PREFAB FACADE SYSTEM WITH BIO-BASED INSULATION AND BIPV

Several models of the RP5 have been created in order to conclude to the final and most efficient RP5 configuration. A summary of the different models is presented below. The detailed report can be found in the annexes.

Initial Proposal- Phase 0

- Vertical structure fixed to the building with thermal insulating BIPV panels.
- Composed of insulation hemp panels with metal plates, a rear metal cover, and a front BIPV photovoltaic panel.

Figure 14: Different layers and conceptual design for integration into RI skeleton

- Study on the installation system led to the definition of supporting brackets mounted on the vertical structure.

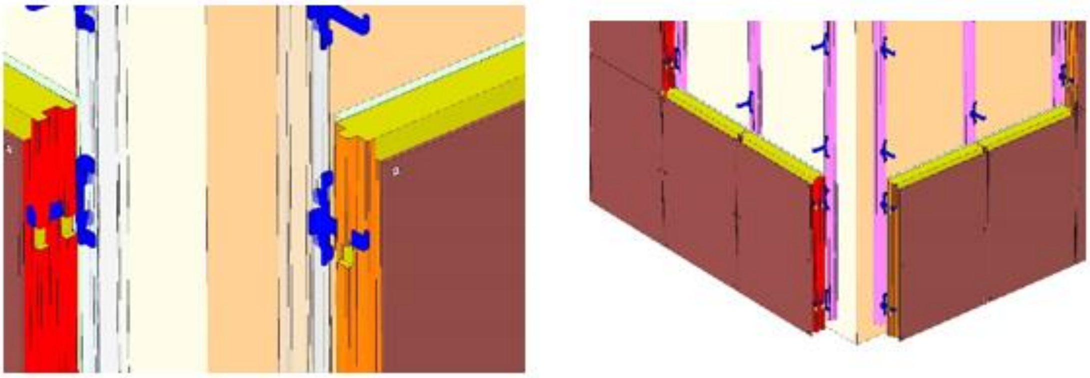


Figure 15: Details of the supporting brackets and substructure

Revision/Phase 1.0

- Introduction of facing panels (initially aluminium honeycomb core panels).

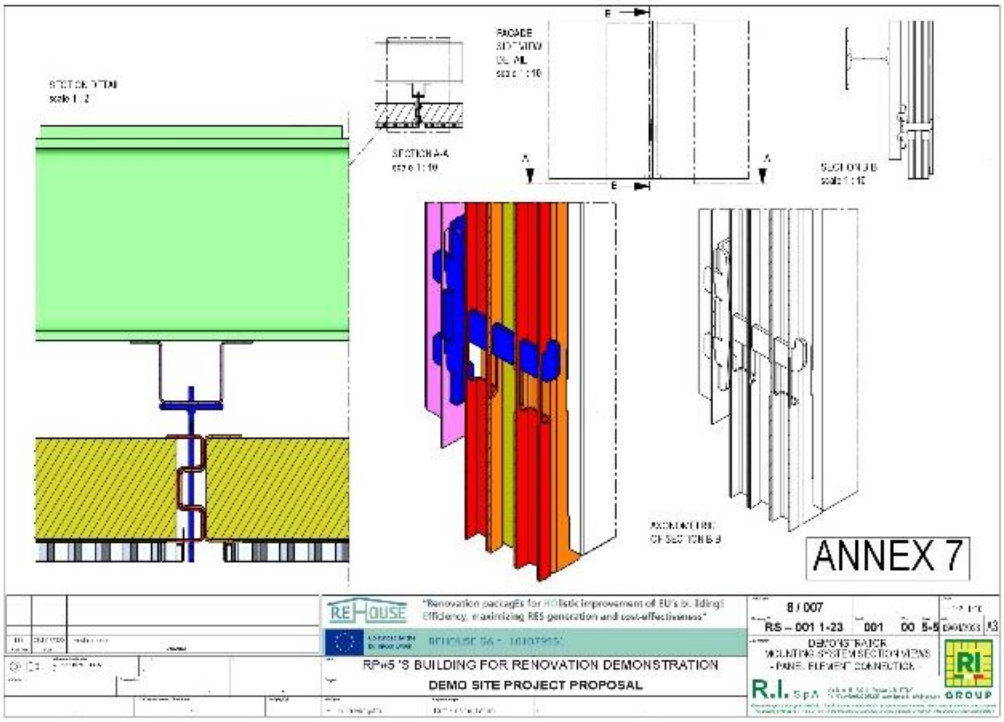


Figure 16: Mounting System Section Views – Panel Element Female Connection

Revision/Phase 2.0

- Integration of insulation hemp panels with BIPV panels and facing honeycomb panels.
- Definition of a new wall supporting structure and supporting brackets.

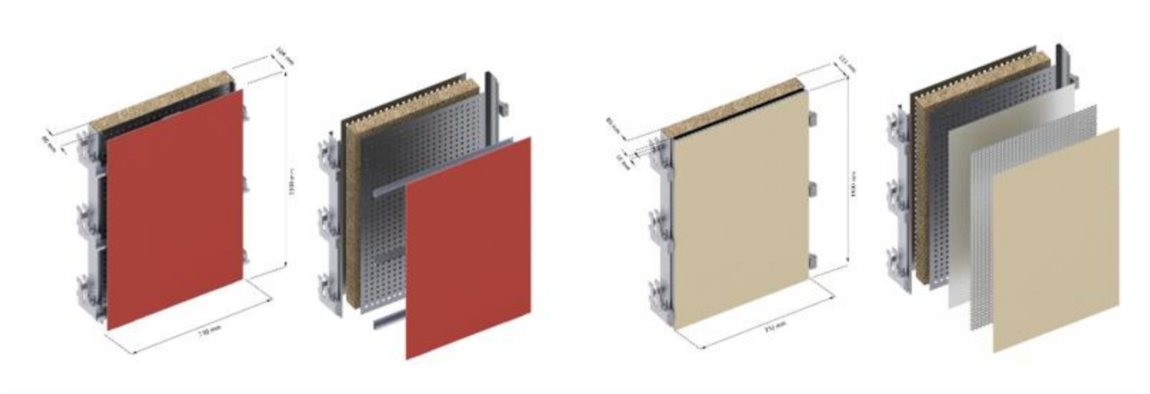
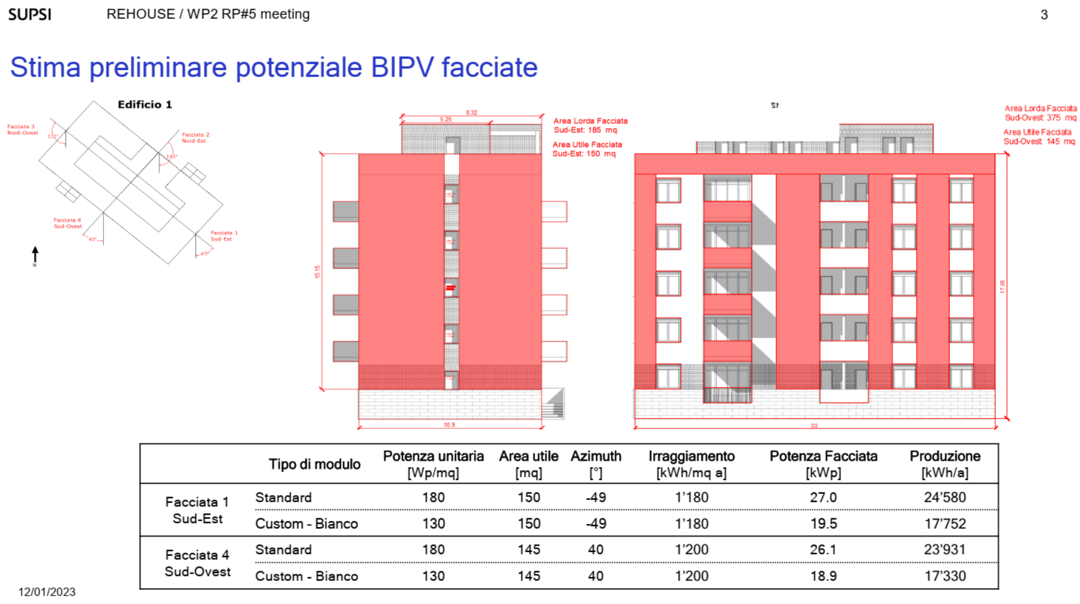


Figure 17: TSAP + PV Render View (left) - TSAP Render View (right)

- Initial evaluation (by SUPSI) of the number and the position of the BIPV panels



SUPSI REHOUSE / WP2 RP#5 meeting 3

Stima preliminare potenziale BIPV facciate

	Tipo di modulo	Potenza unitaria [Wp/mq]	Area utile [mq]	Azimuth [°]	Irraggiamento [kWh/mq a]	Potenza Facciata [kWp]	Produzione [kWh/a]
Facciata 1 Sud-Est	Standard	180	150	-49	1'180	27.0	24'580
	Custom - Bianco	130	150	-49	1'180	19.5	17'752
Facciata 4 Sud-Ovest	Standard	180	145	40	1'200	26.1	23'931
	Custom - Bianco	130	145	40	1'200	18.9	17'330

12/01/2023

Figure 18: Preliminary estimation - potential BIVP facades

Revision/Phase 3.0

- Separation of hemp from BIPV and facing honeycomb panels.
- New supporting brackets to substitute the vertical wall structure.
- New panel structure and layout for panels.

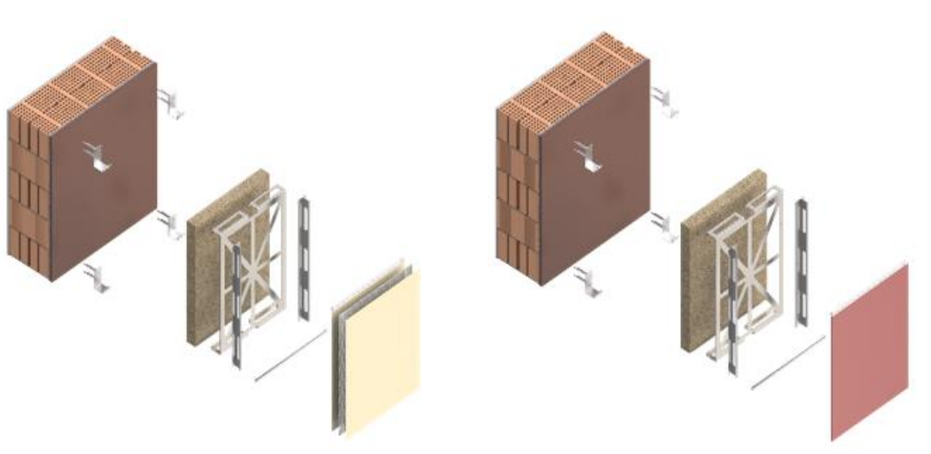


Figure 19: Stratigraphy of the Facades Options

Revision/Phase 4.0

- New solution for MPF to enhance hemp performance.
- Hemp panels mounted on a horizontal structure, detached from the building wall.
- Introduction of aluminium supporting brackets and profiles for MPF beam structure.
- Fibre cement EQUITONE Tectiva panels replace aluminium honeycomb panels.

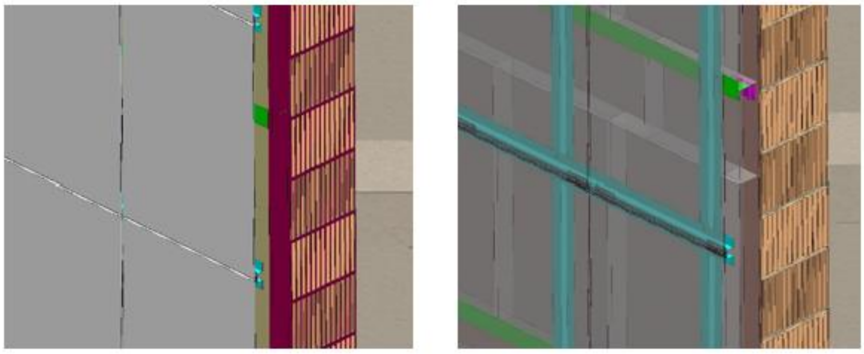


Figure 20: Coplanarity of the two surfaces (left) - Details of the skeleton (right)

In addition, in this phase an initial installation process was defined.

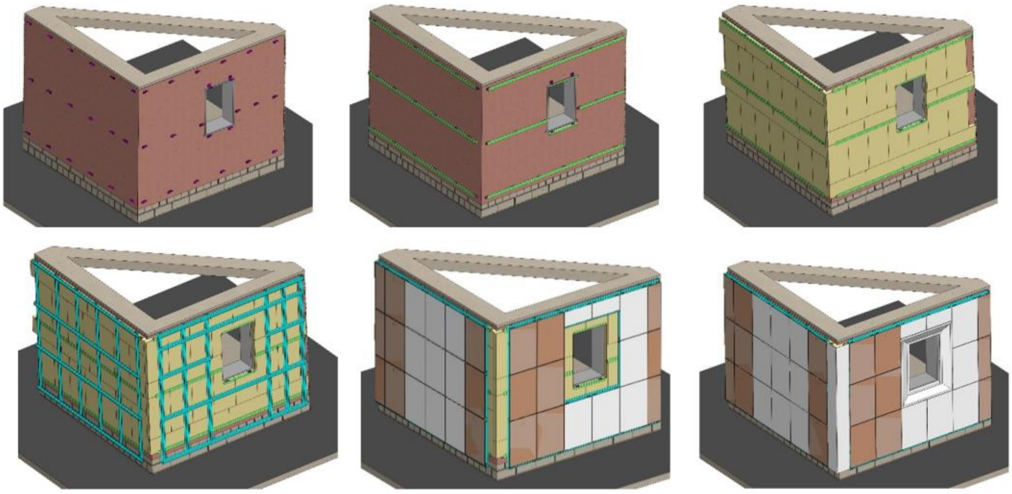


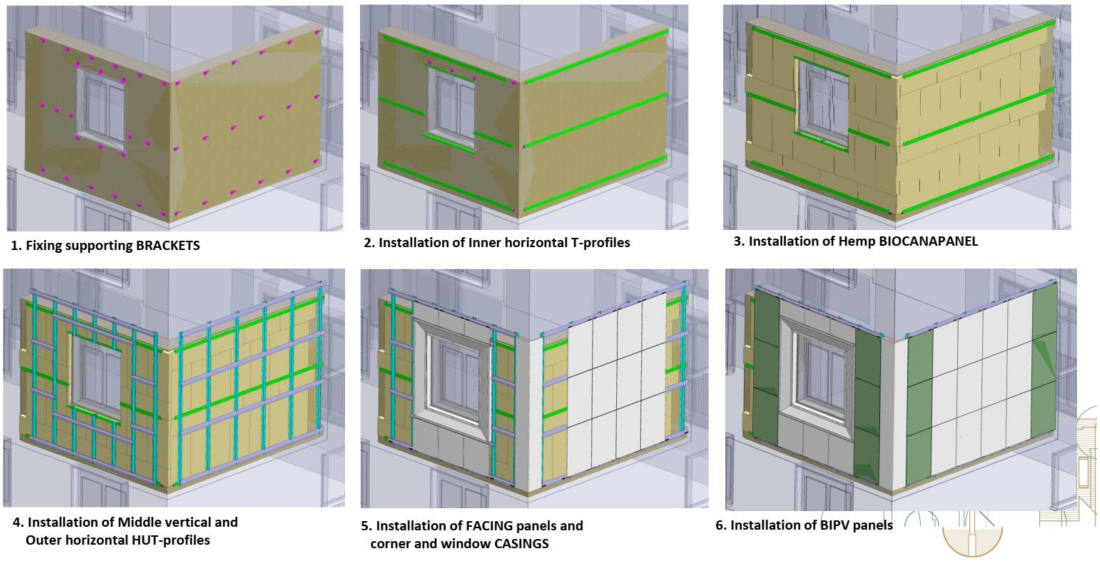
Figure 21: Installation process

Revision/Phase 4.1 (Current)

- Mock-up realization directly on a part of the demo building.

Figure 22: Prototype position on the Demo-site building

- In this phase the installation process has been carefully revised with a focus on enhancing the overall implementation efficiency. Special attention has been dedicated to optimizing prefabrication and off-site construction methodologies.



1. Fixing supporting BRACKETS

2. Installation of Inner horizontal T-profiles

3. Installation of Hemp BIOCANAPANEL

4. Installation of Middle vertical and Outer horizontal HUT-profiles

5. Installation of FACING panels and corner and window CASINGS

6. Installation of BIPV panels

Figure 23: Rendering of the installation phases

- Defined appearance of facing and BIPV panels.

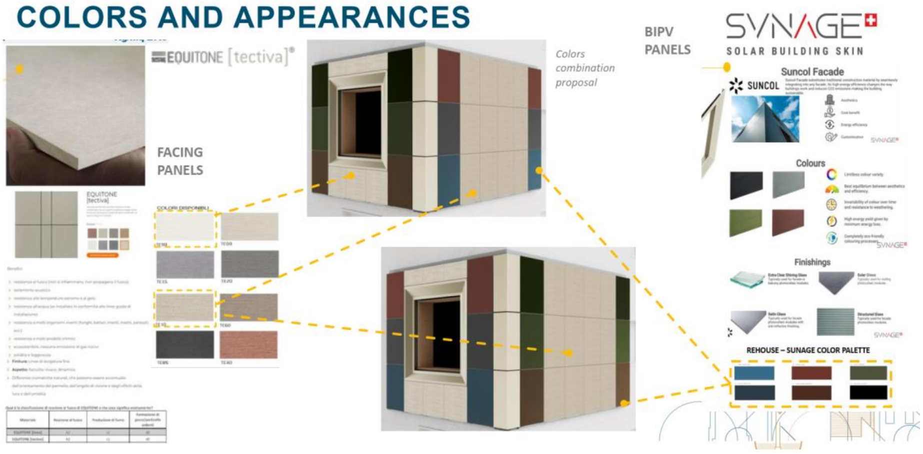


Figure 24: BIPV – Colours and appearances

- Definition of the dimensions and installation operations of the RP5 casing

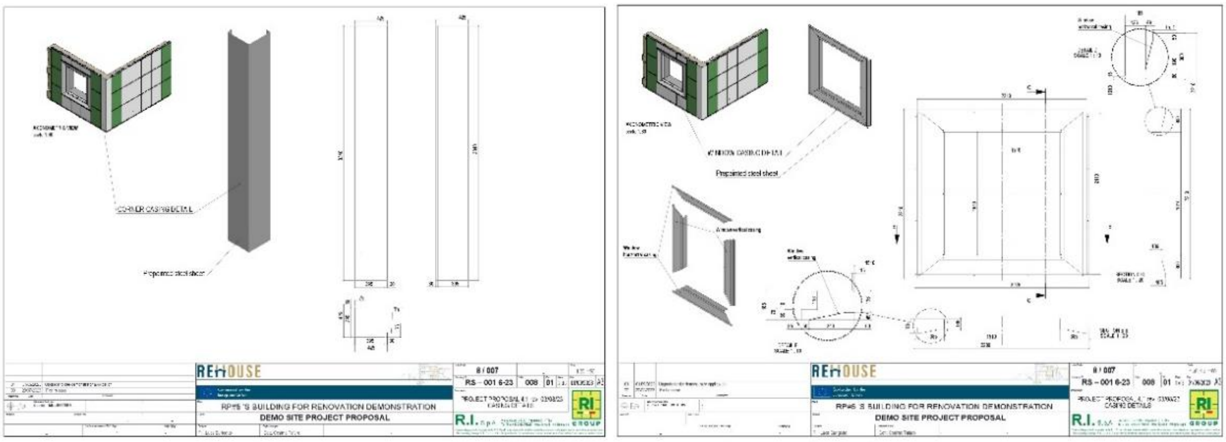


Figure 25: Details of the MPF Prototype Casings

- Analysis and evaluation of BIPV panel performance based on demo building orientation, its sun exposures, and the changing seasons.

3 SIMULATIONS/ ASSESSMENTS OF DEMO SITES

In this chapter, all the simulations and assessments of the demo sites, that were conducted by the responsible partners, are presented. Each report comprises of three main chapters: i) the Baseline Scenario Analysis, ii) the Renovation Scenario Analysis and iii) the Comparison of the Baseline and the Renovation Scenario Analysis. The Baseline Scenario Analysis includes a detailed description of the building elements, a breakdown of the installed energy systems, and the subsequent simulation and assessment results. Meanwhile, the Renovation Scenario Analysis provides a thorough description of the implemented renovation actions and their corresponding simulation and assessment results. Each report concludes with a Comparison of the Renovation and Baseline Scenarios, shedding light on the divergent results between the two scenarios. For the Greek and Hungarian demo sites, an energy analysis and life cycle assessment/cost analysis (LCA/LCC) have been conducted for both the baseline and renovation scenarios. For the Italian and the French demo sites, energy analysis (baseline and the renovation scenario) simulations were carried out.

It is worth mentioning that in this deliverable some of the data used might be different from the final one since assumptions were considered to proceed with the simulations. In other deliverables under WP4 of the project more accurate data will be used. Below are presented the summary reports of the demo-site simulations results, for more information the detailed reports can be found in the annexes.

3.1 GREEK DEMO

3.1.1 ENERGY ANALYSIS

The energy analysis of the Greek demo was conducted with the INTEMA.building tool by CERTH with the collaboration of all the Greek partners. Table 3 below illustrates the basic energy demands of the baseline and the renovated scenarios in kWh. In the analysis all the interventions (innovative and conventional) were considered. The building was separated into two thermal zones in the renovation scenarios because there are different energy systems. It is worth mentioning that three distinct cases within the Renovation scenario were analysed. Specifically,

- In the first case, the renovation scenario is depicted in its fundamental state, where PV energy is exclusively employed for domestic hot water needs.
- The second scenario involves the PV system contributing energy to both domestic hot water and the heat pump.
- The third scenario highlights the PV system fulfilling the entire electrical energy demand for the building.

Table 3: Comparison of basic energy demands between baseline and renovated scenario [kWh]- (GR DEMO)

Energy Quantities [kWh]	**Baseline scenario**	**Renovation scenario**		
	Total	**Thermal Zone 1**	**Thermal Zone 2**	**Total**
Heating energy load	145,213	80,640	72,427	153,067
Energy Load for DHW	38,020	23,916	14,104	38,020
Cooling energy load	No System	No System	26,353	26,353
Boiler energy demand	203,245	142,059	0	142,059
Electricity demand for heating	0	0	15,464	15,464
Electricity demand for cooling	No System	No System	5,549	5,549
Electricity demand for appliances and lighting	58,978	35,977	23,001	58,978
Total net electricity demand	58,978	35,977	44,014	79,991
Electricity production from roof PV system	99,367	-	-	99,367
Electricity production from BIPVs	-	-	6,053	6,053
Scenario 1: Evaluation of the results with PV exploitation for DHW				
Final energy demand	262,223	178,036	44,014	222,050
Primary energy demand	374,281	246,392	127,641	374,033
Scenario 2: Evaluation of the results with PV exploitation for DHW & heat pump				
Final energy demand	262,223	178,036	23,001	201,037
Primary energy demand	374,281	246,392	66,703	313,095
Scenario 3: Evaluation of the results with PV exploitation for DHW, heat pump, appliances & lighting				
Final energy demand	262,223	142,059	0	142,059
Primary energy demand	374,281	142,059	0	142,059

In the baseline scenario, the heating energy demand was calculated at 145,213 kWh whereas in the renovated state the heating demand of the building was calculated at 153,067 kWh. The increase in the heating energy load of the building corresponds to the improvement of the living conditions of the students because the indoor temperature of the building better fulfils the thermal comfort requirements. In the renovated scenario, only thermal zone 1 is served by the biomass boiler and therefore the boiler energy demand was greatly decreased. More specifically, in the baseline scenario, the boiler energy demand was calculated at 203,245 kWh, while for the renovated scenario this value was equal to 142,059 kWh, indicating a decrease of 30.1%. Moreover, in the baseline scenario, the cooling demand of the building was not calculated, since there was no appropriate energy system available. In the renovated scenarios though, thermal zone 2 is equipped with an appropriate energy system and its cooling energy load was calculated at 26,353 kWh. The energy demand for DHW is the same in the two scenarios because the number of residents is considered stable. However, due to the change in the biomass boiler temperature setpoint, the PV contribution to the DHW production was modified. More specifically, in the baseline scenario, the yearly energy input of the PV system was calculated at 7,266 kWh, while for the renovated scenario the energy input was calculated at 17,569 kWh, indicating a significant increase. Finally, the electricity demand for lighting and appliances presents no alteration because no renovation actions were taken aiming at its decrease. Moreover, the above table includes the total final and primary energy consumption. The primary energy conversion factor for electricity was selected at 2.9 and for biomass at 1.0, according to the Greek legislation. For the renovation Scenario 1, in which the electricity produced by the roof PV system was exploited only for the DHW production, in total, 17,569 kWh, the total primary energy consumption of the building was calculated at 374,033 kWh, indicating a slight decrease of 0.07% in comparison with the baseline scenario. Furthermore, in Scenario 2, the electricity production of the roof PV systems covered both the DHW energy demand, as well as the electricity demand of the heat pump operation, totally of 38,582 kWh of electricity. The total primary energy demand for Scenario 2 was calculated at 313,095 kWh, indicating a 16.35% enhancement relative to the baseline scenario. Finally, in Scenario 3 the produced electricity from the roof PV systems covered the DHW energy demand, the electricity demand for the heat pump yearly operation, as well as the electricity demand for the building’s appliances and lighting. In total, 97,560 kWh of PV-produced electricity was exploited, reducing the building’s total primary energy demand by 62.04%, at 142,059 kWh.

3.1.2 LCA/LCC

The LCA/LCC of the Greek demo was conducted through the VERIFY tool by CERTH with the collaboration of all the Greek partners.

The Table 4 below presents significant KPIs for both the baseline and renovation scenarios, with a focus on two distinct cases within the Renovation scenario. Specifically,

- In the first case, the renovation scenario is depicted in its fundamental state, where PV energy is exclusively employed for domestic hot water needs.
- The second scenario involves the PV (DUTh PV) system contributing energy to both domestic hot water and the heat pump.

It is worth mentioning that in the analysis all the interventions (innovative and conventional) were considered.

Table 4: Comparison of LCA/LCC results between the baseline and the renovated scenarios (GR DEMO)

KPI	**Baseline scenario**	**Renovation scenario**	
		Scenario 1: Evaluation of the results with PV exploitation for DHW (fundamental state)	**Scenario 2: Evaluation of the results with PV exploitation for DHW & heat pump**
Life cycle CO_2 Emissions [$kgCO_2$]	1,463,258	1,845,557	1,282,927
Life cycle CO_2 Savings [$kgCO_2$]	NOT APPLICABLE	NO SAVINGS	173,761
Carbon payback period [months]	NOT APPLICABLE	NO PAYBACK	21 months
Life cycle cost [€]	2,070,722	1,564,316.17	1,375,257
Monetary Investment Payback Period [months]	NOT APPLICABLE	123 months	59 months

In scenario 1 (fundamental state), an increase (26%) in Life Cycle CO_2 Emissions [$kgCO_2$] is observed compared to the baseline scenario. This increase occurred because a portion of the biomass, considered CO_2 neutral, was replaced for heating purposes by RP1, which utilizes electrical energy from the grid. However, a significant positive outcome of this change was the expansion of the building's comfort zone, as RP1 was used not only for heating but also for cooling. In scenario 2, due to the increased utilization of PVs, a completely different CO_2 emission profile for the building is observed. Specifically, not only was the Green Energy from the PVs utilized, leading to an increase in CO_2 savings for the building, but also a reduction in CO_2 emissions (12%) was achieved since the building did not rely on Grid Electrical Energy for a portion of its electrical needs. As a main result, it can be stated that as the utilization of photovoltaic energy expands, there is a proportional decrease in CO_2 emissions, resulting in a carbon payback period being achieved. In the Life Cycle Cost (€) KPI, a significant decrease is observed in all scenarios, primarily attributed to the judicious application of PV panels. In the 1st renovation scenario (fundamental state), where PV is exclusively employed for DHW, lower costs are demonstrated compared to the baseline scenario. This reduction can be attributed to diminished cooling and thermal loads, along with the substantial replacement of biomass boiler consumption with the utilization of RP#1, contributing to overall cost efficiency. Regarding the Monetary Payback period KPI, it is observed that the more PV energy utilization is accomplished (scenarios 2), the earlier the Payback period is achieved.

3.2 HUNGARIAN DEMO

3.2.1 ENERGY ANALYSIS

The energy analysis of the Hungarian demo was conducted using the INTEMA.building tool by CERTH with the collaboration of all the Hungarian partners.

The Table 5 below illustrates the basic energy demands of the baseline and the renovated scenario in kWh. In the analysis all the interventions (innovative and conventional) were considered.

Table 5: Comparison of basic energy demands between baseline and renovated scenario [kWh]- (HU DEMO)

Energy Quantities [kWh]	Baseline scenario	Renovation scenario
Heating demand	161,273	43,959
DHW demand	82,792	82,792
Electricity demand for appliances and lighting	57,746	57,746
Boiler energy demand for heating	210,814	57,557
Boiler energy demand for DHW	153,318	153,318
Electricity produced by BIPVs	0	24,860
Electricity demand from the grid	57,746	34,978
Total boiler energy demand	364,132	210,875
Total final energy demand	421,878	245,136
Total primary energy demand	508,877	298,320

In the baseline scenario, the heating energy demand was calculated at 161,273 kWh whereas in the renovated state the heating demand of the building was calculated at 43,959 kWh. The decrease in the heating energy load of the building is combined with the improvement of the living conditions and is equal to 72.7%. In addition, the boiler energy demand for heating was greatly decreased. More specifically, in the baseline scenario, the boiler energy demand for heating was calculated at 210,814 kWh, while for the renovated scenario this value was equal to 57,557 kWh. Consequently, the building's boiler total energy demand was decreased by 153,257 kWh in comparison with the baseline scenario, and therefore the total boiler energy demand was calculated at 210,814 kWh. Furthermore, in the renovated scenario the building was equipped with an area of 162 m^2 of BIPVs (100 panels) which led to the yearly production of 24,860 kWh of electricity, reducing the building's electricity demand from the grid to 34,978 kWh from 57,746 kWh in the baseline scenario. This equals a 39.4% reduction in the building's electricity demand from the grid. Finally, as far as the total primary energy demand is concerned, in the baseline scenario the value was calculated at 508,877, whereas in the renovated scenario the value was equal to 298,320 kWh, indicating a decrease of 41.4%.

3.2.2 LCA/LCC

The LCA/LCC of the Hungarian demo was conducted with the VERIFY tool by CERTH with the collaboration of all the Hungarian partners.

The Table 6 below presents significant KPIs for both the baseline and renovation scenarios. It is worth mentioning that in the analysis all the interventions (innovative and conventional) were considered. In Table 6 the LCA/LCC results between the baseline and the renovated scenarios are compared. The installation of the RPs has resulted in a substantial reduction in the Hungarian demo's CO_2 emissions. Additionally, the monetary costs of the project have decreased significantly, primarily due to lower fuel consumption and reduced reliance on grid-imported electricity.

Table 6: Comparison of LCA/LCC results between the baseline and the renovated scenarios (HU DEMO)

KPI	Baseline scenario	Renovation scenario
Life cycle CO_2 Emissions [kgCO_2]	6,498,550	3,820,467
Life Cycle CO_2 Savings [kgCO_2]	NOT APPLICABLE	2,679,393.07
Carbon payback period [Months]	NOT APPLICABLE	18
Life cycle cost [€]	1,750,145	1,290,946
Monetary Payback Period [Months]	NOT APPLICABLE	71

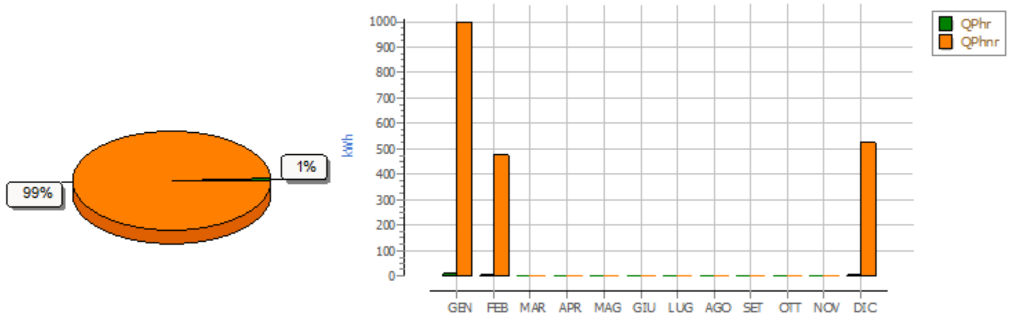
Three innovative technologies were incorporated into the Hungarian demo with the dual aim of decreasing the cooling and thermal demands of the building while simultaneously generating electricity for self-consumption. The reduction in thermal demands resulted in a notable decrease in CO_2 emissions (41%) from the natural gas boiler. Similarly, reduced boiler usage led to lower fuel consumption and subsequently, a reduction in financial costs. However, it is important to note that even with reduced boiler use, the electricity generated from the solar panels may not provide an immediate CO_2 payback or return on investment. Nevertheless, the total investment costs over the fifty-year project duration were lower in the renovation scenario compared to the baseline scenario due to significant reductions in operating costs.

3.3 ITALIAN DEMO

3.3.1 ENERGY ANALYSIS

The energy analysis of the Italian demo was conducted using the TerMus BIM tool by ENEA and UNIBAS with the collaboration of all the Italian partners. In the following figures the results of heating and cooling demands are presented.

FABBISOGNI DI ENERGIA PRIMARIA TOTALE RINNOVABILE E NON RINNOVABILE



FABBISOGNI DI ENERGIA PRIMARIA PER SINGOLO SERVIZIO

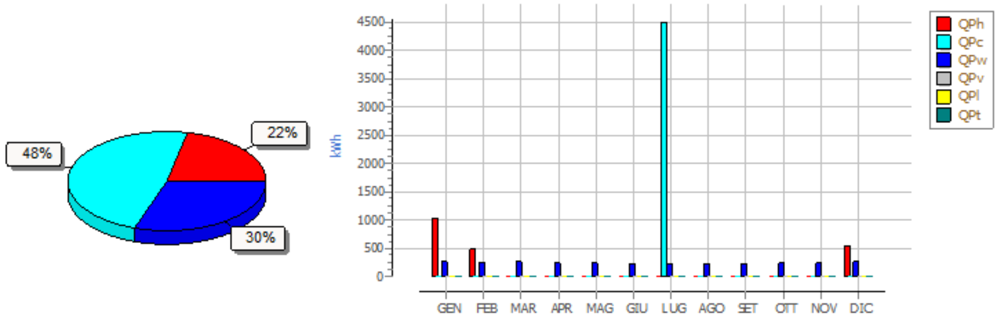
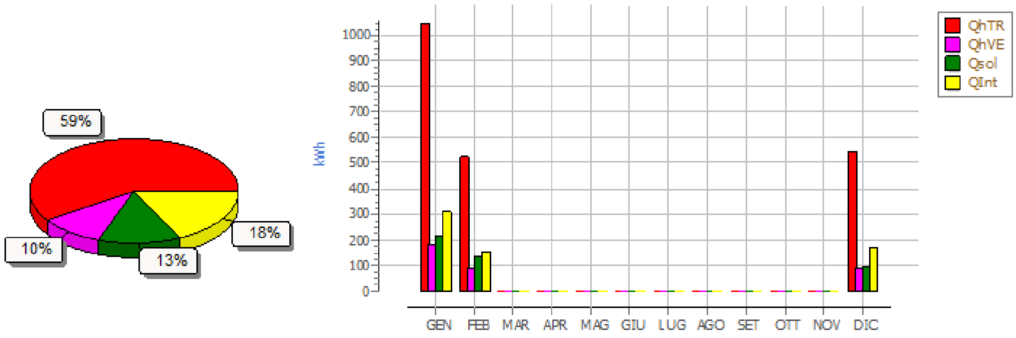


Figure 26: Total (renewable and not renewable) Primary Energy Demand Required

FABBISOGNI DI ENERGIA PER RISCALDAMENTO



FABBISOGNI DI ENERGIA PER RAFFRESCAMENTO

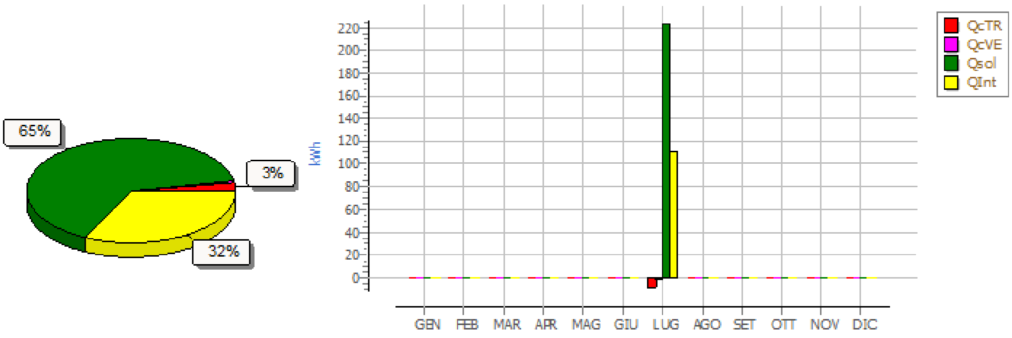


Figure 27: Primary Energy Demand

The Table 7 below illustrates the heating demands of the baseline and the renovated scenario. In the analysis all the interventions (innovative and conventional) were considered.

Table 7: Comparison of the baseline situation and the renovation scenario (IT DEMO)

Indexes	Baseline scenario	Renovation scenario
Heating demands (kWh/ a)	31,668.45	7,937.14
Heating demands (kWh/m²·a)	44.69	11.07
Heating demands reduction (%)	-	75.2%

The annual heating demand of the baseline scenario was calculated at 31,668.45 kWh whereas in the renovated scenario the value was equal to 7,937.14 kWh, indicating a decrease of 75.2%.

3.4 FRENCH DEMO

3.4.1 ENERGY ANALYSIS

The energy analysis of the French demo was conducted with the DesignBuilder tool for the modelling and the EnergyPlus tool for the simulations by CEA with the collaboration of all the French partners.

Four simulations with the different configurations were conducted (Table 8) in order to assess the impact of the different PanoRen and windows configurations. The PanoRen with four layers has a U-value of 0.21 W/m²K and the PanoRen with five layers has a U-value of 0.18 W/m²K.

Table 8: Configuration scenarios

Configuration	Building envelope	Glazing
Configuration 1	PanoRen with 5 layers	Triple-glazed
Configuration 2	PanoRen with 5 layers	Double-glazed
Configuration 3	PanoRen with 4 layers	Triple-glazed
Configuration 4	PanoRen with 4 layers	Double-glazed

The renovation scenario will be the first configuration. The comparison of the energy consumption between the baseline and the renovation (Configuration 1) is presented in the Table 9 below.

Table 9: Comparison of the baseline situation and the renovation scenario (FR DEMO)

KPI	Baseline scenario		Renovation scenario	
	Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]	Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	248,259	184	99,262	65
Energy for heating	170,293	-	25,421	-
Net Primary Energy	301,018	223	59,894	24

In the Renovation scenario, the primary energy for the whole building is 59,894 kWh compare to the 301,018 kWh of the baseline. The energy saving is highly significant (80%) due to a global renovation scenario with the PanoRen, a heat Pump, a double-flow mechanical ventilation, triple-glazed windows and second-life PV module for self-consumption.

4 RPS BIM MODELS

In this chapter the BIM based models of the 8 Renovation Packages of the REHOUSE project which is the main scope of this task and thus of D2.3 are presented. In each RP BIM model the responsible partner for the creation of the BIM model, the software used, the file extension, the level of development and pictures of the models are presented. Some of the RP properties are presented but in deliverable 2.2 the detailed specs of all the RPs can be found. It is worth mentioning that several RPs encompass diverse configurations, leading to the development of multiple BIM models. The final models will be accessible to the general public as a result of Task 2.6 “Digital products (REHOUSE repository of RPs)”, being currently only available in the REHOUSE project repository.

4.1 RP1: MULTI-SOURCE HEAT PUMP

Responsible Partner for BIM Models: **CARTIF**

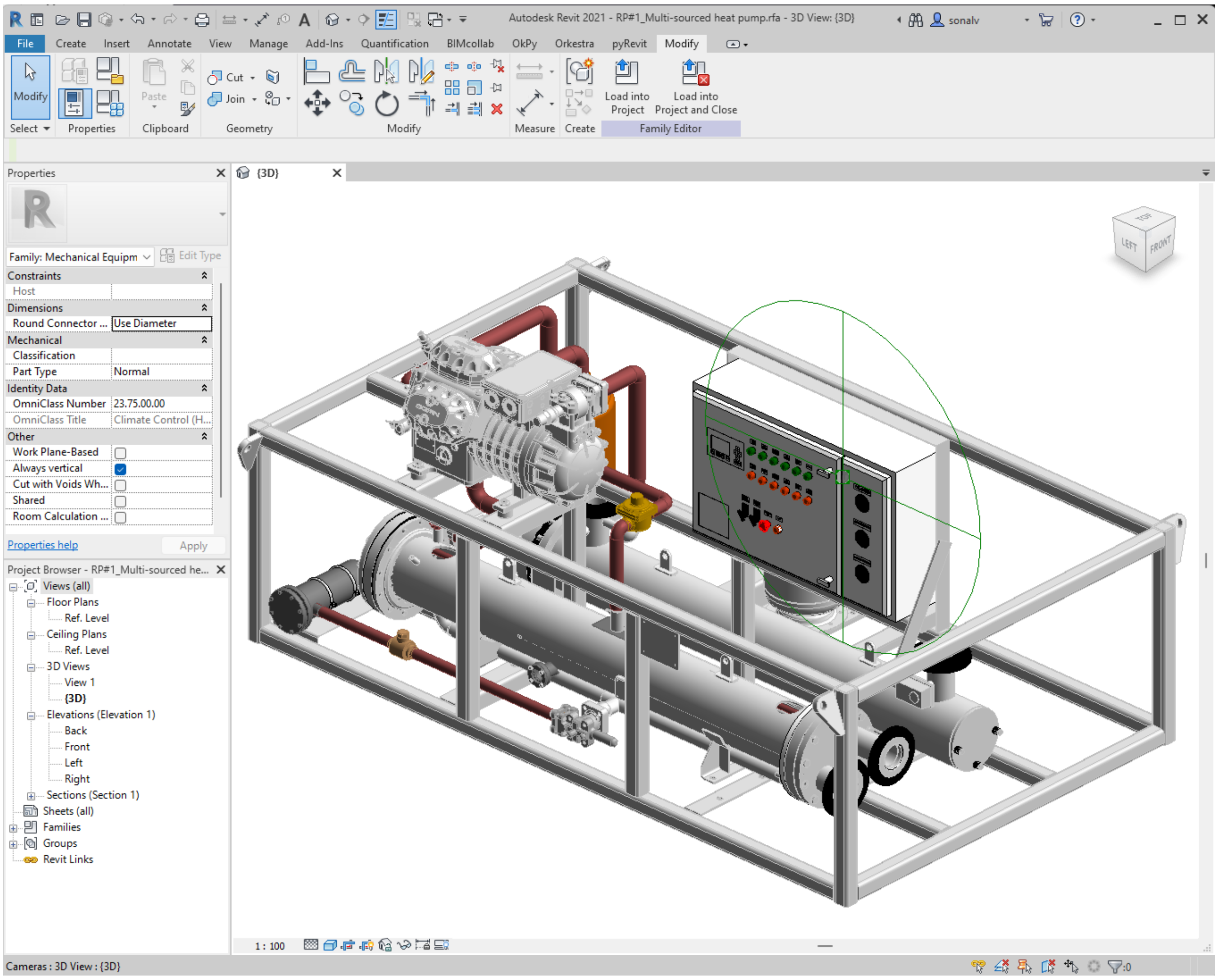
Software used: **Autodesk REVIT**

File Format: **rvt, rfa, ifc**

Level of Development: **200**

- Level of Information: 200
- Level of Geometry: 300

The BIM model created in REVIT software for RP1 is shown in Figure 28 and Figure 29.



Autodesk Revit 2021 - RP#1_Multi-sourced heat pump.rfa - 3D View: {3D}

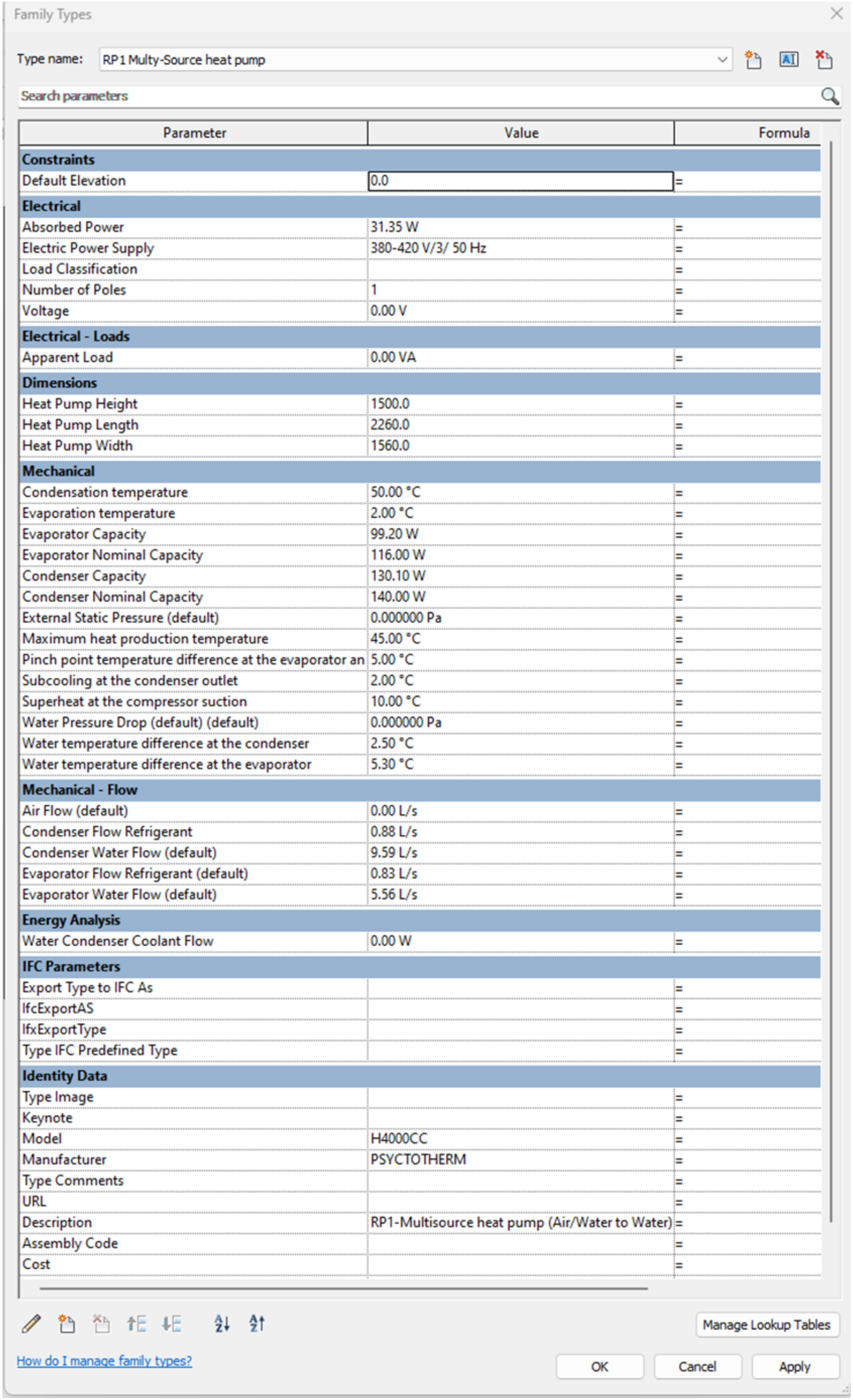
Properties

Family: Mechanical Equipm

Constraints	
Host	
Dimensions	
Round Connector ...	Use Diameter
Mechanical	
Classification	
Part Type	Normal
Identity Data	
OmniClass Number	23.75.00.00
OmniClass Title	Climate Control (H...
Other	
Work Plane-Based	☐
Always vertical	☑
Cut with Voids Wh...	☐
Shared	☐
Room Calculation ...	☐

Cameras : 3D View : {3D}

Figure 28: BIM model of the RP1



Type name: RP1 Multy-Source heat pump

Parameter	Value	Formula
Constraints		
Default Elevation	0.0	=
Electrical		
Absorbed Power	31.35 W	=
Electric Power Supply	380-420 V/3/ 50 Hz	=
Load Classification		=
Number of Poles	1	=
Voltage	0.00 V	=
Electrical - Loads		
Apparent Load	0.00 VA	=
Dimensions		
Heat Pump Height	1500.0	=
Heat Pump Length	2260.0	=
Heat Pump Width	1560.0	=
Mechanical		
Condensation temperature	50.00 °C	=
Evaporation temperature	2.00 °C	=
Evaporator Capacity	99.20 W	=
Evaporator Nominal Capacity	116.00 W	=
Condenser Capacity	130.10 W	=
Condenser Nominal Capacity	140.00 W	=
External Static Pressure (default)	0.000000 Pa	=
Maximum heat production temperature	45.00 °C	=
Pinch point temperature difference at the evaporator an	5.00 °C	=
Subcooling at the condenser outlet	2.00 °C	=
Superheat at the compressor suction	10.00 °C	=
Water Pressure Drop (default) (default)	0.000000 Pa	=
Water temperature difference at the condenser	2.50 °C	=
Water temperature difference at the evaporator	5.30 °C	=
Mechanical - Flow		
Air Flow (default)	0.00 L/s	=
Condenser Flow Refrigerant	0.88 L/s	=
Condenser Water Flow (default)	9.59 L/s	=
Evaporator Flow Refrigerant (default)	0.83 L/s	=
Evaporator Water Flow (default)	5.56 L/s	=
Energy Analysis		
Water Condenser Coolant Flow	0.00 W	=
IFC Parameters		
Export Type to IFC As		=
IfcExportAS		=
IfxExportType		=
Type IFC Predefined Type		=
Identity Data		
Type Image		=
Keynote		=
Model	H4000CC	=
Manufacturer	PSYCTOTHERM	=
Type Comments		=
URL		=
Description	RP1-Multisource heat pump (Air/Water to Water)	=
Assembly Code		=
Cost		=

Figure 29: Properties of the RP1 BIM model

4.2 RP2: ADAPTABLE/DYNAMIC BUILDING ENVELOPE

Responsible Partner for BIM Models: **RINA-C**

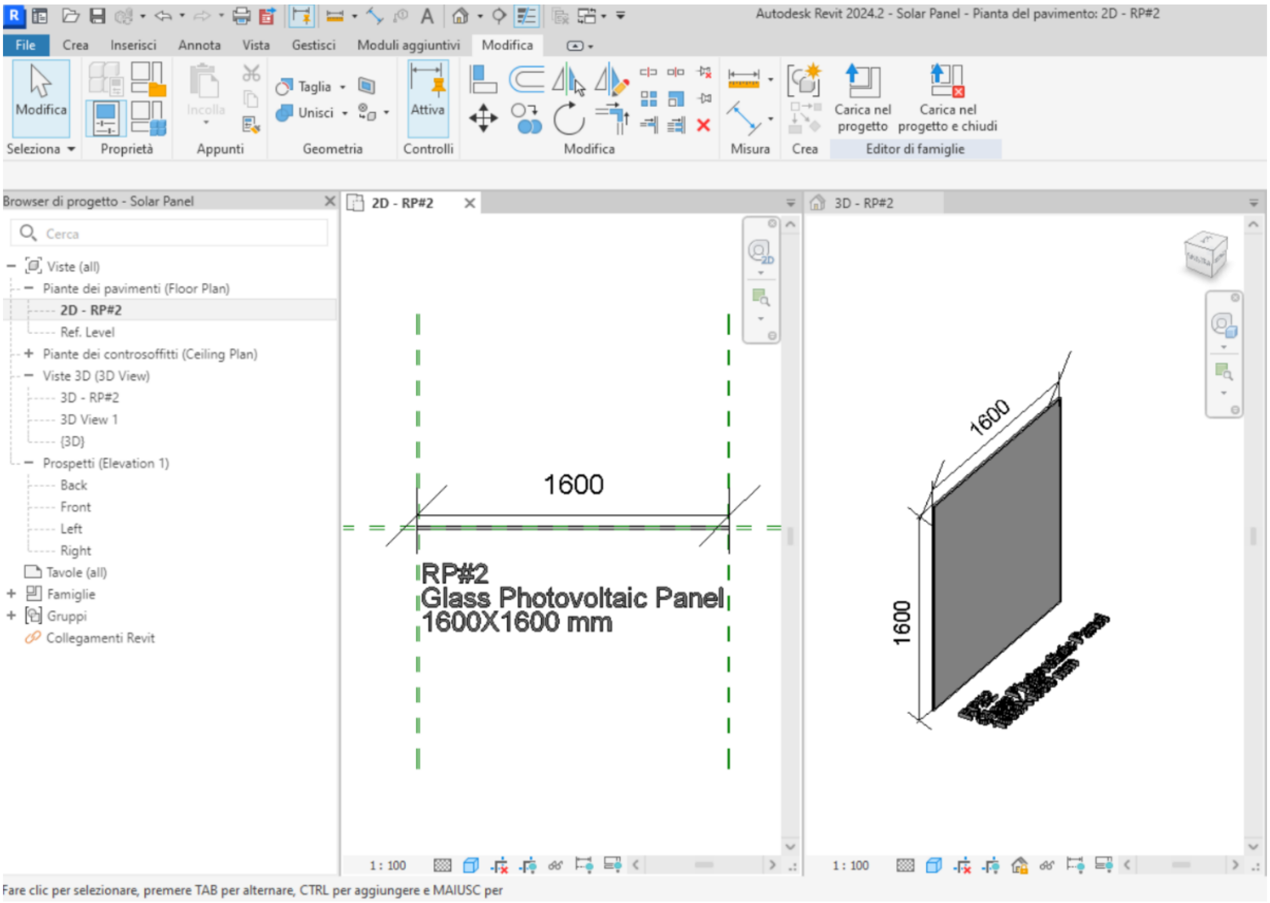
Software used: **Autodesk REVIT**

File Format: **rvt, rfa, ifc**

Level of Development: 200

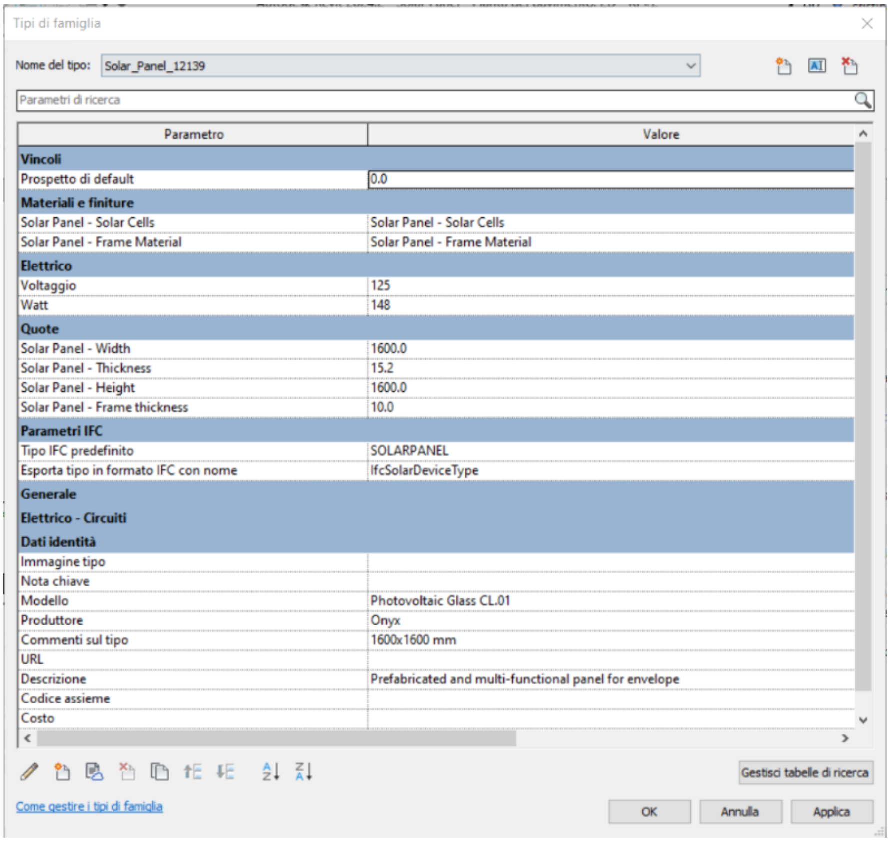
- Level of Information: 2->Properties and information defined by the current design state
- Level of Geometry: Medium->Indicative geometry to represent the visual appearance of the object

The BIM model created in REVIT software for RP1 is shown Figure 30 in and Figure 31.



Fare clic per selezionare, premere TAB per alternare, CTRL per aggiungere e MAIUSC per

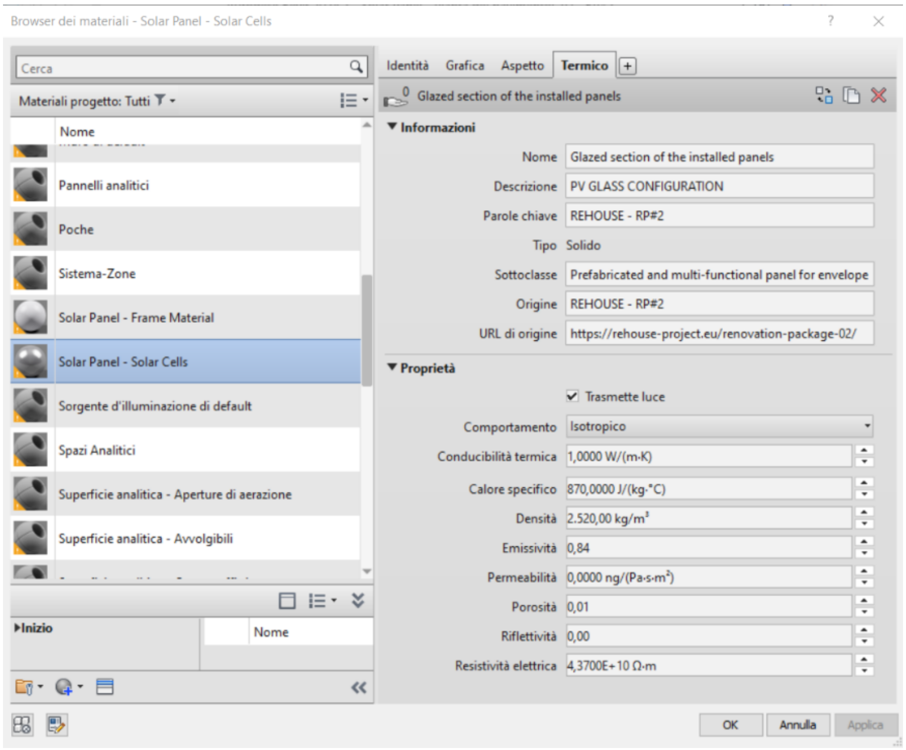
Figure 30: BIM model of the RP2



Nome del tipo: Solar_Panel_12139

Parametro	Valore
Vincoli	
Prospetto di default	0.0
Materiali e finiture	
Solar Panel - Solar Cells	Solar Panel - Solar Cells
Solar Panel - Frame Material	Solar Panel - Frame Material
Elettrico	
Voltaggio	125
Watt	148
Quote	
Solar Panel - Width	1600.0
Solar Panel - Thickness	15.2
Solar Panel - Height	1600.0
Solar Panel - Frame thickness	10.0
Parametri IFC	
Tipo IFC predefinito	SOLARPANEL
Esporta tipo in formato IFC con nome	IfcSolarDeviceType
Generale	
Elettrico - Circuiti	
Dati identità	
Immagine tipo	
Nota chiave	
Modello	Photovoltaic Glass CL.01
Produttore	Onyx
Commenti sul tipo	1600x1600 mm
URL	
Descrizione	Prefabricated and multi-functional panel for envelope
Codice assieme	
Costo	

(a)



Glazed section of the installed panels

Informazioni

Nome: Glazed section of the installed panels
Descrizione: PV GLASS CONFIGURATION
Parole chiave: REHOUSE - RP#2
Tipo: Solido
Sottoclasse: Prefabricated and multi-functional panel for envelope
Origine: REHOUSE - RP#2
URL di origine: https://rehouse-project.eu/renovation-package-02/

Proprietà

☑ Trasmette luce
Comportamento: Isotropico
Conducibilità termica: 1,0000 W/(m·K)
Calore specifico: 870,0000 J/(kg·°C)
Densità: 2.520,00 kg/m³
Emissività: 0,84
Permeabilità: 0,0000 ng/(Pa·s·m²)
Porosità: 0,01
Riflettività: 0,00
Resistività elettrica: 4,3700E+10 Ω·m

(b)

Figure 31: Properties of the RP2 BIM model

4.3 RP3: SMARTWALL

Responsible Partner for BIM Models: **AMS**

Software used: **Autodesk REVIT**

File Format: **rvt, rfa, ifc**

Level of Development: **200**

- Level of Information: **2** - [Properties, values and information required during Technical Design stage (generic elements)]
- Level of Geometry: **Medium** - [Approximate Geometry. The lightest geometry able to represent the object's visual aspect.]

All SmartWall types consist of these 6 basic components, as displayed in the pictures below (a SmartWall with only those components is called **Blank Smartwall**):

1. Cement Board
2. L-Section Steel Framing System – Casing
3. XPS Spacer
4. Insulating Material(s)
5. Cement Board Screws
6. Anchoring Screws

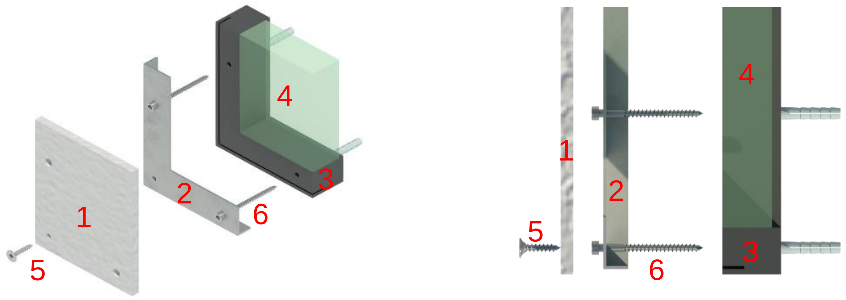


Figure 32: SmartWall basic components – Blank Smartwall

(**Blank SmartWalls** are used on **both facades**, where needed.)

Apart from those basic components, some SmartWalls will also include Windows with Integrated Blinds, PV Panels, Ventilation Units or a combination of those technologies.

The Insulating Materials also differentiate from each other according to the facades' demands. More specifically, for the Greek demo:

- On the north facade of the Greek demo, all SmartWalls contain the configuration of *Mineral Wool + V.I.P. + Mineral Wool* as insulation and "carry" Windows and *PICO Ventilation* (where needed).
- On the south facade of the Greek demo, 1 SmartWall configuration contains plain *Mineral Wool* as insulation, carries *Window, PICO Ventilation* & *PV panel.*

The remaining SmartWalls of the south facade also carry *Windows, Ventilation & PV panels*, but use a combination of *Silica Aerogel* + *Mineral Wool* as insulation.

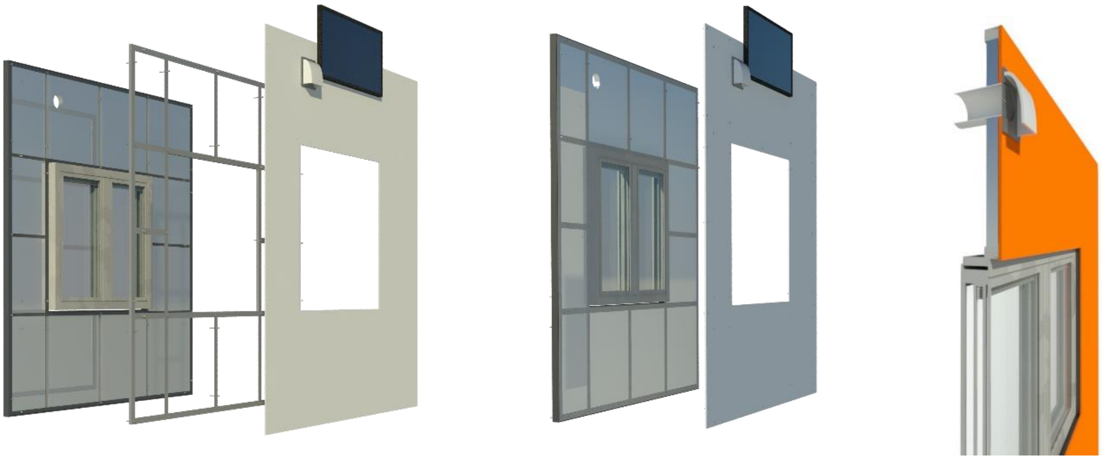
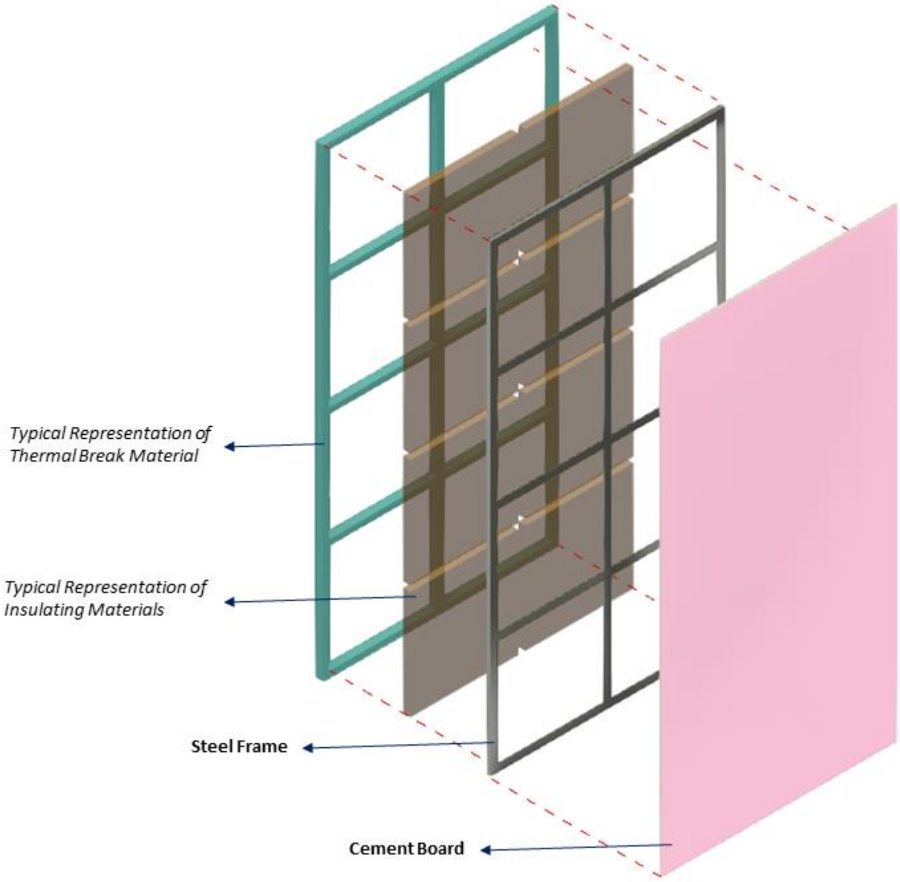


Figure 33: SmartWall incorporating additional components

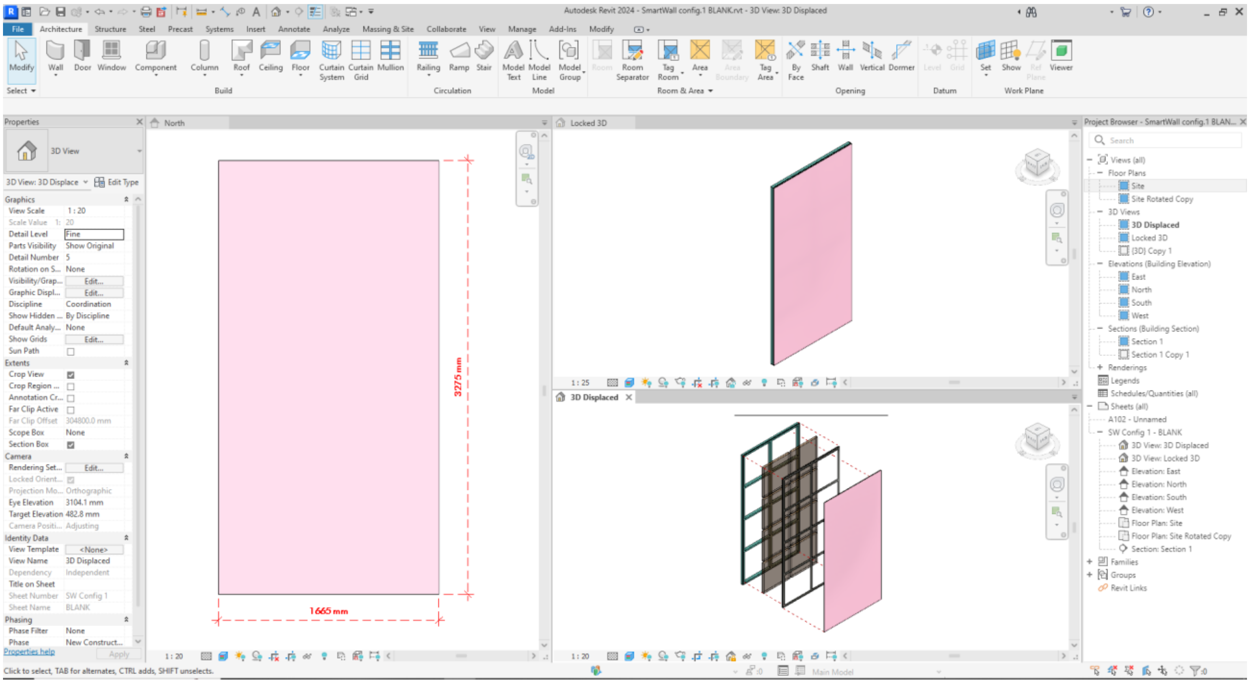
SmartWall Components BIM Modelling:

Some components were downloaded as REVIT families from BIM Libraries and others were exclusively designed by AMS as new REVIT families with the parameters and properties of needed materials.

On the following figures some of the developed RP3 - BIM models and their properties are presented.



(a)



Properties

3D View

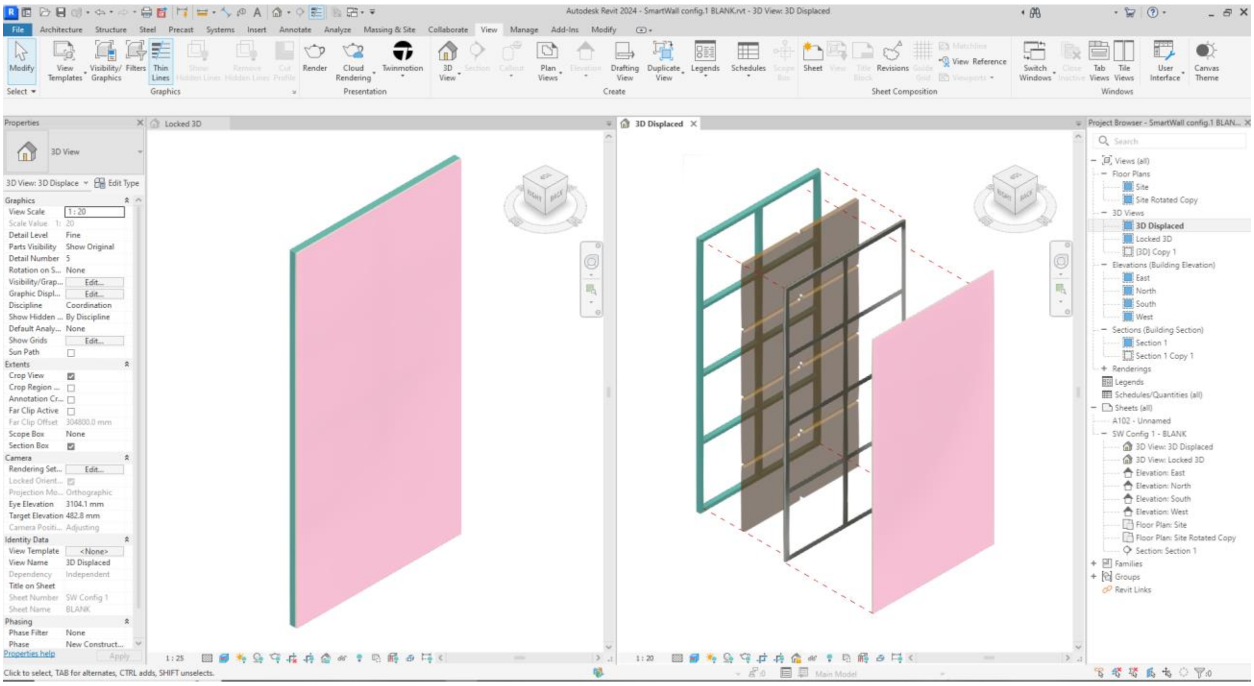
3D View: 3D Displace — Edit Type

Graphics	
View Scale	1 : 20
Scale Value 1:	20
Detail Level	Fine
Parts Visibility	Show Original
Detail Number	5
Rotation on S...	None
Visibility/Grap...	Edit...
Graphic Displ...	Edit...
Discipline	Coordination
Show Hidden ...	By Discipline
Default Analy...	None
Show Grids	Edit...
Sun Path	☐
Extents	
Crop View	☑
Crop Region ...	☐
Annotation Cr...	☐
Far Clip Active	☐
Far Clip Offset	304800.0 mm
Scope Box	None
Section Box	☑
Camera	
Rendering Set...	Edit...
Locked Orient...	☑
Projection Mo...	Orthographic
Eye Elevation	3104.1 mm
Target Elevation	482.8 mm
Camera Positi...	Adjusting
Identity Data	
View Template	<None>
View Name	3D Displaced
Dependency	Independent
Title on Sheet	
Sheet Number	SW Config 1
Sheet Name	BLANK
Phasing	
Phase Filter	None
Phase	New Construct...

Properties help — Apply

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

(b)



Autodesk Revit 2024 - SmartWall config.1 BLANK.rvt - 3D View: 3D Displaced

Properties

3D View

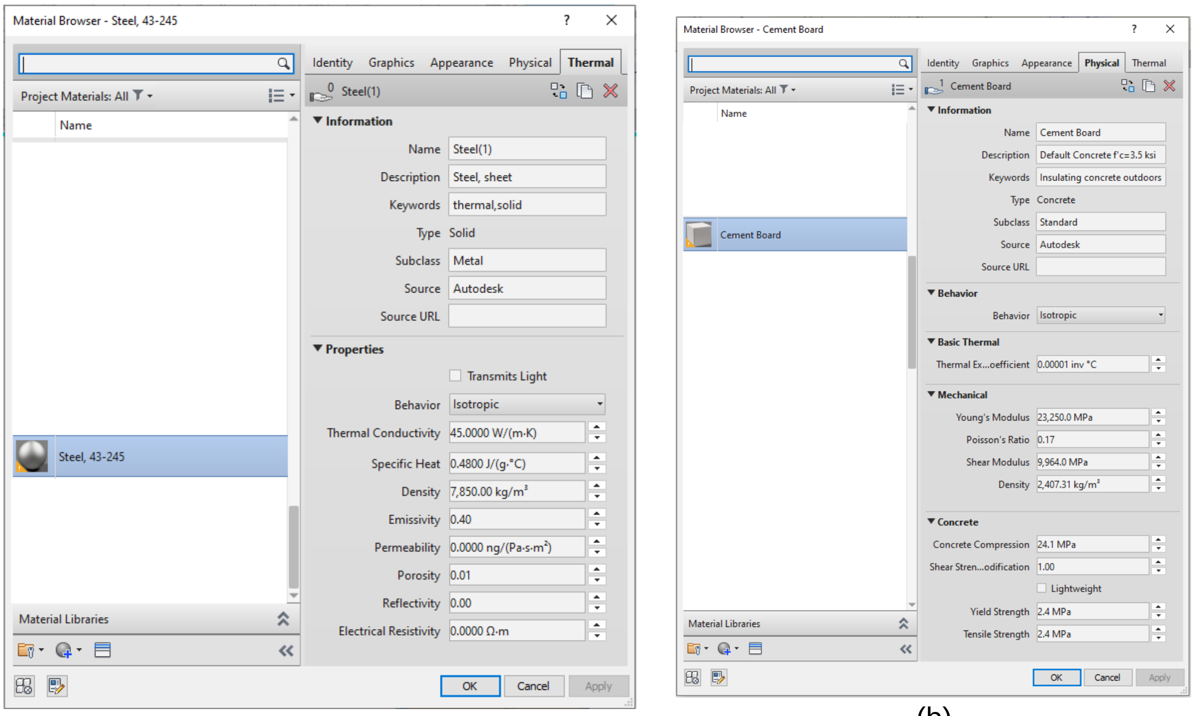
3D View: 3D Displace · Edit Type

Graphics	
View Scale	1 : 20
Scale Value 1:	20
Detail Level	Fine
Parts Visibility	Show Original
Detail Number	5
Rotation on S...	None
Visibility/Grap...	Edit...
Graphic Displ...	Edit...
Discipline	Coordination
Show Hidden ...	By Discipline
Default Analy...	None
Show Grids	Edit...
Sun Path	☐
Extents	
Crop View	☑
Crop Region ...	☐
Annotation Cr...	☐
Far Clip Active	☐
Far Clip Offset	304800.0 mm
Scope Box	None
Section Box	☑
Camera	
Rendering Set...	Edit...
Locked Orient...	☑
Projection Mo...	Orthographic
Eye Elevation	3104.1 mm
Target Elevation	482.8 mm
Camera Positi...	Adjusting
Identity Data	
View Template	<None>
View Name	3D Displaced
Dependency	Independent
Title on Sheet	
Sheet Number	SW Config 1
Sheet Name	BLANK
Phasing	
Phase Filter	None
Phase	New Construct...

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

(c)

Figure 34: BIM models of the RP3



Material Browser - Steel, 43-245

Steel(1)

Information

Name	Steel(1)
Description	Steel, sheet
Keywords	thermal,solid
Type	Solid
Subclass	Metal
Source	Autodesk
Source URL	

Properties

	☐ Transmits Light
Behavior	Isotropic
Thermal Conductivity	45.0000 W/(m·K)
Specific Heat	0.4800 J/(g·°C)
Density	7,850.00 kg/m^3
Emissivity	0.40
Permeability	0.0000 ng/(Pa·s·m^2)
Porosity	0.01
Reflectivity	0.00
Electrical Resistivity	0.0000 Ω·m

(a)

Material Browser - Cement Board

Cement Board

Information

Name	Cement Board
Description	Default Concrete f'c=3.5 ksi
Keywords	Insulating concrete outdoors
Type	Concrete
Subclass	Standard
Source	Autodesk
Source URL	

Behavior

Behavior	Isotropic

Basic Thermal

Thermal Ex...oefficient	0.00001 inv °C

Mechanical

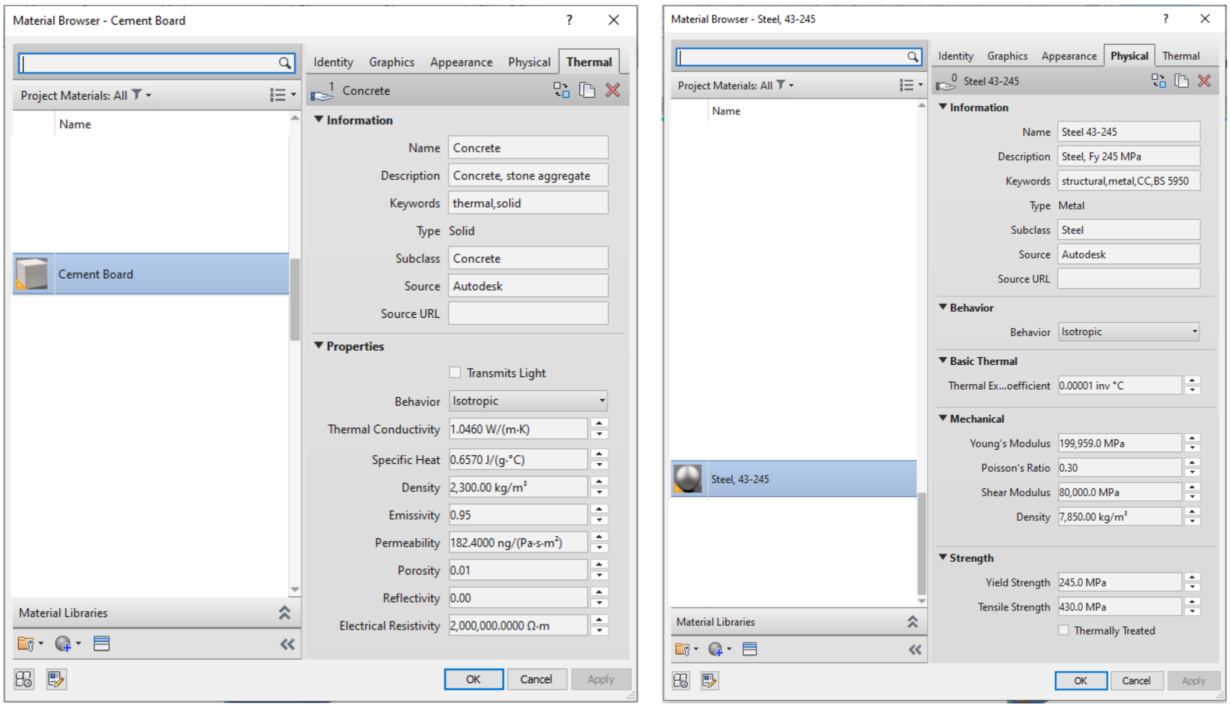
Young's Modulus	23,250.0 MPa
Poisson's Ratio	0.17
Shear Modulus	9,964.0 MPa
Density	2,407.31 kg/m^3

Concrete

Concrete Compression	24.1 MPa
Shear Stren...odification	1.00
	☐ Lightweight
Yield Strength	2.4 MPa
Tensile Strength	2.4 MPa

(b)

Co-funded by the European Union



Material Browser - Cement Board

Cement Board

Concrete

Information

Name: Concrete
Description: Concrete, stone aggregate
Keywords: thermal,solid
Type: Solid
Subclass: Concrete
Source: Autodesk
Source URL:

Properties

☐ Transmits Light
Behavior: Isotropic
Thermal Conductivity: 1.0460 W/(m·K)
Specific Heat: 0.6570 J/(g·°C)
Density: 2,300.00 kg/m³
Emissivity: 0.95
Permeability: 182.4000 ng/(Pa·s·m²)
Porosity: 0.01
Reflectivity: 0.00
Electrical Resistivity: 2,000,000.0000 Ω·m

Material Browser - Steel, 43-245

Steel, 43-245

Steel 43-245

Information

Name: Steel 43-245
Description: Steel, Fy 245 MPa
Keywords: structural,metal,CC,BS 5950
Type: Metal
Subclass: Steel
Source: Autodesk
Source URL:

Behavior

Behavior: Isotropic

Basic Thermal

Thermal Ex...oefficient: 0.00001 inv °C

Mechanical

Young's Modulus: 199,959.0 MPa
Poisson's Ratio: 0.30
Shear Modulus: 80,000.0 MPa
Density: 7,850.00 kg/m³

Strength

Yield Strength: 245.0 MPa
Tensile Strength: 430.0 MPa
☐ Thermally Treated

(c) (d)

Figure 35: Properties of the RP3 BIM model

4.4 RP4: CENTRALIZED HOLISTIC H&C RENOVATION KIT

<u>Responsible Partner for BIM Models:</u> **RINA-C**

<u>Software used:</u> **Revit, Inventor**

<u>File Format:</u> **.ifc, .rvt, .rfa**

<u>Level of Development</u>: **200**

- <u>Level of Information</u>: 2
- <u>Level of Geometry</u>: Medium

In the Renovation Package 4 there are two innovative components:

1. **Heat Pumps**
    - 2 elements of 250 kg each + 1,000 kg of piping

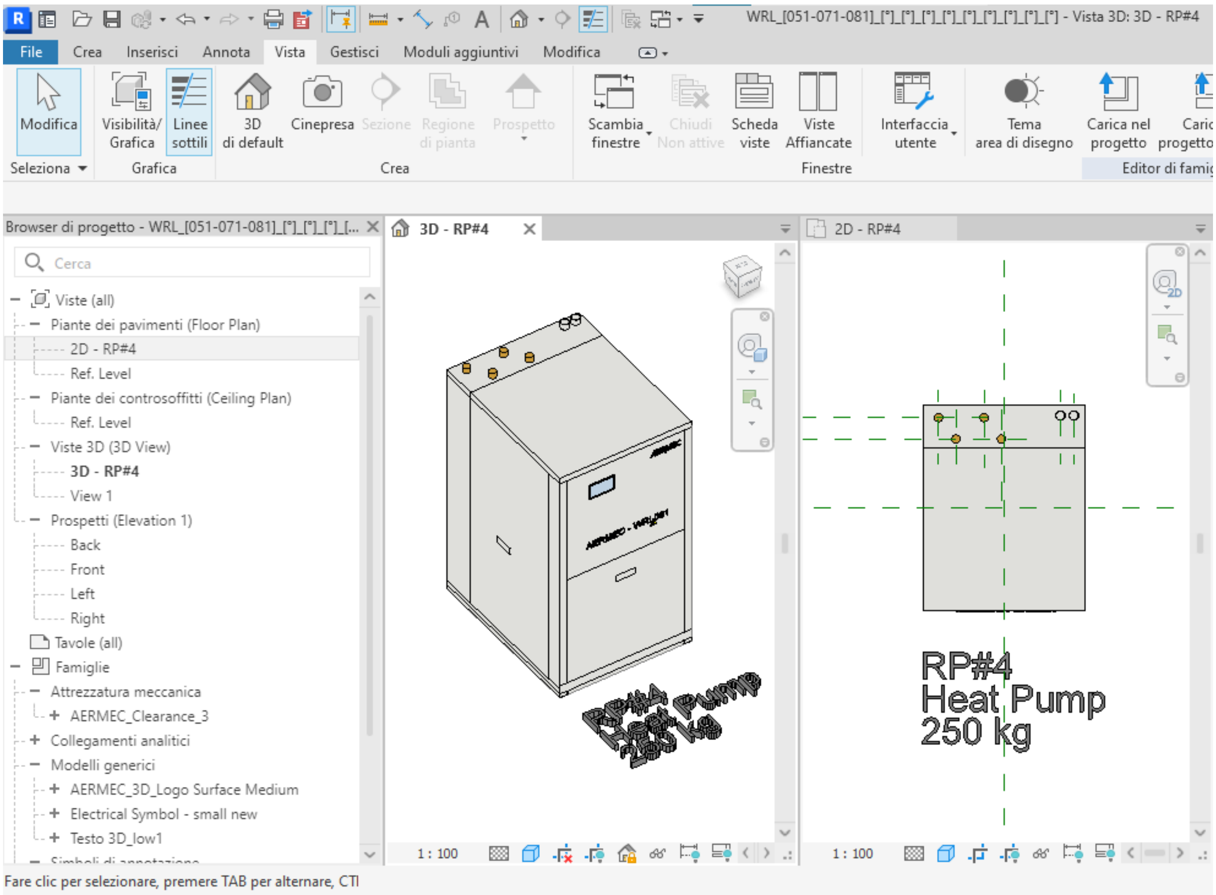
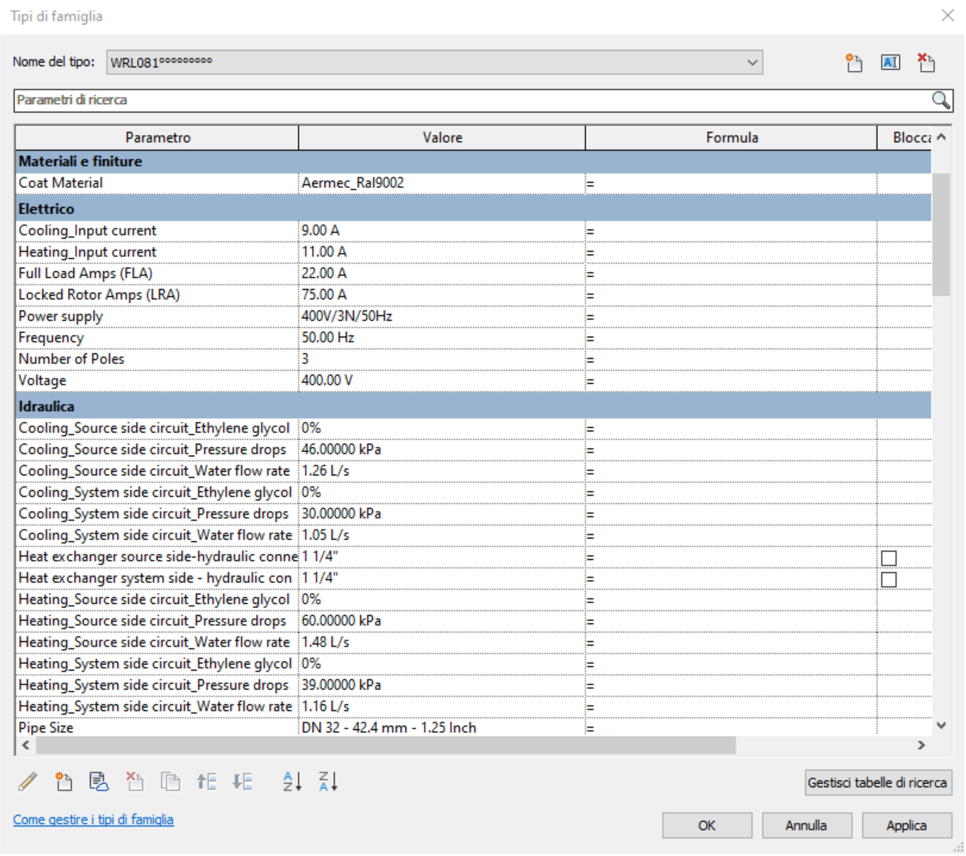


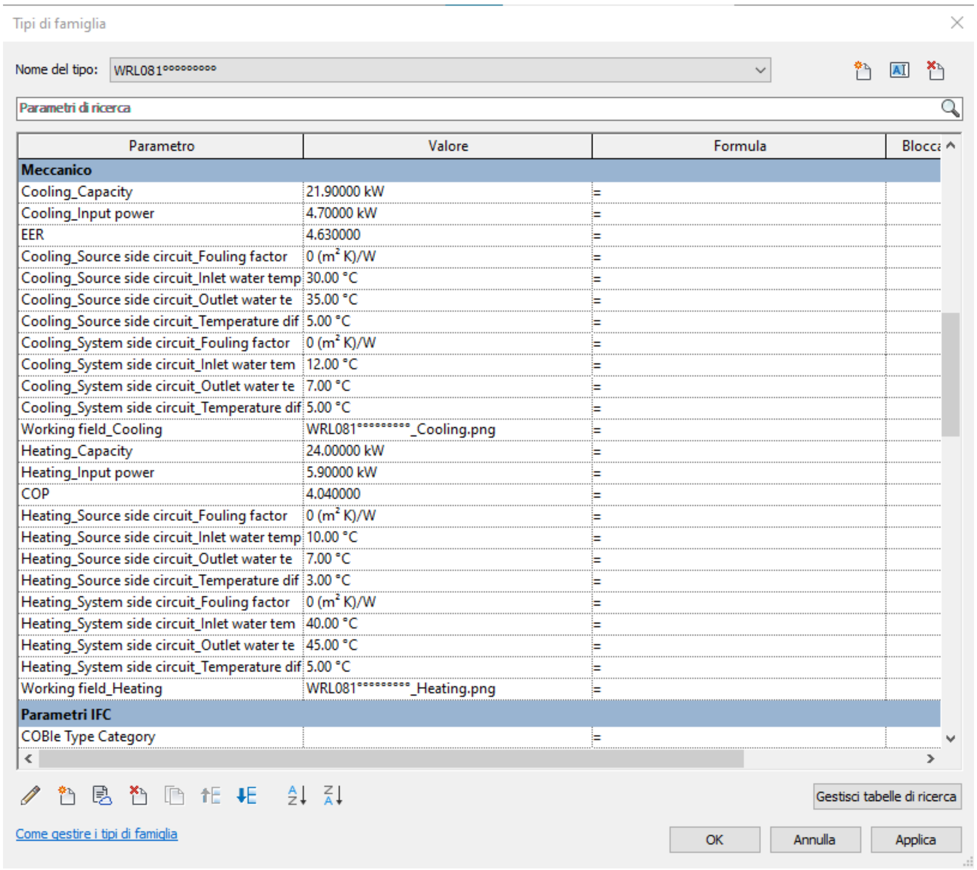
Figure 36: BIM model of the RP4 - Heat Pump



Nome del tipo: WRL081°°°°°°°°°

Parametro	Valore	Formula	Blocca
Materiali e finiture			
Coat Material	Aermec_Ral9002	=	
Elettrico			
Cooling_Input current	9.00 A	=	
Heating_Input current	11.00 A	=	
Full Load Amps (FLA)	22.00 A	=	
Locked Rotor Amps (LRA)	75.00 A	=	
Power supply	400V/3N/50Hz	=	
Frequency	50.00 Hz	=	
Number of Poles	3	=	
Voltage	400.00 V	=	
Idraulica			
Cooling_Source side circuit_Ethylene glycol	0%	=	
Cooling_Source side circuit_Pressure drops	46.00000 kPa	=	
Cooling_Source side circuit_Water flow rate	1.26 L/s	=	
Cooling_System side circuit_Ethylene glycol	0%	=	
Cooling_System side circuit_Pressure drops	30.00000 kPa	=	
Cooling_System side circuit_Water flow rate	1.05 L/s	=	
Heat exchanger source side-hydraulic conne	1 1/4"	=	☐
Heat exchanger system side - hydraulic con	1 1/4"	=	☐
Heating_Source side circuit_Ethylene glycol	0%	=	
Heating_Source side circuit_Pressure drops	60.00000 kPa	=	
Heating_Source side circuit_Water flow rate	1.48 L/s	=	
Heating_System side circuit_Ethylene glycol	0%	=	
Heating_System side circuit_Pressure drops	39.00000 kPa	=	
Heating_System side circuit_Water flow rate	1.16 L/s	=	
Pipe Size	DN 32 - 42.4 mm - 1.25 Inch	=	

(a)



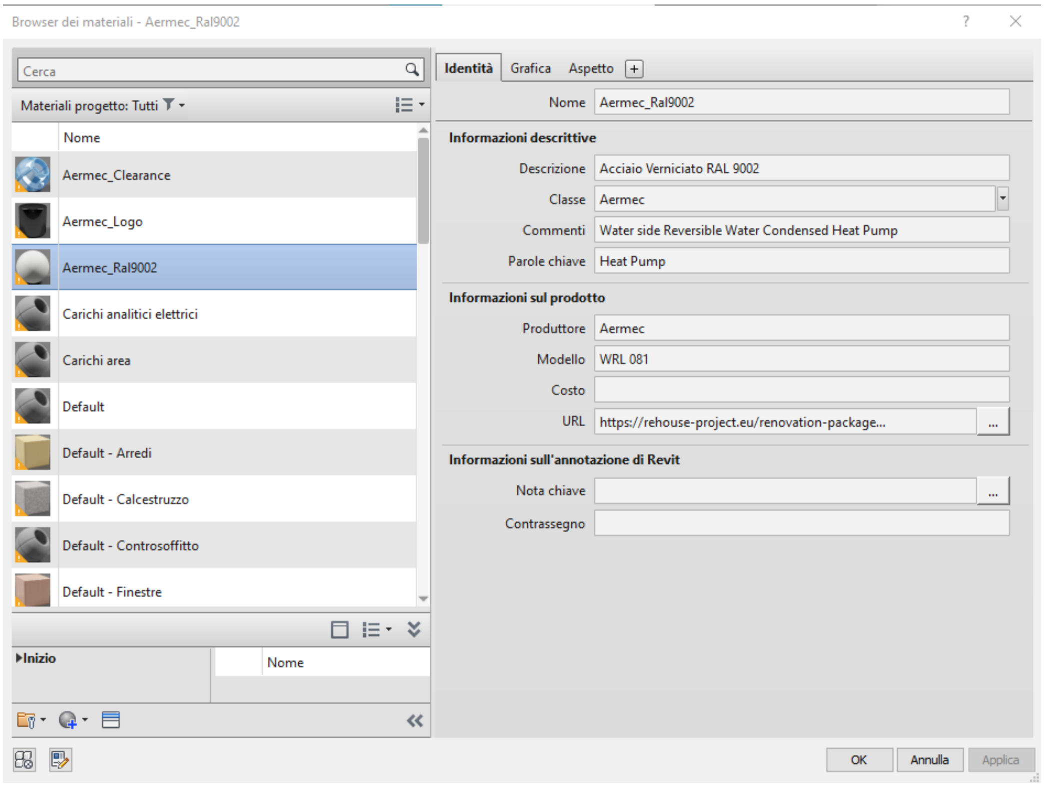
Tipi di famiglia

Nome del tipo: WRL081°°°°°°°°°

Parametri di ricerca

Parametro	Valore	Formula	Blocc
Meccanico			
Cooling_Capacity	21.90000 kW	=	
Cooling_Input power	4.70000 kW	=	
EER	4.630000	=	
Cooling_Source side circuit_Fouling factor	0 (m² K)/W	=	
Cooling_Source side circuit_Inlet water temp	30.00 °C	=	
Cooling_Source side circuit_Outlet water te	35.00 °C	=	
Cooling_Source side circuit_Temperature dif	5.00 °C	=	
Cooling_System side circuit_Fouling factor	0 (m² K)/W	=	
Cooling_System side circuit_Inlet water tem	12.00 °C	=	
Cooling_System side circuit_Outlet water te	7.00 °C	=	
Cooling_System side circuit_Temperature dif	5.00 °C	=	
Working field_Cooling	WRL081°°°°°°°°°_Cooling.png	=	
Heating_Capacity	24.00000 kW	=	
Heating_Input power	5.90000 kW	=	
COP	4.040000	=	
Heating_Source side circuit_Fouling factor	0 (m² K)/W	=	
Heating_Source side circuit_Inlet water temp	10.00 °C	=	
Heating_Source side circuit_Outlet water te	7.00 °C	=	
Heating_Source side circuit_Temperature dif	3.00 °C	=	
Heating_System side circuit_Fouling factor	0 (m² K)/W	=	
Heating_System side circuit_Inlet water tem	40.00 °C	=	
Heating_System side circuit_Outlet water te	45.00 °C	=	
Heating_System side circuit_Temperature dif	5.00 °C	=	
Working field_Heating	WRL081°°°°°°°°°_Heating.png	=	
Parametri IFC			
COBie Type Category		=	

(b)



Browser dei materiali - Aermec_Ral9002

Nome: Aermec_Ral9002

Informazioni descrittive

Descrizione: Acciaio Verniciato RAL 9002
Classe: Aermec
Commenti: Water side Reversible Water Condensed Heat Pump
Parole chiave: Heat Pump

Informazioni sul prodotto

Produttore: Aermec
Modello: WRL 081
Costo:
URL: https://rehouse-project.eu/renovation-package...

Informazioni sull'annotazione di Revit

Nota chiave:
Contrassegno:

(c)

Figure 37: Properties of the RP4 - Heat Pump BIM model

2. Stratified PMC Tanks

- 2 elements of 100 litters and 1,700 kg each

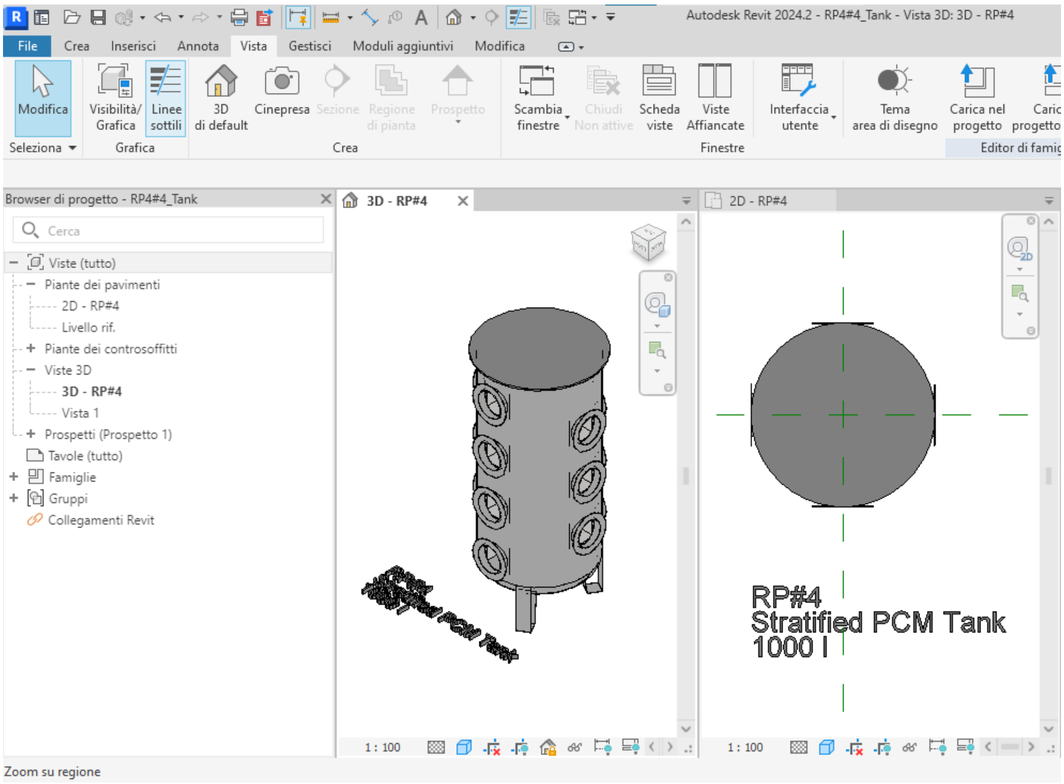
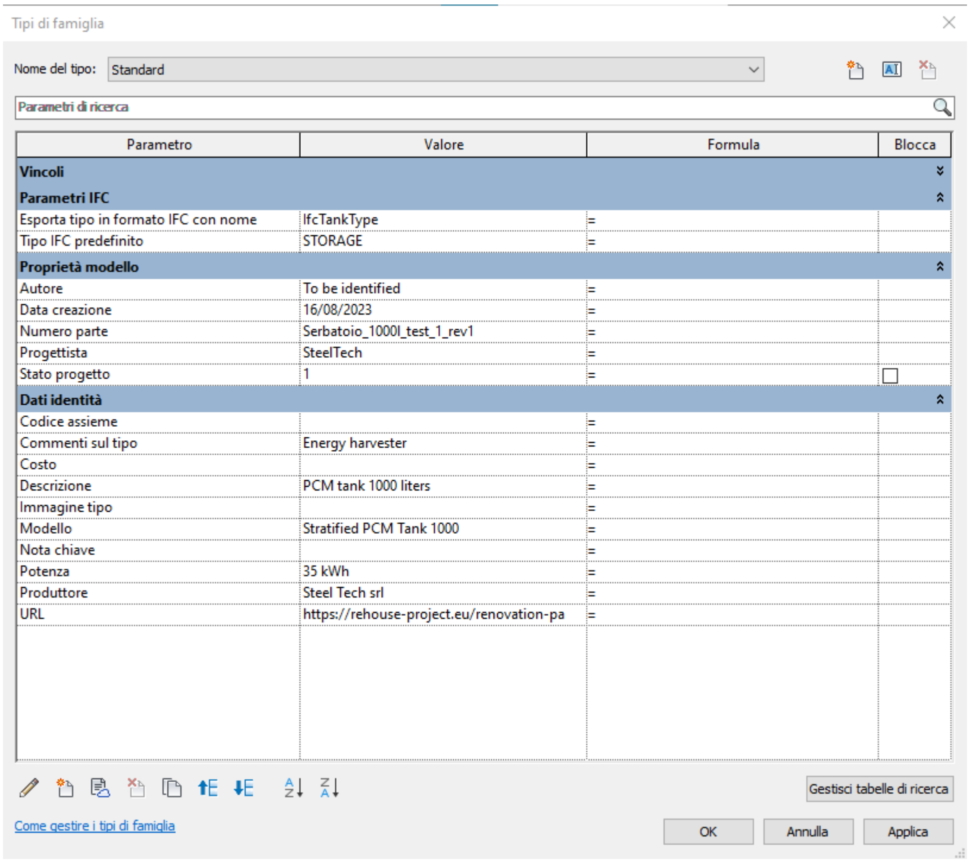


Figure 38: BIM model of the RP4 - Stratified PCM Tanks



Tipi di famiglia

Nome del tipo: Standard

Parametri di ricerca

Parametro	Valore	Formula	Blocca
Vincoli			
Parametri IFC			
Esporta tipo in formato IFC con nome	IfcTankType	=	
Tipo IFC predefinito	STORAGE	=	
Proprietà modello			
Autore	To be identified	=	
Data creazione	16/08/2023	=	
Numero parte	Serbatoio_1000l_test_1_rev1	=	
Progettista	SteelTech	=	
Stato progetto	1	=	☐
Dati identità			
Codice assieme		=	
Commenti sul tipo	Energy harvester	=	
Costo		=	
Descrizione	PCM tank 1000 liters	=	
Immagine tipo		=	
Modello	Stratified PCM Tank 1000	=	
Nota chiave		=	
Potenza	35 kWh	=	
Produttore	Steel Tech srl	=	
URL	https://rehouse-project.eu/renovation-pa	=	

Figure 39: Properties of the RP4 - Stratified PCM Tanks BIM model

4.5 RP5: MULTIPURPOSE PREFAB FACADE SYSTEM WITH BIO-BASED INSULATION AND BIPV

The RP5 has been developed using SolidWorks, AutoCAD, and Revit. The figures below illustrate the Multipurpose Facade model created in both SolidWorks and Revit. As of the current deliverable stage, the following components have been developed:

- Solidworks 3D parametric models of Theorical Demo Building.
- Solidworks 3D parametric models of MDF project proposal.
- Solidworks 2D drawing tables of MDF project proposal.
- BIM IFC models of Theorical Demo Building.
- BIM IFC models of Theorical Demo Building beam structure.
- BIM IFC models of Effective real Demo Building.
- BIM IFC models of MPF project proposal.

Software used: **SolidWorks**

File Format: **SLDASM /. SLDPRT**

File Name: ***RP#5 Multipurpose Facade – only structural, casing and facing – front view***

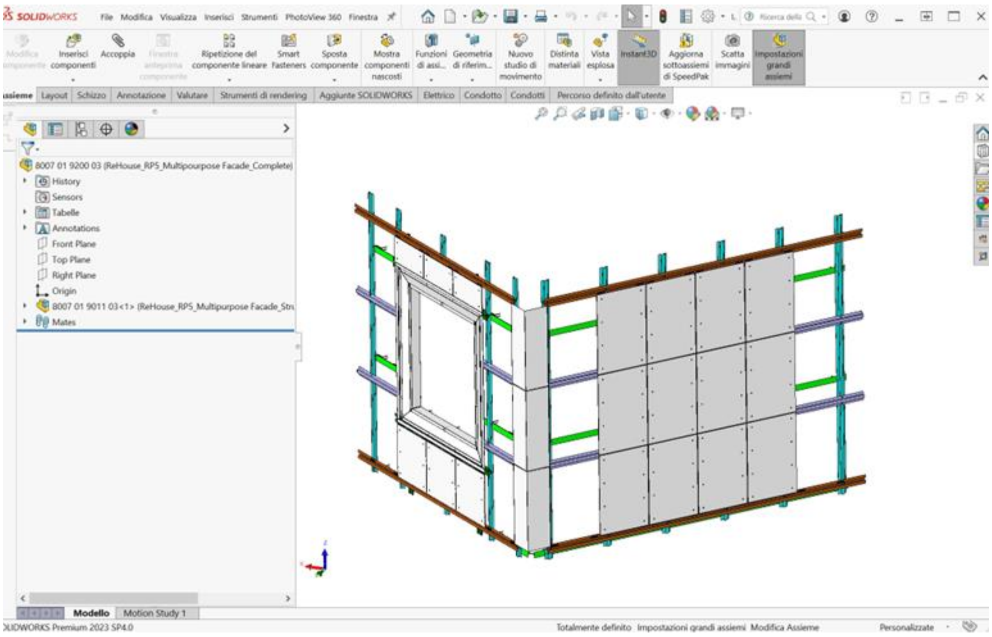


Figure 40: RP5 model in SolidWorks. Structural, Casing and Facing – front view

Software used: **SolidWorks**

File Format: **SLDASM /. SLDPRT**

File Name: ***RP#5 Multipurpose Facade – only structural, casing and facing – rear view***

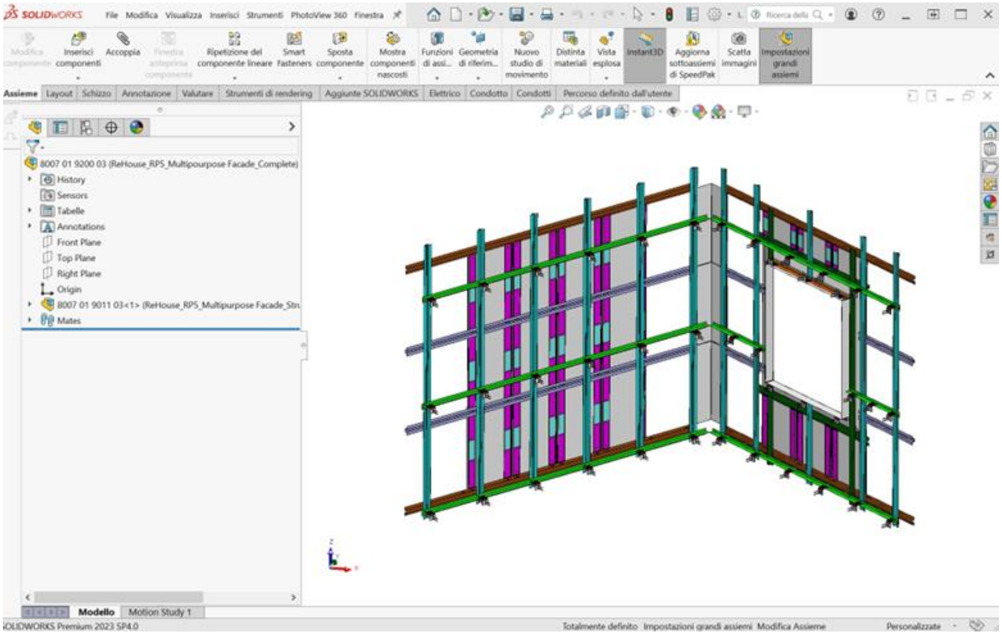


Figure 41: RP5 model in SolidWorks. Structural, Casing and Facing – rear view

Software used: **Revit**

File Format: **.ifc 2x3**

File Name: ***RP#5 Demo site building***

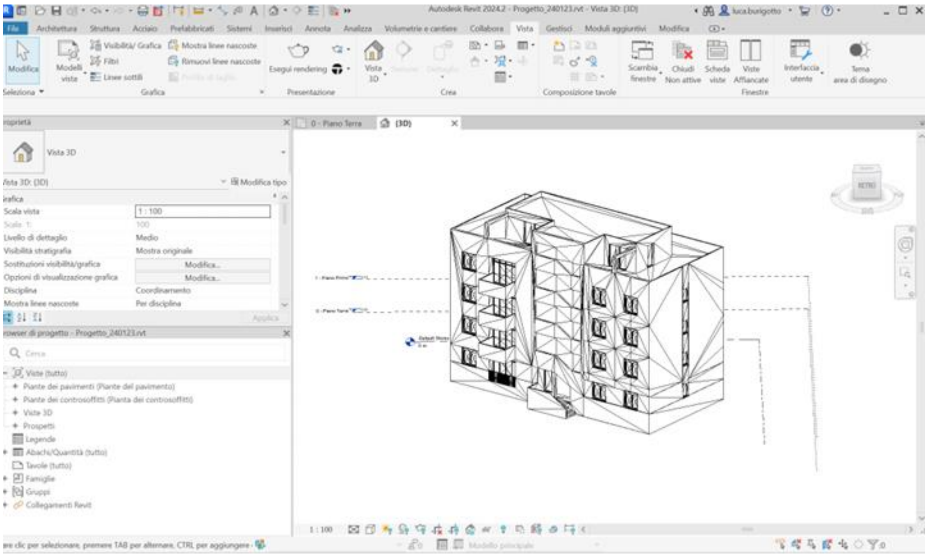


Figure 42: RP5 in the IT Demo

Software used: **Revit**

File Format: **.ifc 2x3**

File Name: ***RP#5 Multipurpose Facade – only structural, casing and facing***

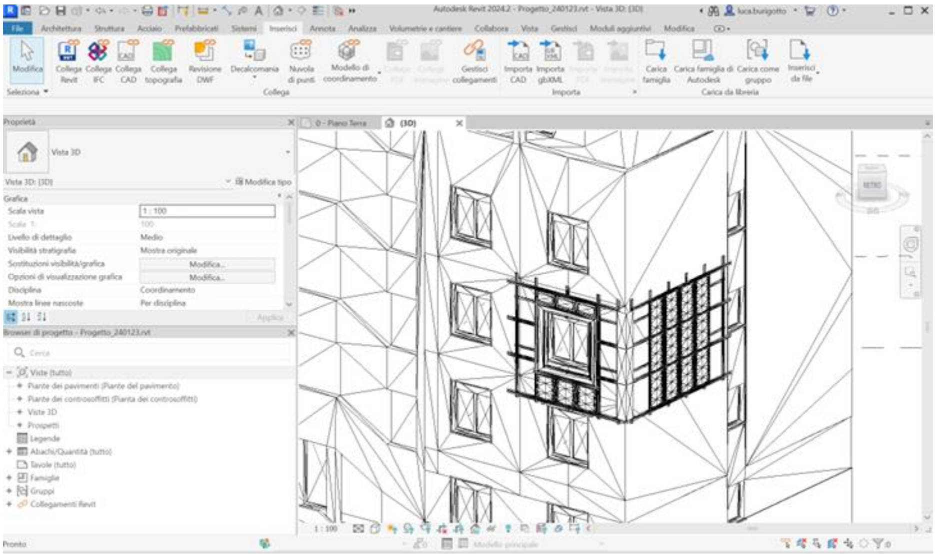


Figure 43: RP5 Multipurpose Façade- BIM model in REVIT. Structural, Casing and Facing

<u>Software used:</u> **Revit**
<u>File Format:</u> **.ifc 2x3**
<u>File Name:</u> ***RP#5 Multipurpose Facade – complete***

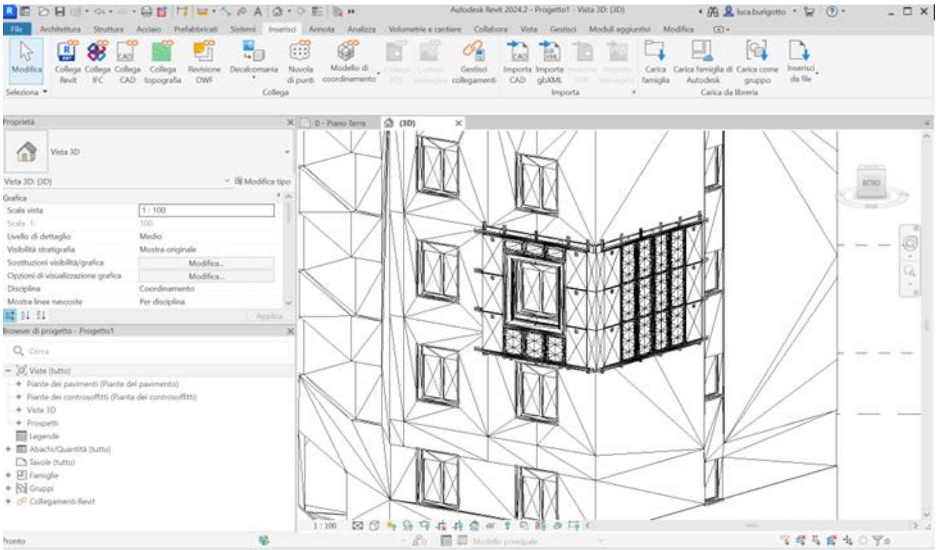


Figure 44: RP5 Multipurpose Façade- BIM model in REVIT. Complete

Next Steps

Following an initial planning, the workflow for the creation of a "loadable 3D parametric family" (i.e. suitable to be imported onto the BIM model of the entire building) continues with the actual design.

The procedure shall consist of:

1- <u>Structure definition;</u> with insertion of lines and reference planes to set the conformation of the family.

2- Parameter creation; with definition of the dimensional parameters associated with the family structure.
3- Geometric realization; with modeling of the volume and constraint of the same to the reference planes.
4- Family management; Family modeling with verification of volumetric and geometry parameters for correct operation, type modulation, saving and use of the family.

REVIT software will be used for the final design of RP5 BIM modelling. At the moment, the working group of RP5 is planning the multi-parametric implementation phases of components and materials being defined for the executive project. This planning foresees the release of the executive project within the next 3 months. Then the entire BIM modelling of the Multi-purpose Facade of RP5 will be elaborated.

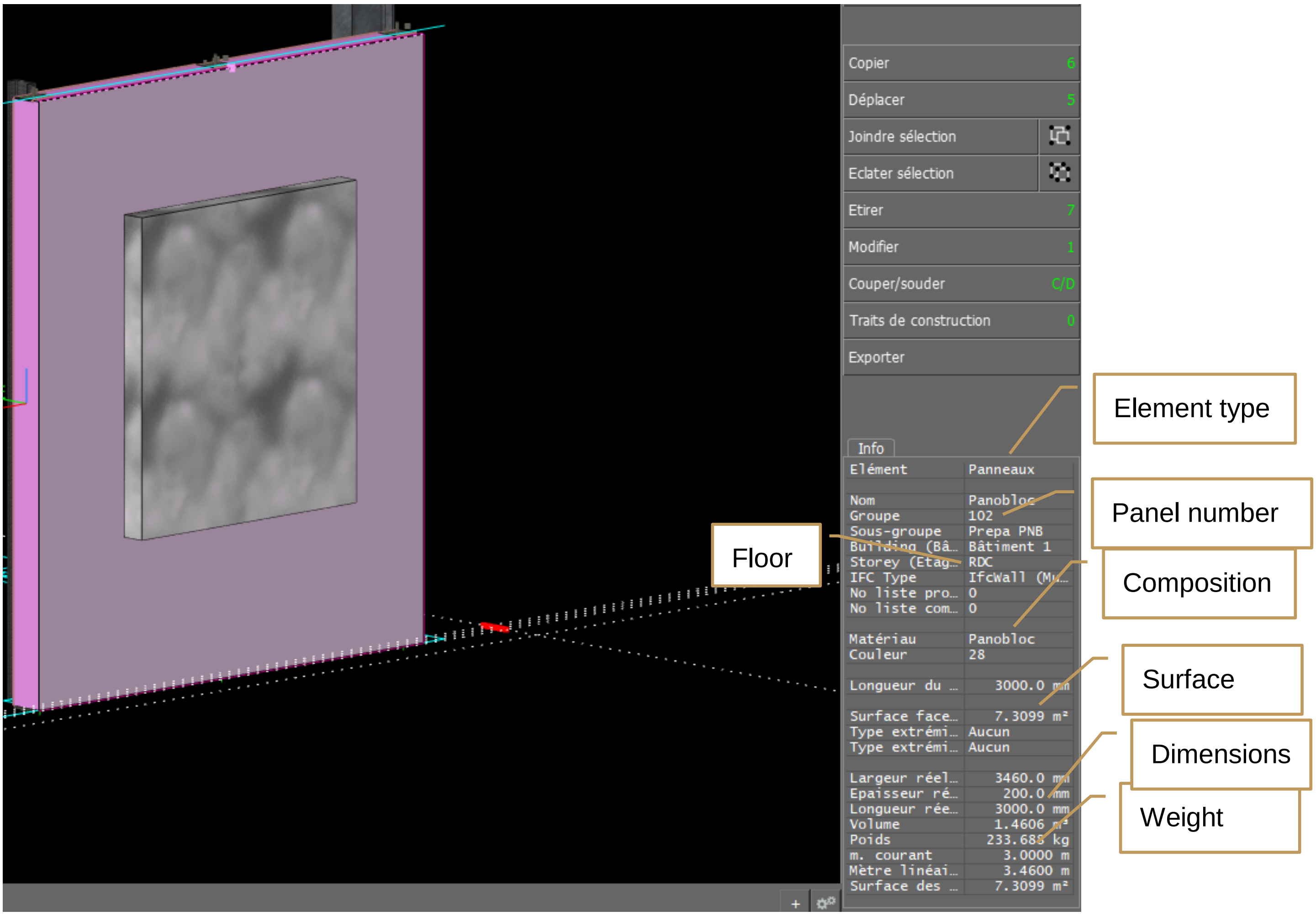
4.6 RP6: PANOREN

Responsible Partner for BIM Models: **TWR**

Software used: **CADWORK**

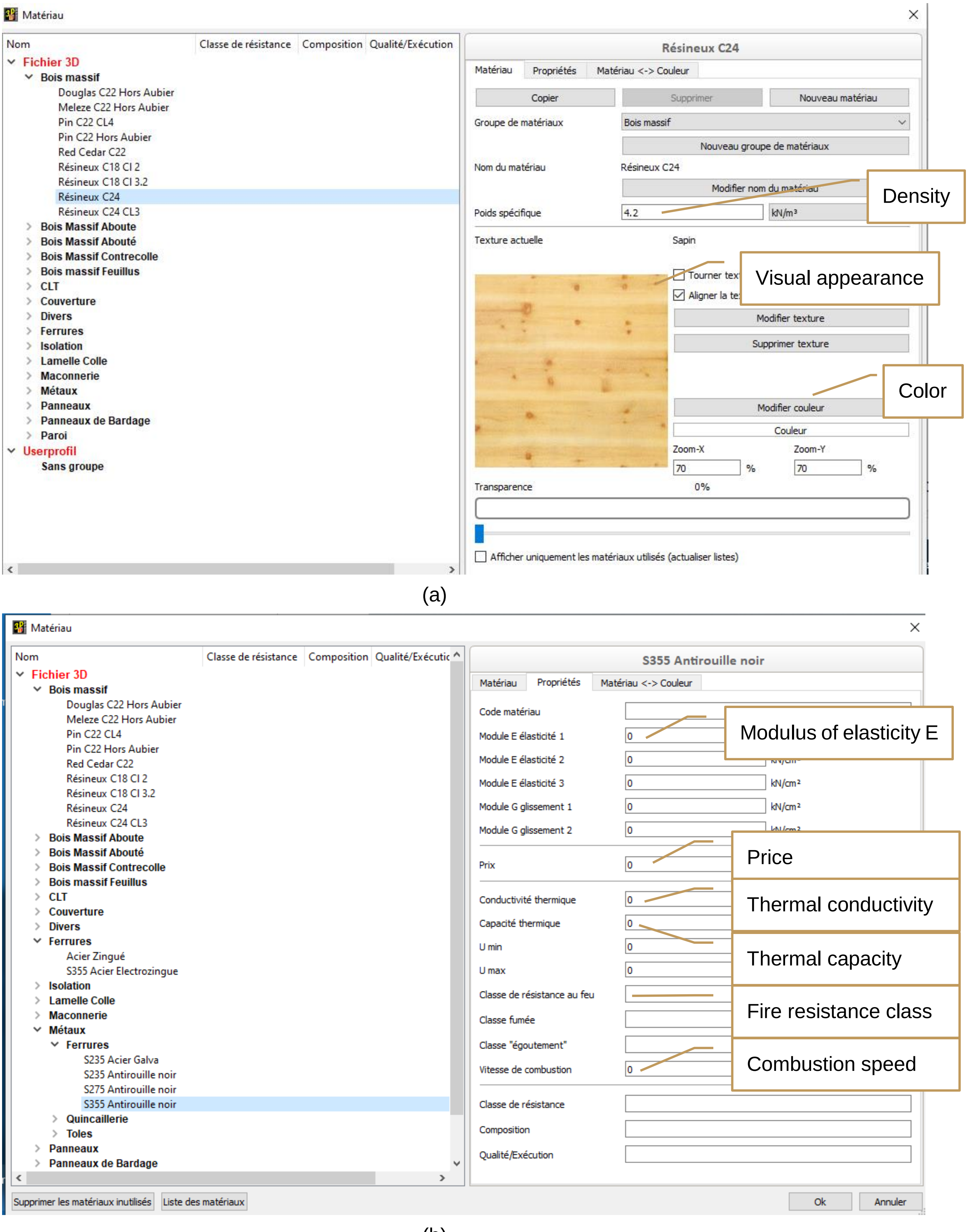
File Format: **.ifc, .dxf**

Level of Development: **200**



Elément	Panneaux
Nom	Panobloc
Groupe	102
Sous-groupe	Prepa PNB
Building (Bâ…	Bâtiment 1
Storey (Etag…	RDC
IFC Type	IfcWall (Mu…
No liste pro…	0
No liste com…	0
Matériau	Panobloc
Couleur	28
Longueur du …	3000.0 mm
Surface face…	7.3099 m²
Type extrémi…	Aucun
Type extrémi…	Aucun
Largeur réel…	3460.0 mm
Epaisseur ré…	200.0 mm
Longueur rée…	3000.0 mm
Volume	1.4606 m³
Poids	233.688 kg
m. courant	3.0000 m
Mètre linéai…	3.4600 m
Surface des …	7.3099 m²

Figure 45: BIM model of the RP6



Matériau

Nom	Classe de résistance	Composition	Qualité/Exécution

- Fichier 3D
  - Bois massif
    - Douglas C22 Hors Aubier
    - Meleze C22 Hors Aubier
    - Pin C22 CL4
    - Pin C22 Hors Aubier
    - Red Cedar C22
    - Résineux C18 Cl 2
    - Résineux C18 Cl 3.2
    - Résineux C24
    - Résineux C24 CL3
  - Bois Massif Aboute
  - Bois Massif Abouté
  - Bois Massif Contrecolle
  - Bois massif Feuillus
  - CLT
  - Couverture
  - Divers
  - Ferrures
  - Isolation
  - Lamelle Colle
  - Maconnerie
  - Métaux
  - Panneaux
  - Panneaux de Bardage
  - Paroi
- Userprofil
  - Sans groupe

Résineux C24

Matériau | Propriétés | Matériau <-> Couleur

Copier | Supprimer | Nouveau matériau

Groupe de matériaux: Bois massif

Nouveau groupe de matériaux

Nom du matériau: Résineux C24

Modifier nom du matériau

Poids spécifique: 4.2 kN/m³

Texture actuelle: Sapin

☐ Tourner tex

☑ Aligner la te

Modifier texture

Supprimer texture

Modifier couleur

Couleur

Zoom-X: 70 %

Zoom-Y: 70 %

Transparence: 0%

☐ Afficher uniquement les matériaux utilisés (actualiser listes)

Density

Visual appearance

Color

(a)

Matériau

Nom	Classe de résistance	Composition	Qualité/Exécutic

- Fichier 3D
  - Bois massif
    - Douglas C22 Hors Aubier
    - Meleze C22 Hors Aubier
    - Pin C22 CL4
    - Pin C22 Hors Aubier
    - Red Cedar C22
    - Résineux C18 Cl 2
    - Résineux C18 Cl 3.2
    - Résineux C24
    - Résineux C24 CL3
  - Bois Massif Aboute
  - Bois Massif Abouté
  - Bois Massif Contrecolle
  - Bois massif Feuillus
  - CLT
  - Couverture
  - Divers
  - Ferrures
    - Acier Zingué
    - S355 Acier Electrozingue
  - Isolation
  - Lamelle Colle
  - Maconnerie
  - Métaux
    - Ferrures
      - S235 Acier Galva
      - S235 Antirouille noir
      - S275 Antirouille noir
      - S355 Antirouille noir
    - Quincaillerie
    - Toles
  - Panneaux
  - Panneaux de Bardage

S355 Antirouille noir

Matériau | Propriétés | Matériau <-> Couleur

Code matériau:

Module E élasticité 1: 0

Module E élasticité 2: 0

Module E élasticité 3: 0 kN/cm²

Module G glissement 1: 0 kN/cm²

Module G glissement 2: 0

Prix: 0

Conductivité thermique: 0

Capacité thermique: 0

U min: 0

U max: 0

Classe de résistance au feu:

Classe fumée:

Classe "égoutement":

Vitesse de combustion: 0

Classe de résistance:

Composition:

Qualité/Exécution:

Supprimer les matériaux inutilisés | Liste des matériaux | Ok | Annuler

Modulus of elasticity E

Price

Thermal conductivity

Thermal capacity

Fire resistance class

Combustion speed

(b)

Figure 46: Properties of the RP6 BIM model

The mechanical data can also be added, this information is not required, so it is not filled in (Figure 46b)

4.7 RP7: 100% ENVIRONMENT-FRIENDLY ACTIVATED CELLULOSE THERMAL INSULATION MADE OF WOOD WASTE

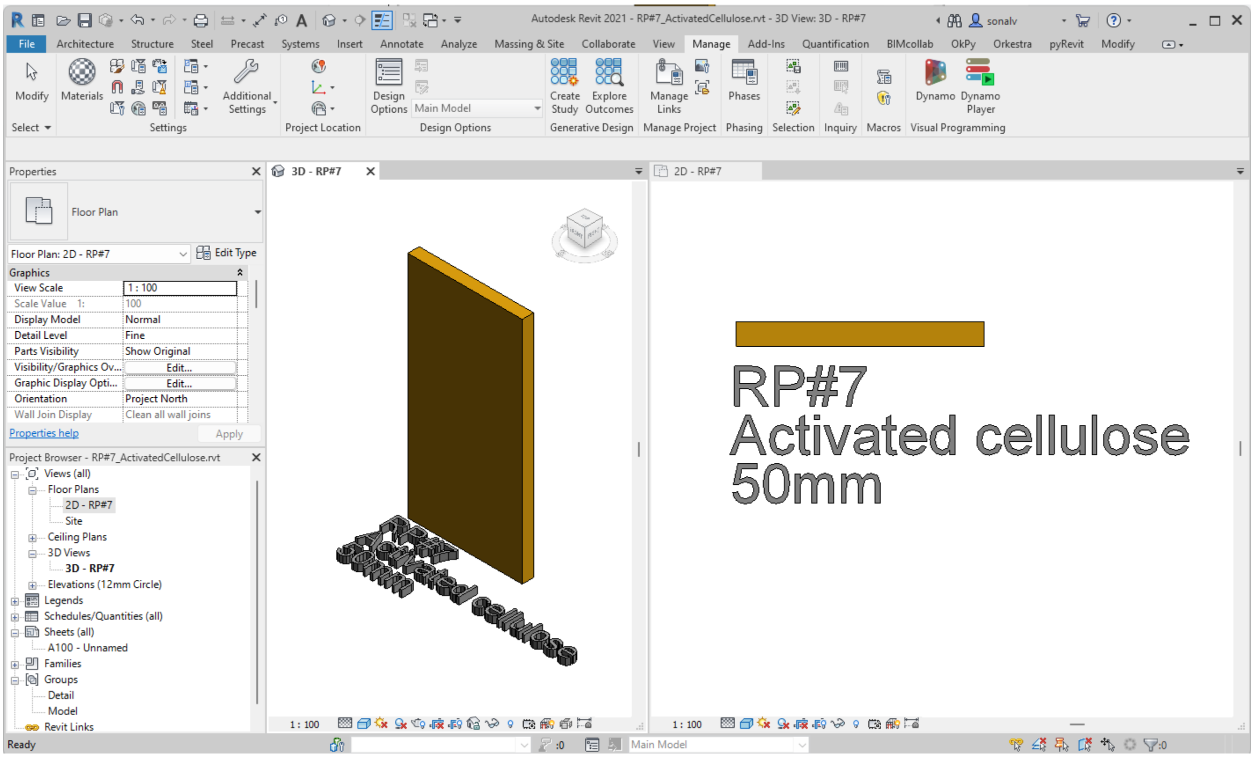
<u>Responsible Partner for BIM Models:</u> **CARTIF**

<u>Software used:</u> **Autodesk REVIT**

<u>File Format:</u> **rvt, rfa, ifc**

<u>Level of Development</u>: **200**

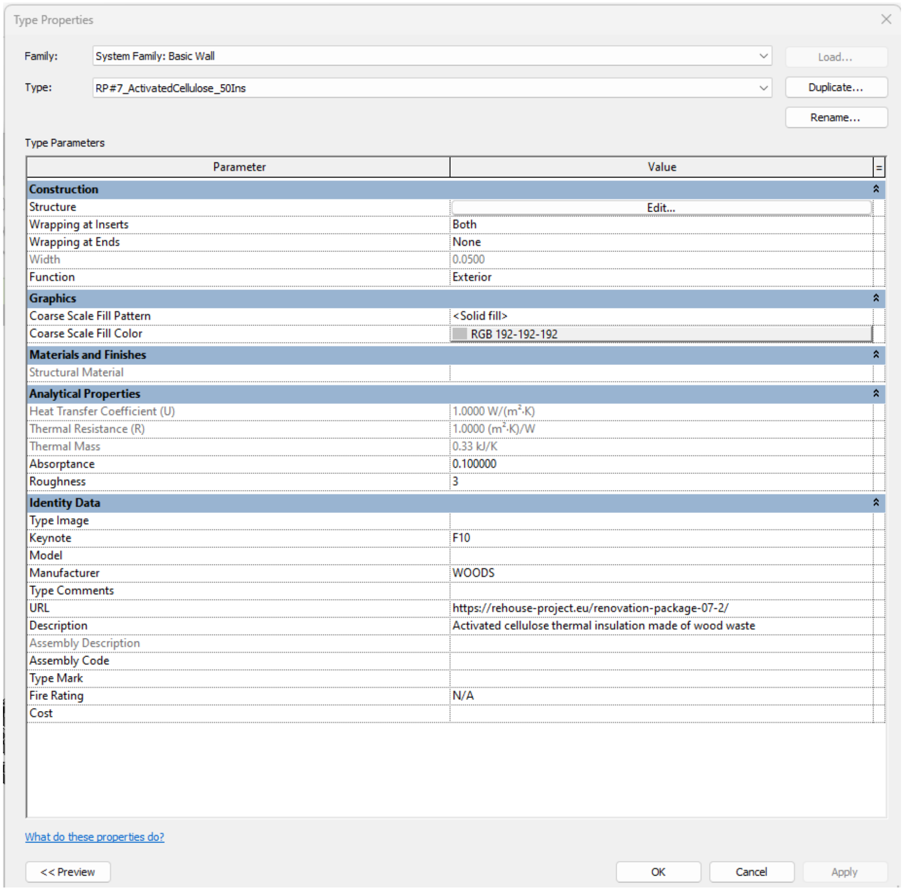
The BIM model created in REVIT software for RP7 is shown in Figure 47 and Figure 48.



Floor Plan: 2D - RP#7

View Scale	1 : 100
Scale Value 1:	100
Display Model	Normal
Detail Level	Fine
Parts Visibility	Show Original
Visibility/Graphics Ov...	Edit...
Graphic Display Opti...	Edit...
Orientation	Project North
Wall Join Display	Clean all wall joins

Figure 47: BIM model of the RP4- Heat Pump



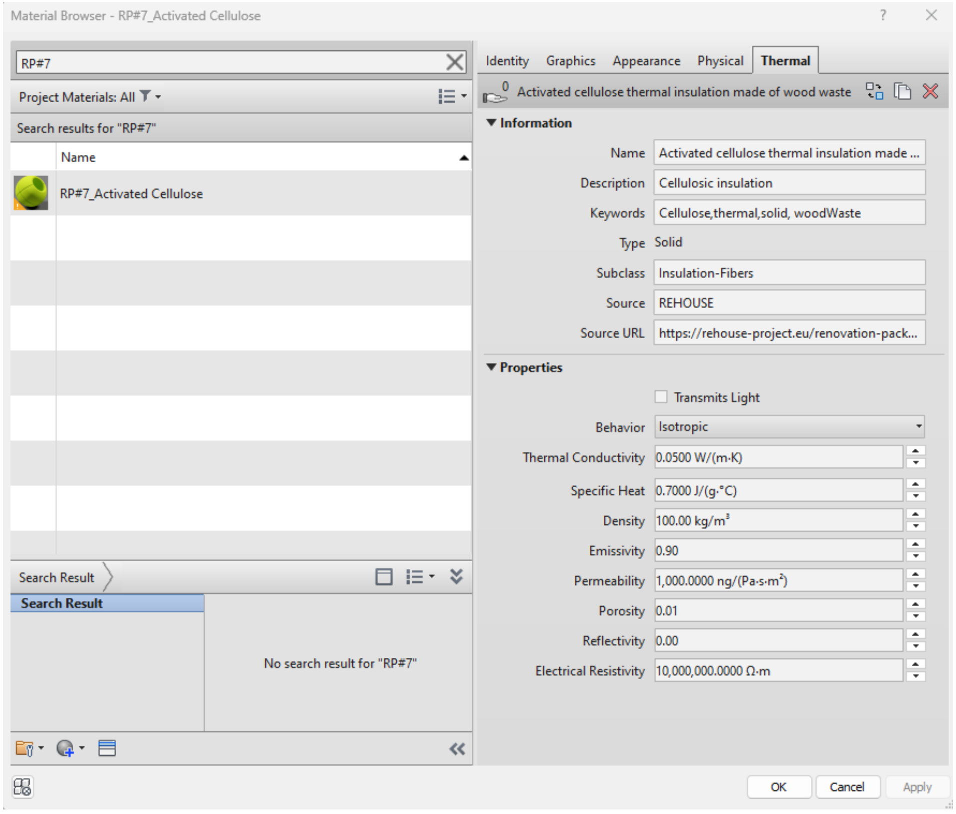
Family: System Family: Basic Wall

Type: RP#7_ActivatedCellulose_50Ins

Type Parameters

Parameter	Value
Construction	
Structure	Edit...
Wrapping at Inserts	Both
Wrapping at Ends	None
Width	0.0500
Function	Exterior
Graphics	
Coarse Scale Fill Pattern	<Solid fill>
Coarse Scale Fill Color	RGB 192-192-192
Materials and Finishes	
Structural Material	
Analytical Properties	
Heat Transfer Coefficient (U)	1.0000 W/(m²·K)
Thermal Resistance (R)	1.0000 (m²·K)/W
Thermal Mass	0.33 kJ/K
Absorptance	0.100000
Roughness	3
Identity Data	
Type Image	
Keynote	F10
Model	
Manufacturer	WOODS
Type Comments	
URL	https://rehouse-project.eu/renovation-package-07-2/
Description	Activated cellulose thermal insulation made of wood waste
Assembly Description	
Assembly Code	
Type Mark	
Fire Rating	N/A
Cost	

(a)



RP#7

RP#7_Activated Cellulose

Activated cellulose thermal insulation made of wood waste

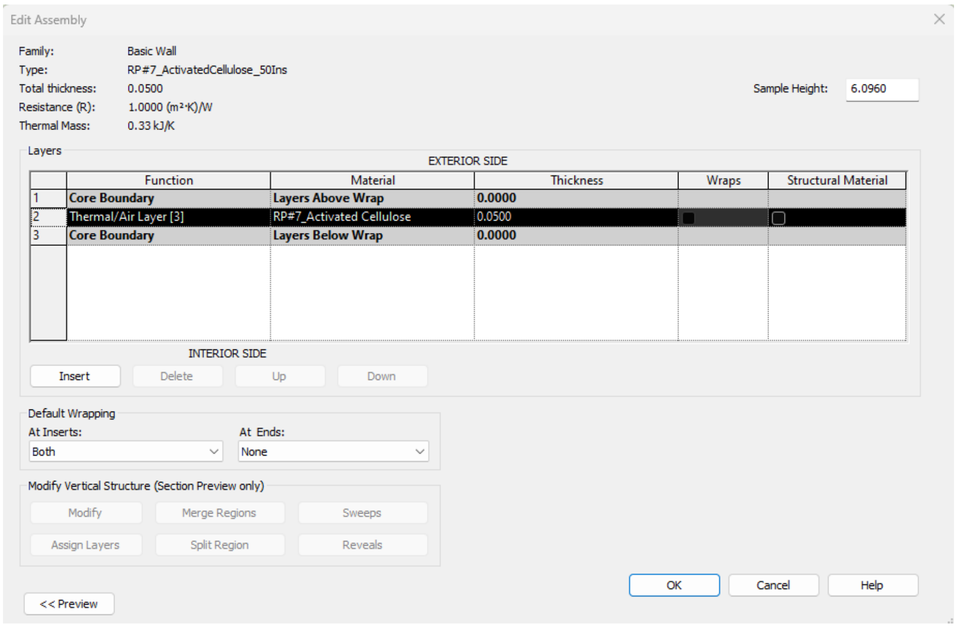
Information

Name: Activated cellulose thermal insulation made ...
Description: Cellulosic insulation
Keywords: Cellulose,thermal,solid, woodWaste
Type: Solid
Subclass: Insulation-Fibers
Source: REHOUSE
Source URL: https://rehouse-project.eu/renovation-pack...

Properties

☐ Transmits Light
Behavior: Isotropic
Thermal Conductivity: 0.0500 W/(m·K)
Specific Heat: 0.7000 J/(g·°C)
Density: 100.00 kg/m³
Emissivity: 0.90
Permeability: 1,000.0000 ng/(Pa·s·m²)
Porosity: 0.01
Reflectivity: 0.00
Electrical Resistivity: 10,000,000.0000 Ω·m

(b)



Edit Assembly

Family: Basic Wall
Type: RP#7_ActivatedCellulose_50Ins
Total thickness: 0.0500
Resistance (R): 1.0000 (m²·K)/W
Thermal Mass: 0.33 kJ/K
Sample Height: 6.0960

Layers

EXTERIOR SIDE

	Function	Material	Thickness	Wraps	Structural Material
1	**Core Boundary**	**Layers Above Wrap**	**0.0000**		
2	Thermal/Air Layer [3]	RP#7_Activated Cellulose	0.0500	■	☐
3	**Core Boundary**	**Layers Below Wrap**	**0.0000**		

INTERIOR SIDE

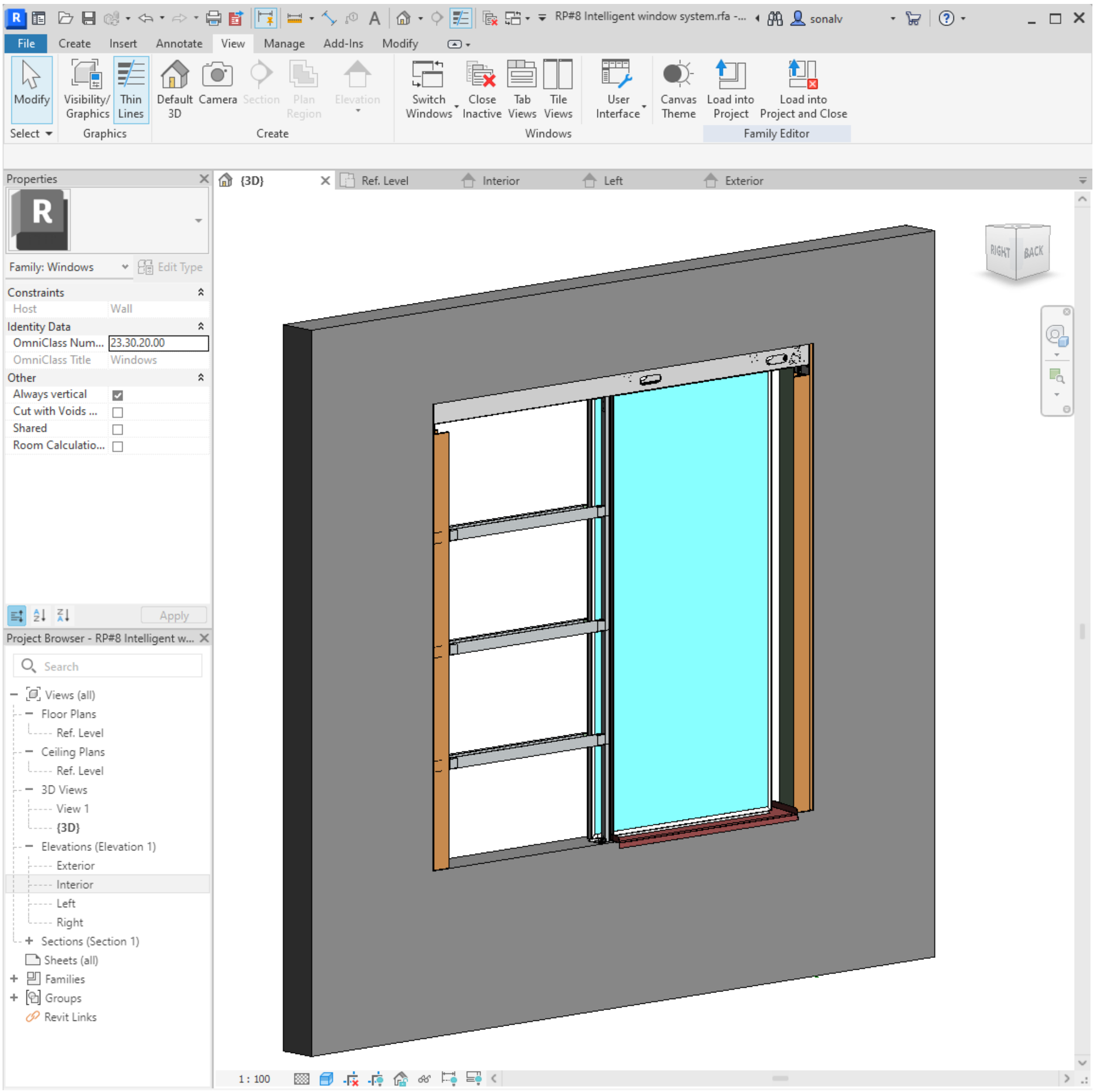
Default Wrapping
At Inserts: Both
At Ends: None

(c)

Figure 48: Properties of the RP7 BIM model

4.8 RP8: INTELLIGENT WINDOW SYSTEM

<u>Responsible Partner for BIM Models:</u> **CARTIF**
<u>Software used:</u> **Autodesk REVIT**
<u>File Format:</u> **rvt, rfa, ifc**
<u>Level of Development</u>: **200**
The BIM model created in REVIT software for RP8 is shown in Figure 49 and Figure 50.



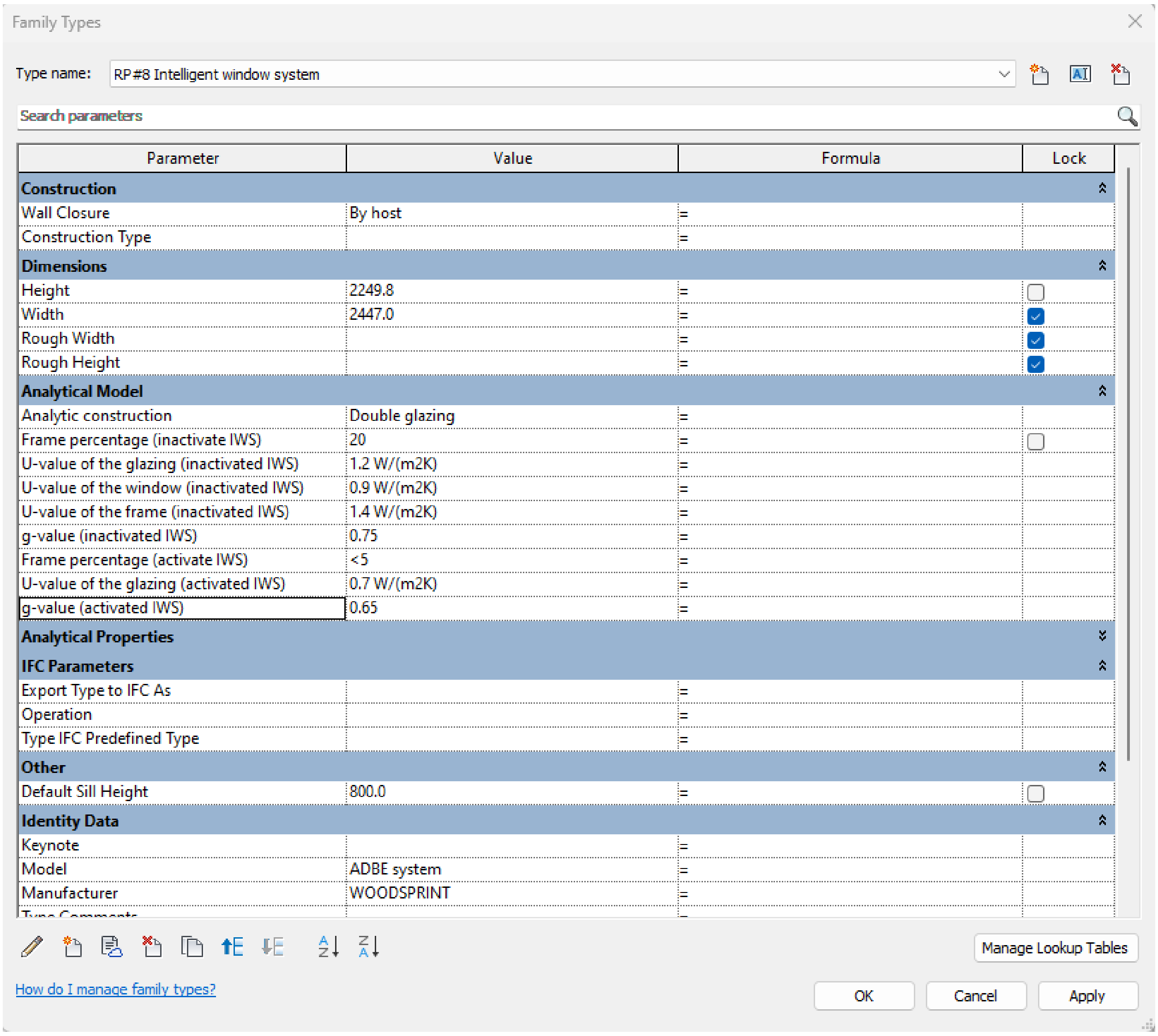
Family: Windows

Constraints
Host: Wall

Identity Data
OmniClass Num...: 23.30.20.00
OmniClass Title: Windows

Other
Always vertical ☑
Cut with Voids ... ☐
Shared ☐
Room Calculatio... ☐

Figure 49: BIM model of the RP8



Type name: RP#8 Intelligent window system

Parameter	Value	Formula	Lock
Construction			
Wall Closure	By host	=	
Construction Type		=	
Dimensions			
Height	2249.8	=	☐
Width	2447.0	=	☑
Rough Width		=	☑
Rough Height		=	☑
Analytical Model			
Analytic construction	Double glazing	=	
Frame percentage (inactivate IWS)	20	=	☐
U-value of the glazing (inactivated IWS)	1.2 W/(m2K)	=	
U-value of the window (inactivated IWS)	0.9 W/(m2K)	=	
U-value of the frame (inactivated IWS)	1.4 W/(m2K)	=	
g-value (inactivated IWS)	0.75	=	
Frame percentage (activate IWS)	<5	=	
U-value of the glazing (activated IWS)	0.7 W/(m2K)	=	
g-value (activated IWS)	0.65	=	
Analytical Properties			
IFC Parameters			
Export Type to IFC As		=	
Operation		=	
Type IFC Predefined Type		=	
Other			
Default Sill Height	800.0	=	☐
Identity Data			
Keynote		=	
Model	ADBE system	=	
Manufacturer	WOODSPRINT	=	

Figure 50: Properties of the RP8 BIM model

5 CONCLUSION

This report is created as outcome of the project activities in Task 2.3 “*Modelling, Control, and Improvement of Prefab/Off-site Construction of Renovation Packages”* of the REHOUSE project. The main aim of this task was the development of comprehensive BIM models of the 8 RPs which are integral to the project.

This report present as main result the Building Information Modelling (BIM) models of the 8 REHOUSE renovation packages. All the BIM models are currently accessible in the respective folders within the REHOUSE repository, and will be accessible to the general public once the REHOUSE repository of renovation packages is completed as part of the Task 2.6 “*Digital products (REHOUSE Repository of renovation packages”* of the project.

In addition, the document details the simulations conducted to bridge the gap between the as-designed and as-built models. It outlines the prefabrication and off-site construction strategies employed for certain components of various RPs, along with the control algorithms utilized for the active parts. Furthermore, the development of multiple models at the RP level is described. These models are integral in supporting and implementing the prefabrication and off-site construction methodologies. Noteworthy advancements were made through the implementation of control algorithms for the active elements of select RPs, contributing significantly to the refinement of their overall systems. Transitioning to the demo level, simulations emerged as a critical tool in bridging the divergence between as-designed and as-built models. This rigorous approach aimed to ensure that the final performance of renovated buildings closely aligns with the envisioned outcomes during the design phase.

This deliverable presented encapsulates pivotal components, such as the development of RP models with preliminary analyses, simulations and assessments of demo sites, and the BIM models for the RPs. It is imperative to acknowledge that while certain data assumptions were requisite for simulations in this deliverable, subsequent deliverables under WP4 “*Demonstration of the 8 renovation packages (TRL7)”* will leverage more accurate data. The summarized presentation of all the models and simulations (RP and demo level) in this document can benefit numerous other tasks of the REHOUSE project.

6 ANNEXES

6.1 DEVELOPMENT OF RPS MODELS AND PRELIMINARY ANALYSIS

6.1.1 ENERGY MODELS AND CONTROL ALGORITHMS/SYSTEMS CREATION - INTEMA.BUILDING

Each of the subsequent sub-chapters was independently developed as a separate report, resulting in unique numbering for equations and references within each chapter, as explicitly presented at the end of each individual report. However, it's noteworthy that the numbering of figures and tables follows the sequential order of the entire document.

6.1.1.1 RP1

Multi-Source Heat Pump

1. Description

The multi-source PSYC heat pump is a technological solution that integrated thermal energy storage, thermal panels, and HFO (HydroFluoro-Olefins) refrigerants. This heat pump configuration can achieve high performance adjusted for the temperature ranges of modern heating appliances in both new and renovated buildings.

The multi-source PSYC heat pump promotes the following innovations:

(i) The multi-source operation combines different natural heat sources such as ambient air, solar thermal energy, and geothermal energy.

(ii) The integration with local thermal energy storage systems

(iii) The advanced energy management and control system of the multi-source solution optimizes operation according to resource availability, smart exploitation of buffer capacities, and demand response schemes.

(iv) The use of HFO refrigerant ensures suitability for future applications compliant with the F-gas regulation constraints.

As far as the performance of the multi-source heat pump is concerned, the aim is to reach a nominal COP of 4.5 for heating at design conditions. A COP up to 6 for a low-temperature lift will be possible using R454C or a similar refrigerant with a very low GWP as a working medium. The heat pump at heating mode can be supplied with heat from either a geothermal source, ambient air, or solar source, with a very low temperature (below 25°C). Similarly, in cooling mode, the possible heat sinks are the ground, thermal storage tank, and ambient air. It can be scaled from a few kW (minimum of 6-8 kW of heat) up to a few hundred kW, with the latter capacity meeting the needs of very large buildings. Figure 51 and Figure 52 illustrate the examined heat pump prototype and possible integration layouts.

Co-funded by the European Union

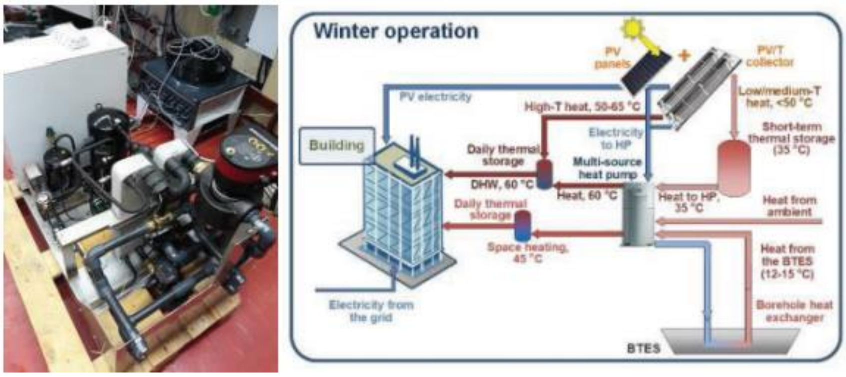


Figure 51. Multi-source heat pump prototype and possible integration layouts

(a) **(b)**

Figure 52. An illustration of the developed heat pump system

2. Technical data

The multi-source heat pump is connected to a solar thermal system, geothermal energy system, and ambient air. The source selection and the operation of the technology are adjusted by a smart control system to ensure the most efficient operation of the system. The heat pump is designed to have two heat exchangers on the heat sources' side. More precisely, the heat pump configuration is equipped with one water-cooled heat exchanger to receive water from the geothermal source and the solar thermal system, and one air-cooled heat exchanger to utilize the environmental air. As far as the cooling mode is concerned, the heat pump system is designed to use the geothermal field as a sink for the condenser. Figure 53a illustrates a simplified scheme of the system's configuration and the connections between the multi-source heat pump with the geothermal field, the solar thermal system, and the ambient air, whereas Figure 53b depicts the Modelica-developed model.

The main innovation of this system is its design to serve the simultaneous operation of the air and water-cooled heat exchangers (combined operation of the air-cooled and the water-cooled operation) when it can provide a better performance either for the heating or the cooling mode. This configuration demands a special refrigerant circuit and a specific control approach.

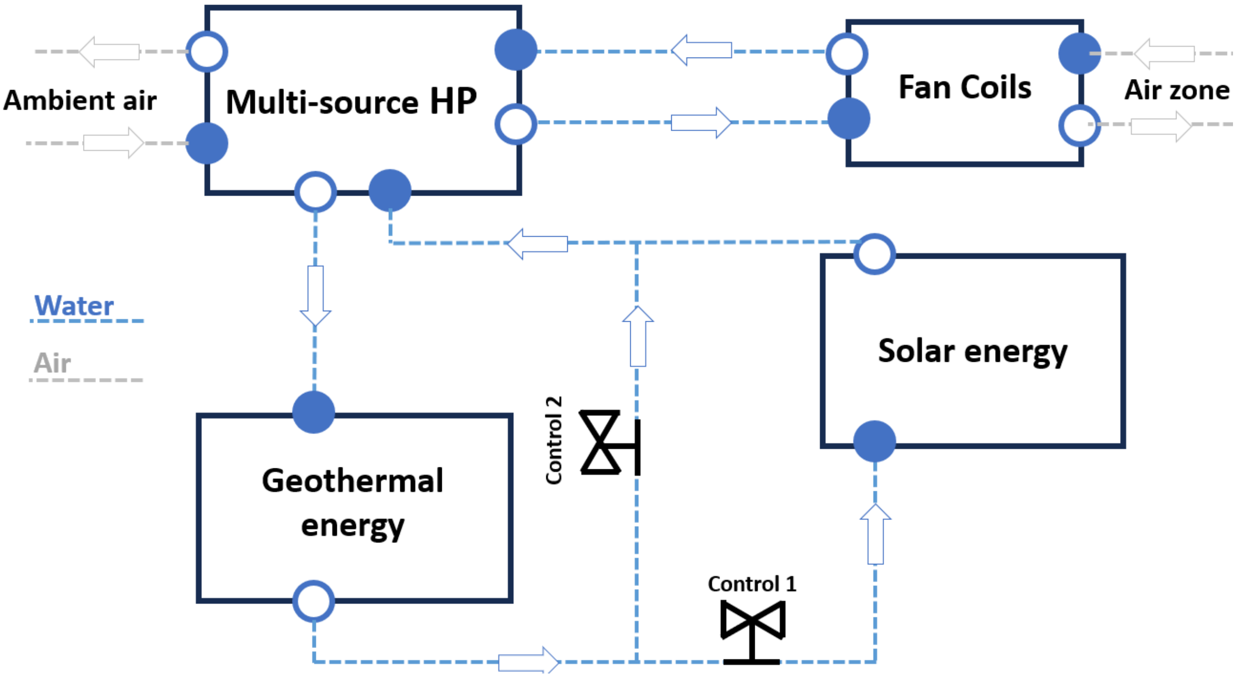
Table 10 includes basic data for the heat pump operation.

Table 10. Basic data of the suggested design

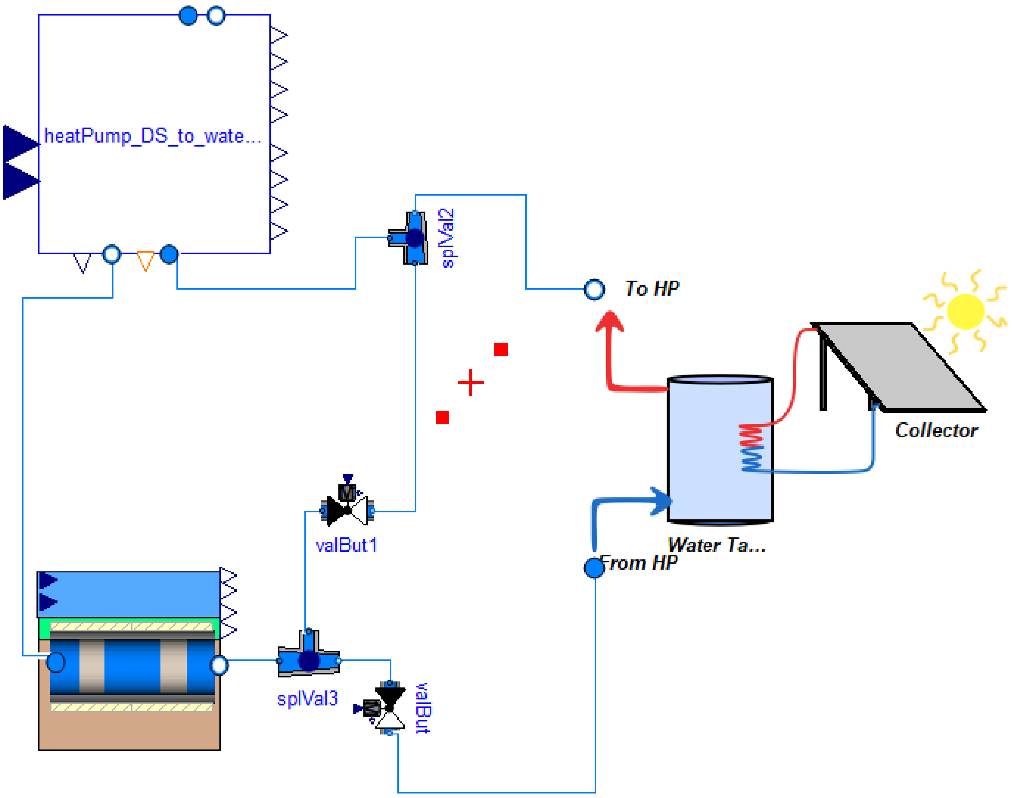
Parameter	Value
Heat Pump	
Nominal COP (heating)*	4.17
Nominal EER (cooling)**	3.17
Nominal heating capacity	130.54 kW
Nominal cooling capacity	99.2 kW
Refrigerant	R407C

** For ambient air 5°C and condensation at 45°C*

*** For cold water at 7°C and air-cooled condenser*



(a)



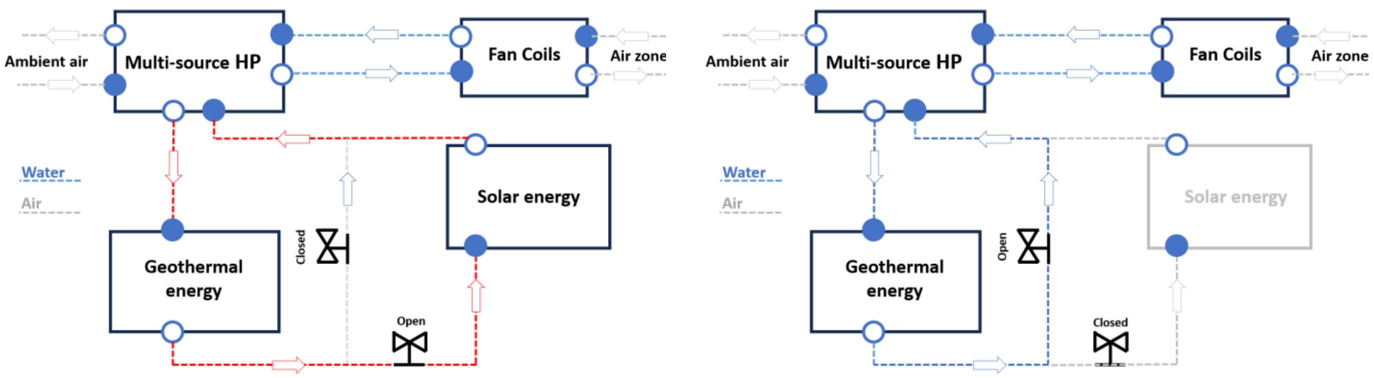
(b)

Figure 53. (a) Simplified scheme of multi-source heat pump combined with ambient air, geothermal and solar energy and fan coil system, and (b) Modelica developed model of the multi-source heat pump in connection with geothermal and solar energy and ambient air

3. Developed model

For the simulation of the multi-source heat pump, a detailed model is developed in Modelica language using the INTEMA.building tool. Figure 1a illustrates the configuration of the multi-source heat pump that is connected to a fan coil system that feeds the air zone with treated air. Figure 1b focuses on the model of the multi-source heat pump. The multi-source heat pump uses as sources the ambient air, geothermal energy (geothermal field), and/or solar energy (solar thermal collectors) through the water.

The developed multi-source heat pump has a reversible mode, serving a building's both heating and cooling needs. In the cooling mode, the multi-source heat pump is using both air and water as sources, according to an appropriate temperature criterion. In the case of water, after the heat pump's outlet, the water is driven through the geothermal field bypassing the solar thermal system in order to return to the heat pump's inlet (Figure 54a). On the other hand, in the heating mode, and in the case of the water source, after the geothermal field water is driven toward the solar thermal system of collectors in order to return back to the heat pump (Figure 54b). The water's flow into the geothermal field and the solar thermal system is controlled by two butterfly valves that remain open or closed according to the heat pump's mode.



(a) **(b)**

Figure 54. The water's flow in the geothermal field and solar thermal system according to the heat pump's mode, (a) heating mode, and (b) cooling mode

The heat pump can operate with both sources of water and air simultaneously. The selection of the source is based on the sources' temperatures and a developed criterion that defines the percentage of contribution for each source ($\text{Water}_{\text{Selection}}$ and $\text{Air}_{\text{Selection}}$). However, if the water temperature is below a determined value ($T_{\text{water, min}}$) then water is not selected as a source. For the selection of air, a mean temperature value ($T_{\text{air, mean}}$) is defined for the erf function. The erf function is an error function encountered in integrating the normal distribution (which is a normalized form of the Gaussian function). It is an entire function defined as:

$$\operatorname{erf}(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-t^2}\, dt \tag{1}$$

$$water_{flag} = \frac{erf\left(\frac{T_w - T_{water_{min}}}{0.1}\right) + 1}{2} \tag{2}$$

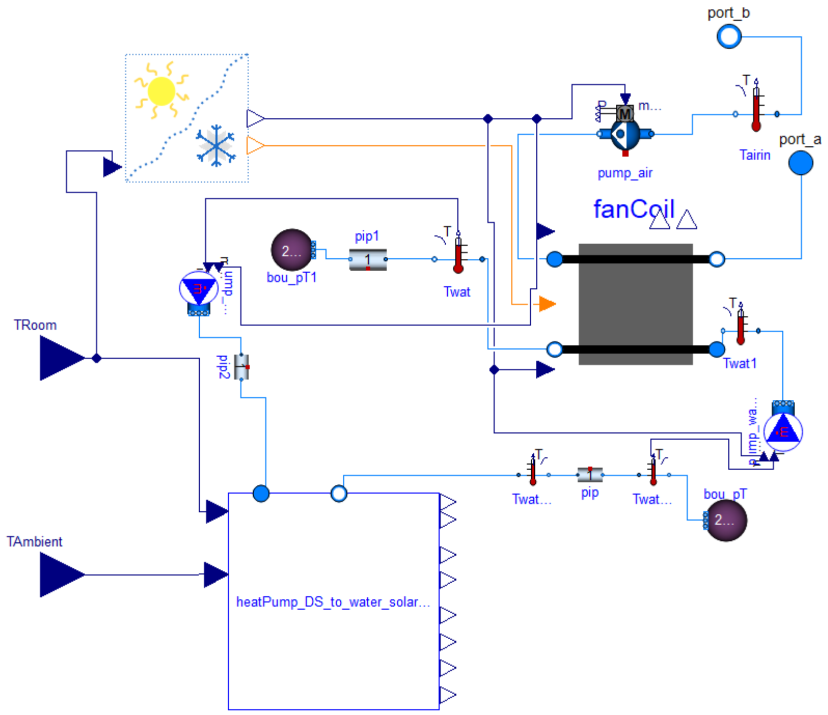
$$Water_{selection} = water_{flag} \cdot \frac{\left(1 - \operatorname{erf}\left(\frac{T_{air} - T_{air_{mean}}}{20}\right)\right) + 1}{2} \tag{3}$$

$$Air_{selection} = 1 - Water_{selection} \tag{4}$$

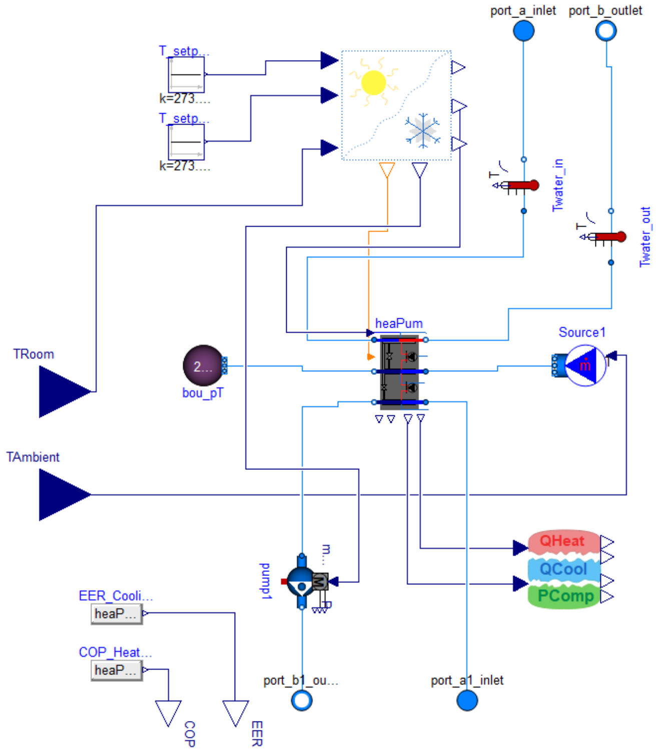
The temperature of the heat pumps' source is calculated as the aggregation of the water's (T_{water}) and air's (T_{air}) temperature multiplied by their contribution percentage:

$$T_{source} = T_{water} \cdot Water_{selection} + T_{air} \cdot Air_{selection} \tag{5}$$

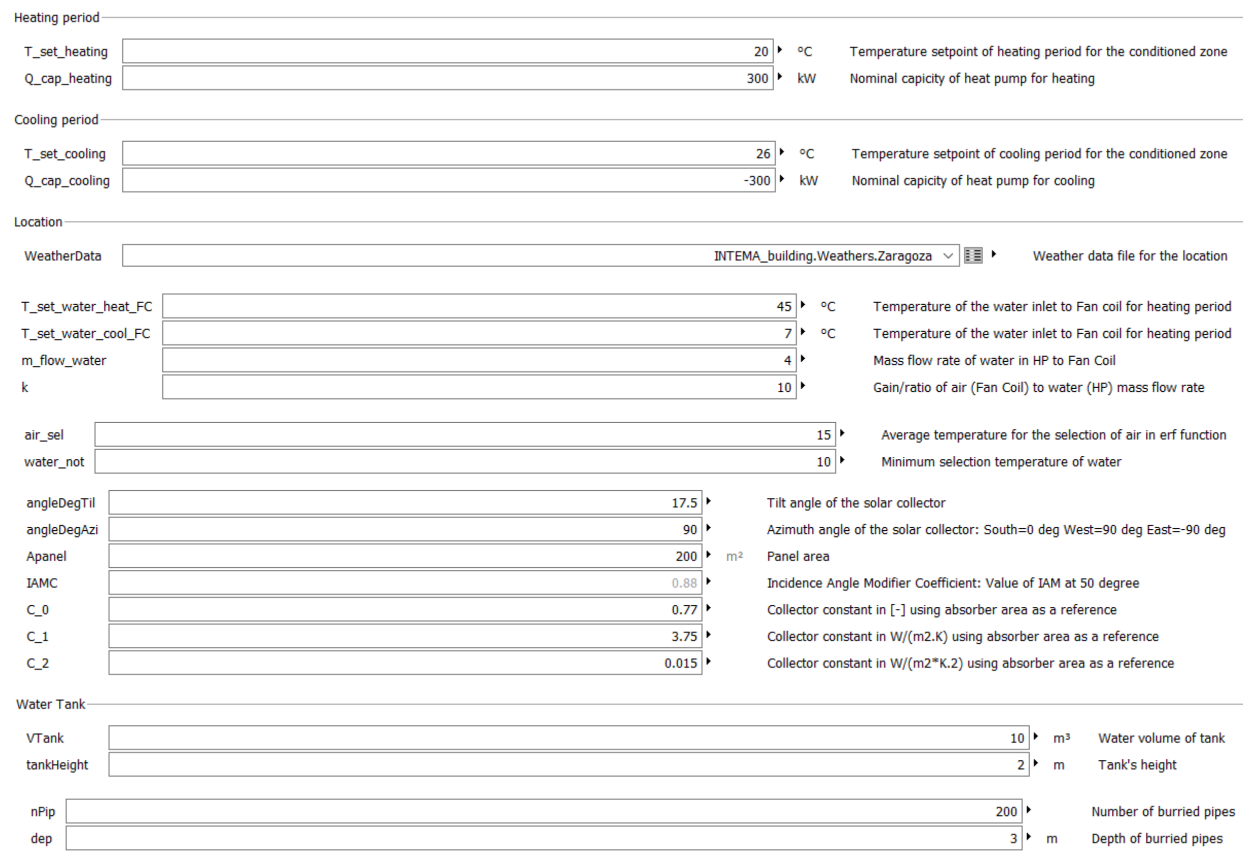
The required parameters for the simulation of the complete configuration of the multi-source heat pump in connection with the ambient air, the geothermal field, and the solar thermal system are depicted in Figure 1c. These parameters concern the heating (T_set_heating) and cooling (T_set_cooling) setpoint of the air-treated zone, the nominal capacity of the heat pump for the heating (Q_cap_heating) and cooling mode (Q_cap_cooling), the meteorological data of the building site, the water temperature in the heat-pump outlet/fan coil inlet for the heating mode (T_set_water_heat_FC) and the cooling mode (T_set_water_cool_FC), the water's and air's mass flow rate in the fan coil system (m_flow_water and k· m_flow_water), as well as the minimum water temperature for the selection of water (water_not) and the mean air temperature for the selection of air as source (air_sel). In addition, some more parameters that concern the geothermal field and solar thermal system are required. As far as the geothermal field is concerned, the number of pipes (nPip) and their depth (dep) are needed. For the solar thermal system, the required parameters are the collector area (Apanel), the azimuth (angleDegAzi) and tilted angle (angleDegTil), the incident angle modifier (IAMC), and the collector's coefficients (C_0, C_1, and C_2), and lastly, the system's tank's volume (VTank) and height (tankHeight).


port_b
m...
pump_air
T
Tairin
port_a
fanCoil
2...
bou_pT1
pip1
1
T
Twat
ump_...
TRoom
pip2
T
Twat1
pump_wa...
Twat...
pip
Twat...
bou_pT
2...
TAmbient
heatPump_DS_to_water_solar...

(a)


port_a_inlet
port_b_outlet
T_setp...
k=273....
T_setp...
k=273....
T
Twater_in
T
Twater_out
heaPum
Source1
TRoom
2...
bou_pT
TAmbient
QHeat
QCool
PComp
m...
pump1
EER_Cooli...
heaP...
COP_Heat...
heaP...
port_b1_ou...
port_a1_inlet
COP
EER

(b)



Heating period

T_set_heating	20	°C	Temperature setpoint of heating period for the conditioned zone
Q_cap_heating	300	kW	Nominal capicity of heat pump for heating

Cooling period

T_set_cooling	26	°C	Temperature setpoint of cooling period for the conditioned zone
Q_cap_cooling	-300	kW	Nominal capicity of heat pump for cooling

Location

WeatherData	INTEMA_building.Weathers.Zaragoza		Weather data file for the location
T_set_water_heat_FC	45	°C	Temperature of the water inlet to Fan coil for heating period
T_set_water_cool_FC	7	°C	Temperature of the water inlet to Fan coil for heating period
m_flow_water	4		Mass flow rate of water in HP to Fan Coil
k	10		Gain/ratio of air (Fan Coil) to water (HP) mass flow rate
air_sel	15		Average temperature for the selection of air in erf function
water_not	10		Minimum selection temperature of water
angleDegTil	17.5		Tilt angle of the solar collector
angleDegAzi	90		Azimuth angle of the solar collector: South=0 deg West=90 deg East=-90 deg
Apanel	200	m²	Panel area
IAMC	0.88		Incidence Angle Modifier Coefficient: Value of IAM at 50 degree
C_0	0.77		Collector constant in [-] using absorber area as a reference
C_1	3.75		Collector constant in W/(m2.K) using absorber area as a reference
C_2	0.015		Collector constant in W/(m2*K.2) using absorber area as a reference

Water Tank

VTank	10	m³	Water volume of tank
tankHeight	2	m	Tank's height
nPip	200		Number of burried pipes
dep	3	m	Depth of burried pipes

(c)

Figure 55. The developed model in Modelica, (a) Model of the multi-source heat pump in connection with the fan coil system, (b) Model of the multi-source heat pump, and (c) The required parameters for the simulation of the entire configuration

4. Basic mathematical formulation part

The thermodynamic cycle of the heat pump in heating and cooling mode is depicted in Figure 56 in a simplified way. Below, the main equations that are needed for the simulation of the cycle are given.

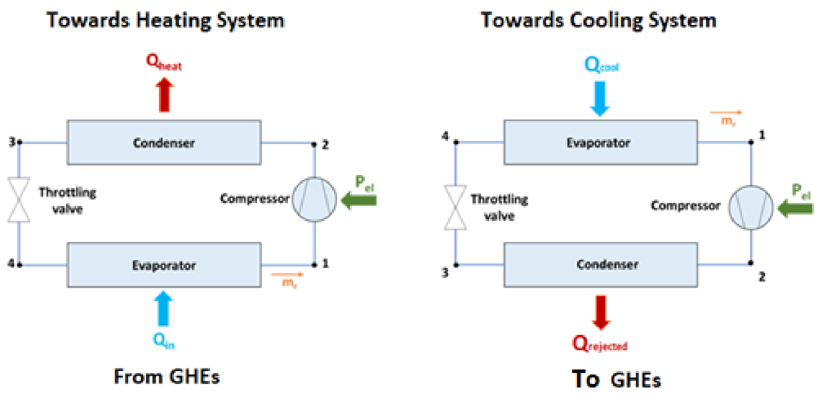


Figure 56. Simplified depiction of the heat pump thermodynamic cycle

The heat input in the system (Q_{in}) is given as:

$$Q_{evaporator} = m_r \cdot (h_1 - h_3) \tag{6}$$

The electricity demand in the compressor (P_{el}) is given as:

$$P_{el} = m_r \cdot (h_2 - h_1) \quad (7)$$

The heat production to the building (Q_{heat}) is given as:

$$Q_{heat} = Q_{evaporator} + P_{el} = m_r \cdot (h_2 - h_3) \quad (8)$$

The global isentropic efficiency of the compressor (η_{is}) is defined as:

$$\eta_{is} = \frac{h_{2,is} - h_1}{h_2 - h_1} \quad (9)$$

The point "2is" has the same entropy as the state point 1 and also it has the high pressure of the cycle.

The compressor's isentropic efficiency can be provided by the manufacturer and therefore handled by the digital twin model as a constant efficiency factor, or it can be approximated by a usual (indicative) formula as a function of the pressure ratio ($\pi_c = P_{high}/P_{low}$).

$$\eta_{is} = 0.874 - 0.0135 \cdot \pi_c \quad (10)$$

The expansion in the throttling valve is assumed to be ideal, therefore:

$$h_4 = h_3 \quad (11)$$

Moreover, the examined cycle has no superheating in the evaporator outlet and no subcooling in the condenser outlet. The proper coupling of the evaporator with the input heat sources is conducted by applying a temperature difference between the fluids at around 5 K which is a reasonable assumption[1].

The reverse cycle in which heat is absorbed from the air-conditioned space through the fan-coil heat exchanger connected to the HP's evaporator and ejected to the borehole sink through the HP's condenser configuration corresponds to cooling mode. In this case, the cool input in the system ($Q_{evaporator}$) is given as:

$$Q_{cool} = Q_{condenser} - P_{el} = m_r \cdot (h_1 - h_4) \quad (12)$$

The Coefficient of Performance (COP) and Energy Efficiency Ratio (EER) are measures of a heat pump heating and cooling efficiency. They indicate a ratio of useful heating or cooling produced by the unit against the energy it consumes. Therefore, they are calculated as:

$$COP = \frac{Q_{heat}}{P_{el}} \quad (13)$$

$$EER = \frac{Q_{cool}}{P_{el}} \quad (14)$$

The performance coefficient (COP and EER) of the heat pump is considered to be constant.

As far as the fan coil modeling is concerned, the energy balance in the water stream (subscript

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[1] E. Bellos et al., 'Multicriteria Analysis of a Solar-Assisted Space Heating Unit with a High-Temperature Heat Pump for the Greek Climate Conditions', Applied Sciences, vol. 13, no. 6, Art. no. 6, Jan. 2023, doi: 10.3390/app13064066.

“w” symbolizes water stream) is described by:

$Q_{heat}=m_w \cdot c_{p,w} \cdot (T_{w,in}-T_{w, out})$, (15)

while the corresponding energy balance in the air stream (subscript “a” symbolizes air stream) is given by:

$Q_{heat}=m_a \cdot c_{p, a} \cdot (T_{a,out}-T_{a, in})$, (16)

The heat transfer between the two streams is modelled by using the logarithmic mean temperature difference (ΔTlm) as below[2]:

$Q_{heat}=(UA)_{FC} \cdot \Delta T_{lm}$, (17)

The total heat transfer coefficient $(UA)_{FC}$ in [W/K] is the product of the thermal transmittance (U) in [W/m^{2}K] and of the heat exchanging area (A) in [m^2]. This is a characteristic parameter of the fan coil unit.

The logarithmic mean temperature difference (ΔTlm) is defined below:

$$\Delta T_{lm} = \frac{(T_{w,in}-T_{a,out})-(T_{w,out}-T_{a,in})}{\ln\left[\frac{T_{w,in}-T_{a,out}}{T_{w,out}-T_{a,in}}\right]}$$

(18)

5. Simulation results

In this section, a multi-story building is modelled and simulated for the climatic conditions of Zaragoza and on a yearly basis, as depicted in Figure 57. The building is equipped with a multi-source heat pump that is fed with ambient air and water from a geothermal field and a solar thermal system. Figure 58 depicts the indoor temperature fluctuation of the examined building.

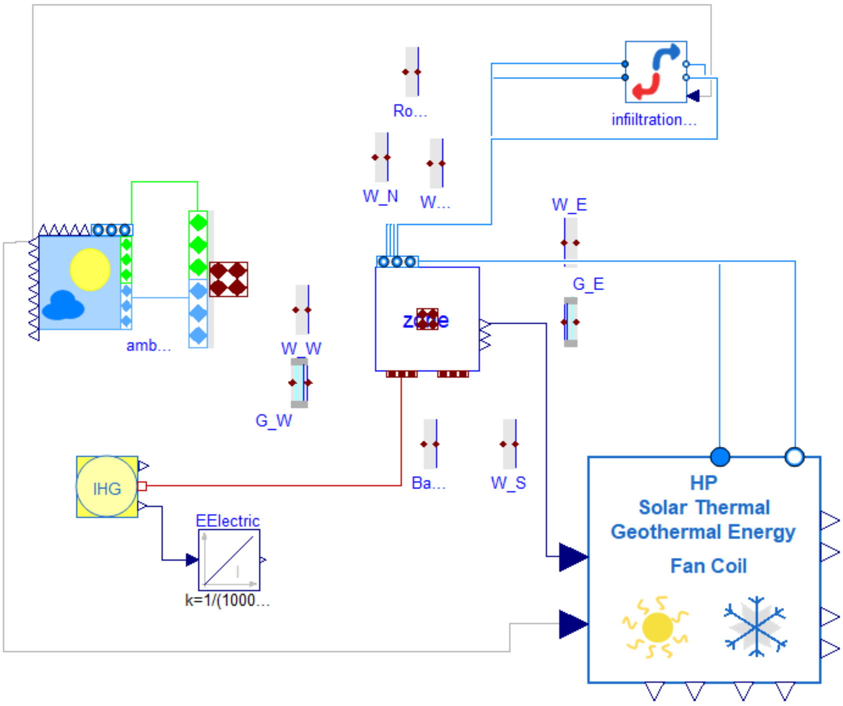

Figure 57. Configuration of the simplified building equipped with the multi-source heat pump technology

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[2] B. Bueno, M. Street, T. Pflug, and C. Braesch, ‘A co-simulation modelling approach for the assessment of a ventilated double-skin complex fenestration system coupled with a compact fan-coil unit’, Energy and Buildings, vol. 151, pp. 18–27, Sep. 2017, doi: 10.1016/j.enbuild.2017.04.029.

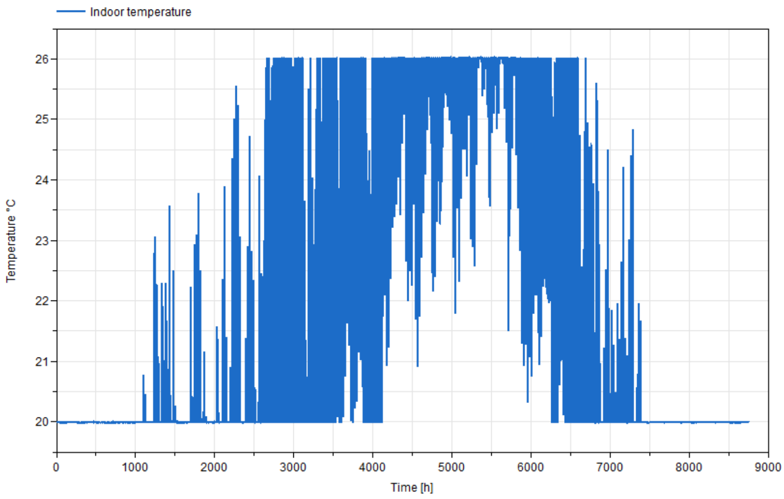
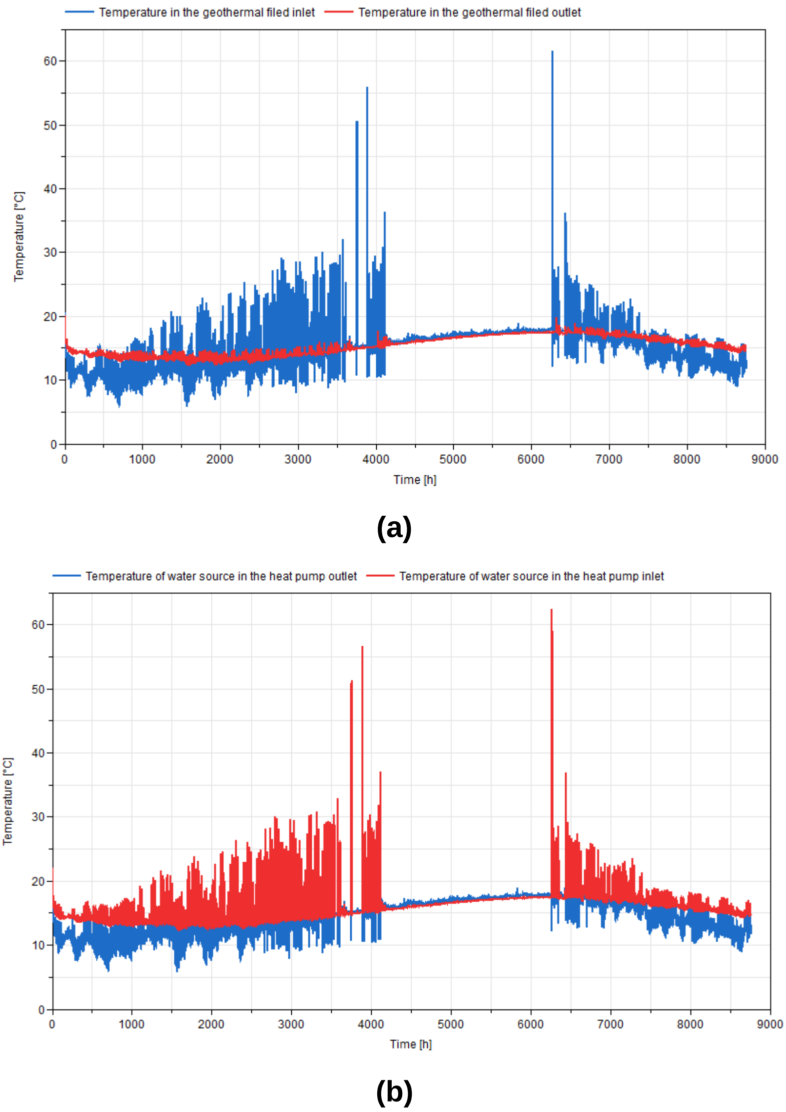
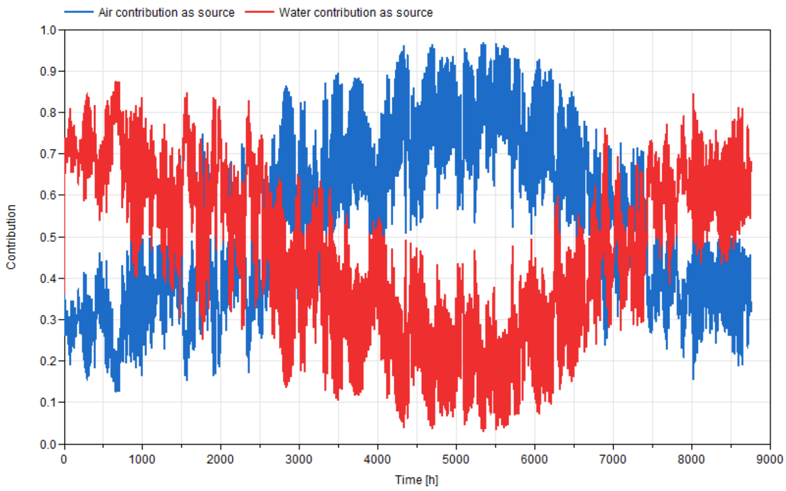


Figure 58. Indoor temperature of the examined building



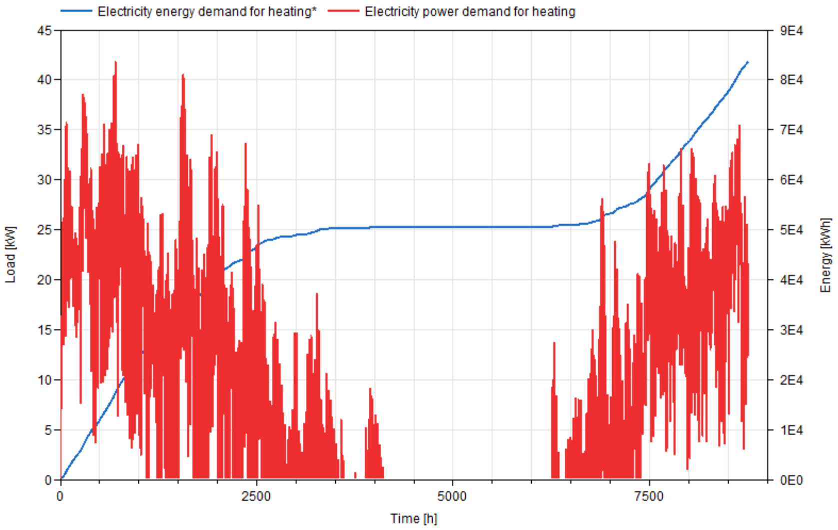


(c)

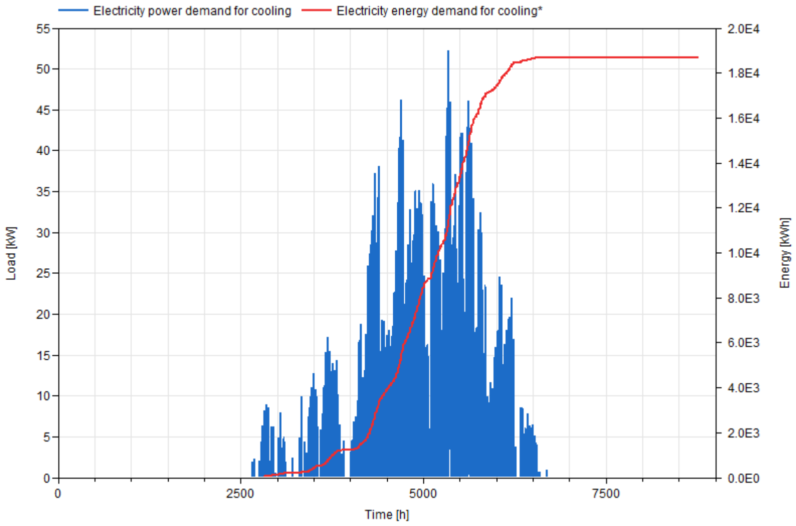
Figure 59. (a) Temperature of water source in the geothermal field inlet and outlet, (b) Temperature of the water source in the heat pump inlet and outlet, and (c) The contribution of water and air as a source to the multi-source heat pump.

Figure 59a depicts the temperature of the heat pump's water source in the geothermal field inlet and outlet. The water is driven through the geothermal field throughout the entire year with a variable mass flow rate, according to the thermal needs of the examined building. Figure 59b depicts the temperature of the water source in the heat pump inlet and outlet, whereas Figure 59c shows the contribution factor of the water and air source in the heat pump's operation.

Figure 60a depicts the electricity power and energy demand for heating for the examined building configuration. The yearly cumulative electricity demand for heating is calculated at 83,649 kWh. Figure 60b depicts the electricity power and energy demand for cooling for the examined building configuration. The yearly cumulative electricity demand for cooling is calculated at 18,691 kWh.



(a)



(b)

Figure 60. Electricity loads and cumulative energy demand of the examined building, (a) Electricity power and energy demand for heating, (b) Electricity power and energy demand for cooling

6.1.1.2 RP2

Adaptable/dynamic building envelope (ADBE)

1. Description

The Adaptable Building Envelope (ADBE) is a technology that generally combines insulation, HVAC units, battery, and photovoltaics. It enables adaptability to various geometry topologies thanks to its modular nature and high level of prefabrication and customization. It is based on a modular prefabricated structure made of recyclable materials (aluminium), contributing to the reduction of the building's carbon footprint and to the acceleration of the renovation time. All of the ADBE components are manufactured in the factory and delivered by truck to the installation site, where the installation crews installed them with the help of cranes. The installation procedure does not require expensive scaffolding or special training from the technicians.

The ADBE technology contributes to the improvement of a building’s sustainability due to its careful design, which is capable of allocating BIPV panels and battery storage for increased onsite RES production, HVAC ducts, and other technical facilities, as well as environment-friendly insulation materials. Figure 61 illustrates the unit-based ADBE façade elements that can be combined in order to create a holistic envelope product. Moreover, the controllability and smart energy operation of the building is also promoted through the embedment of the necessary sensors and actuators that allow users/owners to control the façade behaviour for energy minimization and better quality of the indoor environment. Finally, the outer skin of the façade elements consists of weather-resistant panels, and the whole solution is proofed against major disruptive phenomena (e.g.: weather, fire, earthquake events, etc.).

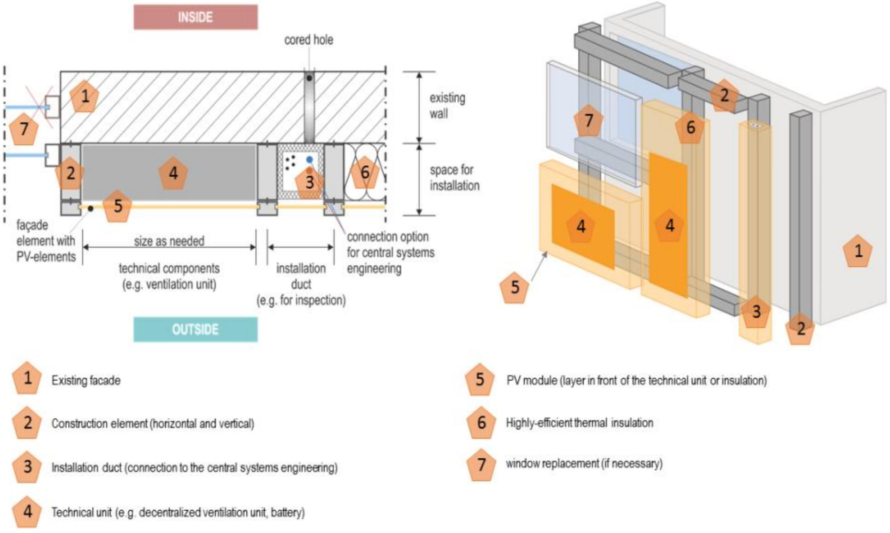
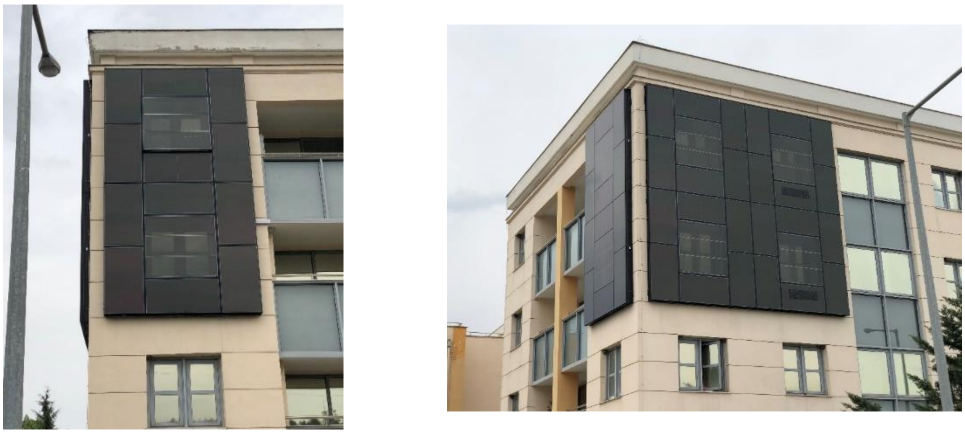


Figure 61. ADBE components and technical drawing (Legend: 1.- Existing façade 2.- Construction element 3.- Installation duct 4.- Technical unit (HVAC, battery) 5.- PV module 6.- High-efficient insulation 7.- Window replacement)

The ADBE prototype forms a structural ecosystem where an aluminium-glass façade design, based on modern construction standards and flexible specifications, enables its installation to almost any building's architectural design, both in residential and non-residential buildings, offering multiple additional functionalities to the existing building envelope. Figure 62 depicts a building on which the ADBE technology is installed. Because of the curtain wall, the construction is done outside of the existing building, which enables a refurbishment to be conducted without disrupting the operation of the building, eliminating the possibility of technical incidents. The aluminium-based profile ensures construction 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 according to the building's orientation, structural design, and illumination needs. Figure 63 shows the PV glass technology by Onyx Solar that is integrated into the ADBE façade technology.

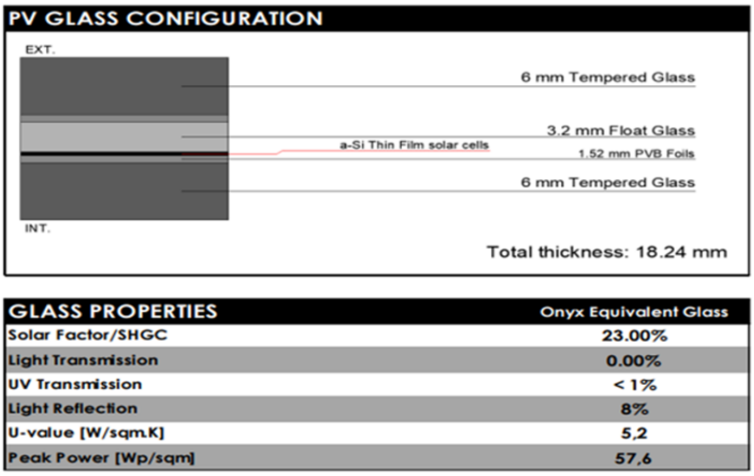
The main advantages of the proposed multi-functional façade solution are:

1) Modular design with fully prefabricated units in various sizes: enabling fully customized fabrication, according to each building's façade topology,
2) Easy to install: no need for extensive and expensive renovation actions,
3) Integration of multiple off-the-self solutions: including modern (e.g., bio-based) insulation materials, PV solar panels, electric batteries, HVAC units, etc.,
4) Integration of monitoring and actuation sensors to enable the full control and monitoring of the installed equipment.



(a) (b)

Figure 62. Real images of the examined technology



GLASS PROPERTIES	Onyx Equivalent Glass
Solar Factor/SHGC	23.00%
Light Transmission	0.00%
UV Transmission	< 1%
Light Reflection	8%
U-value [W/sqm.K]	5,2
Peak Power [Wp/sqm]	57,6

Figure 63. The PV glass technology by Onyx Solar

2. Technical data

The ADBE system can be used for residential and non-residential buildings. In contrast to existing concepts, an entire module is not prefabricated in the factory, but the individual elements are produced according to measurements and requirements (support structure, insulation, decentralized ventilation units) and attached to the existing façade at the building site. The ADBE layer prototype forms a structural ecosystem where an aluminium-glass façade design - based on modern construction standards and flexible specifications enabling its installation to almost any building's architectural design – extends the existing building cell (envelope). The ADBE exploits an aluminium-based profile ensuring construction inexpensiveness, stability, solidity and lightness as well as mounting flexibility. Table 11 summarizes the main information of this design.

Table 11. Technical data of the ADBE technology

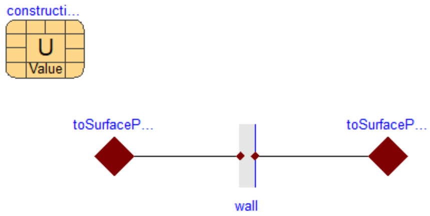
Parameter	Value
PV technology (Onyx Solar)	
Nominal total capacity [kW_p]	4.7
Dimensions [m x m]	1.6 x 1.6
Reference electrical efficiency [%]	5.76

Parameter	Value
Maximum Production Capacity [W_p/m^2]	57.6
Open Circuit Voltage [V]	125
Short Circuit Current [A]	1.93
Voltage at nominal power – V_{mpp} [V]	86
Current at nominal power – I_{mpp} [A]	1.72
Nominal Power [W]	147
Inverter efficiency [%]	94
Power temperature coefficient [%/°C]	-0.19
Voltage temperature coefficient [%/°C]	-0.28
Current temperature coefficient [%/°C]	0.09
U-value [W/m^2K]	5.2
Thickness [mm]	18.24
Material thermal properties	
Thermal transmittance of the glass [W/m^2K]	5.2
Thickness [mm]	6.0+3.2+6.0
Wall U-value after the renovation with insulation [W/m^2K]	0.22 (before 0.45)
U-value [W/m^2K] of ADBE façade with insulation	0.431

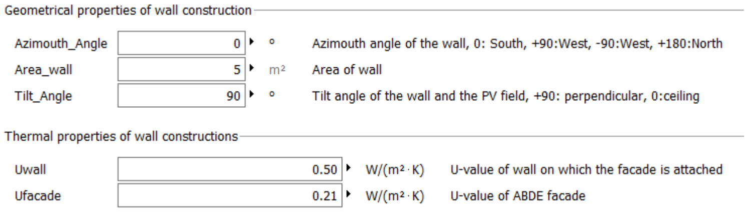
3. Developed model

Four types of façade systems with integrated PV panels structures were developed in Modelica language and tested using the INTEMA building tool: (a) an opaque building element on which the ADBE façade with the building-integrated PV panel is attached (b) an opaque building element on which the ADBE façade with the insulation element and the building-integrated PV panel is attached, (c) an opaque building element on which the ADBE façade with the insulation element and the building-integrated PV panel as well as a window element are attached, and (d) a wall and window construction on which the ADBE façade with the insulation element and the PV panel are integrated.

The simplest model of the ADBE façade is the one that simulates a typical wall construction on which a PV element is integrated. This consists the technological solution that will be utilized in the Greek Demo Site in Kimmeria. If the model of the ADBE façade includes an insulation element then ADBE façade element is also includes an extra thermal layer. Figure 64a illustrates the developed model of the ADBE façade with the insulation element, whereas Figure 64b shows the necessary parameters for the simulation of the model. The ADBE façade with the insulation element is described by the basic geometrical characteristics of the wall construction on which it is applied, namely, the azimuth [Azimuth_Angle] and tilted angle [Tilted_Angle] and the area of the wall [Area_wall]. In addition, the insulation façade model is characterized by two U-values: i) the U-value of the façade itself [Ufaçade], and ii) the U-value of the wall construction on which the insulation façade is attached to [U_wall].



(a)



Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimouth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	5	m²	Area of wall
Tilt_Angle	90	°	Tilt angle of the wall and the PV field, +90: perpendicular, 0:ceiling

Thermal properties of wall constructions

Uwall	0.50	W/(m²·K)	U-value of wall on which the facade is attached
Ufacade	0.21	W/(m²·K)	U-value of ABDE facade

(b)

Figure 64. The ADBE façade with the insulation element, (a) Developed model in Modelica, and (b) Parameters required for the simulation of the insulation technology

Figure 65a depicts the developed model of the ADBE façade with the insulation element and the building-integrated PV panel, whereas Figure 65b shows the developed model of the ADBE façade element of the window element with a building-integrated PV panel. The type of connection between the PV panel (pvmodule) and the external wall (wall) or window (window) determines the thermal equations and the operation of the system. Figure 65c shows the model of the building integrated PV panel (pvmodule) which is an MPP (maximum power point) controlled one-diode model of a PV module. This model calculates the solar cell's operating system (Tcell), the power, the voltage and the current of the PV field. A building-integrated PV panel is attached to the building's external wall or window and is in full contact with the building's thermal envelope. Therefore, the PV panel module and the external wall or window are thermally connected. More precisely, the building-integrated PV panel is in contact with the ambient and the external wall or window is in contact with the back side of the PV panel. In order to calculate the PV panel's operating temperature (Tcell), and therefore the boundary condition of the external wall (Tsur1= Tcell), a linear expression (Equation 1) was used [3].

$$\mathrm{T_{cell}} = \mathrm{T_{amb}} + \mathrm{f} \cdot \mathrm{I_{tot}} \qquad (1)$$

where Tamb is the ambient temperature and Itot is the total solar incident radiation flux on the PV module. The f parameter, known as the Ross coefficient, is a dimensional empirical temperature factor and its value is depended on the kind of the building integrated PV and on the way that it is connected to the wall. More specifically, in the case of the PV modules in touch with the wall, the f parameter is equal to 0.0538 Km2/W.

Figure 66 shows the thermal model of the PV generator that is used for the calculation of the Tcell and the thermal communication (through the heatPortOut connector) with the external wall in which the PV panel is integrated.

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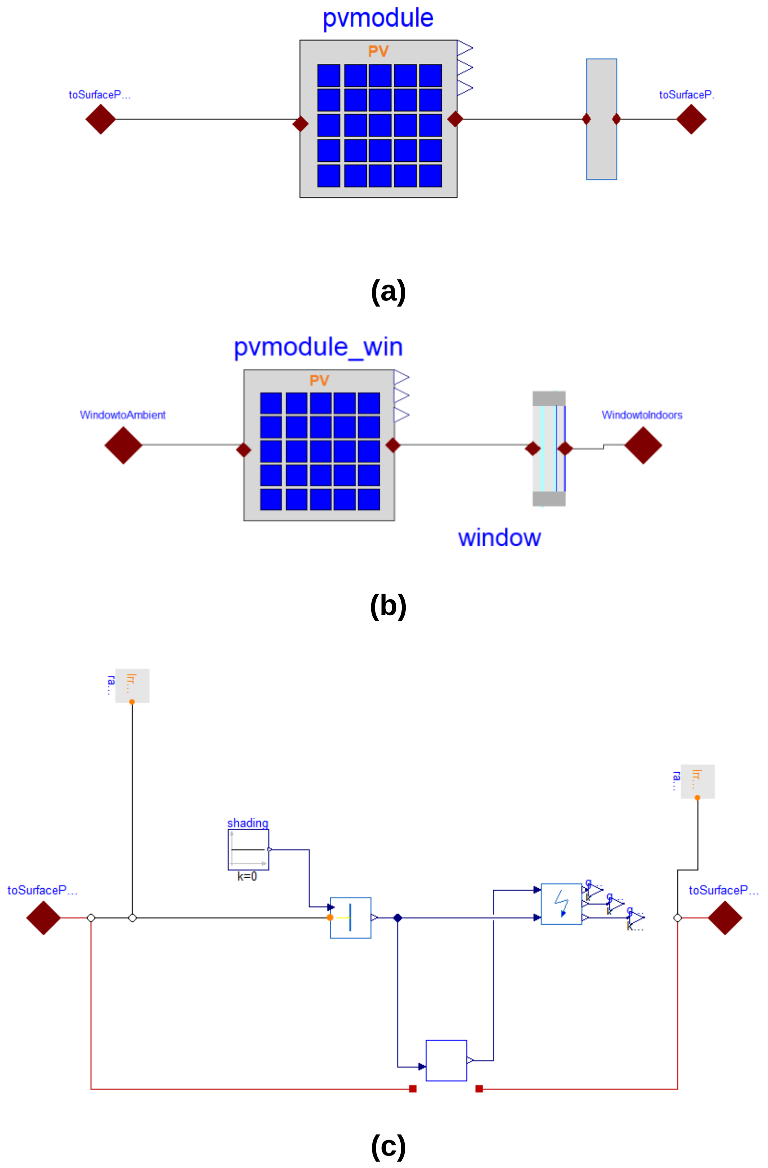
[3] E. Skoplaki and J. A. Palyvos, 'Operating temperature of photovoltaic modules: A survey of pertinent correlations', Renewable Energy, vol. 34, no. 1, pp. 23–29, 2009, doi: https://doi.org/10.1016/j.renene.2008.04.009.

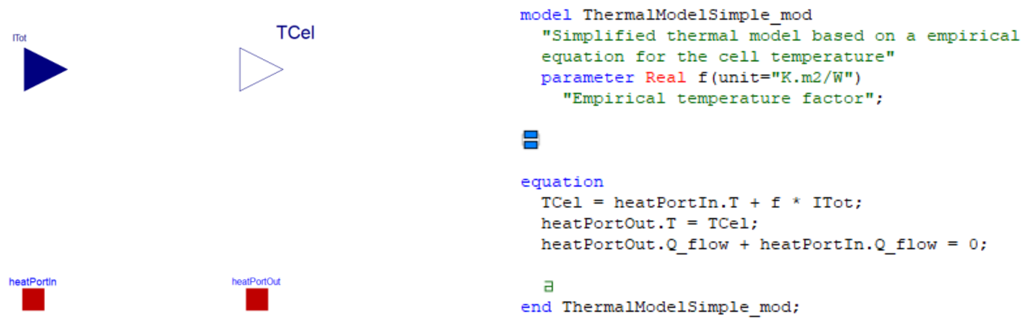


(a)

(b)

(c)

Figure 65. (a) Model of the ADBE façade with the insulation element and the building-integrated PV panel, (b) Model of the ADBE façade element of the window element with a building-integrated PV panel, and (c) Model of PV modules



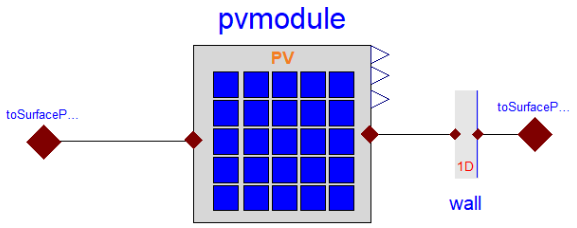
```
model ThermalModelSimple_mod
  "Simplified thermal model based on a empirical
  equation for the cell temperature"
  parameter Real f(unit="K.m2/W")
    "Empirical temperature factor";

equation
  TCel = heatPortIn.T + f * ITot;
  heatPortOut.T = TCel;
  heatPortOut.Q_flow + heatPortIn.Q_flow = 0;

end ThermalModelSimple_mod;
```

(a) (b)

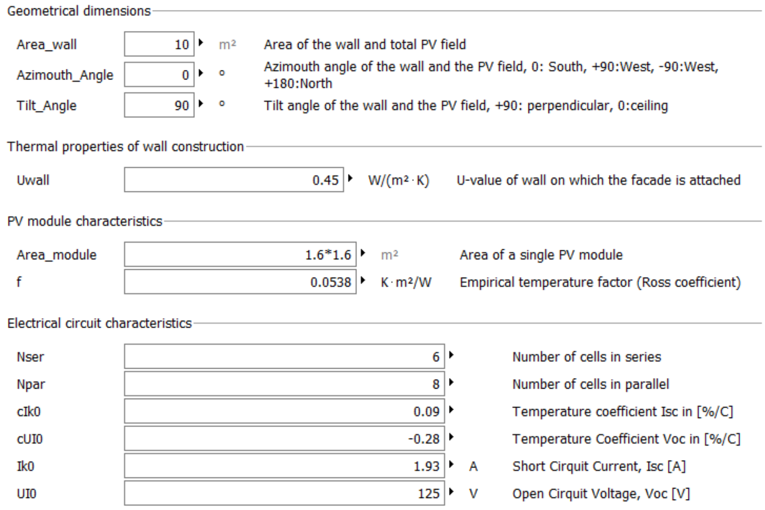
Figure 66. The thermal model of the photovoltaic generator for a building integrated PV module, (a) in Dymola, (b) in text with the developed code

a. ADBE façade with a PV panel integrated into a wall construction (ADBE #1)

A model is developed that simulates a wall construction on which the ADBE façade, which consists of a PV panel, is attached and illustrated in Figure 67a. The required parameters for the simulation of the ADBE #1 technology are shown in Figure 67b.



(a)



Geometrical dimensions

Area_wall	10	m²	Area of the wall and total PV field
Azimouth_Angle	0	°	Azimouth angle of the wall and the PV field, 0: South, +90:West, -90:West, +180:North
Tilt_Angle	90	°	Tilt angle of the wall and the PV field, +90: perpendicular, 0:ceiling

Thermal properties of wall construction

Uwall	0.45	W/(m²·K)	U-value of wall on which the facade is attached

PV module characteristics

Area_module	1.6*1.6	m²	Area of a single PV module
f	0.0538	K·m²/W	Empirical temperature factor (Ross coefficient)

Electrical circuit characteristics

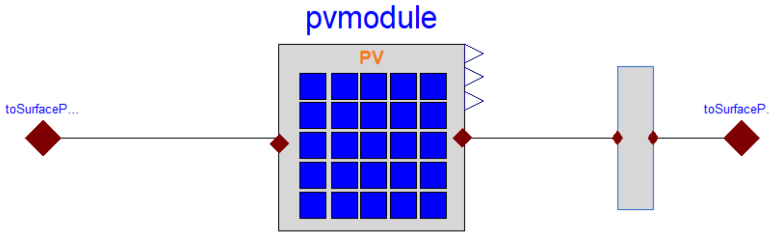
Nser	6		Number of cells in series
Npar	8		Number of cells in parallel
cIk0	0.09		Temperature coefficient Isc in [%/C]
cUI0	-0.28		Temperature Coefficient Voc in [%/C]
Ik0	1.93	A	Short Cirquit Current, Isc [A]
UI0	125	V	Open Cirquit Voltage, Voc [V]

(b)

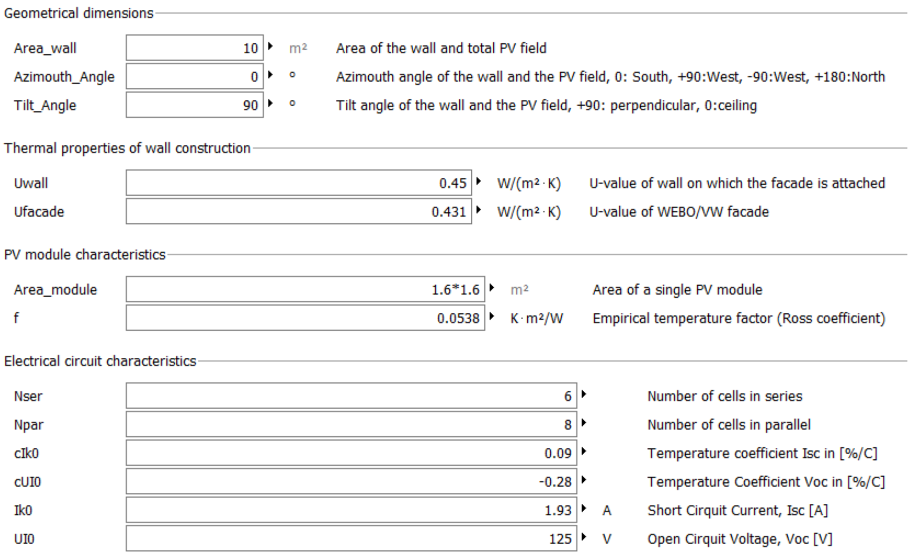
Figure 67. The developed model of the ADBE #1 technology, (a) In Modelica, (b) Parameters required for the simulation of the technology

b. ADBE façade with an insulation element and PV panel integrated into a wall construction (ADBE #2)

A model that simulates a wall construction on which the ADBE façade insulation element and the PV panel are attached is developed and illustrated in Figure 68a. The required parameters for the simulation of the ADBE #2 technology are shown in Figure 68b.



(a)



Geometrical dimensions

Area_wall	10	m²	Area of the wall and total PV field
Azimouth_Angle	0	°	Azimouth angle of the wall and the PV field, 0: South, +90:West, -90:West, +180:North
Tilt_Angle	90	°	Tilt angle of the wall and the PV field, +90: perpendicular, 0:ceiling

Thermal properties of wall construction

Uwall	0.45	W/(m²·K)	U-value of wall on which the facade is attached
Ufacade	0.431	W/(m²·K)	U-value of WEBO/VW facade

PV module characteristics

Area_module	1.6*1.6	m²	Area of a single PV module
f	0.0538	K·m²/W	Empirical temperature factor (Ross coefficient)

Electrical circuit characteristics

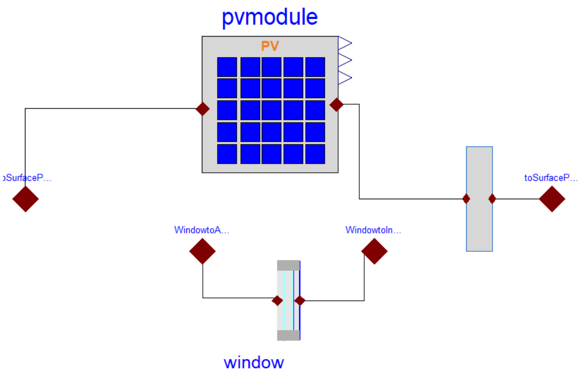
Nser	6		Number of cells in series
Npar	8		Number of cells in parallel
cIk0	0.09		Temperature coefficient Isc in [%/C]
cUl0	-0.28		Temperature Coefficient Voc in [%/C]
Ik0	1.93	A	Short Cirquit Current, Isc [A]
Ul0	125	V	Open Cirquit Voltage, Voc [V]

(b)

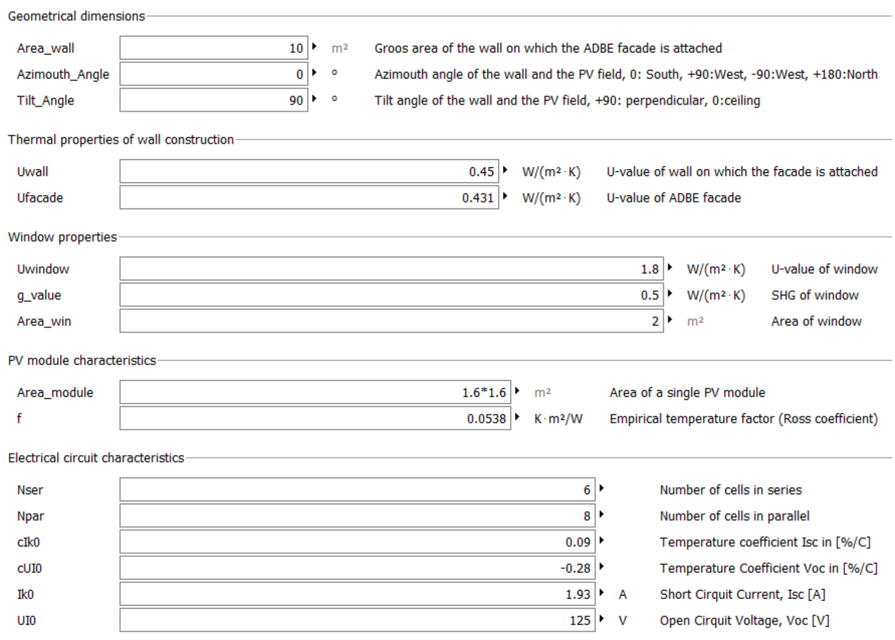
Figure 68. The developed model of the ADBE #2 technology, (a) In Modelica, (b) Parameters required for the simulation of the technology

c. A window element & ADBE façade with an insulation element and a PV panel integrated in a wall construction & (ADBE #3)

A model that simulates a wall construction on which a window element, the ADBE façade insulation element and the PV panel is attached is developed and illustrated in Figure 69a. The required parameters for the simulation of the ADBE #3 technology are shown in Figure 69b.



(a)



Geometrical dimensions

Area_wall	10	m²	Groos area of the wall on which the ADBE facade is attached
Azimouth_Angle	0	°	Azimouth angle of the wall and the PV field, 0: South, +90:West, -90:West, +180:North
Tilt_Angle	90	°	Tilt angle of the wall and the PV field, +90: perpendicular, 0:ceiling

Thermal properties of wall construction

Uwall	0.45	W/(m²·K)	U-value of wall on which the facade is attached
Ufacade	0.431	W/(m²·K)	U-value of ADBE facade

Window properties

Uwindow	1.8	W/(m²·K)	U-value of window
g_value	0.5	W/(m²·K)	SHG of window
Area_win	2	m²	Area of window

PV module characteristics

Area_module	1.6*1.6	m²	Area of a single PV module
f	0.0538	K·m²/W	Empirical temperature factor (Ross coefficient)

Electrical circuit characteristics

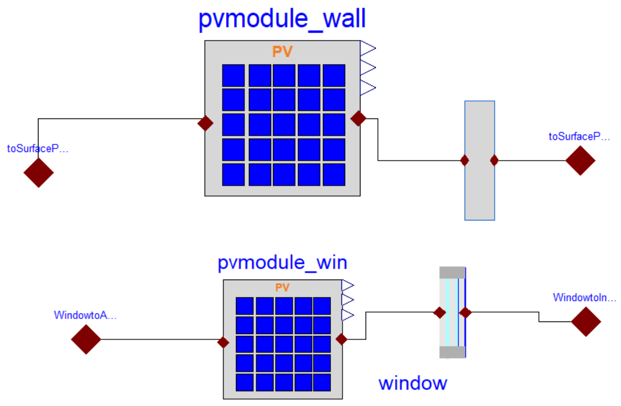
Nser	6		Number of cells in series
Npar	8		Number of cells in parallel
cIk0	0.09		Temperature coefficient Isc in [%/C]
cUI0	-0.28		Temperature Coefficient Voc in [%/C]
Ik0	1.93	A	Short Cirquit Current, Isc [A]
UI0	125	V	Open Circuit Voltage, Voc [V]

(b)

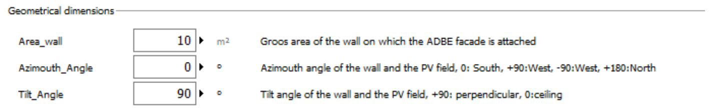
Figure 69. The developed model of the ADBE #3 technology, (a) In Modelica, (b) Parameters required for the simulation of the technology

d. ADBE façade with an insulation element and a PV panel integrated in both a wall and window construction (ADBE #4)

A model that simulates a wall and window construction on which the ADBE façade insulation element and the PV panel are attached is developed and illustrated in Figure 70a. The required parameters for the simulation of the ADBE #4 technology are shown in Figure 70b.

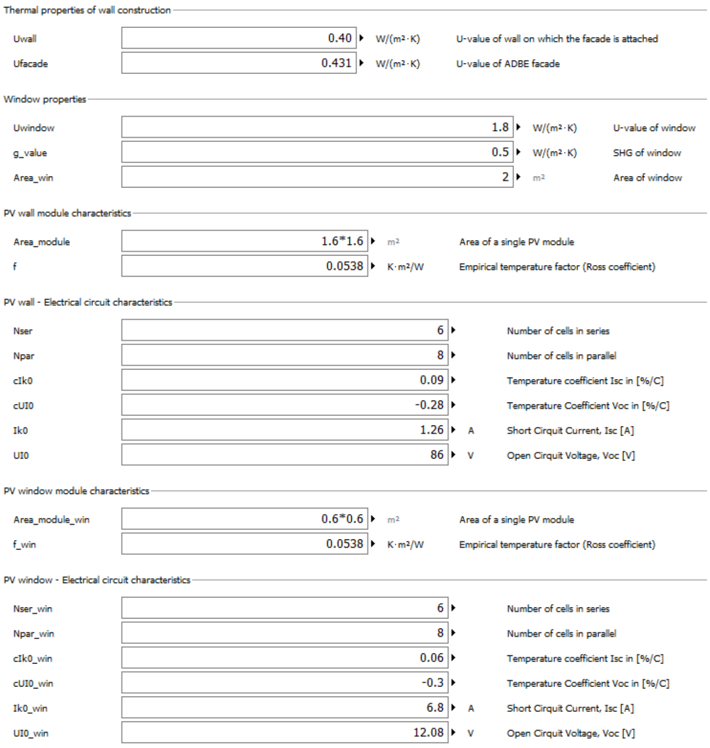


(a)



Geometrical dimensions

Area_wall	10	m²	Groos area of the wall on which the ADBE facade is attached
Azimouth_Angle	0	°	Azimouth angle of the wall and the PV field, 0: South, +90:West, -90:West, +180:North
Tilt_Angle	90	°	Tilt angle of the wall and the PV field, +90: perpendicular, 0:ceiling



Thermal properties of wall construction

Uwall	0.40	W/(m²·K)	U-value of wall on which the facade is attached
Ufacade	0.431	W/(m²·K)	U-value of ADBE facade

Window properties

Uwindow	1.8	W/(m²·K)	U-value of window
g_value	0.5	W/(m²·K)	SHG of window
Area_win	2	m²	Area of window

PV wall module characteristics

Area_module	1.6*1.6	m²	Area of a single PV module
f	0.0538	K·m²/W	Empirical temperature factor (Ross coefficient)

PV wall - Electrical circuit characteristics

Nser	6		Number of cells in series
Npar	8		Number of cells in parallel
cIk0	0.09		Temperature coefficient Isc in [%/C]
cUI0	-0.28		Temperature Coefficient Voc in [%/C]
Ik0	1.26	A	Short Cirquit Current, Isc [A]
UI0	86	V	Open Cirquit Voltage, Voc [V]

PV window module characteristics

Area_module_win	0.6*0.6	m²	Area of a single PV module
f_win	0.0538	K·m²/W	Empirical temperature factor (Ross coefficient)

PV window - Electrical circuit characteristics

Nser_win	6		Number of cells in series
Npar_win	8		Number of cells in parallel
cIk0_win	0.06		Temperature coefficient Isc in [%/C]
cUI0_win	-0.3		Temperature Coefficient Voc in [%/C]
Ik0_win	6.8	A	Short Cirquit Current, Isc [A]
UI0_win	12.08	V	Open Cirquit Voltage, Voc [V]

(b)

Figure 70. The developed model of the ADBE #4 technology, (a) In Modelica, (b) Parameters required for the simulation of the technology

4. Basic mathematical formulation part

The thermal transmittance (U-value) of the wall element is calculated as:

$$U = \frac{1}{\frac{1}{h_{in}} + \sum_{1}^{i} \frac{t_i}{k_i} + \frac{1}{h_{out}}} \tag{2}$$

A wall element composes of (i) layers of materials.

The convective coefficients are selected from ISO 6946:2017[4] . For the perpendicular structural element of the external walls and the prefabricated façade, the heat convection coefficient for the internal surface is equal to h_{in}=7.7 W/m^{2}K, and for the external surface h_{out}=25 W/m^{2}K. These values are also following the Greek legislation[5].

In the present modelling, the requirement (U_{eq}) of the total structure can be found by using the following expression including the façade (U_{facade}) and the wall (U_{wall}):

$$U_{eq} = \frac{1}{\frac{1}{U_{wall}} + \frac{1}{U_{facade}} - \frac{1}{h_{in}} - \frac{1}{h_{out}}} \tag{3}$$

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[4] ‘ISO 6946:2017’, ISO. https://www.iso.org/standard/65708.html (accessed Jan. 20, 2023).

[5] ‘TOTEE_20701-1_2017_TEE_1st_Edition.pdf’. Accessed: Jan. 18, 2023. [Online]. Available: http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/files/TOTEE_20701-1_2017_TEE_1st_Edition.pdf

The window thermal transmittance (U_{window}) is defined as:

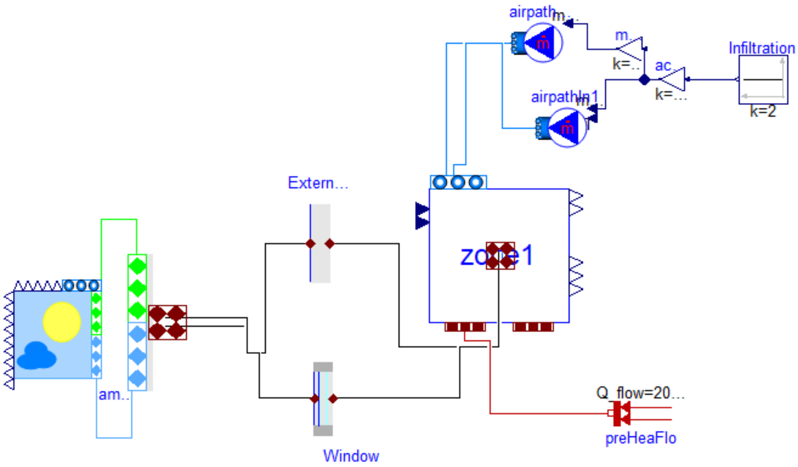
$$U_{window} = \frac{A_{glass} \cdot U_{glass} + A_{frame} \cdot U_{frame} + L_{gf} \cdot \Psi_{gf}}{A_{glass} + A_{frame}} \tag{4}$$

where (U_{glass}) is the glass's U-value, (U_{frame}) is the frame's thermal transmittance, (A_{glass}) is the glass's area, (A_{frame}) is the frame's area, (L_{gf}) is the length of the thermal bridge between the glass and frame and (Ψ_{gf}) is the specific thermal conductance of the thermal bridge.

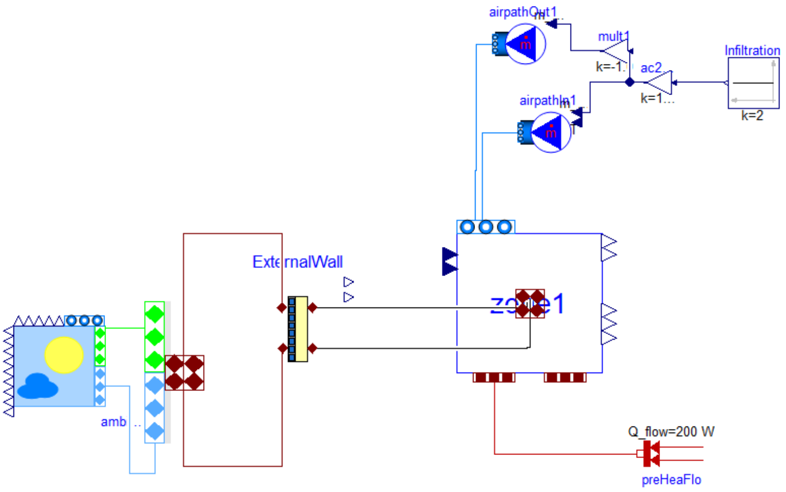
The coefficient of solar heat gain [g-value] is an index that ranges between 0 and 1 and measures the percentage of the incident solar energy that is finally transferred through the glazing to the inside. The total transferred solar energy is the sum of the solar energy that is directly transmitted through the glazing and secondarily transferred through radiation, convection and conduction from the windows' mass from which it was absorbed.

5. Simulation results

In this section, two configurations of a simplified building with one wall and window element are simulated and compared: i) a baseline scenario of the building depicted in Figure 71a, ii) a renovated scenario in which the ADBE façade technology #2 (a window element and the ADBE façade with the insulation element and PV panel integrated into a wall construction) is attached to the building's core, depicted in Figure 71b. In both scenarios, the geometrical data that concern the dimensions of the wall and window, as well as the azimuth angle of the elements are equal. In addition, the U-value of the building's external wall and window is equal to 0.45 W/m^{2}K and 1.8 W/m^{2}K, respectively, whereas the g-value is equal to 0.5 in both scenarios. The U-value of the attached ADBE façade element is equal to 0.431 W/m^{2}K.



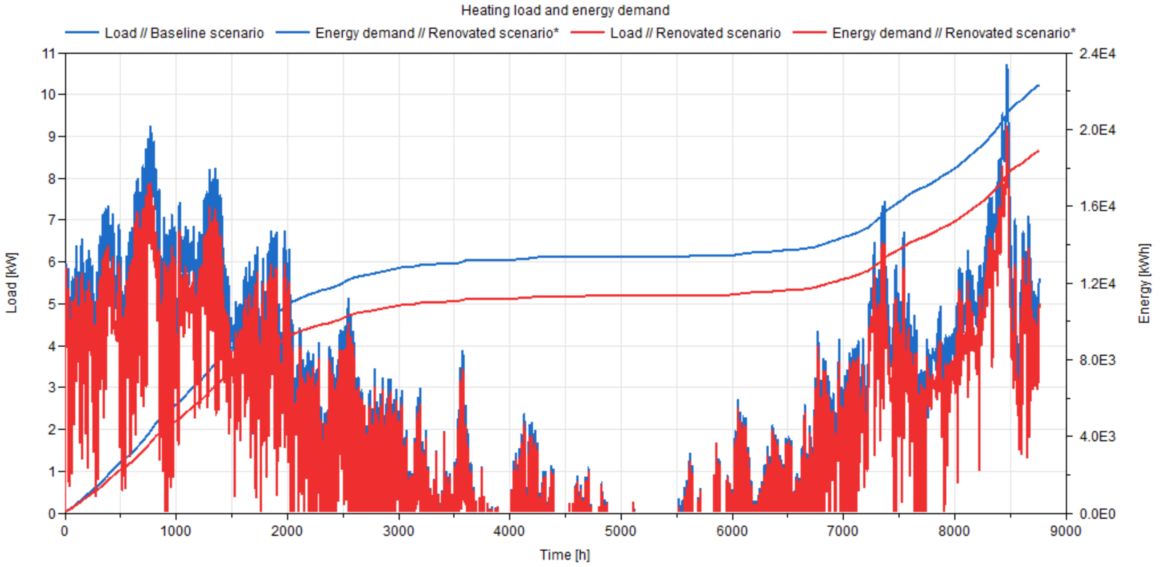
(a)



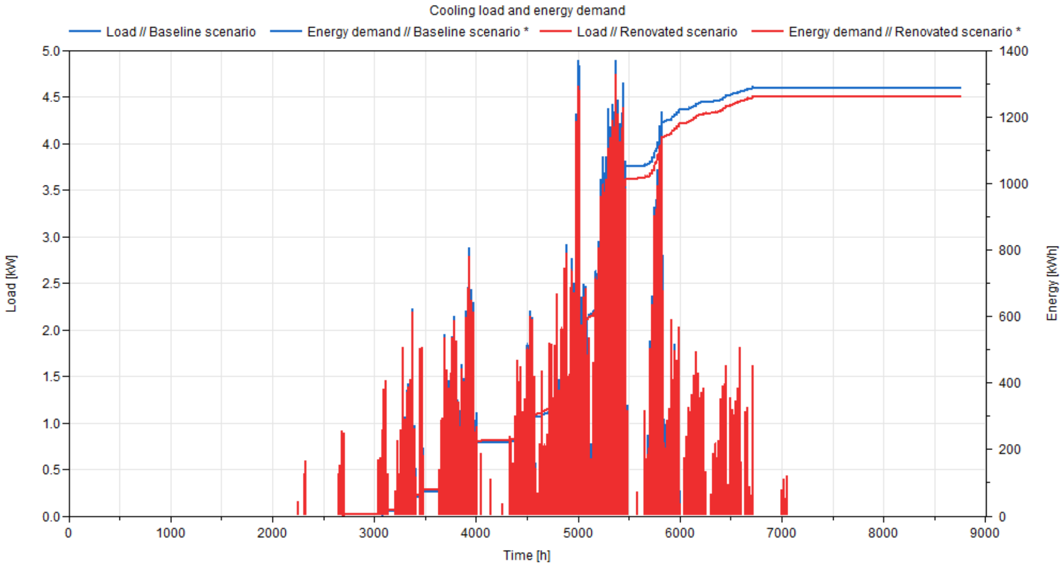
(b)

Figure 71. The examined model of a single-zone building with (a) a typical external wall construction (b) ADBE #2 façade technology

Figure 72 depicts the thermal loads and the cumulative energy demand for the baseline and the renovated scenario. More specifically, Figure 72a shows the heating load and the heating energy demand for the two examined scenarios. The application of the ADBE façade on the building's core resulted in the reduction of the building's heating demand and more precisely the decrease of the building's cumulative energy demand for heating by 3432 kWh (15.37% reduction). Similarly, Figure 72b shows the cooling load and the cooling energy demand for the baseline and renovated scenarios. The addition of the prefabricated façade has a positive effect on the building's cooling load and cumulative energy demand for cooling. The decrease in the energy demand for cooling is calculated at 27 kWh (2.09% reduction).



(a)



(b)

Figure 72. Thermal loads and cumulative energy demand of the baseline and the renovated scenario, (a) Heating load and heating energy demand, (b) Cooling load and cooling energy demand

6.1.1.3 RP3

SmartWall

1. Description

SmartWall technology is a multifunctional wall system that integrates various systems such as fan coils or other types of heating/cooling devices, windows or balcony doors, PV panels, and other electromechanical components. The SmartWall technology is versatile and adaptable to the needs of each project and therefore the components of its basic structure can be also modified, if needed, depending on the building and the country of installation. Figure 73 depicts a conceptual view of the SmartWall technology.

SmartWall technology improves the capabilities of existing multi-functional envelope concepts because of its compatibility with other technologies. More specifically, the SmartWall fan coils are customized to assemble different innovative production systems, while the whole integrated envelope is designed to be compatible with modular interlocking systems ensuring perfect stability, accurate assembly, and improved thermal performance via the minimization of thermal bridges in linear and point junctions. Furthermore, SmartWall technology is characterized by architectural-structural innovation. Precisely, a variety of different materials can be used for the construction of the structural frame, for instance, aluminium, high-performance polymers such as engineering PEEK, PE, PC, or industrial plastics such as PLA, ABS, or ASA, developed using 3D printing technology. This feature ensures that SmartWall integrates cutting-edge solutions in terms of structural materials enabling positive impacts on installation easiness through 3D printing of complex fittings for plug-and-play features, reduced production time and costs thanks to in-house custom-made components, enhanced thermophysical properties (UV resistance, thermal conductivity, acoustic behaviour), and material recyclability, like using PETG from bottles or bags.

Lastly, SmartWall technology is described by efficient environmental and thermal performance. A set of innovative technologies will contribute to new sophisticated SmartWall prototypes focusing on the use of recyclable mineral wool, a 60-min fire-retarding intumescent paint for improved thermal and fire performance, low-emission and IR-reflective coatings on the inner and outer surfaces of windows' glazing respectively, and a commercial certified system (BlazeCut T series) applied for active automatic protection of those components vulnerable to fire (e.g. batteries, fan-coil, inverter, motors, etc.).

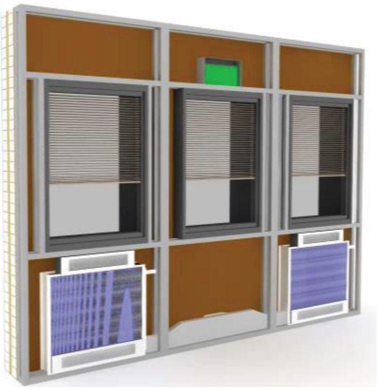
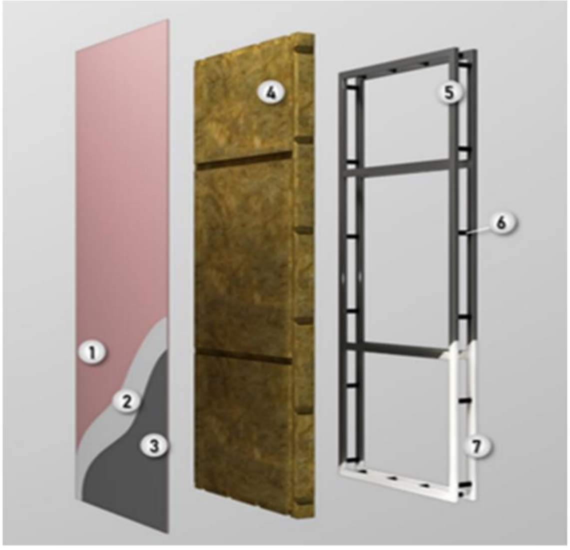
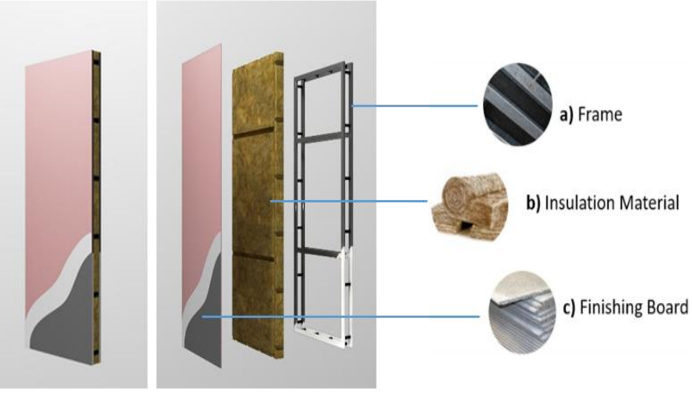


Figure 73. SmartWall conceptual view including BIPV, HVAC ducts, FCUs, batteries and smart blinds



BLANK TYPE STRUCTURE
1: Cladding
2 &3: Intumescent paint & funtional paint
4: Insulation
5:Main Frame (steel structured)
6: Heat breakers (part of the frame)
7: Intumescent paint

(a)



(b)

Figure 74. Basic description of the examined technology

2. Technical data

The SmartWall is a technology that consists of various active or inactive elements, such as eco-friendly insulation, slim-type fan coil for heating and cooling, mechanical ventilation, IEQ control system consisting of filters, energy recovery system, batteries, PV panels, and windows. The generic blank version of the SmartWall technology includes the frame, the rubber, the insulation, the gypsum or cement board and the intumescent or multifunctional paint, as it is illustrated in Figure 74. Table 12 summarizes the basic data of the wall structure, while Figure 76 shows the typical cross-section of the Smartwall.

Table 12. Technical data of SmartWall technology

Parameter	Value
Materials	
Cement board thermal conductivity [W/mK]	0.35
Cement board thickness [m]	0.0125
Insulation thermal conductivity [W/mK]	0.033*
Insulation thickness [m]	0.050
Rubber thermal conductivity [W/mK]	0.10
Rubber thickness [m]	0.009

** This value regards the rockwool insulation case*

The AMS Smartwall technology can be developed with the inclusion of various types of insulation. For instance, apart from rockwool insulation that is presented in The multi-source heat pump is connected to a solar thermal system, geothermal energy system, and ambient air. The source selection and the operation of the technology are adjusted by a smart control system to ensure the most efficient operation of the system. The heat pump is designed to have two heat exchangers on the heat sources' side. More precisely, the heat pump configuration is equipped with one water-cooled heat exchanger to receive water from the geothermal source and the solar thermal system, and one air-cooled heat exchanger to utilize the environmental air. As far as the cooling mode is concerned, the heat pump system is designed to use the geothermal field as a sink for the condenser. Figure 75a illustrates a simplified scheme of the system’s configuration and the connections between the multi-source heat pump with the geothermal field, the solar thermal system, and the ambient air, whereas Figure 75b depicts the Modelica-developed model.

The main innovation of this system is its design to serve the simultaneous operation of the air and water-cooled heat exchangers (combined operation of the air-cooled and the water-cooled operation) when it can provide a better performance either for the heating or the cooling mode. This configuration demands a special refrigerant circuit and a specific control approach.

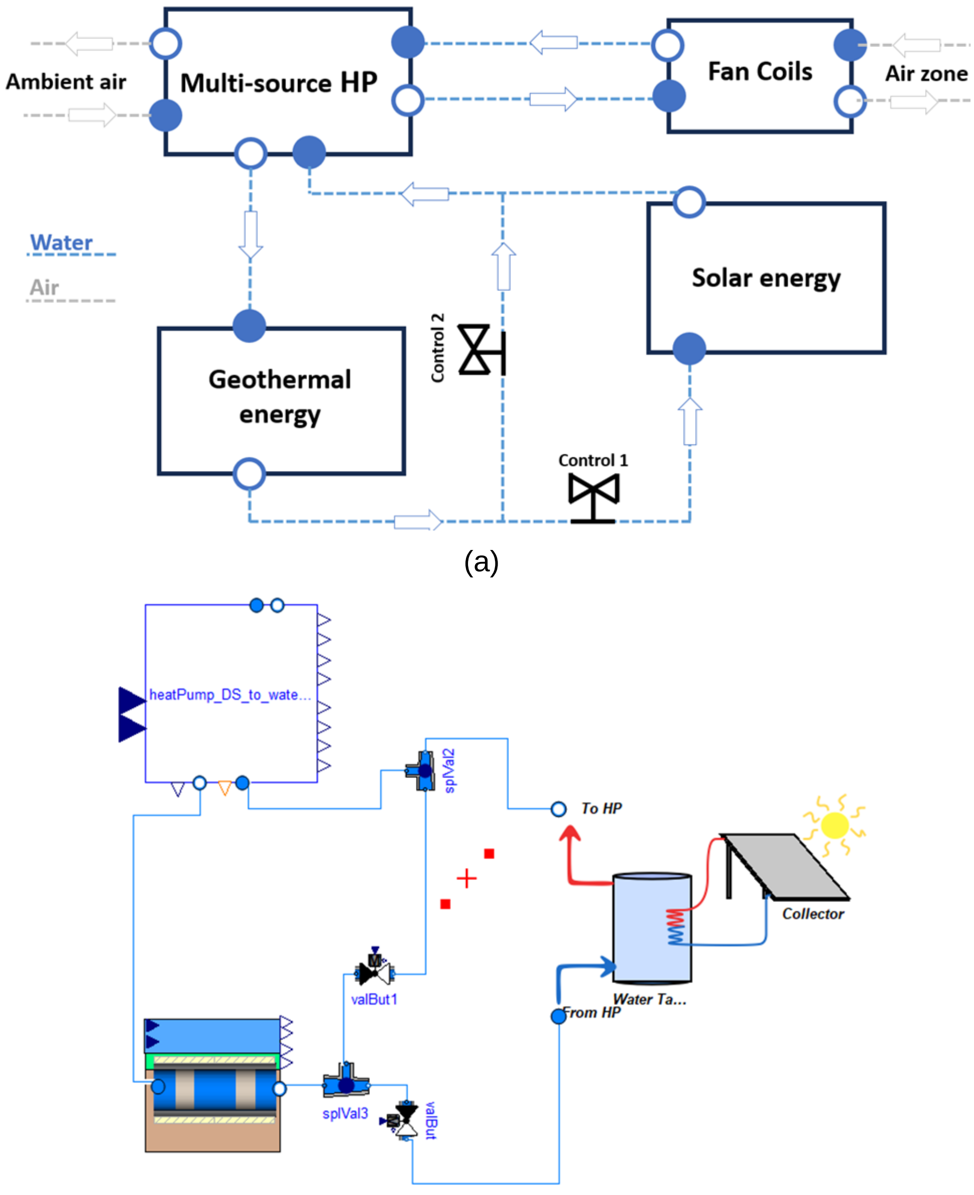
Table 13. Basic data of the suggested design

Parameter	Value
Heat Pump	
Nominal COP (heating)*	4.17
Nominal EER (cooling)**	3.17

Parameter	Value
Nominal heating capacity	130.54 kW
Nominal cooling capacity	99.2 kW
Refrigerant	R407C

*For ambient air 5oC and condensation at 45oC

** For cold water at 7oC and air-cooled condenser



(a)

(b)

Figure 75. (a) Simplified scheme of multi-source heat pump combined with ambient air, geothermal and solar energy and fan coil system, and (b) Modelica developed model of the multi-source heat pump in connection with geothermal and solar energy and ambient air

The AMS Smartwall technology can be developed with the inclusion of various types of insulation.

For instance, apart from rockwool insulation that is presented in Figure 76. VIP panels can alternatively be used, or even a combination of the two types of insulation, resulting in different constructions of the Smartwall façade. Assuming typical values for heat convection coefficients, namely for the internal surface the heat convection coefficient is equal to h_{in}=7.7 W/m^{2}K and for the external surface equal to h_{out}=25 W/m^{2}K, the U-value of the SmartWall is estimated at 0.552 W/m^{2}K and its respective thermal resistance (without convection) at 1.61 m^{2}K/W. The aforementioned values regard the worst-case scenario with rockwool insulation instead of VIP. However, in this case, the final total U-value of the wall with the SmartWall façade attached will be lower than 0.4 W/m^{2}K which is an acceptable value.

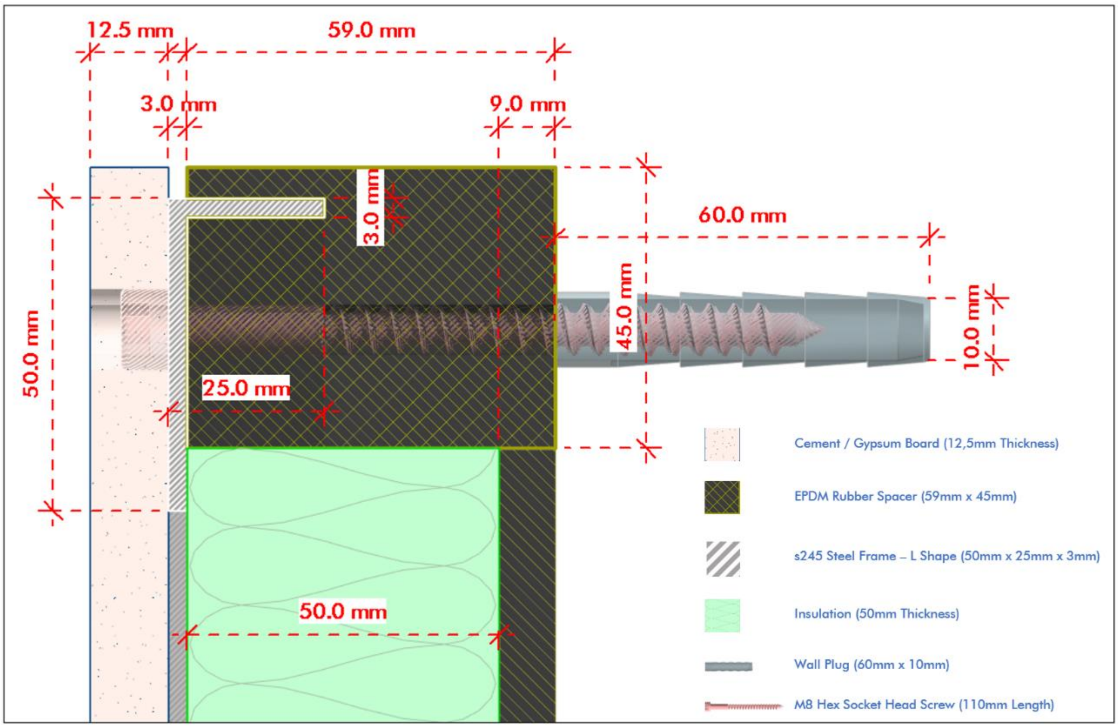


Figure 76. Typical cross-section of the Smartwall technology

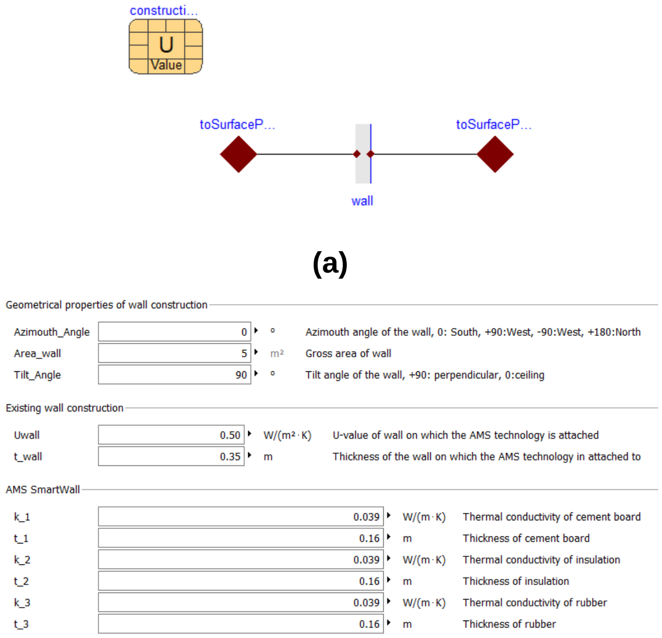
3. Developed model

For the simulation of the SmartWall technology, four models were developed and tested in INTEMA.building tool using Modelica language: i) SmartWall façade that comprises of a thermal insulation element attached on a wall component, ii) SmartWall façade that comprises of a thermal insulation element attached on a wall component and a glazing system, iii) SmartWall façade that comprises of a thermal insulation element attached on a wall component, a glazing system, and a fan coil system, and iv) SmartWall façade that comprises of a thermal insulation element attached on a wall component, a glazing system, a fan coil system and a mechanical ventilation system with heat recovery. More specifically these four models simulate a simple wall construction on which the SmartWalls façade is attached as an extra construction layer. The SmartWall façade may or may not include a glazing system, a fan coil system, and a mechanical ventilation system.

3.1. SmartWall façade with a thermal insulation element

Figure 77 Figure 1a shows the developed model in Modelica that simulates the SmartWall façade that comprises a thermal insulation element attached to a wall component. This model simulates a simple wall element which is constructed of multiple thermal layers that represent a building’s external wall and the SmartWall façade that is attached to it externally. No transparent element is included in this model. Figure 77b depicts the required parameters for the simulation of the model.

Firstly, the geometrical data that concern the wall's area [Area_wall], as well as the wall's azimuth [Azimuth_Angle] and tilted [Tilt_Angle] angle are required. Secondly, the thermal transmittance value of the external wall [Uwall] on which the façade is attached, as well as its thickness [t_wall]. Finally, the thermal conductivity values [k_1, k_2, k_3], and the thicknesses of the façade's construction layers [t_1, t_2, t_3] are required.



(a)

Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimuth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	5	m²	Gross area of wall
Tilt_Angle	90	°	Tilt angle of the wall, +90: perpendicular, 0:ceiling

Existing wall construction

Uwall	0.50	W/(m²·K)	U-value of wall on which the AMS technology is attached
t_wall	0.35	m	Thickness of the wall on which the AMS technology in attached to

AMS SmartWall

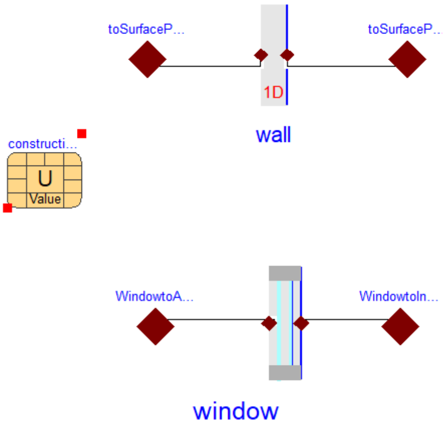
k_1	0.039	W/(m·K)	Thermal conductivity of cement board
t_1	0.16	m	Thickness of cement board
k_2	0.039	W/(m·K)	Thermal conductivity of insulation
t_2	0.16	m	Thickness of insulation
k_3	0.039	W/(m·K)	Thermal conductivity of rubber
t_3	0.16	m	Thickness of rubber

(b)

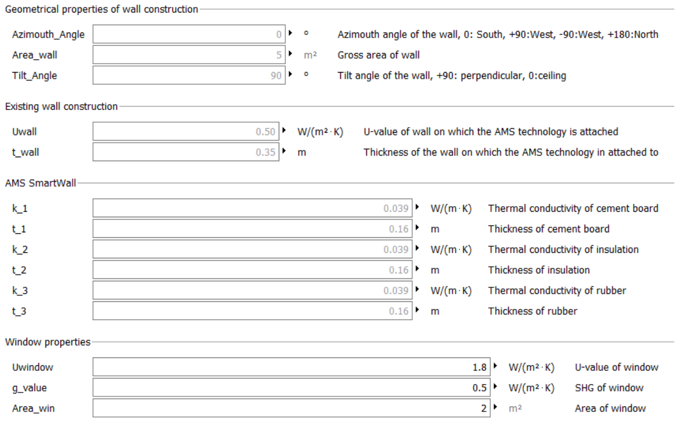
Figure 77. The developed model of the SmartWall technology that comprises a thermal insulation element, (a) Model developed in Modelica, (b) Parameters required for the simulation of the façade technology

a. SmartWall façade with a thermal insulation element and a glazing system

Figure 78a shows the developed model in Modelica that simulates the SmartWall façade that comprises a thermal insulation element attached to a wall component and a glazing system. This model simulates a simple wall element which is constructed of multiple thermal layers that represent a building's external wall on which the SmartWall façade is attached. In addition, a window element is included in this model. Figure 78b depicts the required parameters for the simulation of the model. Firstly, the geometrical data that concern the wall's [Area_wall] and window's [Area_win] areas, as well as the wall's azimuth [Azimuth_Angle] and tilted [Tilt_Angle] angle are required. Secondly, the thermal transmittance values of the external wall [Uwall] on which the façade is attached and its thickness [t_wall], as well as the window's thermal transmittance [Uwindow] and, solar heat gain coefficient [g_value] are required. Finally, the thermal conductivity values [k_1, k_2, k_3], and the thicknesses of the SmartWall façade's construction layers [t_1, t_2, t_3] are required.



(a)



Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimouth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	5	m²	Gross area of wall
Tilt_Angle	90	°	Tilt angle of the wall, +90: perpendicular, 0:ceiling

Existing wall construction

Uwall	0.50	W/(m²·K)	U-value of wall on which the AMS technology is attached
t_wall	0.35	m	Thickness of the wall on which the AMS technology in attached to

AMS SmartWall

k_1	0.039	W/(m·K)	Thermal conductivity of cement board
t_1	0.16	m	Thickness of cement board
k_2	0.039	W/(m·K)	Thermal conductivity of insulation
t_2	0.16	m	Thickness of insulation
k_3	0.039	W/(m·K)	Thermal conductivity of rubber
t_3	0.16	m	Thickness of rubber

Window properties

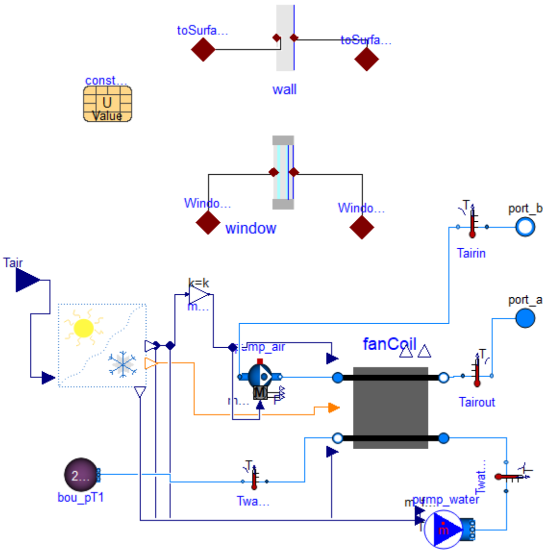
Uwindow	1.8	W/(m²·K)	U-value of window
g_value	0.5	W/(m²·K)	SHG of window
Area_win	2	m²	Area of window

(b)

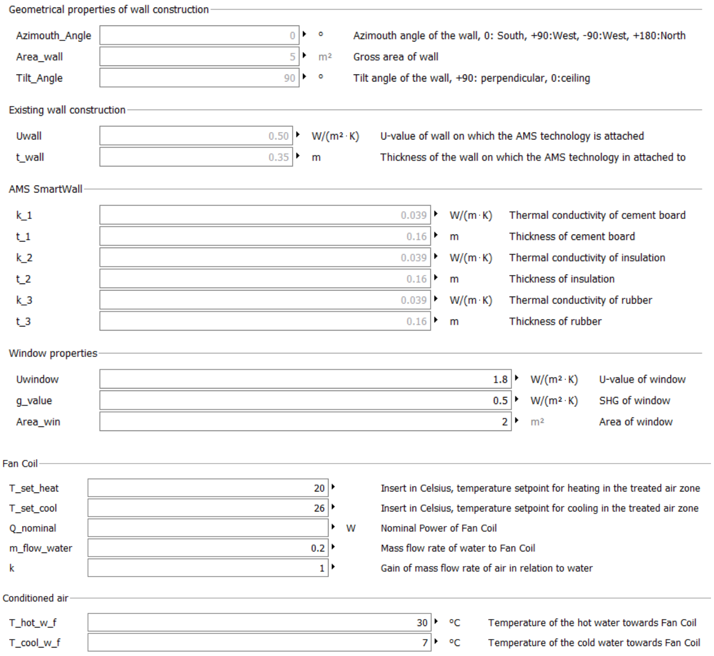
Figure 78. The developed model of the SmartWall technology that comprises a thermal insulation element and a glazing system, (a) Model developed in Modelica, (b) Parameters required for the simulation of the façade technology

b. SmartWall façade with a thermal insulation element, a glazing system and a fan coil

Figure 79a shows the developed model in Modelica that simulates the SmartWall façade that comprises a thermal insulation element attached to a wall component, a glazing system, and a fan coil system. This model simulates a simple wall element which is constructed of multiple thermal layers that represent a building's external wall on which the SmartWall façade is attached. In addition, a window element, as well as a fan coil system, is included in this model. Figure 79b depicts the required parameters for the simulation of the model. Firstly, the geometrical data that concern the wall's [Area_wall] and window's [Area_win] areas, as well as the wall's azimuth [Azimuth_Angle] and tilted [Tilt_Angle] angle are required. Secondly, the thermal transmittance values of the external wall [Uwall] on which the façade is attached and its thickness [t_wall], as well as the window's thermal transmittance [Uwindow] and, solar heat gain coefficient [g_value] are required. Finally, the thermal conductivity values [k_1, k_2, k_3], and the thicknesses of the SmartWall façade's construction layers [t_1, t_2, t_3] are required. Lastly, the parameters that describe the function of the fan coil system are required. The nominal power of the systems is inserted as [Q_nominal], whereas the mass flow rates of the water and air fluids are described as [m_flow]. The water that is inserted into the fan coil is produced by an air-to-water heat pump that is not simulated. On the contrary, a model of a water source with variable mass flow rate and temperature is used. During the heating season, the temperature setpoint of the water is described as [T_hot_w_f], while for the cooling season a [T_cool_w_f]. The temperature setpoint of the treated air zone is set as [T_set_heat] for the heating season and [T_set_cool] for the cooling season.



(a)



Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimouth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	5	m²	Gross area of wall
Tilt_Angle	90	°	Tilt angle of the wall, +90: perpendicular, 0:ceiling

Existing wall construction

Uwall	0.50	W/(m²·K)	U-value of wall on which the AMS technology is attached
t_wall	0.35	m	Thickness of the wall on which the AMS technology in attached to

AMS SmartWall

k_1	0.039	W/(m·K)	Thermal conductivity of cement board
t_1	0.16	m	Thickness of cement board
k_2	0.039	W/(m·K)	Thermal conductivity of insulation
t_2	0.16	m	Thickness of insulation
k_3	0.039	W/(m·K)	Thermal conductivity of rubber
t_3	0.16	m	Thickness of rubber

Window properties

Uwindow	1.8	W/(m²·K)	U-value of window
g_value	0.5	W/(m²·K)	SHG of window
Area_win	2	m²	Area of window

Fan Coil

T_set_heat	20		Insert in Celsius, temperature setpoint for heating in the treated air zone
T_set_cool	26		Insert in Celsius, temperature setpoint for cooling in the treated air zone
Q_nominal		W	Nominal Power of Fan Coil
m_flow_water	0.2		Mass flow rate of water to Fan Coil
k	1		Gain of mass flow rate of air in relation to water

Conditioned air

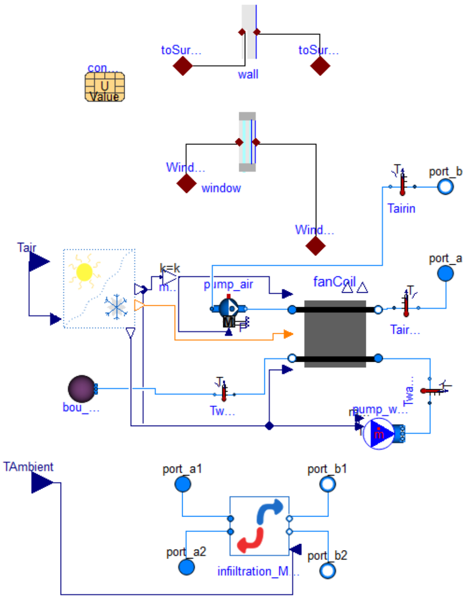
T_hot_w_f	30	°C	Temperature of the hot water towards Fan Coil
T_cool_w_f	7	°C	Temperature of the cold water towards Fan Coil

(b)

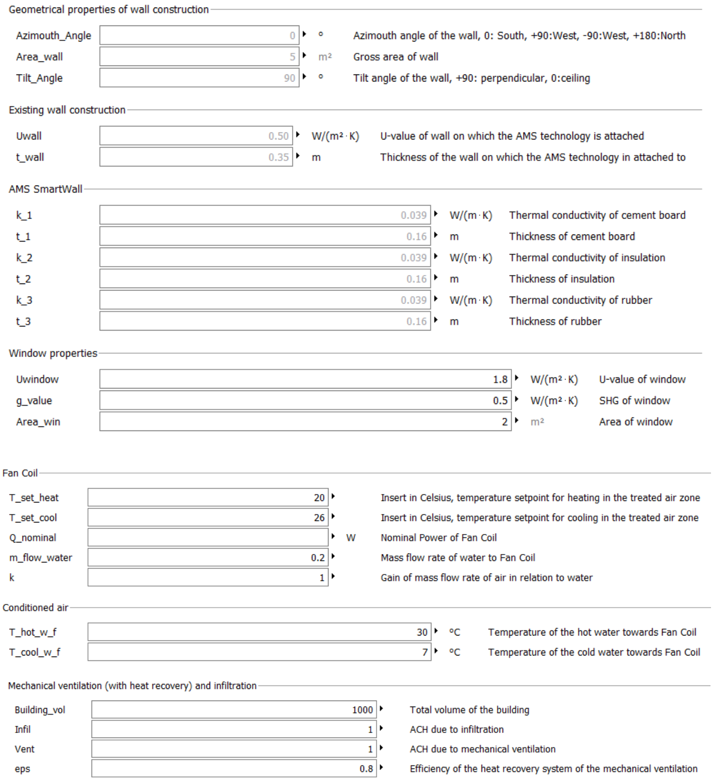
Figure 79. The developed model of the SmartWall technology that comprises a thermal insulation element, a glazing system, and a fan coil system, (a) Model developed in Modelica, (b) Parameters required for the simulation of the façade technology

c. SmartWall façade with a thermal insulation element, a glazing system, a fan coil and a mechanical ventilation system

Figure 80a shows the developed model in Modelica that simulates the SmartWall façade that comprises a thermal insulation element attached to a wall component, a glazing system, a fan coil, and a mechanical ventilation system with heat recovery. This model simulates a simple wall element which is constructed of multiple thermal layers that represent a building's external wall on which the SmartWall façade is attached. In addition, a window element, as well as a fan coil system, is included in this model. Figure 81b depicts the required parameters for the simulation of the model. Firstly, the geometrical data that concern the wall's [Area_wall] and window's [Area_win] areas, as well as the wall's azimuth [Azimuth_Angle] and tilted [Tilt_Angle] angle are required. Secondly, the thermal transmittance values of the external wall [Uwall] on which the façade is attached and its thickness [t_wall], as well as the window's thermal transmittance [Uwindow] and, solar heat gain coefficient [g_value] are required. Finally, the thermal conductivity values [k_1, k_2, k_3], and the thicknesses of the SmartWall façade's construction layers [t_1, t_2, t_3] are required. Furthermore, the parameters that describe the function of the fan coil system are required. The nominal power of the systems is inserted as [Q_nominal], whereas the mass flow rates of the water and air fluids are described as [m_flow]. The water that is inserted into the fan coil is produced by an air-to-water heat pump that is not simulated. On the contrary, a model of a water source with variable mass flow rate and temperature is used. During the heating season, the temperature setpoint of the water is described as [T_hot_w_f], while for the cooling season a [T_cool_w_f]. The temperature setpoint of the treated air zone is set as [T_set_heat] for the heating season and [T_set_cool] for the cooling season. Lastly, the mechanical ventilation system requires four parameters that concern the treated air zone's volume [Building_V], the air changes per hour of the infiltration [Infil], the air changes per hour of the mechanical ventilation [Vent], and the heat recovery efficiency [eps]. If there is no heat recovery, then eps is equal to 0.



(a)



Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimouth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	5	m²	Gross area of wall
Tilt_Angle	90	°	Tilt angle of the wall, +90: perpendicular, 0:ceiling

Existing wall construction

Uwall	0.50	W/(m²·K)	U-value of wall on which the AMS technology is attached
t_wall	0.35	m	Thickness of the wall on which the AMS technology in attached to

AMS SmartWall

k_1	0.039	W/(m·K)	Thermal conductivity of cement board
t_1	0.16	m	Thickness of cement board
k_2	0.039	W/(m·K)	Thermal conductivity of insulation
t_2	0.16	m	Thickness of insulation
k_3	0.039	W/(m·K)	Thermal conductivity of rubber
t_3	0.16	m	Thickness of rubber

Window properties

Uwindow	1.8	W/(m²·K)	U-value of window
g_value	0.5	W/(m²·K)	SHG of window
Area_win	2	m²	Area of window

Fan Coil

T_set_heat	20		Insert in Celsius, temperature setpoint for heating in the treated air zone
T_set_cool	26		Insert in Celsius, temperature setpoint for cooling in the treated air zone
Q_nominal		W	Nominal Power of Fan Coil
m_flow_water	0.2		Mass flow rate of water to Fan Coil
k	1		Gain of mass flow rate of air in relation to water

Conditioned air

T_hot_w_f	30	°C	Temperature of the hot water towards Fan Coil
T_cool_w_f	7	°C	Temperature of the cold water towards Fan Coil

Mechanical ventilation (with heat recovery) and infiltration

Building_vol	1000	Total volume of the building
Infil	1	ACH due to infiltration
Vent	1	ACH due to mechanical ventilation
eps	0.8	Efficiency of the heat recovery system of the mechanical ventilation

(b)

Figure 80. The developed model of the SmartWall technology that comprises a thermal insulation element, a glazing system, a fan coil system, and a mechanical ventilation system with heat recovery (a) Model developed in Modelica, (b) Parameters required for the simulation of the façade technology

4. Basic mathematical formulation part

The thermal transmittance (U-value) of the wall and façade elements are calculated as[6]:

$$\mathrm{U} = \frac{1}{\frac{1}{\mathrm{h_{in}}}+\sum_{1}^{i}\frac{\mathrm{t_i}}{\mathrm{k_i}}+\frac{1}{\mathrm{h_{out}}}} \tag{1}$$

A wall element composes of (i) layers of materials.

The convective coefficients are selected from ISO 6946:2017[7]. For the perpendicular structural element of the external walls and the prefabricated façade, the heat convection coefficient for the internal surface is equal to h_{in}=7.7 W/m^{2}K and for the external surface h_{out}=25 W/m^{2}K. These values are also following the Greek legislation.

The window thermal transmittance (U_{window}) is defined as:

$$\mathrm{U_{window}} = \frac{\mathrm{A_{glass}}\cdot\mathrm{U_{glass}}+\mathrm{A_{frame}}\cdot\mathrm{U_{frame}}+\mathrm{L_{gf}}\cdot\Psi_{\mathrm{gf}}}{\mathrm{A_{glass}}+\mathrm{A_{frame}}} \tag{2}$$

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[6] ‘TOTEE_20701-1_2017_TEE_1st_Edition.pdf’. Accessed: Jan. 18, 2023. [Online]. Available: http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/files/TOTEE_20701-1_2017_TEE_1st_Edition.pdf

[7] ISO 6946:2017’, ISO. https://www.iso.org/standard/65708.html (accessed Jan. 20, 2023)

where (U_{glass}) is the glass's U-value, (U_{frame}) is the frame's thermal transmittance, (A_{glass}) is the glass's area, (A_{frame}) is the frame's area, (L_{gf}) is the length of the thermal bridge between the glass and frame and (Ψ_{gf}) is the specific thermal conductance of the thermal bridge.

The coefficient of solar heat gain [g-value] is an index that ranges between 0 and 1 and measures the percentage of the incident solar energy that is finally transferred through the glazing to the inside. The total transferred solar energy is the sum of the solar energy that is directly transmitted through the glazing and secondarily transferred through radiation, convection and conduction from the windows' mass from which it was absorbed.

In the present modeling, the requirement (U_{eq}) of the total structure can be found by using the following expression including the façade ($k_{façade,}$ t_{facade}) for all the materials of the Smartwall (N in our case) and the wall (U_{wall} and $Area_{wall}$)

$$\mathrm{U_{eq}} = \frac{1}{\frac{1}{\mathrm{U_{wall}}}+\sum_{i=1}^{i=N}\left(\frac{t_{facade_i}}{k_{facade_i}}\right)} \tag{3}$$

As far as the fan coil modelling is concerned, the energy balance in the water stream (subscript "w" symbolizes water stream) is described by:

$$Q\_heat=m_w \cdot c_{p,w} \cdot (T_{w,in}-T_{w,\ out}), \tag{4}$$

while the corresponding energy balance in the air stream (subscript "a" symbolizes air stream) is given by:

$$Q\_heat=m_a \cdot c_{p,a} \cdot (T_{a,out}-T_{a,\ in}), \tag{5}$$

The heat transfer between the two streams is modeled by using the logarithmic mean temperature difference (ΔTlm) as below [3]:

$$Q\_heat=(UA)_{FC} \cdot \Delta T_{lm}, \tag{6}$$

The total heat transfer coefficient $(UA)_{FC}$ in [W/K] is the product of the thermal transmittance (U) in [W/m^2K] and of the heat exchanging area (A) in [m^2]. This is a characteristic parameter of the fan coil unit.

The logarithmic mean temperature difference (ΔT_{lm}) is defined below:

$$\Delta \mathrm{T_{lm}} = \frac{(\mathrm{T_{w,in}}-\mathrm{T_{a,out}})-(\mathrm{T_{w,out}}-\mathrm{T_{a,in}})}{\ln\left[\frac{\mathrm{T_{w,in}}-\mathrm{T_{a,out}}}{\mathrm{T_{w,out}}-\mathrm{T_{a,in}}}\right]}$$

(7)

5. Simulation results

In this section, a configuration of a simplified building of 3.5 m internal height, and 140 m^2 external wall surface is simulated with one wall and window element. In this scenario, a SmartWall façade with the insulation element and a glazing system are attached to the building's core. The U-value of the building's existing external wall and window is equal to 1.0 W/m^2K and 1.8 W/m^2K, respectively, whereas the window's g-value is equal to 0.5. The addition of the SmartWall technology to the building's existing wall results in a decreased total thermal transmittance value of 0.379 W/m^2K.

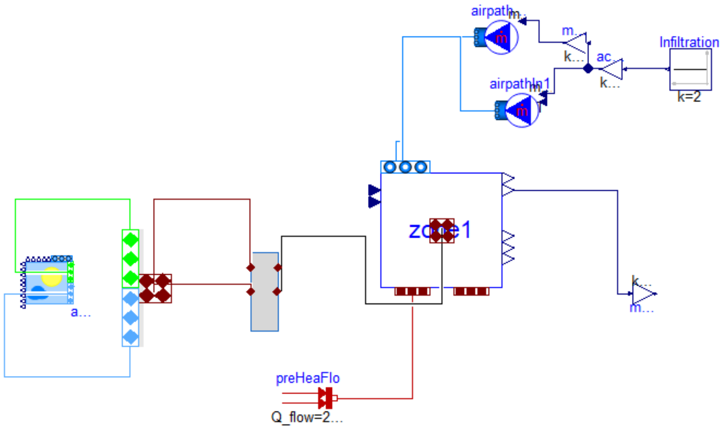


Figure 81. Configuration of simplified building with the SmartWall technology

Figure 82a shows the building's heating load and the heating energy demand. More precisely the building's cumulative energy demand for heating is calculated at 6,675 kWh. Similarly, Figure 82b shows the building's cooling load and the cooling energy demand, which is calculated at 877 kWh.

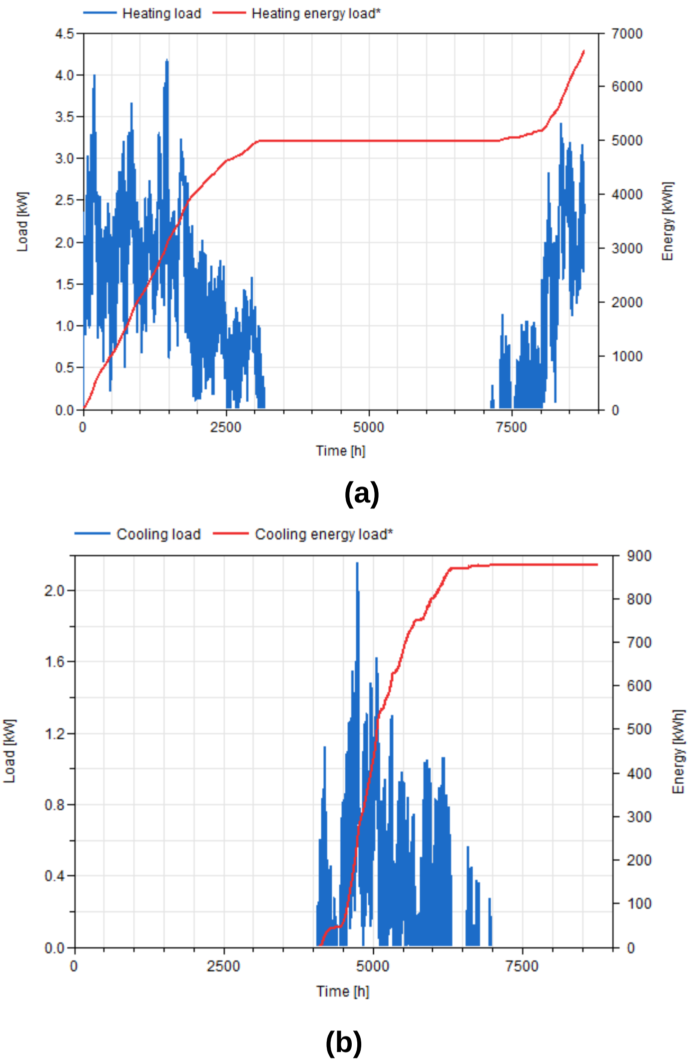


Figure 82. Thermal loads and cumulative energy demand of the baseline and the renovated scenario, (a) Heating load and heating energy demand, (b) Cooling load and cooling energy demand

6.1.1.4 RP7

Activated cellulose thermal insulation made of wood waste

1. Description

The activated cellulose thermal insulation made by WOODS is a bio-sourced – reused and recycled insulation material. It is a technological solution that is 100% fabricated with recycled and/or reused material. More specifically, it is constructed with activated cellulose made of sawdust (Figure 83), a technology that meets all the requirements of a circular economy and fits well into the green products standards. In particular, the main advantage consists of no adhesive being added to the product, making it a 100% chemical-free material. The key strengths of this new type of insulation material are environmental friendliness, high thermal performance, and easy recyclability.

Figure 83. Activated cellulose thermal insulation

2. Technical data

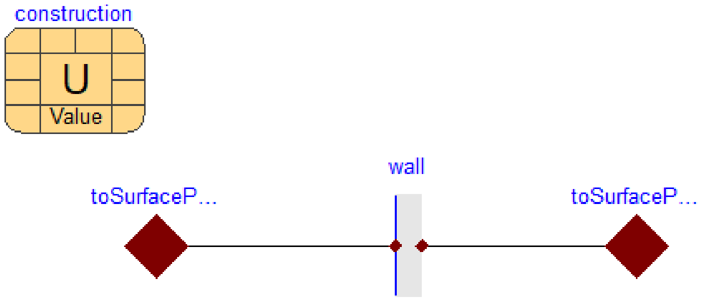
The activated cellulose thermal insulation consists of a hard insulation material panel made of wood waste such as sawdust without adding any adhesive or bonding materials. The used sawdust is a wood waste and instead of burning this waste, it is used for producing thermal insulation panels. The insulation panel is a rigid solid material having higher compression strength and low thermal conductivity. One important advantage of this new material is its recyclability after the life cycle; thus, it fully meets the requirements of circular economy principles. The insulation material can be used alongside the ABDE façade system. Table 14 summarizes the main properties and characteristics of the present technology.

Table 14. Technical data of the insulation layer

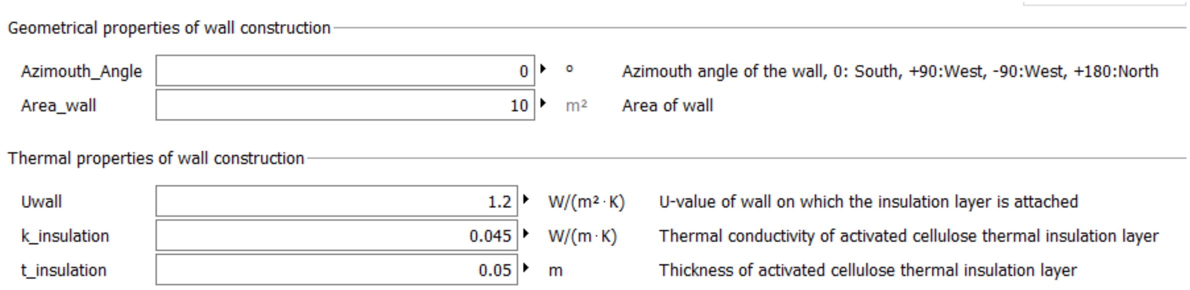
Parameter	Value
Thickness [m]	0.02 to 0.05
Density [kg/m^3]	100-150
Specific heat capacity [J/(kg·K)]	700-1100
Thermal conductivity [W/mK]	0.042-0.09 (~0.07)
Emissivity	0.9

3. Developed model

For the simulation of the activated cellulose thermal insulation block, a model of a wall component was developed and tested in the INTEMA.building tool using Modelica language. More specifically this model simulates a simple wall construction on which the activated cellulose insulation block is attached as an extra thermal layer. Figure 84a shows the developed model in Modelica. The developed model simulates a simple wall element which is constructed of multiple thermal layers that represent a building's external wall and a top, external layer that represents the activated cellulose insulation block. Figure 84b depicts the required parameters for the simulation of the model. Firstly, the geometrical data that concern the wall's area, as well as the wall's azimuth angle are required. Secondly, the thermal transmittance value of the external wall [Uwall] on which the activated cellulose thermal insulation is attached, as well as the thermal conductivity [k_insulation] and the thickness of the insulation [t_insulation] are required.



(a)



Geometrical properties of wall construction

Azimouth_Angle	0	°	Azimouth angle of the wall, 0: South, +90:West, -90:West, +180:North
Area_wall	10	m²	Area of wall

Thermal properties of wall construction

Uwall	1.2	W/(m²·K)	U-value of wall on which the insulation layer is attached
k_insulation	0.045	W/(m·K)	Thermal conductivity of activated cellulose thermal insulation layer
t_insulation	0.05	m	Thickness of activated cellulose thermal insulation layer

(b)

Figure 84. The developed model of the activated cellulose insulation layer, (a) Model developed in Modelica, (b) Parameters required for the simulation of the insulation technology

4. Basic mathematical formulation part

The thermal transmittance (U-value) of the wall element is calculated as:

$$\mathrm{U} = \frac{1}{\frac{1}{\mathrm{h_{in}}} + \sum_{1}^{i} \frac{\mathrm{t_i}}{\mathrm{k_i}} + \frac{1}{\mathrm{h_{out}}}} \qquad (1)$$

A wall element composes of (i) layers of materials.

The convective coefficients are selected from ISO 6946:2017[8]. For the perpendicular structural element of the external walls and the prefabricated façade, the heat convection coefficient for the internal surface is equal to h_{in}=7.7 W/m^{2}K and for the external surface h_{out}=25 W/m^{2}K. These

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[8] ISO 6946:2017', ISO. https://www.iso.org/standard/65708.html (accessed Jan. 20, 2023).

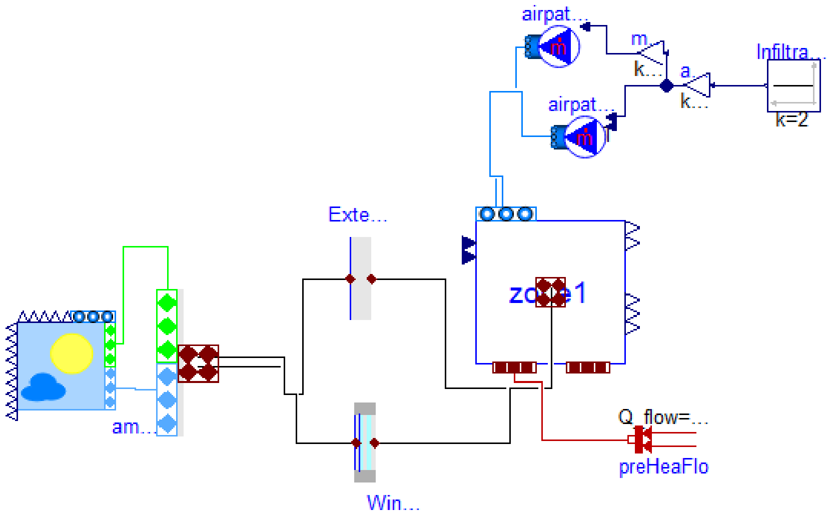
values are also following the Greek legislation[9].

In the present modeling, the requirement (U_{eq}) of the total wall structure can be found by using the following expression including the wall (U_{wall}), the insulation layer [$t_{insulation}$] and [$k_{insulation}$]:

$$\mathrm{U_{eq}} = \frac{1}{\frac{1}{\mathrm{U_{wall}}} + \frac{t_{insulation}}{k_{\mathrm{insulation}}}} \tag{2}$$

5. Simulation results

In this section, two configurations of a simplified building with one wall and window element are simulated and compared for the climatic data of Athens: i) a baseline scenario of the building Figure 85a, ii) a renovated scenario in which an activated cellulose insulation layer is attached to the building's external wall Figure 85b. In both scenarios, the geometrical data that concern the dimensions of the wall and window, as well as the azimuth angle of the elements are equal. In addition, the U-value of the building's external wall and window is equal to 1 W/m^{2}K and 1.5 W/m^{2}K, respectively, whereas the g-value of the window is equal to 0.6, in both scenarios. In the renovated scenario an insulation layer of 0.05 m thickness and thermal conductivity of 0.042 W/mK is applicated on the building's external wall.



(a)

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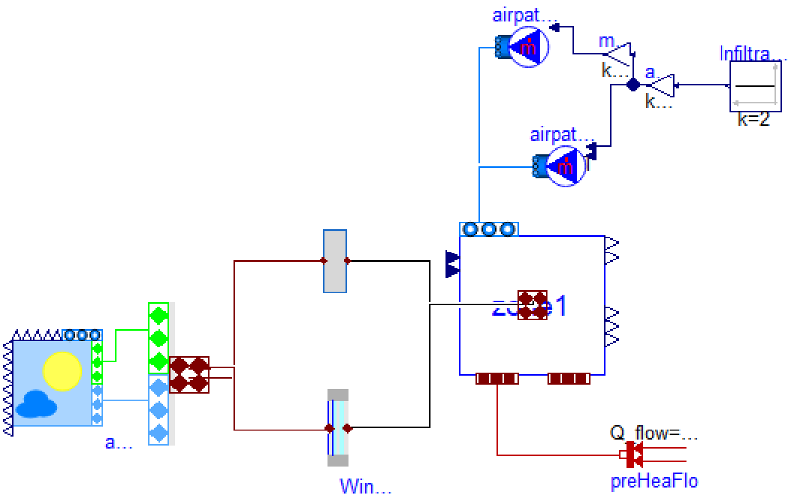
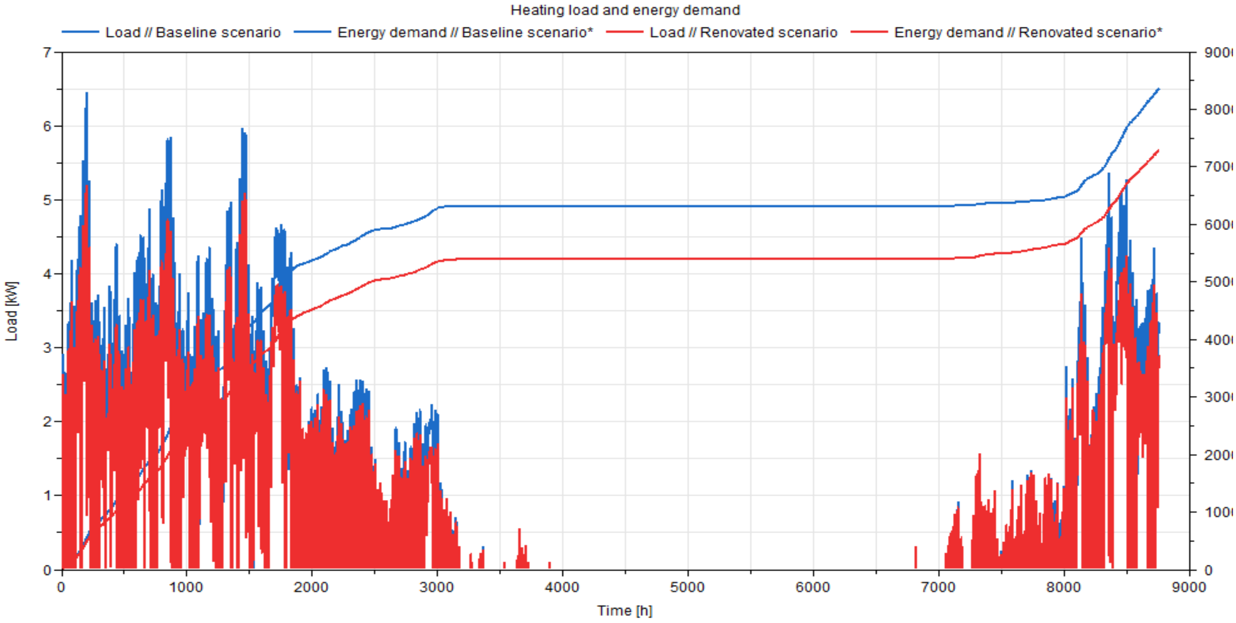
[9] TOTEE_20701-1_2017_TEE_1st_Edition.pdf'. Accessed: Jan. 18, 2023. [Online]. Available: http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/files/TOTEE_20701-1_2017_TEE_1st_Edition.pdf



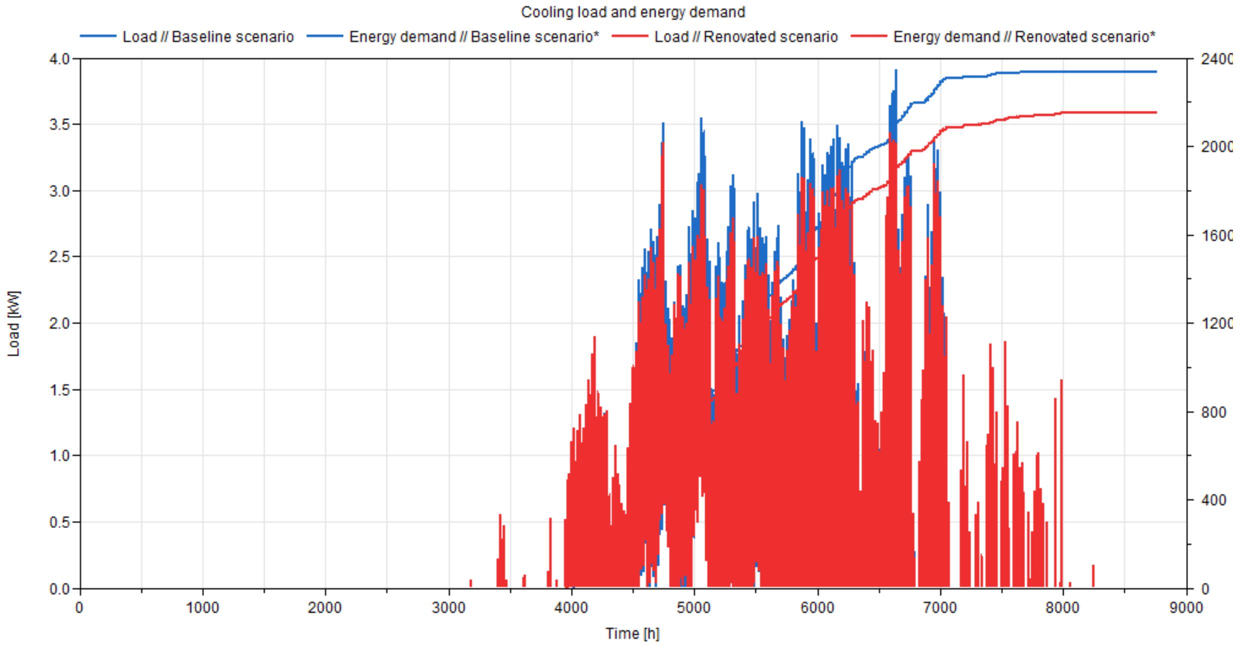
(b)

Figure 85. Configuration of simplified building, (a) Baseline scenario, (b) Renovated scenario with the activated cellulose insulation technology

Figure 86depicts the thermal loads and the cumulative energy demand for the baseline and the renovated scenario. More specifically, Figure 86a shows the heating load and the heating energy demand for the two examined scenarios. The applied RP7 on the building's core resulted in the reduction of the building's heating demand and more precisely the decrease of the building's cumulative energy demand for heating by 1064 kWh (12.72% reduction). Similarly, Figure 86b shows the cooling load and the cooling energy demand for the baseline and renovated scenarios. The addition of the insulation has a positive effect on the building's cooling load and cumulative energy demand for cooling. The decrease in the energy demand for cooling is calculated at 188 kWh (8.03% reduction).



(a)



(b)

Figure 86. Thermal loads and cumulative energy demand of the baseline and the renovated scenario, (a) Heating load and heating energy demand, (b) Cooling load and cooling energy demand

6.1.1.5 RP8

Intelligent Window System

1. Description

The Intelligent Window System (IWS) comprises a modular, low-cost solution that can be easily adapted to the outer skin of new or existing buildings and for any type of window (Figure 87). A house renovation usually involves the replacement of the window installations and in this case, the old installations become waste. However, the solution of IWS allows the original windows to remain in place and fulfil their original function, but with smarter and adjustable thermal and optical properties. The IWS technology is applied as an adapter, fixed on the outer side of an existing window that incorporates a smart management system (sensors and microcontrollers) that determines the availability of solar gaining and simultaneously reduces the renovation disturbance to the building's occupants to the minimum.

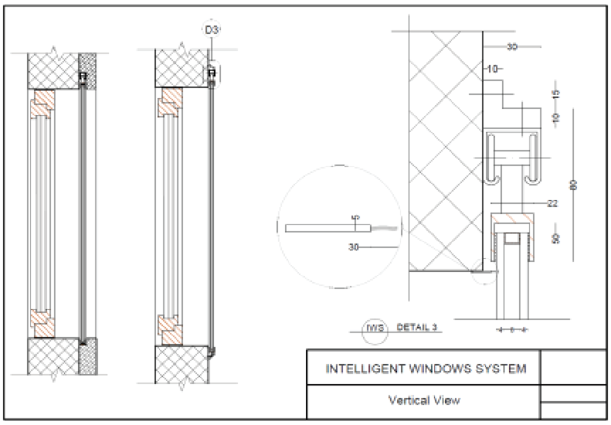


Figure 87. Intelligent window system

2. Technical data

The IWS technology enhances the thermal comfort conditions of a building by altering its solar gain coefficient and thermal transmittance value. The IWS technology utilizes intelligent sensors and microcontrollers that determine the availability of solar gaining in winter, and according to the energy demand of the building decreases the thermal insulation of the window and increases the g-value of the windows glazing. When solar radiation is not available, the system automatically improves its thermal transmittance value, reducing heat losses. The IWS technology ultimately reduces HVAC energy consumption by protecting normal windows from solar radiation in summer without restricting the usage of the original windows.

The IWS technology is controlled automatically without offering the option for the user to force switching. This technology can be directly integrated into multipurpose envelope solutions. More specifically, it will be integrated into the ADBE (Adaptable/dynamic building envelope) system and applied to the Hungarian Demo Site. The ADBE will contain the IWS like a module and during renovation, an additional window adapter will be built hidden behind the façade on the building's opening. If the window needs higher thermal resistance either in winter to protect heat or in summer to protect cold then the system will close automatically the additional double glassing IWS. The frame of the IWS will be the ADBE module itself. It will be designed so that the user cannot see a real frame just an edge the glass connects to. The IWS is equipped with an oven-moving electric engine driven either by an electric grid or oven-source solar panels and battery. Figure 88depicts the IWS technology that consists of the passive element of the opening and the active element system of the moving solar thermal system mechanism. Also, Table 15 includes basic technical data of the examined technology.

(a) (b)

Figure 88. The IWS technology and its, (a) passive element (opening), (b) active element (solar thermal system)

Table 15. Technical data of IWS technology

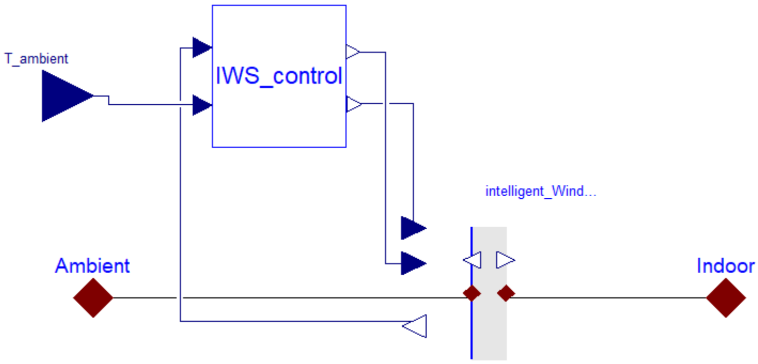
Parameter	Value
Existing windows (Inactivated IWS)	
Frame percentage [%]	20
U-value of the glazing [W/m^{2}K]	1.2
U-value of the frame [W/m^{2}K]	1.4
U-value of the window [W/m^{2}K]	0.9
g-value	0.75
With the Intelligent window system (Activated IWS)	

Parameter	Value
Frame percentage (%)	< 5
U-value of the glazing (W/m^{2}K)	< 0.7
U-value of the frame (W/m^{2}K)	No frame
U-value of the window (W/m^{2}K)	< 0.6
g-value	0.65

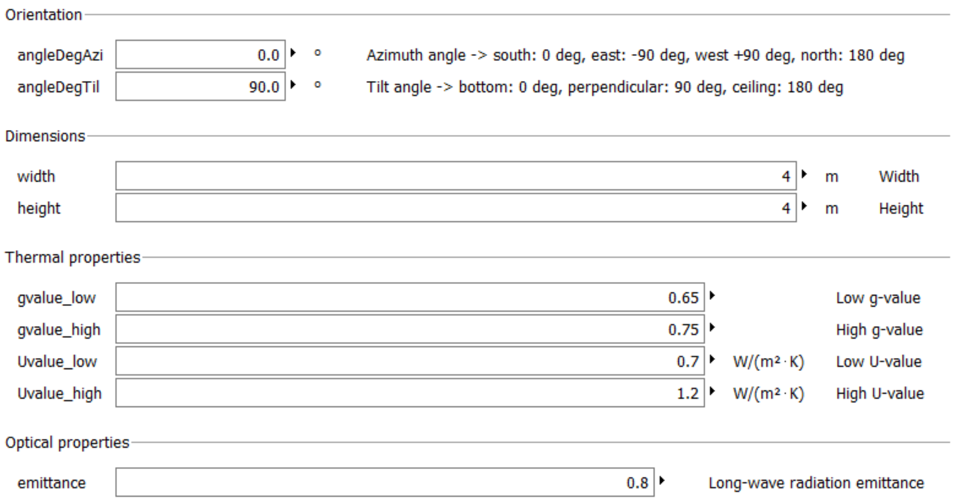
3. Developed model

For the simulation of the IWS technology, a model of a window with modular thermal properties was developed and tested in the INTEMA.building tool using Modelica language. More specifically this model simulates a simple window construction on which the IWS technology is attached as a top window layer that reversibly switches the window's properties.

Figure 89 shows the developed model in Modelica that simulates a window construction, on which the IWS is attached and whose thermal transmittance value and g-value are adjusted by a control system according to the external stimuli of the ambient temperature and the incident solar radiation. Figure 89b depicts the required parameters for the simulation of the model. Firstly, the geometrical data that concern the window's height and width, as well as the window's azimuth and tilted angle are required. Secondly, the thermal transmittance values [Uvalue_low, Uvalue_high] and g-values [gvalue_low, gvalue_high] of the window construction are required. These two values describe the state of the existing window installation of the building (non-activated IWS) [Uvalue_high and g_value_high] and the state that the IWS is activated [Uvalue_low and g_value_low]. The final parameter [emittance] concerns the emittance value of the window's glass.



(a)



Orientation

angleDegAzi 0.0 ° Azimuth angle -> south: 0 deg, east: -90 deg, west +90 deg, north: 180 deg

angleDegTil 90.0 ° Tilt angle -> bottom: 0 deg, perpendicular: 90 deg, ceiling: 180 deg

Dimensions

width 4 m Width

height 4 m Height

Thermal properties

gvalue_low 0.65 Low g-value

gvalue_high 0.75 High g-value

Uvalue_low 0.7 W/(m²·K) Low U-value

Uvalue_high 1.2 W/(m²·K) High U-value

Optical properties

emittance 0.8 Long-wave radiation emittance

(b)

Figure 89. The developed model of the IWS technology, (a) Model developed in Modelica, (b) Parameters required for the simulation of the window system

The window's properties of thermal transmittance (U-value) and solar heat gain coefficient (g-value) are modular and controlled by a solar thermal management system that is intrigued by the external stimuli of ambient temperature and incident solar radiation. Specifically, the IWS is activated if the ambient temperature (Tambient) is above 17°C and the incident solar radiation (Radiationincident) is above 150W/m^{2}K or if the ambient temperature (Tambient) is below 17°C and the incident solar radiation (Radiationincident) is below 150W/m^{2}K. Otherwise, the IWS remains inactivated. Equations 1& 2 describe the modulation of the window's properties.

$$U - value = \begin{cases} U - value_{low}, & T_{ambient} > 17^{o}C \quad and\ Radiation_{incident} > 150\ \frac{W}{m^2K} \\ & or \\ & T_{ambient} < 17^{o}C \quad and\ Radiation_{incident} < 150\ \frac{W}{m^2K} \\ U - value_{high}, & in\ any\ other\ case \end{cases}$$

(1)

$$g - value = \begin{cases} g - value_{low}, & T_{ambient} > 17^{o}C \quad and\ Radiation_{incident} > 150\ \frac{W}{m^2K} \\ & or \\ & T_{ambient} < 17^{o}C \quad and\ Radiation_{incident} < 150\ \frac{W}{m^2K} \\ g - value_{high}, & in\ any\ other\ case \end{cases}$$

(2)

4. Basic mathematical formulation part

The window thermal transmittance (U_{window}) is defined as:

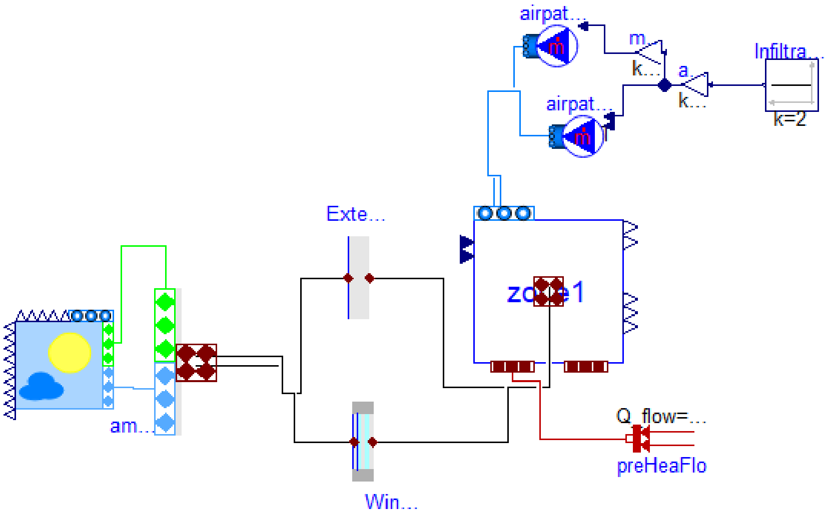
$$\mathrm{U_{window}} = \frac{\mathrm{A_{glass} \cdot U_{glass} + A_{frame} \cdot U_{frame} + L_{gf} \cdot \Psi_{gf}}}{\mathrm{A_{glass} + A_{frame}}} \tag{3}$$

where (U_{glass}) is the glass's U-value, (U_{frame}) is the frame's thermal transmittance, (A_{glass}) is the glass's area, (A_{frame}) is the frame's area, (L_{gf}) is the length of the thermal bridge between the glass and frame and (Ψ_{gf}) is the specific thermal conductance of the thermal bridge[10] [1].

The coefficient of solar heat gain [g-value] is an index that ranges between 0 and 1 and measures the percentage of the incident solar energy that is finally transferred through the glazing to the inside. The total transferred solar energy is the sum of the solar energy that is directly transmitted through the glazing and secondarily transferred through radiation, convection and conduction from the windows' mass from which it was absorbed.

5. Simulation results

In this section, two configurations of a simplified building with one wall and window element are simulated and compared: i) a baseline scenario of the building, and ii) a renovated scenario in which the IWS technology is attached to the building's core. In both scenarios, the geometrical data that concern the dimensions of the wall and window, as well as the azimuth angle of the elements are equal. In addition, the U-value of the building's external wall is equal to 1 W/m^{2}K in both scenarios. For the baseline scenario, the U-value of the window is equal to 1.2 W/m^{2}K and the g-value is equal to 0.75. In the renovated scenario, the window's high and low U-values are equal to 1.2 W/m^{2}K (inactivated IWS) and 0.7 W/m^{2}K (activated IWS), respectively, whereas the window's high and low g-values are equal to 0.75 (inactivated IWS) and 0.65 (activated IWS), respectively. Both scenarios are simulated for the meteorological data of Budapest.



(a)

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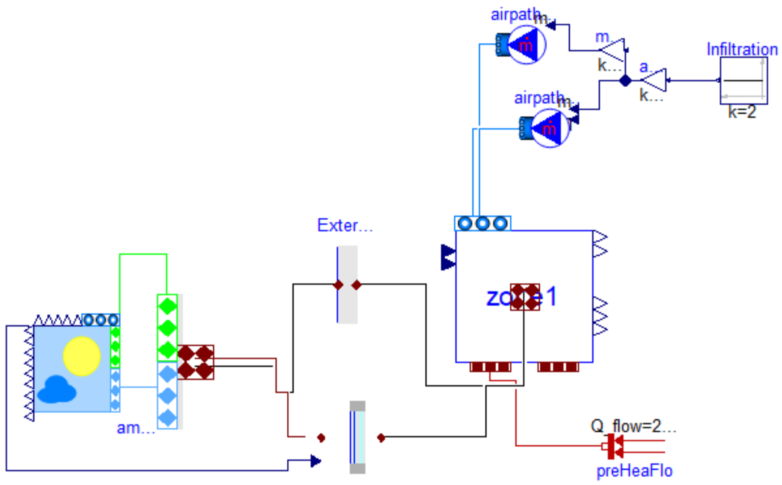
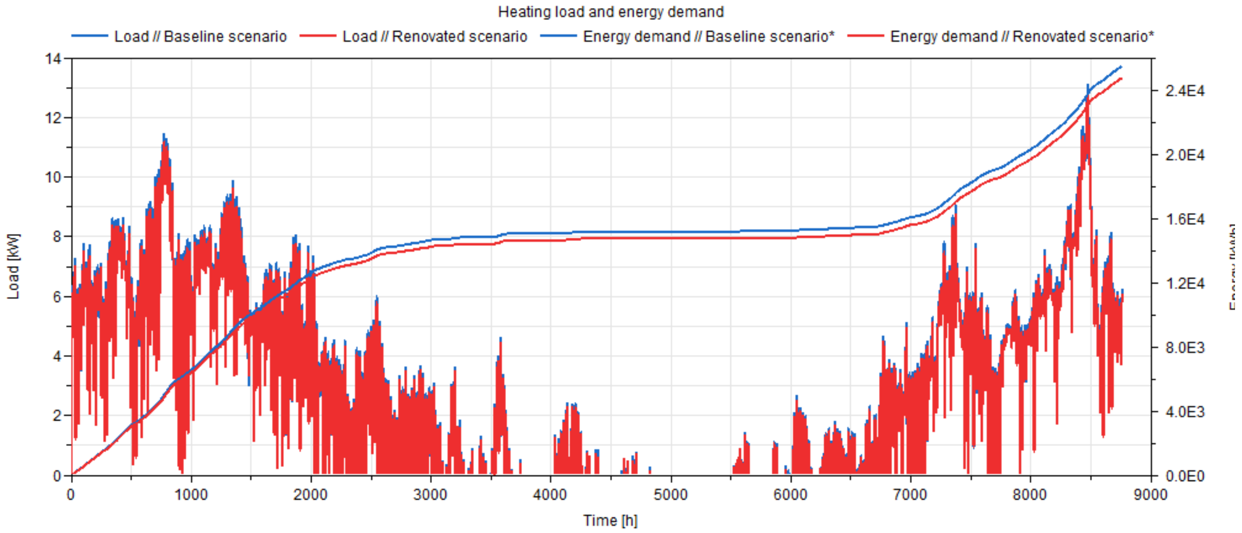
[10] 'TOTEE_20701-1_2017_TEE_1st_Edition.pdf'. Accessed: Jan. 18, 2023. [Online]. Available: http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/files/TOTEE_20701-1_2017_TEE_1st_Edition.pdf



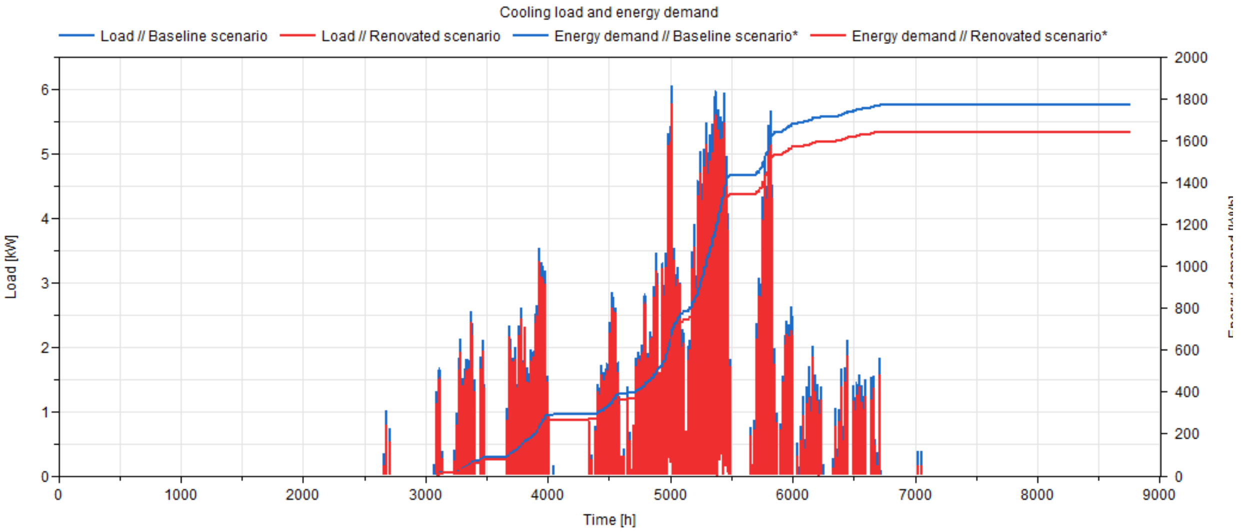
(b)

Figure 90. Configuration of simplified building, (a) Baseline scenario, (b) Renovated scenario with the IWS technology

Figure 91depicts the thermal loads and the cumulative energy demand for the baseline and the renovated scenario. More specifically, Figure 91a shows the heating load and the heating energy demand for the two examined scenarios. The application of the IWS technology on the building's core resulted in the reduction of the building's heating demand and more precisely the decrease of the building's cumulative energy demand for heating by 734 kWh (2.88% reduction). Similarly, Figure 91b shows the cooling load and the cooling energy demand for the baseline and renovated scenarios. The addition of the intelligent window has a positive effect on the building's cooling load and cumulative energy demand for cooling. The decrease in the energy demand for cooling is calculated at 130 kWh (7.33% reduction).



(a)



(b)

Figure 91. Thermal loads and cumulative energy demand of the baseline and the renovated scenario, (a) Heating load and heating energy demand, (b) Cooling load and cooling energy demand

6.1.2 OTHER MODELS/SIMULATIONS

6.1.2.1 RP3

Simulation of RP3 in TRNSYS software

The RP3 (SmartWall) and its supply system are simulated using TRNSYS software, quantifying the potential upgrade of the building energy performance. The energy analysis of the HVAC and PV system's behavior is based on iterative transient computations. An overview of the simulation approach to SmartWall operation is depicted in Figure 92. The supply system, including a heat pump (HP) and auxiliary equipment (diverters, mixing valves, tank, etc.) is separately modelled using the suitable components from the TRNSYS library. The main components used to supply the SmartWall with heat are described below.

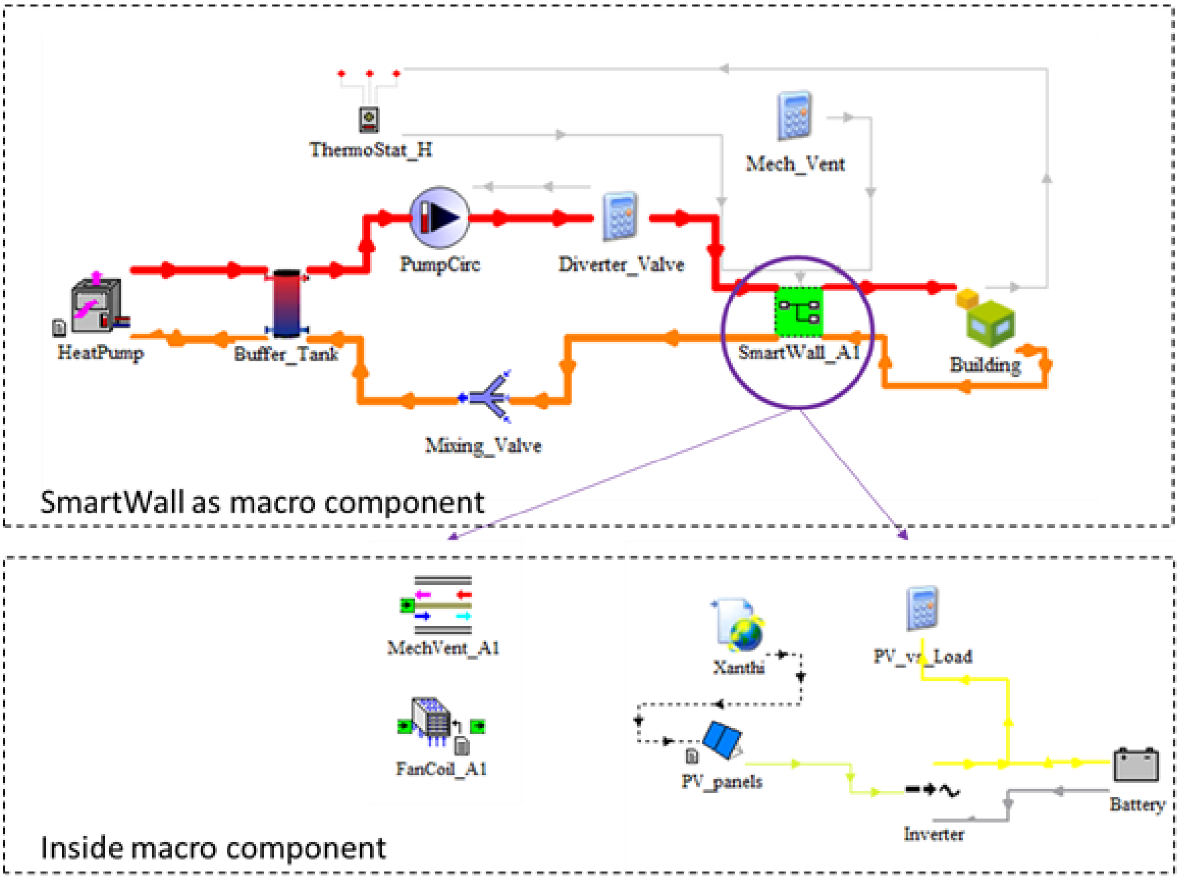


Figure 92. The SmartWall component modelled in TRNSYS studio.

The heat source is a conventional air-to-water **heat pump** (HP)with an inverter compressor simulated using the component from TRNSYS library type525b. One HP unit is assigned for the supply of the renovated area with the SmartWall (RP3). It has a heating capacity of 9 kW and a nominal COP of 4.91. In the current set up, the HP is responsible to maintain the temperature inside the linked buffer tank to the pre-set levels of 40°C.

The **Buffer Tank** (Type534-NoHX) with a capacity of 100 L is responsible for offering buffer support and optimizing the system's operation by storing heat, generated by the heat pump, in the form of hot water and supplying the incorporated fan coils of SmartWall panels for space heating. The tank is considered to be held inside the building, so there is no exposure to ambient conditions, and its walls are insulated with a total U-value of 0.4W/(m²·K). In order to simulate the natural temperature gradient inside the tank, it is divided into five stratification nodes where the top one (1st) is characterized by the higher temperature and the bottom one (5th) by the lowest.

The "**PumpCirc**" (Type110) is a variable speed pump (of 560 kg/h rated mass flow rate) used for water circulation between the HP and the terminal units. In case every zone needs active heating, the pump will operate at its rated conditions and circulate conditioned water throughout the fan coil units of the SmartWall panels. In the most common case that a number of zones needs heating while some others do not, the circulation pump is controlled accordingly so that it supplies the exact flow rate needed from the active heated zones.

The **"Building" unit** (type56) incorporates all parameters and regimes concerning the building i.e., the geometry and operation (occupancy, heating schedules, etc.) and elements' characteristics (walls, roof, floor, windows, etc.). It is also the channel that connects the systems (space heating, mechanical ventilation, etc.) with the building and the thermal zones. Details of the building characteristics are presented in the next section. The distribution inside the zones is accomplished by the attached terminal unit and its corresponding **thermostat** (Thermostat_H). The temperature for heating is set to 21.5 °C, while a dead band of 1.5°C is considered.

A SmartWall unit is considered as a macro component and it is therefore assigned to each thermal zone that is conditioned with the RP3. Each SmartWall macro consists of the fan coil for heating and the mechanical ventilation unit, as well as the PV array with its connected system (inverter and battery).

The **Fan-coil unit** (Type996) is a typical fan-coil with a variable fan speed function model that relies on a user-provided external data file containing the performance of the coils as a function of the entering air and water conditions (temperature and flow rate). In this regard, a standard performance map file is used provided by the TRNSYS libraries. The commercial FWXV-ATV3 fan-coil was chosen from DAIKIN catalogues, with rated conditions of 2.8 kW heating capacity, 20 W fan power, 294 m³/h volumetric air flowrate and 180 kg/h water flowrate. The variable fan speed function is exploited by operating the fan in three different speeds based on the room's temperature. The **thermostat component** used (Type 698) models a 5-stage room thermostat that is able to monitor up to 30 different zones. Out of the five stages, three are used for heating, which facilitates a 3-stage heating/fan control. All three heating stages share a temperature dead band of 1°C, while the 1st, 2nd, and 3rd stages have different setpoints of 22.5°C, 21.5°C and 20.5°C respectively. The water circuit is controlled differently but still based on the room thermostat. Whenever the zone needs heating (any stage), the circulation pump is enabled. The complete fan-coil control strategy is summarized in Table 16.

Table 16. Triple-stage fan control of the fan-coil unit

T_{ZONE} [°C]	≤20	$20 \leq T_{ZONE} \leq 21$	$21 \leq T_{ZONE} \leq 22$	$22 \leq T_{ZONE} \leq 23$	$23 \leq T_{ZONE}$
1st stage	1	1	1	1	0
2nd stage	1	1	1	0	0
3rd stage	1	1	0	0	0
Fan control	1	1	0.45	0.15	0
Water circuit control	1	1	1	1	0

The fan-coil unit calculates the temperature, humidity, and flow rate of its outlet air, which serves as inputs for the building (Type56). These inputs determine the ventilation settings for the corresponding thermal zone, providing the necessary heat.

Inside the SmartWall module, a **mechanical ventilation unit** (Type667) with a 90% heat recovery rate is integrated. The ventilation rate is adjusted based on occupancy to supply fresh air, reducing CO_2 levels from occupants. Each zone receives fresh air according to its occupancy and floor area. Heat recovery occurs through a cross-flow air-to-air heat exchanger between fresh and exhaust streams. Instead of allowing the cold outdoor air to enter, it is preheated by exhaust air exiting the zones. Each room's ventilation settings are factored into the total energy balance for the thermal zone.

Last but not least, the incorporated **PV array** (type 190c) used can model monocrystalline, polycrystalline or thin-film PV panels, while encompassing a maximum power point tracker (MPPT). Since the modules are anchored on the external surface of the renovated façade, all PVs are vertically tilted. For each SmartWall panel installed on the south of the building façade (3 panels in total), a PV array of 100W is incorporated together with an inverter and a 12V battery. The PV's power outlet is connected to the inverter so it can be consumed either directly by the SmartWall's HVAC equipment or by the building's electrical needs. The nominal efficiency of the PV array at standard test conditions is 21%.

Simulation of Greek demo building

For the calculation of the relevant KPIs of RP3, the Greek demo building is simulated in TRNSYS (Figure 93) for the pre-renovated state (existing) and after the implementation of RP3 (renovated state), focusing on the impact of RP3 on the building energy performance. The total reference floor area (RFA) of the building is 1371 m^2, excluding the basement. The RP3 is planned to be installed in seven rooms on the western side of the ground floor, as illustrated in Figure 94, with a total area of 109.8 m^2, representing approximately 8% of the building's total floor area. Each of the aforementioned rooms is modeled as a separate thermal zone, while the rest of the building is segmented into 4 conditioned (rooms) and 4 unconditioned (common areas). The azimuth angle is considered 0^o. In the surrounding area, some shading elements have been added in order to simulate the effect of sunlight blocking due to balconies, overhangs and peripheral shading.

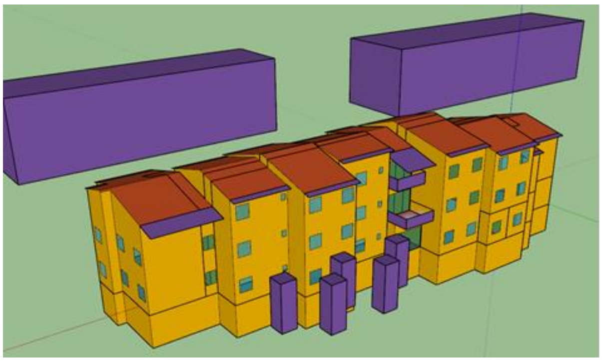


Figure 93. Building geometry in Google SketchUp.

Figure 94. The rooms of Greek Demo building where the RP3 is planned to be installed.

The building accommodates 62 occupants, which is distributed evenly throughout the main 3 floors, besides the basement, with a thermal load equal to 80 W per occupant. The infiltration is assumed equal to 0.4 h^{-1} and a natural ventilation assumption of 0.3 h^{-1} for a total of 0.7 air change per hour. Additionally, the heating season was assumed to take place from 15 October up to 15

April, which is the usual heating period in Greece. The thermostat temperature for the conditioned zones is set at 20ºC, whilst the temperature regulation is enabled only during the heating season. Further details regarding the operating parameters such as occupancy, lighting, and appliances are presented in Table 17.

Table 17. Operating parameters of the building.

Parameters	Value
Number of occupants	62
Thermal load of the occupants	80 W/occupant
Mean operating fraction of the occupants	67 %
Specific lighting electrical load	7 W/m^2
Mean operating fraction of the lighting	19 %
Specific appliances electrical load	10 W/m^2
Mean operating fraction of the appliances	35 %
Infiltration rate	0.4 ACH / 0.3 ACH
Natural ventilation rate	0.3 ACH
Heating Season	01/01 - 15/04 and 15/10 - 31/12
Zone thermostat	20ºC
Weather conditions	Xanthi

Table 18 summarizes the basic characteristics of the structural elements of the examined building. The estimation of the U-values includes also the impact of thermal bridges. The ground floor is an uninsulated element that is located over the basement, while the remaining elements have a thin insulation layer. The existing windows are single glazed with aluminium frame and significant thermal bridges.

In the renovated state (using only the RP3), the SmartWall is added externally to the existing walls offering significant thermal insulation, while seven new windows are also installed. Regarding the ETICS layer, XPS insulation with finishing mortar is added at the external walls with eastern and western orientation (light blue in Figure 93), as well as to the southern basement wall partitions that are exposed to ambient air. A combination of three different SmartWall types is used for insulating the southern and northern walls of the 7 examined zones. The new windows are low-e, double glazed with aluminium frame.

Table 18. Thermal transmittance values of the examined building envelopes.

Envelope elements	U-value (W/m^2·K)
Ground and Inner partition floor	3.10
Roof	1.25
External walls	1.05
Existing Windows	4.2
ETICS (XPS)	0.461

Envelope elements	U-value (W/m²·K)
SmartWall	0.27 ÷ 0.53
External Wall with ETICS	0.339
External Walls with RP3	0.22 ÷ 0.37
New Windows	1.1

The results presented below refer only to the reference renovated area, meaning the seven rooms on the ground floor where the RP3 is planned to be installed. The energy analysis indicates that if the boundary condition of the floor of these rooms is assigned as adjacent to the basement, there is no significant need for cooling, as the basement is cooler during the summer months. However, if the boundary condition of the floor of these rooms is set as adiabatic surface, there are significant cooling needs accounting for approximately 10% of the total energy demands (heating and cooling). Taking into consideration that the adiabatic surface hardly refers to a realistic scenario, the results presented below derive from the case where the basement's ceiling is actively adjacent to the examined floor area.

The heating needs of the existing state are calculated following two steps. Firstly, the annual heating demands of each of the 7 renovated rooms (total area 109.8 m^2) are calculated, assuming an ideal heating system at 20°C. Then the whole heating system including the biomass boiler, the radiators, and the auxiliary components is simulated to determine the corresponding energy consumption. On the other hand, the same steps are followed for the RP3 - renovated state, focusing on the refurbished zones and the reduction of heating demand and consumption. The terminal units (radiator for the existing and fan-coil for the renovated state) are controlled by a thermostat with a temperature deadband of 3°C (20°C - 23°C).

Figure 95 illustrates the outdoor and indoor temperatures of three representative rooms for the existing (pre-renovated) and the renovated with RP3 state. The examined rooms are the North-oriented Room 20, the South-oriented Room 21, and the North-West-oriented Room 24. The outside conditions depict that the temperature ranges between -11°C to 33°C, with daily fluctuation up to 12°C during summer months (Figure 95).

The investigation of the indoor temperatures indicates that the temperatures of the northern room do not exceed 25°C, while the temperatures of the other rooms reach up to 26°C proving the low need for cooling due to the adjacency to the basement. Besides, the indoor temperatures after 15 April are below 20°C, for both the existing and the renovated case since the system is deactivated. This indicates that the heating period should be extended in Spring. During this period, it is shown that the temperatures in the renovated state are by ca. 1.5 °C higher than the temperature of the existing state due to the upgrade of the building envelope, reducing the thermal transmittance (U-value) and infiltration rates.

On the other hand, according to the operational schedules of the building, the heating period begins on 15 October, while the rooms need heating after 10 November for the existing state and after 25 November for the renovated state. This reveals the significance of the high-insulated building envelope of the renovated rooms, since despite the reduction of energy needs, it delays the start of the heating period.

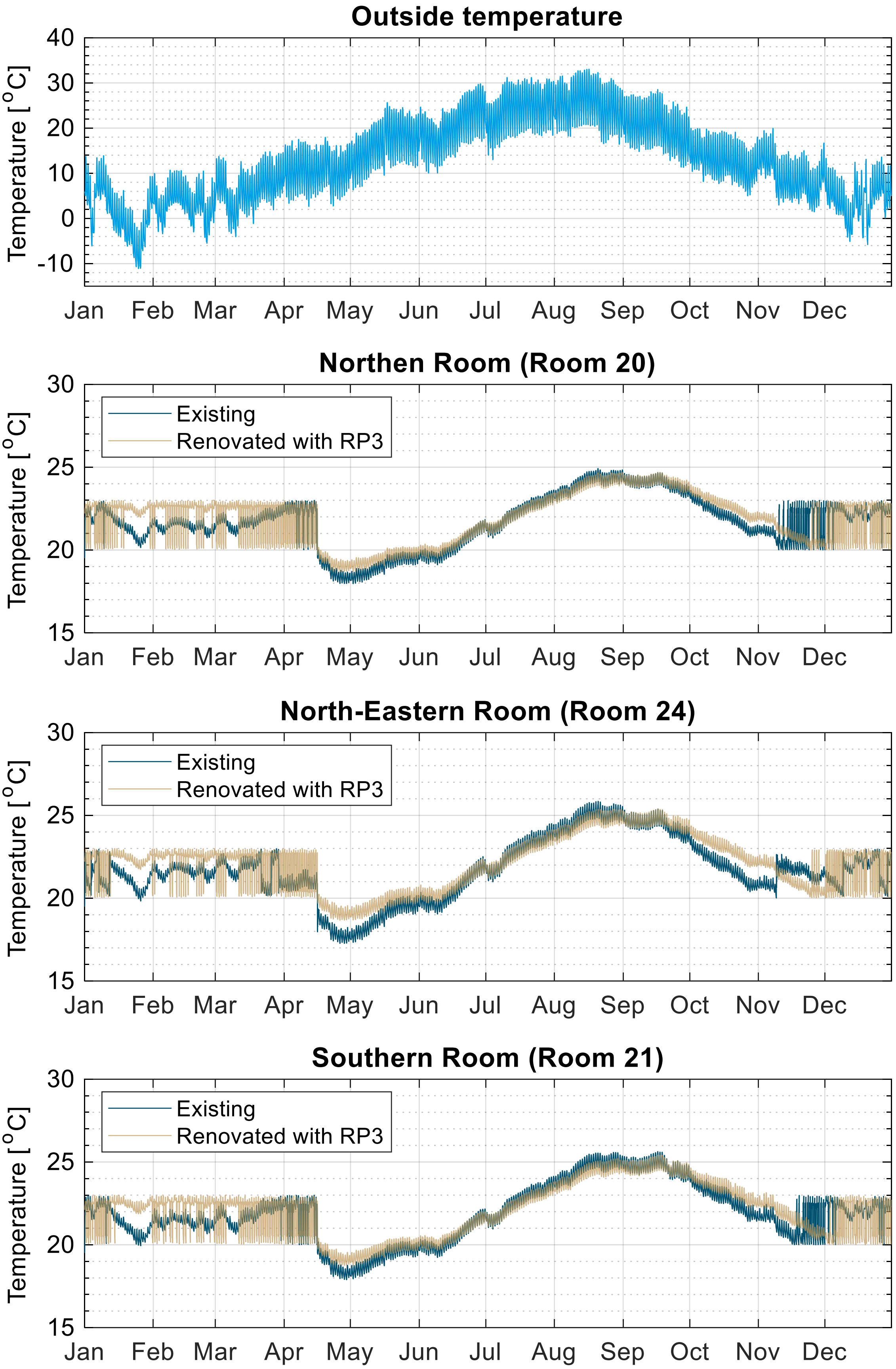


Figure 95. Outdoor and indoor temperatures for three representative rooms for the existing and renovated state.

Table 19 summarizes the heating demands before and after the implementation of SmartWall on the 7 zones. The final outcome for both the existing and the renovated cases is calculated assuming that the heating period follows Table 17, keeping the indoor temperature above 20ºC for the whole day to fairly compare the energy demands and consumptions. It is observed that a reduction of 38.5% in the heating demands is achieved due to the envelope thermal performance upgrade by installing the RP3 and the ETICS on the external walls. The implementation of more efficient energy systems, replacing the biomass boiler and radiators with a commercial heat pump and fan-coils further reduces the final energy consumption for heating. Last but not least, the PVs (3.5m^2 in total) that are installed at the Southern oriented SmartWall produce 312 kWh.

Table 19. Heating demands for the 7 zones before and after the renovation with RP3.

Envelope elements	Existing state	Renovation with RP3	Reduction
Heating demands	96.3 kWh/m^2·a	59.2 kWh/m^2·a	38.5 %
Heating load	165.1 kWh/m^2·a	105.3 kWh/m^2·a	36.2%
Finale energy for heating	212.3 kWh/m^2·a (biomass)	28.3 kWh/m^2·a (electricity)	86.7%
PV production		312 kWh	

The primary energy for heating is calculated by multiplying the delivered (fuel) energy with the corresponding primary energy factor, meaning 1.0 for biomass (existing) and 2.9 for electricity (renovated)[11]. Figure 96 illustrates the primary energy consumption for heating for the existing and renovated case. The implementation of the RP3 in the seven rooms results in a reduction of primary energy consumption by 61.3%

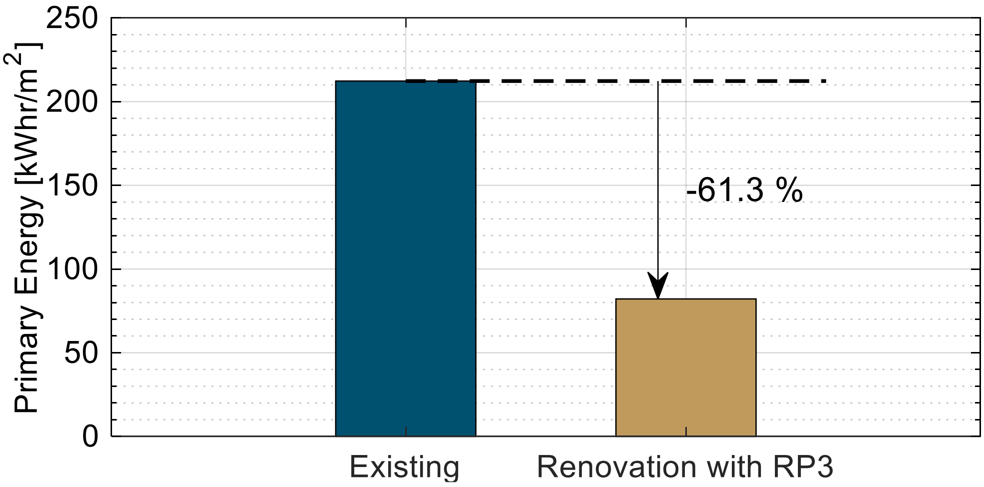


Figure 96. Primary energy consumption for heating for the two examined cases.

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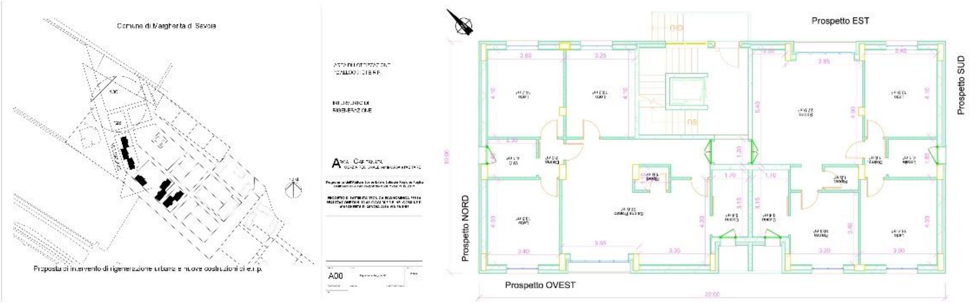
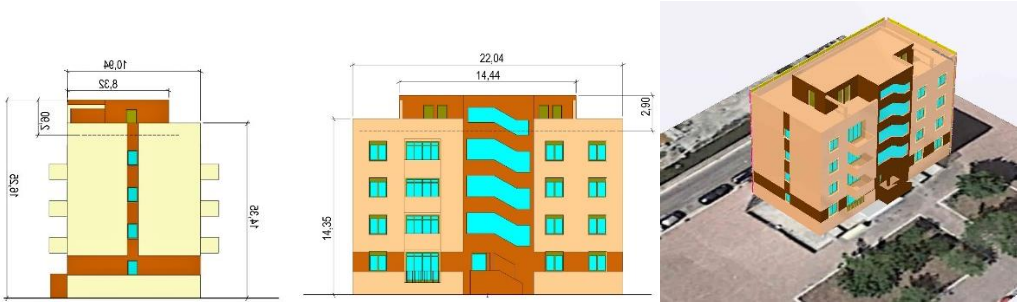
[11] Hellenic Regulation for buildings (KENAK)

6.1.2.2 RP5

On the base of dwg drawings made by ARCA capitanata, the first step of model creation by a parametric 3D model of the existing building, was created.

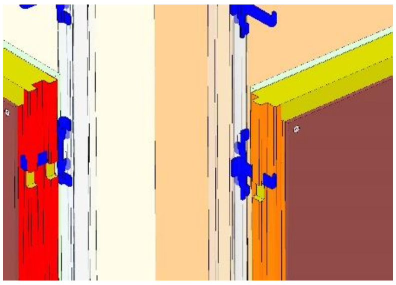


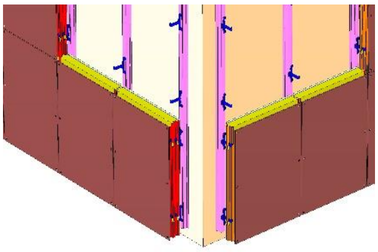


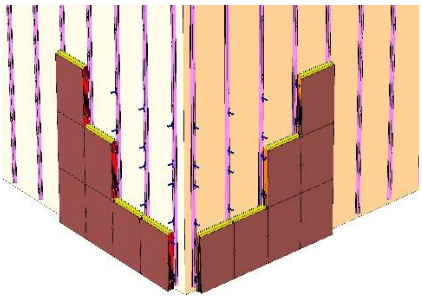
That was the basic element on which to develop the proposal for REHOUSE project for the Italian Demo.

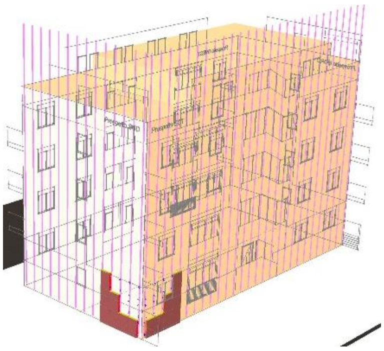
The initial proposal of Multi-Purpose Façade, MPF, was consisting of vertical structure fixed to wall building on which thermal insulating BIPV panels would be installed, composed by an insulation hemp panel, with 2 side supporting metal plates, a rear cover metal plate and a front BIPV photovoltaic panel.

After that, the model was integrated by the study on installation system of the panel; so, a system of supporting brackets was defined, to be mounted on vertical structure, and on which to place the panels.

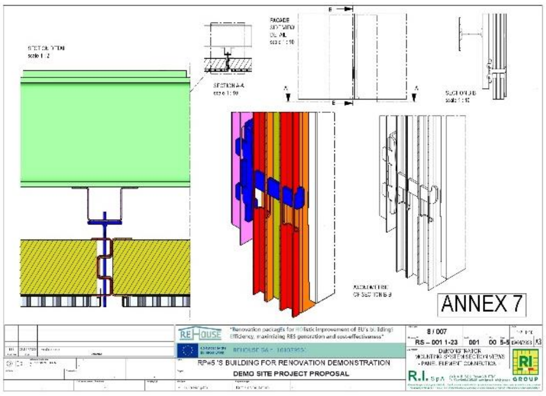




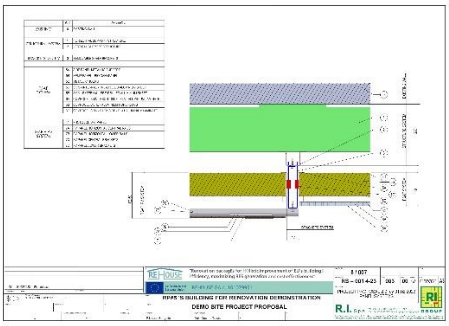


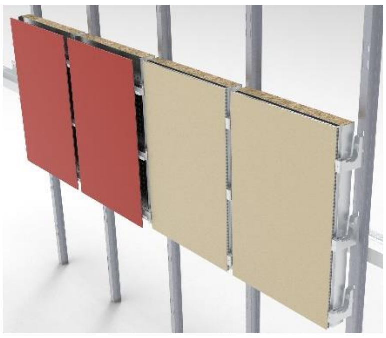


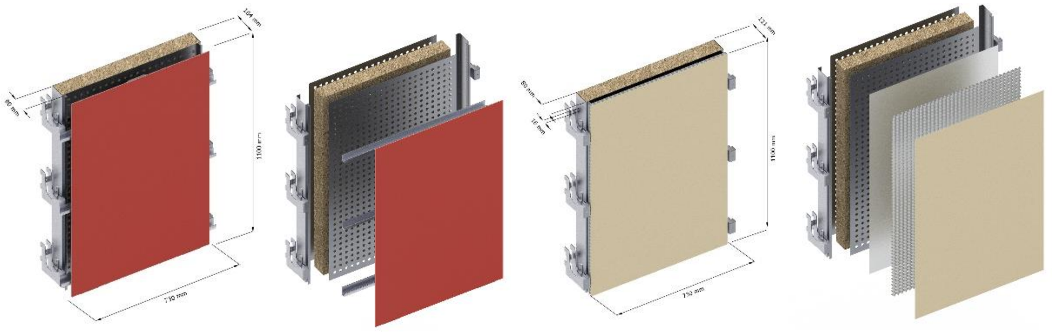
The revision 1.0 of the project proposal of MPF was consisting of the introduction of facing panels (initially made of aluminium honey comb core panels) and of the early study of solution's implementation for the whole demo building.



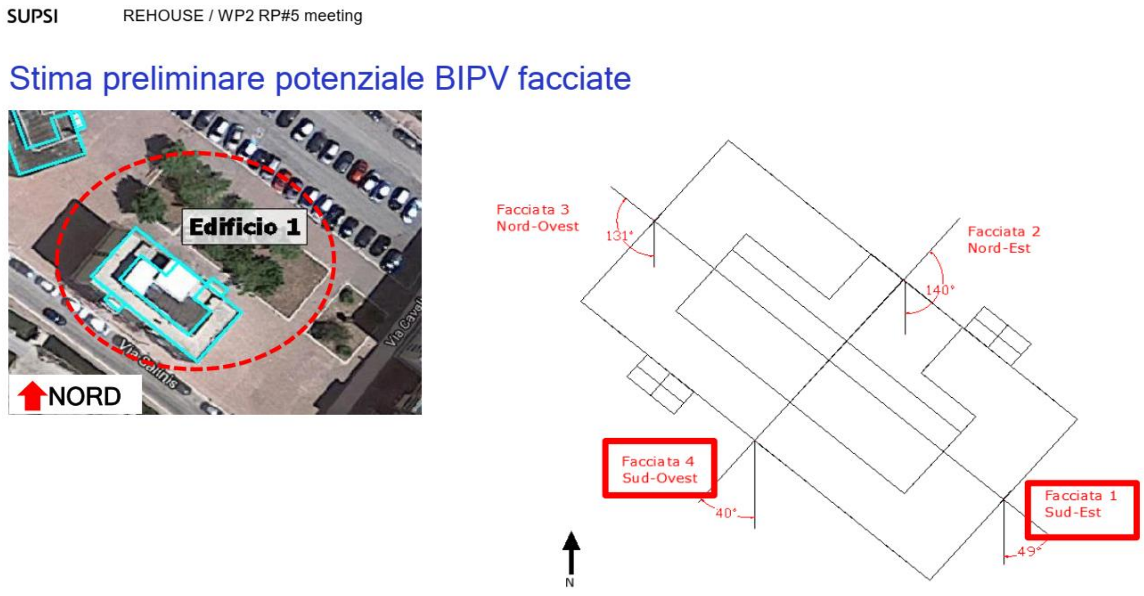
The revision 2.0 of the project proposal of MPF was consisting in implementation and integration of insulation hemp panels with BIPV panels and facing honeycomb panels, defining new wall supporting structure and supporting brackets and new lay-out of the panels.





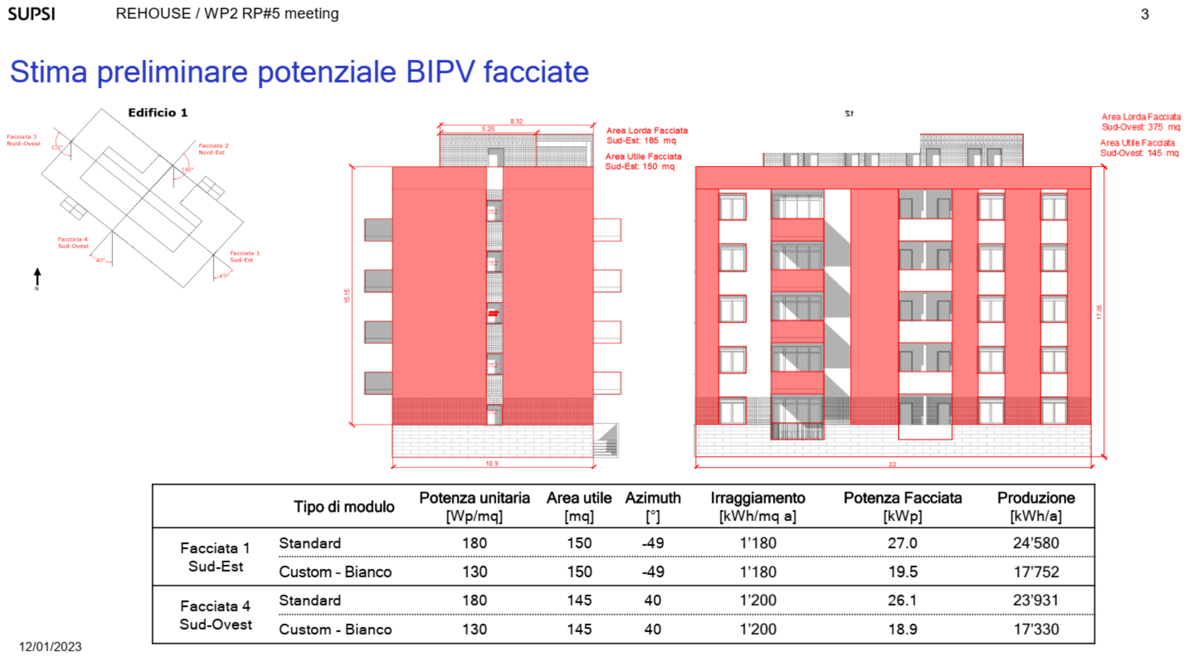


It was made an early evaluation (by SUPSI) of number and position of BIPV panel to achieve the KPI objectives



SUPSI REHOUSE / WP2 RP#5 meeting

Stima preliminare potenziale BIPV facciate



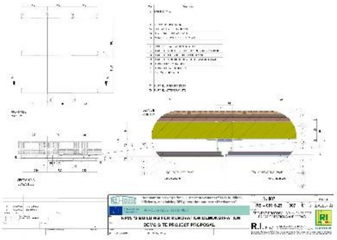
SUPSI REHOUSE / WP2 RP#5 meeting 3

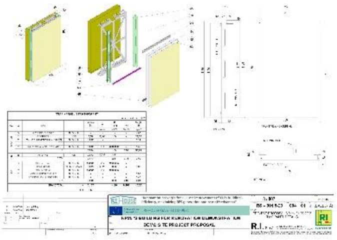
Stima preliminare potenziale BIPV facciate

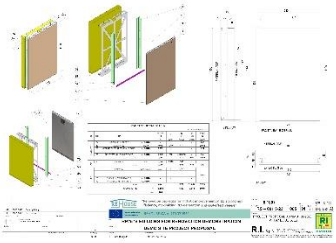
	Tipo di modulo	Potenza unitaria [Wp/mq]	Area utile [mq]	Azimuth [°]	Irraggiamento [kWh/mq a]	Potenza Facciata [kWp]	Produzione [kWh/a]
Facciata 1 Sud-Est	Standard	180	150	-49	1'180	27.0	24'580
	Custom - Bianco	130	150	-49	1'180	19.5	17'752
Facciata 4 Sud-Ovest	Standard	180	145	40	1'200	26.1	23'931
	Custom - Bianco	130	145	40	1'200	18.9	17'330

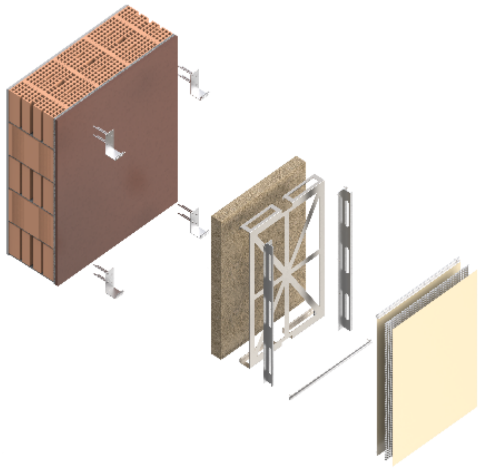
12/01/2023

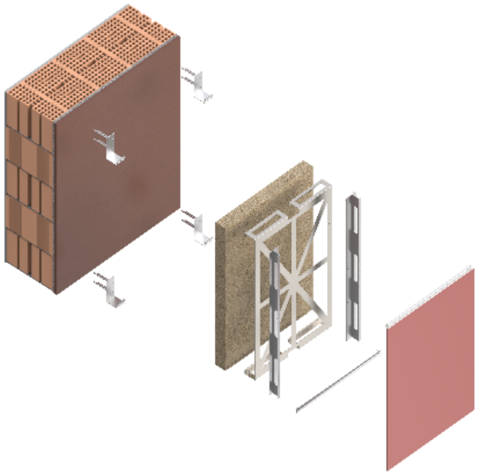
The revision 3.0 of the project proposal of MPF, due to necessity to ensure the complete performance of hemp insulation material, was consisting in the separation of the hemp from BIPV and facing honeycomb panels, to place hemp directly at contact with the wall building in a separate panel.



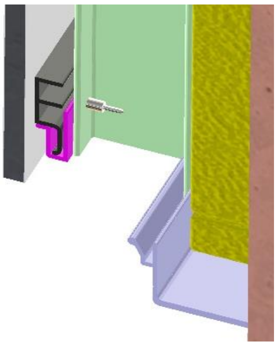


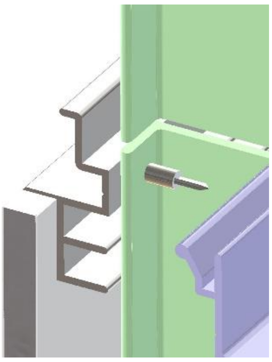




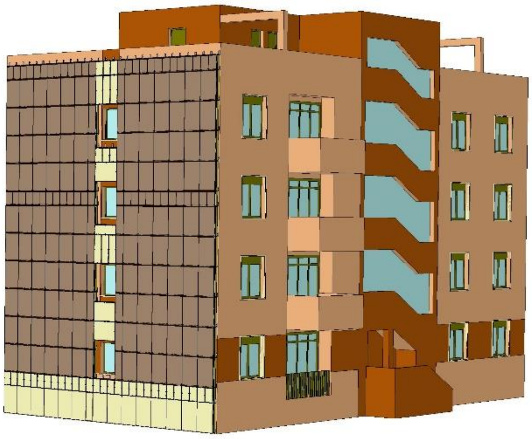


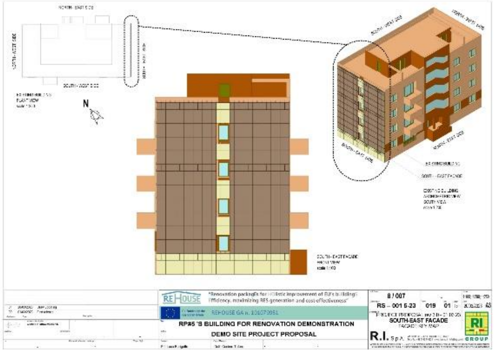
This bring to definition of a new concept and defintion of the project proposal: new supporting brackets to substitute the vertical wall structure, new panel structure, introduction of panel mounting system for facing and BIPV panels directly taken from the mounting system of the photovoltaic panels (SUNAGE Suncol Puzzle).





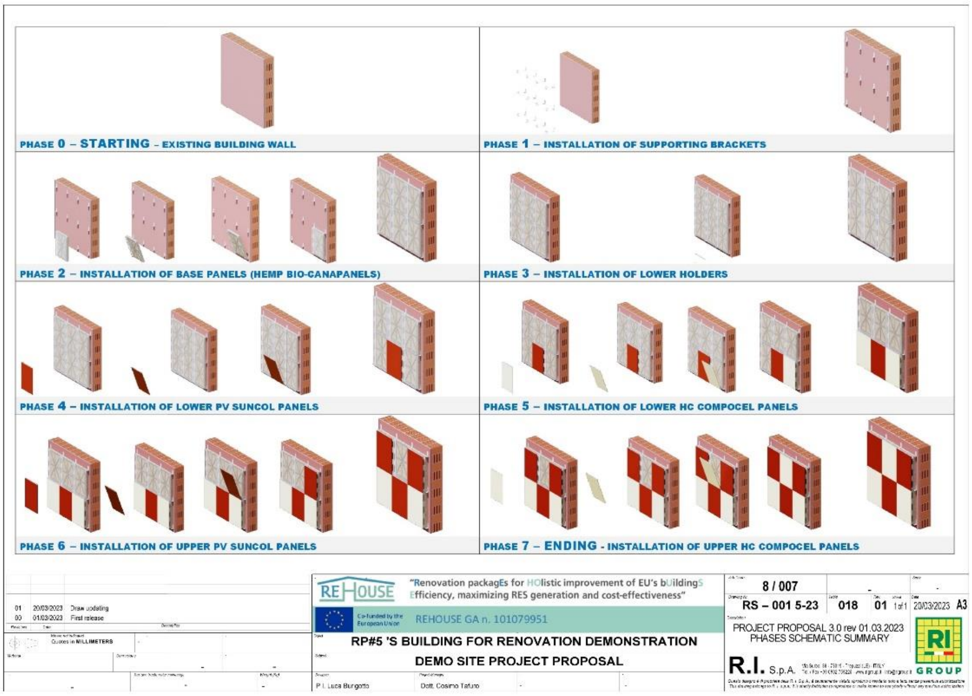
It was realized a complete 3D model of walls, to simulated the exact dimensions and consistencies of existing bricks walls of the demo building.





It was started the study of the new implemetation of MPF on demo building facades, to improove the energy production by the BIPV panels.

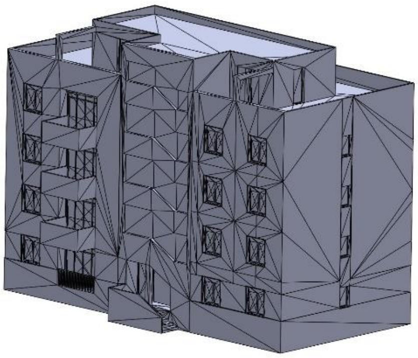
It was defined the complete sequency of assembly operations on demo building of all Msupporting brackets, insulation panels and facings / BIPV panels.

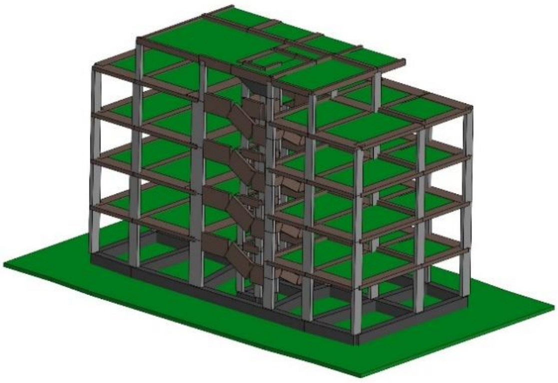


It was produced the BIM .ifc file of demo building correctly oriented with respect to the four cardinal directions

It was disseminated to partners for their activity and implementations.

At same time it was produced (by UNIBAS) the early BIM .ifc file of bearing structure of demo building



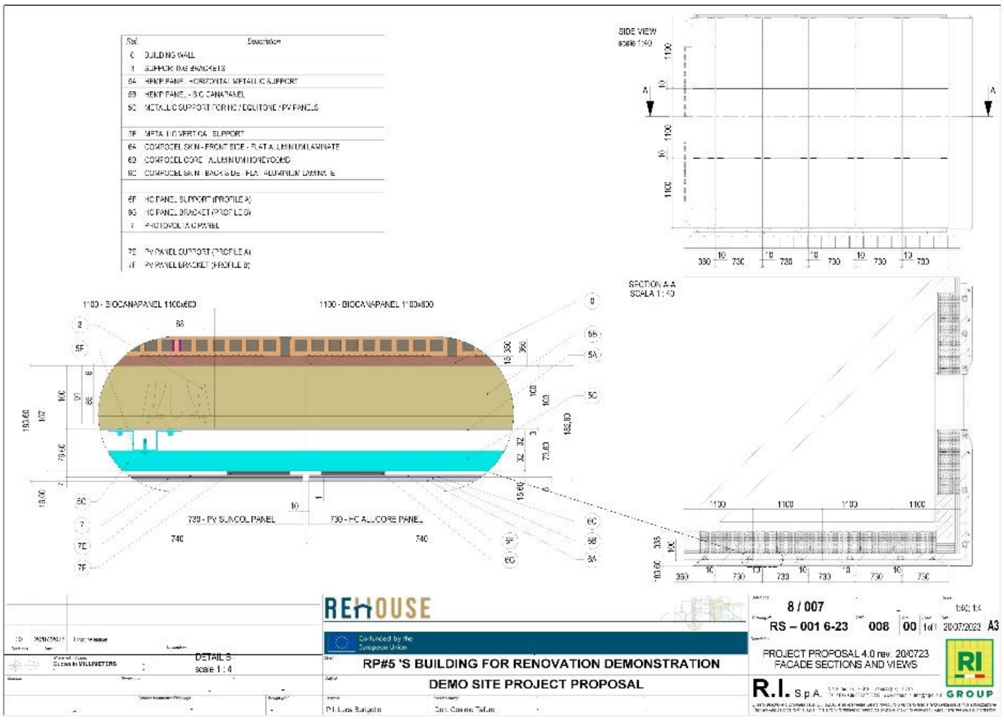


It was updated the evaluation of number and position (by SUPSI) considering different colors (then performances).

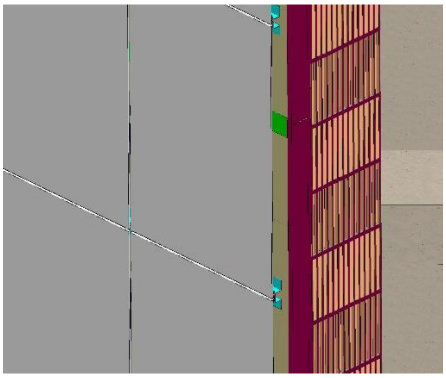
In the revision 4.0 of the project proposal of MPF, was definined a new solution for MPF.

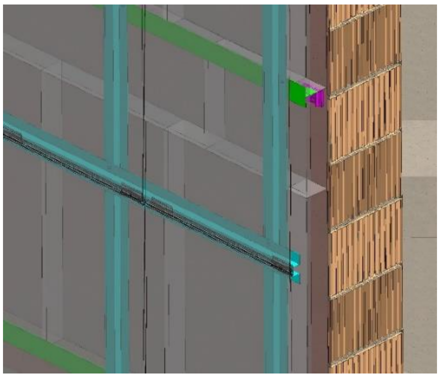
It aimed to further improve the performance of hemp and avoid leakage between this and wall.

So hemp lost any metal support (removing metal side and rear metal plate from hemp panels) and be mounted on horizontal structure, detached from the building wall to avoid thermal bridges, to ensure the complete contact of whole hemp inner surface to building wall.

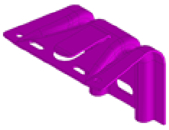


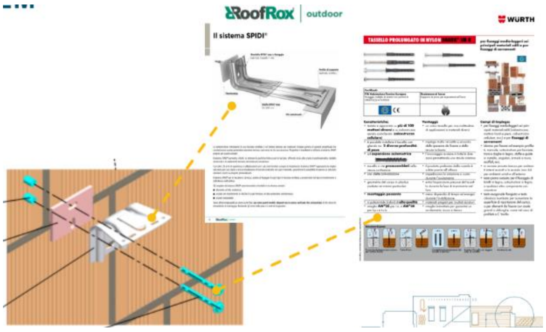
This resulted a new concept of MDF and beam structure and panels support system.



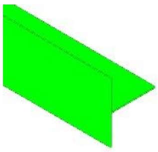


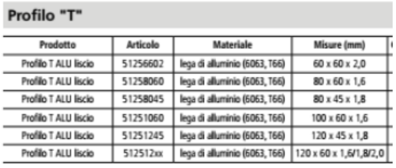
It is made of aluminum supporting brackets fixed to wall building by means of screw with dowel.





Installed on brackets, are horizontal aluminum “T” profiles, that are the inner part of MPF beam structure and support of hemp panels.

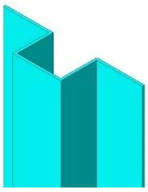


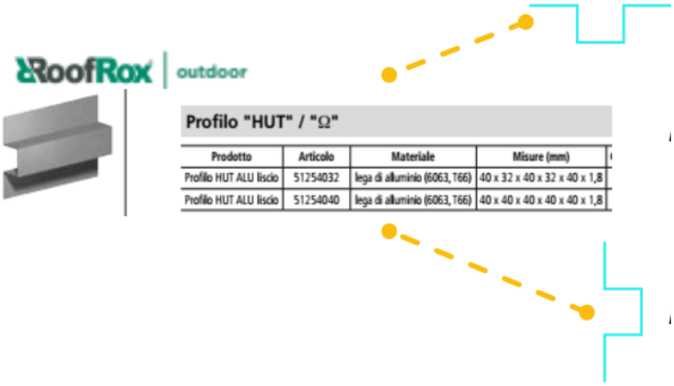


Profilo "T"

Prodotto	Articolo	Materiale	Misure (mm)
Profilo T ALU liscio	51256602	lega di alluminio (6063, T66)	60 x 60 x 2,0
Profilo T ALU liscio	51258060	lega di alluminio (6063, T66)	80 x 60 x 1,6
Profilo T ALU liscio	51258045	lega di alluminio (6063, T66)	80 x 45 x 1,8
Profilo T ALU liscio	51251060	lega di alluminio (6063, T66)	100 x 60 x 1,6
Profilo T ALU liscio	51251245	lega di alluminio (6063, T66)	120 x 45 x 1,8
Profilo T ALU liscio	512512xx	lega di alluminio (6063, T66)	120 x 60 x 1,6/1,8/2,0

The middle part of MPF beam structure is a series of vertical aluminum “HUT” profiles, for supporting of outer beam structure.

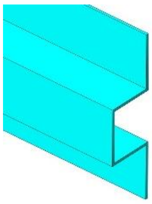




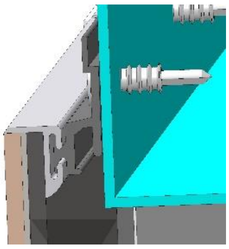
Profilo "HUT" / "Ω"

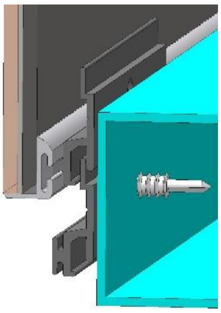
Prodotto	Articolo	Materiale	Misure (mm)
Profilo HUT ALU liscio	51254032	lega di alluminio (6063, T66)	40 x 32 x 40 x 32 x 40 x 1,8
Profilo HUT ALU liscio	51254040	lega di alluminio (6063, T66)	40 x 40 x 40 x 40 x 40 x 1,8

The outer part of MPF beam structure is a series of horizontal aluminum “HUT” profiles, for supporting of facing and BIPV panels.



Those also integrated the new panel fixing system of PV panels (devoleped by SUNAGE) used for BIPV and facing panel.





Fiber cement EQUITONE Tectiva panels replaced aluminum honey comb panels, thanks to their better performances for LCA, more external colours options and better external appearance.

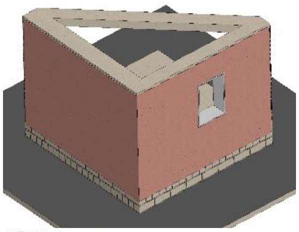
Benefici

- resistenza al fuoco (non si infiammano, non propagano il fuoco)
- isolamento acustico
- resistenza alle temperature estreme e al gelo
- resistenza all'acqua (se installato in conformità alle linee guida di installazione)
- resistenza a molti organismi viventi (funghi, batteri, insetti, insetti, parassiti, ecc.)
- resistenza a molti prodotti chimici
- ecosostenbile, nessuna emissione di gas nocivi
- solidità e leggerezza
- **Finitura:** Linee di levigatura fine
- **Aspetto:** Asciutto, vivace, dinamico
- Differenze cromatiche naturali, che possono essere accentuate dall'orientamento del pannello, dall'angolo di visione e dagli effetti della luce e dell'umidità

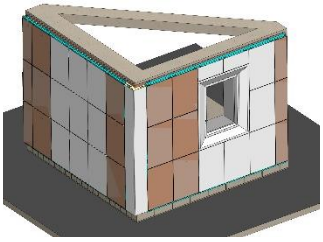
Qual è la classificazione di reazione al fuoco di EQUITONE e che cosa significa esattamente?

Materiale	Reazione al fuoco	Produzione di fumo	Formazione di gocce/particelle ardenti
EQUITONE [linea]	A2	s1	d0
EQUITONE [tectiva]	A2	s1	d0

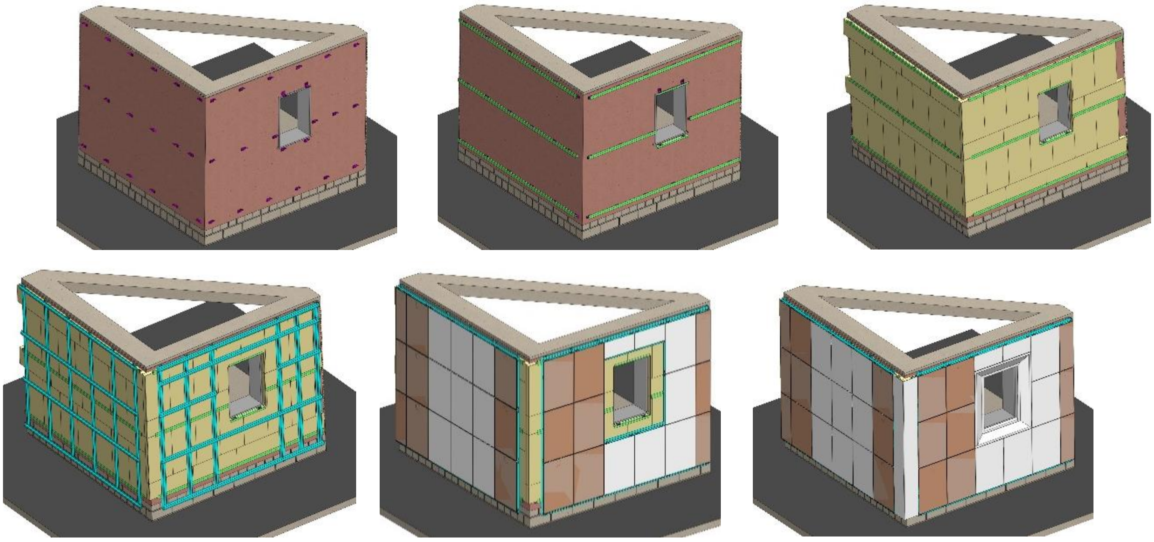
To verify in advance performances of MPF and its beam structure, it was defined to realize a new mock-up made of concrete beam structure, wall and etc. having the same type of materials and manufactured at same way of the beam structure and walls of demo building, replicating a part of its South-West side.



On that would be installed a reproduction of complete MPF to check materials and installation operations.



It was defined the early sequence of installation operations.

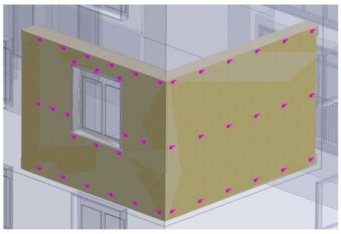


The revision 4.1 is the evolution of previous, where the main difference is the mock-up to be realized directly on demo building on a part of a its side.

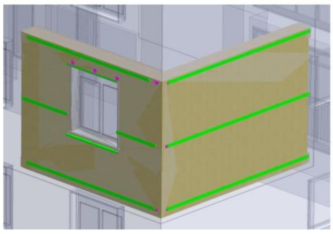
After site inspections, when were identified the existing obstacles (electrical cables, gas pipes, etc.) for the installation of mock-up, it was defined to install it on the corner between north-west and south-east sides of demo building.

It was started the defintion and the commercial research for worksite realization.

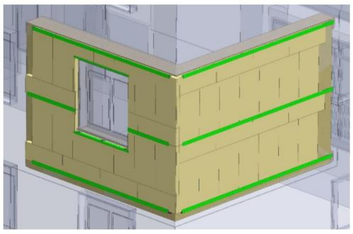
It was update the sequence of installation operations.



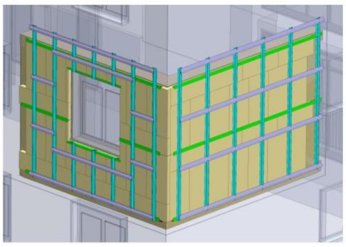
1. Fixing supporting BRACKETS



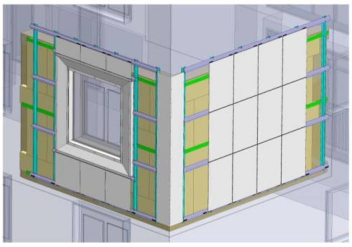
2. Installation of Inner horizontal T-profiles



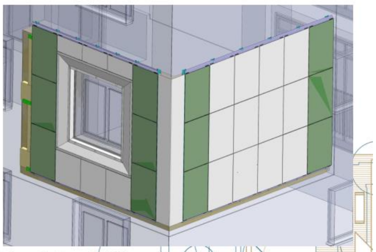
3. Installation of Hemp BIOCANAPANEL



4. Installation of Middle vertical and Outer horizontal HUT-profiles

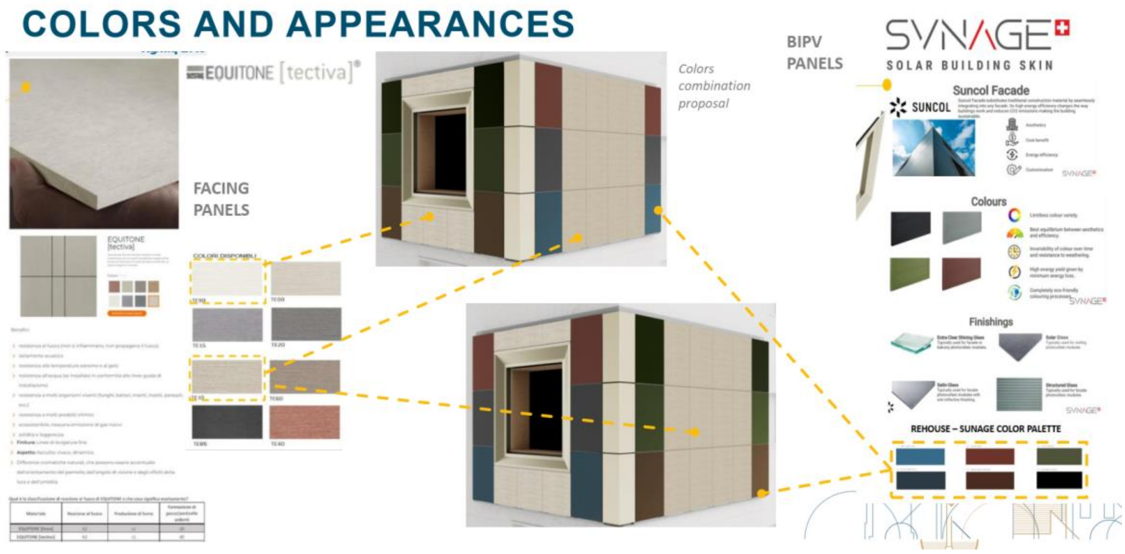


5. Installation of FACING panels and corner and window CASINGS

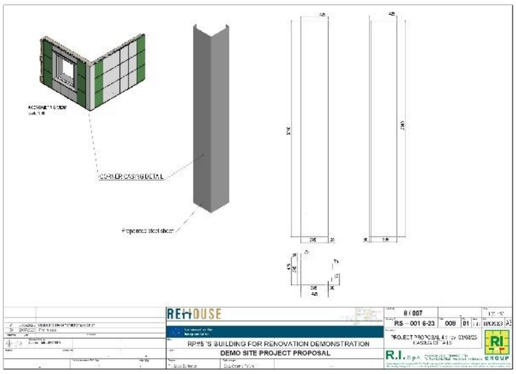


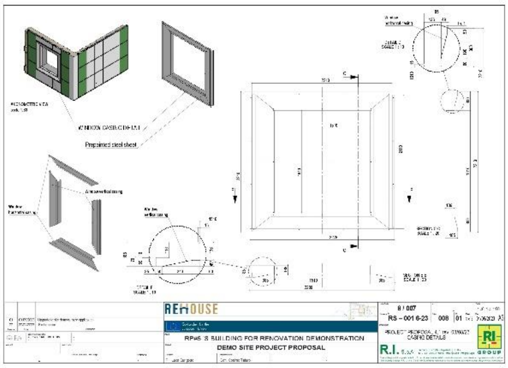
6. Installation of BIPV panels

It was defined the appearance of facing and BIPV panels.

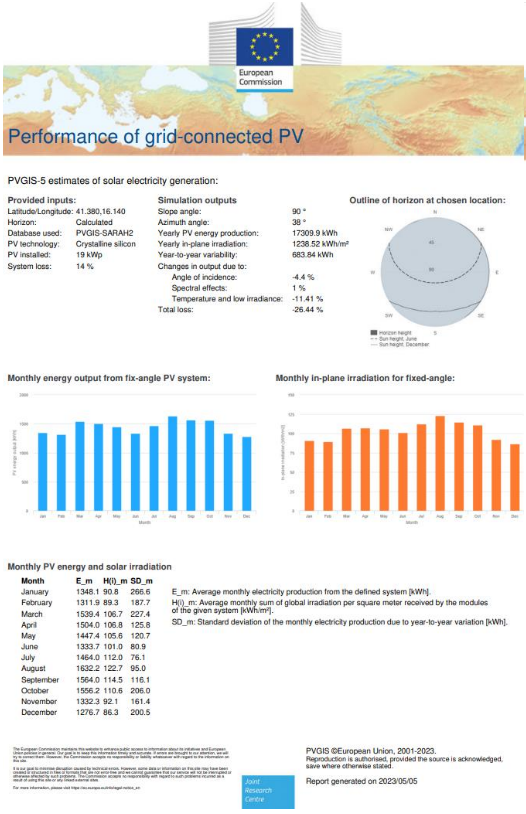


They were defined dimensions and installation operations of MPF casing.





It was made an analysis and evalutaion of performance of BIPV panels considering positions of Demo Building, and its sun expositions and seasons changing.



European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

Latitude/Longitude:	41.380,16.140
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	19 kWp
System loss:	14 %

Simulation outputs

Slope angle:	90 °
Azimuth angle:	38 °
Yearly PV energy production:	17309.9 kWh
Yearly in-plane irradiation:	1238.52 kWh/m²
Year-to-year variability:	683.84 kWh
Changes in output due to:	
Angle of incidence:	-4.4 %
Spectral effects:	1 %
Temperature and low irradiance:	-11.41 %
Total loss:	-26.44 %

Outline of horizon at chosen location:

Monthly energy output from fix-angle PV system:

Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	1348.1	90.8	266.6
February	1311.9	89.3	187.7
March	1539.4	106.7	227.4
April	1504.0	106.8	125.8
May	1447.4	105.6	120.7
June	1333.7	101.0	80.9
July	1464.0	112.0	76.1
August	1632.2	122.7	95.0
September	1564.0	114.5	116.1
October	1556.2	110.6	206.0
November	1332.3	92.1	161.4
December	1276.7	86.3	200.5

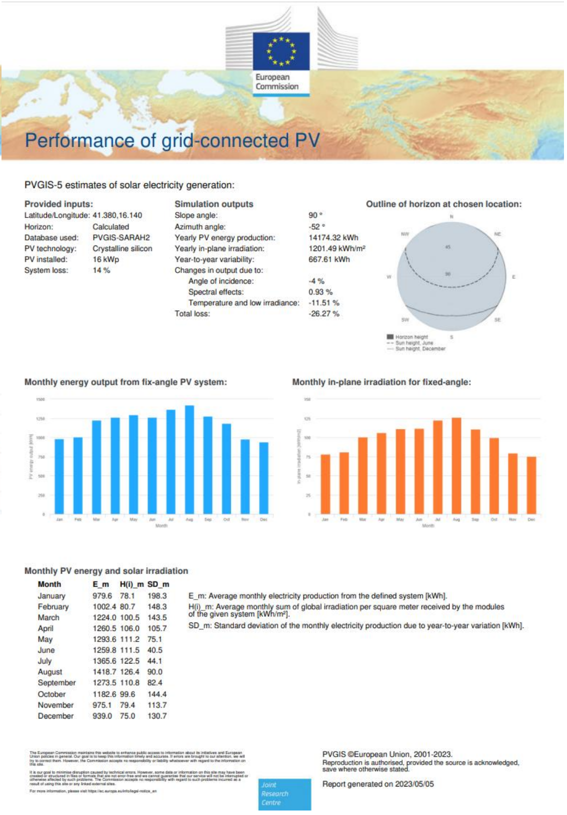
E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Joint Research Centre

Report generated on 2023/05/05



European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

Latitude/Longitude:	41.380,16.140
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	16 kWp
System loss:	14 %

Simulation outputs

Slope angle:	90 °
Azimuth angle:	-52 °
Yearly PV energy production:	14174.32 kWh
Yearly in-plane irradiation:	1201.49 kWh/m²
Year-to-year variability:	667.61 kWh
Changes in output due to:	
Angle of incidence:	-4 %
Spectral effects:	0.93 %
Temperature and low irradiance:	-11.51 %
Total loss:	-26.27 %

Outline of horizon at chosen location:

Monthly energy output from fix-angle PV system:

Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	979.6	78.1	198.3
February	1002.4	80.7	148.3
March	1224.0	100.5	143.5
April	1260.5	106.0	105.7
May	1293.6	111.2	75.1
June	1259.8	111.5	40.5
July	1365.6	122.5	44.1
August	1418.7	126.4	90.0
September	1273.5	110.8	82.4
October	1182.6	99.6	144.4
November	975.1	79.4	113.7
December	939.0	75.0	130.7

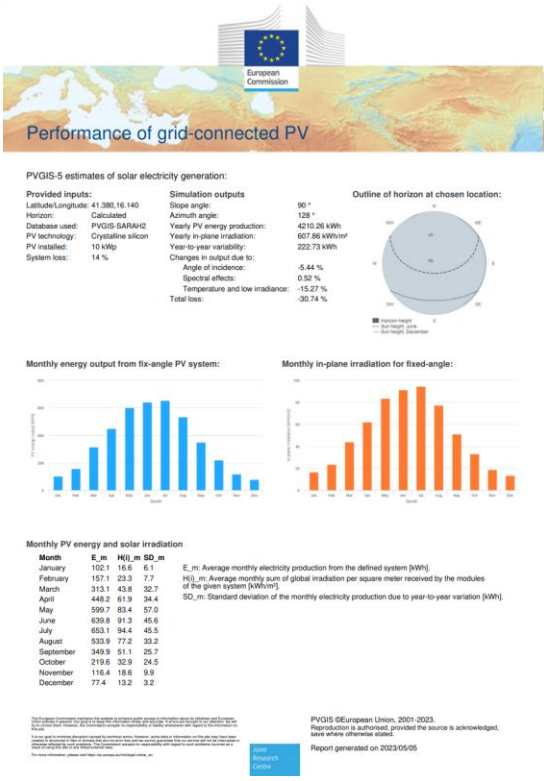
E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Joint Research Centre

Report generated on 2023/05/05



European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

Latitude/Longitude:	41.380,16.140
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	10 kWp
System loss:	14 %

Simulation outputs

Slope angle:	90 °
Azimuth angle:	128 °
Yearly PV energy production:	4210.26 kWh
Yearly in-plane irradiation:	607.86 kWh/m²
Year-to-year variability:	222.73 kWh
Changes in output due to:	
Angle of incidence:	-5.44 %
Spectral effects:	0.52 %
Temperature and low irradiance:	-15.27 %
Total loss:	-30.74 %

Outline of horizon at chosen location:

Monthly energy output from fix-angle PV system:

Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	102.1	16.6	6.1
February	157.1	23.3	7.7
March	313.1	43.8	32.7
April	448.2	61.9	34.4
May	599.7	83.4	57.0
June	639.8	91.3	45.6
July	653.1	94.4	45.5
August	533.9	77.2	33.2
September	349.9	51.1	25.7
October	219.6	32.9	24.5
November	116.4	18.6	9.9
December	77.4	13.2	3.2

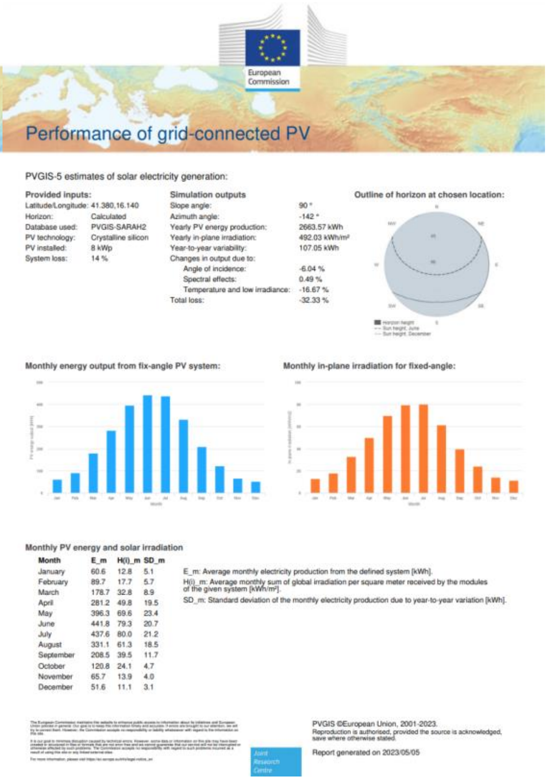
E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Joint Research Centre

Report generated on 2023/05/05



European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

Latitude/Longitude:	41.380,16.140
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	8 kWp
System loss:	14 %

Simulation outputs

Slope angle:	90 °
Azimuth angle:	-142 °
Yearly PV energy production:	2663.57 kWh
Yearly in-plane irradiation:	492.03 kWh/m²
Year-to-year variability:	107.05 kWh
Changes in output due to:	
Angle of incidence:	-6.04 %
Spectral effects:	0.49 %
Temperature and low irradiance:	-16.67 %
Total loss:	-32.33 %

Outline of horizon at chosen location:

Monthly energy output from fix-angle PV system:

Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	60.6	12.8	5.1
February	89.7	17.7	5.7
March	178.7	32.8	8.9
April	281.2	49.8	19.5
May	396.3	69.6	23.4
June	441.8	79.3	20.7
July	437.6	80.0	21.2
August	331.1	61.3	18.5
September	208.5	39.5	11.7
October	120.8	24.1	4.7
November	65.7	13.9	4.0
December	51.6	11.1	3.1

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

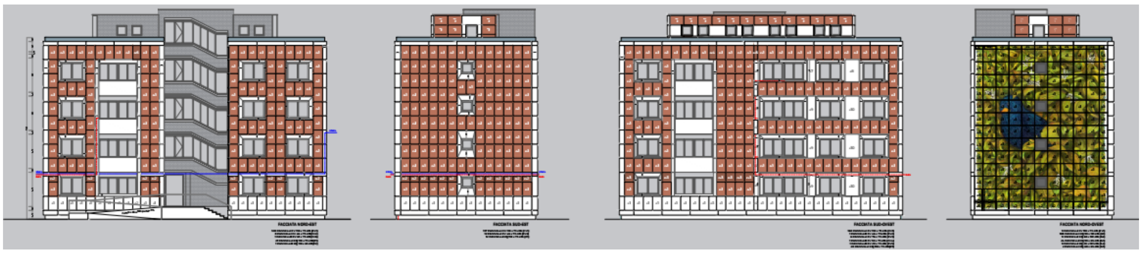
Joint Research Centre

Report generated on 2023/05/05

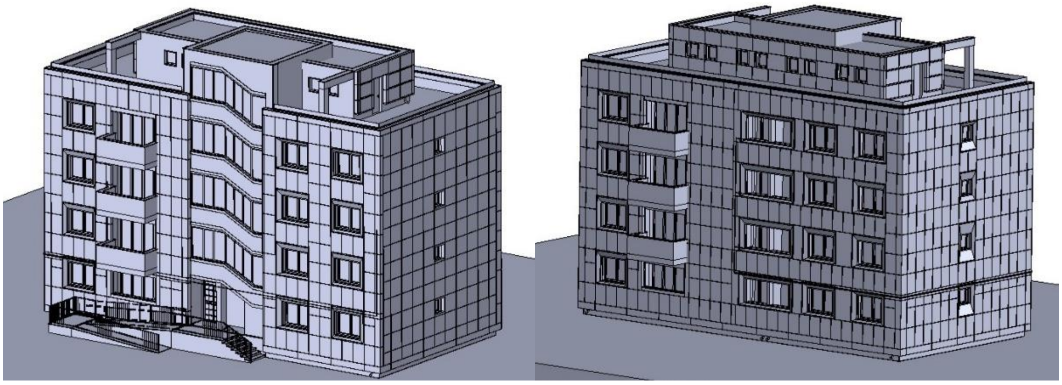
This revision was applied to all sides of the complete demo building, to obtain quantity and dimensions of MDF material to get.

At this time, the project manager (Arch. T. Bibbò), nominated by ARCA, made the detection of effective real dimensions and positions of demo building constituent parts, obtaining the new BIM model of demo building.

On the base of this BIM Model he realized the definitive appearance of MPF (positions and colors of BIPV and facing panels), that consider number and position of BIPV to respect the related KPI.



Actually the project proposal is focused to apply the new demo building model and MPF configuration for the definition of dimensions and quantity of support structure, facing panels and casing elements, finalized to obtain costs and time of manufacturing.



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6.2 SIMULATIONS/ ASSESSMENTS OF DEMO SITES

Each of the subsequent sub-chapters was independently developed as a separate report, resulting in unique numbering for equations and references within each chapter, as explicitly presented at the end of each individual report. However, it's noteworthy that the numbering of figures and tables follows the sequential order of the entire document.

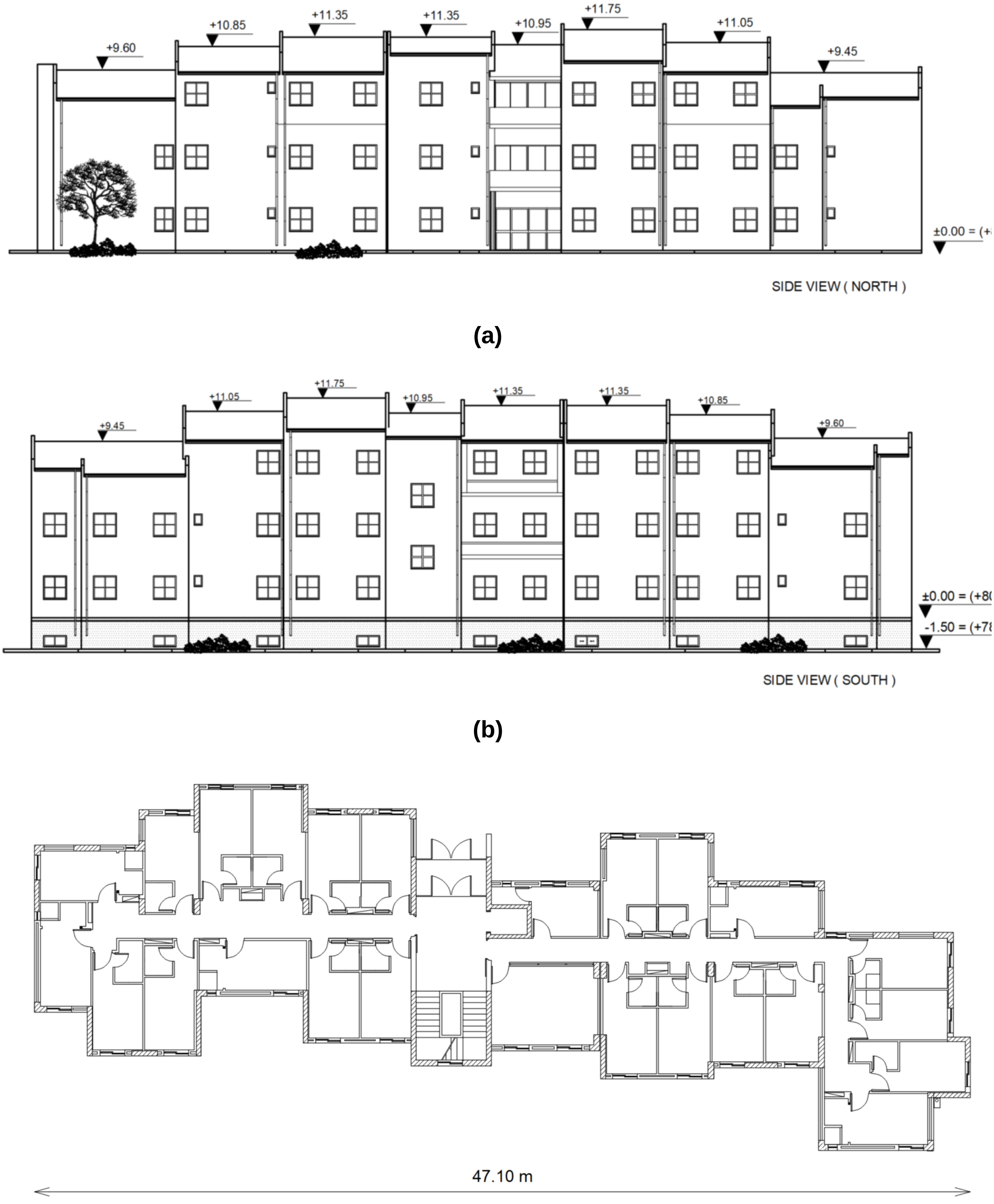
6.2.1 GREEK DEMO

The Greek Demo refers to a students' dormitory building inside the Democritus University of Thrace (DUTH) Campus built in 1997. The demo site is located at Kimmeria municipality, close to the city of Xanthi in the region of Thrace. The building's specific location coordinates consist of 41.1468407º latitude and 24.9140676º longitude. Moreover, the present analysis emphasizes the study of the dormitory block named 'Building C2' which is just a part of the total campus area. Figure 97 depicts a satellite photo of the Campus area taken from Google Maps, which contains 8 buildings including the examined building highlighted with a red cycle. Figure 98 depicts real photographs of the examined demo site, one from the north entrance and one from the east side. The design drawings and construction plans of the present building were used as a basis for the estimation of the building's geometrical dimensions. Drawings of the building in CAD are demonstrated in Figure 99 and more specifically, the north façade, the south facade and the ground floor top view are illustrated.

Figure 97. The examined demo inside the University Campus

(a) **(b)**

Figure 98. Images of the examined building (a) North side – entrance of the building, (b) East side of the building



(c)

Figure 99. Cad drawings of the Greek demo (a) Front north façade, (b) Back south façade (c) Top view of the ground floor

6.2.1.1 ENERGY SIMULATION (INTEMA.BUILDING)

6.2.1.1.1 BASELINE SCENARIO ANALYSIS

The present building houses 62 residents living in separate rooms of the dormitory block. All the rooms use radiators to cover their heating needs with a predefined operating program (6 hours per day during the winter period). Thus, all the rooms together can be assumed to be in the same thermal zone. This is a justified and reasonable assumption in accordance with Greek legislation [1]. The building's total floor area was estimated at 1371 m^2 and the net common area at about 334 m^2 according to the drawings. The inclined roof is split into two parts, one in the south and one in the north direction with a 15^o slope.

Table 20 includes the basic structural components of the examined building and their composition. The ground floor is an uninsulated element that is located over the basement. This component has a nominal U-value of 3.1 W/m^{2}K according to the Greek technical guidelines [1]. In the present simulation, the basement is an unheated area and thus it is not taken into consideration. For this case, the Greek technical guidelines indicate that the equivalent U-value of the ground floor is approximately 2.0 W/m^{2}K [1] in order to incorporate the presence of air inside the basement in the boundary conditions evaluation. The external walls are reinforced with a thin insulation layer of some centimetres and for this case, the U-value is estimated to be 1.05 W/m^{2}K, including the respective thermal bridges [1]. As far as the roof is concerned, the total thermal transmittance is estimated at 1.25 W/m2K [1] including in the calculations of the effect of thermal bridges. The present building’s glazing system consists of double-pane windows with a U-value of 4.2 W/m^{2}K including the glazing, frame and thermal bridge effects.

Table 20. Description of the basic structural components of the building

Structural elements	Materials	Thickness (mm)	U-value (W/m^{2}K)
Ground and Inner Partition floor	Concrete, mortar, ceramic tiles	26	3.10
External walls	Plaster, Insulation, Concrete	34	1.05
Roof	Plaster, Concrete, Insulation, cement mortar	35	1.25
Windows	Double-glazed with aluminium frame	30	4.20

Table 21 includes basic information regarding the detailed description of the examined building. The absorbance of the opaque structural elements was estimated at 60% and the emittance at 80% which are typical values according to [1]. As far as the windows are concerned, the emittance value is estimated at 90% and the g-value at 80%. The Table 21 includes the external structural elements measured in different directions. It is mentioned, that the present building has windows in all directions with the widest opening areas standing for the south and north-oriented façades.

Table 21. Basic data for the description of the examined building

Parameters	Values
Gross total floor area (ground, 1st and 2nd)	1371 m^2
Net total floor area (ground, 1st and 2nd)	1177 m^2

Parameters	Values
Net total common area (ground, 1st and 2nd)	334 m^2
Area of the south wall	374 m^2
Area of the west wall	259 m^2
Area of the north wall	370 m^2
Area of the east wall	248 m^2
Area of the south roof	275 m^2
Area of the north roof	251 m^2
Slope of the south roof	15^o
Slope of the north roof	15^o
Area of the south windows	61 m^2
Area of the west windows	4 m^2
Area of the north windows	72 m^2
Area of the east windows	10 m^2
Opaque element absorbance	60%
Opaque element emittance	80%
Window g-value	80%
Window emittance	90%

The next step is the description of extra parameters that are correlated with the operation of the building and play a significant role in its thermal behavior. Table 22 includes the parameters for the internal loads and for the infiltration/ventilation loads. It has to be commented that the specific loads are given per gross area which is 1371 m^2. The mean operating factors were estimated according to the usual occupancy of the building. Moreover, it is useful to state that the daily operating profile of the building follows the profile of Figure 100 which has been taken by Ref. [2]. The infiltration and natural ventilation rates were selected at 0.4 and 0.3 air changes per hour (ACH) respectively which are appropriate values for the examined demo and in accordance with the Greek regulations [1].

Table 22. Operating parameters of the examined building

Parameter	Value
Number of occupants	62
Thermal load of the occupants	80 W/occupant
Mean operating fraction of the occupants (%)	67
Specific lighting electrical load (W/m^2)	7
Mean operating fraction of the lighting (%)	19
Specific appliances electrical load (W/m^2)	10
Mean operating fraction of the appliances (%)	35

Parameter	Value
Infiltration rate	0.4 ACH
Natural ventilation rate	0.3 ACH

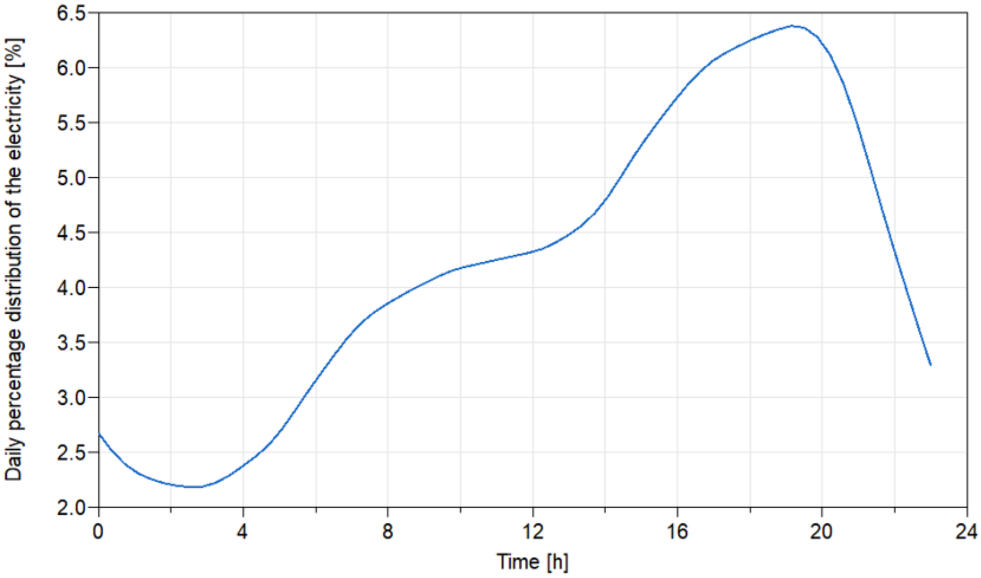


Figure 100. Daily distribution of the electrical energy consumption of the building [2]

6.2.1.1.1.1 BASELINE SCENARIO - DESCRIPTION OF THE ENERGY SYSTEMS

The examined building is the C2 Building of the campus, while the campus includes 8 residential buildings. There is a hybrid solar-biomass system for covering the space heating and domestic hot water (DHW) needs of the campus. There is also, a PV system installed on its roof for covering a part of its electrical needs, mainly for DHW. There is no cooling system because there are no important cooling loads in this demo and also its occupancy is reduced during the summer period.

Systems basic description

The solar field of the present demo includes flat plate collectors coupled with a thermal storage tank. There is a biomass-fuelled boiler in line with the previous system to provide extra thermal energy for achieving the desired temperature level of 75ºC. Inside the building, radiators exist as terminal units to provide space heating to the rooms. The radiators' operation schedule is divided into three two-hour periods each day during the heating season. Specifically, radiators operate from 7:00 to 9:00, from 14:00 to 16:00, and from 20:00 to 22:00. In addition, the building is equipped with an auxiliary storage tank that stores hot water for covering the DHW needs. The DHW tank includes also a thermal resistance with a nominal power of 8 kW for increasing the hot water temperature at the desired limits. This thermal resistance is supplied by the PVs which are arranged on the roof of the building. The resistance schedule is divided into three hours of operation in the morning (9:00 – 12:00) and three hours of operation in the afternoon (19:00 – 22:00) accordingly. The PVs are located on the roof facing the south direction with a slope of 15º and there is a battery system for storing the electrical production. The PVs are not connected to the grid and so they are used only for self-consumption, while there is a battery storage system for storing the electricity properly.

Solar field and thermal storage tank

The examined demo (Building C2) is responsible for about 13% of the total campus thermal loads (assuming proportional loads to the area) and thus the respective percentages of the solar field area and the storage tank volume were assumed to be devoted to the present demo. After these adjustments, the solar field area for the examined demo is 243 m^2 and the respective thermal storage tank (Tank-1) has a volume of 5.2 m^3. The solar thermal collector is a selective flat plate collector and its efficiency can be described with a second-order formula. Table 23 includes the basic information regarding the solar thermal field and the storage tank[12].

Table 23. Parameters of the solar field and the Tank-1

Parameter	Value
Total collecting area	243 m^2
Collector module area	2.58 m^2
Collector tilt angle	45^o
Collector azimuth angle	0^o (south)
Zero-order collector efficiency coefficient (a_0)	0.79
First-order collector efficiency coefficient (a_1)	3.342 W/m^2K
Second-order collector efficiency coefficient (a_2)	0.016 W/m^2K^2
Incident angle modifier at 50^o incident angle	0.89
Thermal storage tank volume	5.2 m^3
Insulation thickness of the storage tank	10 cm

Biomass boiler

A biomass-fuelled boiler is applied to the present heating system adding thermal energy to the hot water that leaves the solar thermal storage tank (Tank-1). The biomass boiler heats the water to 75^{o}C which is a sufficient temperature to balance the building's thermal needs. The seasonal efficiency of the boiler is 85% while the distribution of thermal losses is estimated to be 16% due to the piping system. The selected biomass is in the form of pellets with a lower heating value of 18000 kJ/kg. In the present analysis, the total nominal capacity of the system was selected to be used and so it was selected at 250 kW by taking into account that the present simulation examines only one building and not all the campus. Table 24 includes the basic simulation data regarding the biomass boiler system.

Table 24. Parameters of the biomass boiler

Parameter	Value
Nominal capacity	250 kW
Boiler nominal efficiency	85%
Distribution of thermal losses from the piping system	16%
Water temperature at the boiler outlet	75^{o}C
Biomass type	Pellet
Biomass lower heating value	18000 kJ/kg

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[12] B. Bueno, M. Street, T. Pflug, and C. Braesch, 'A co-simulation modelling approach for the assessment of a ventilated double-skin complex fenestration system coupled with a compact fan-coil unit', Energy and Buildings, vol. 151, pp. 18–27, Sep. 2017, doi: 10.1016/j.enbuild.2017.04.029

DHW system

The domestic hot water needs of the residence are covered by a separate DHW tank (Tank-2) which is located in the basement of the building. The tank volume is 2 m^3 and it is used to store thermal energy deriving from the central system. An internal pipe heat exchanger is then implemented in order to transfer heat from the central system into the DHW tank. In addition, the tank includes a thermal resistance of 8 kW increasing its thermal energy according to an operating schedule during the day. This schedule operates for 3 hours in the morning and for three hours in the afternoon and it is given from the PV-battery system. The DHW temperature set point of 45^{o}C and the occupants' specific daily demand of 50 L per person is selected according to Greek legalization [1]. A typical profile representing the daily hot water demand distribution is shown in Figure 101 in compliance with Ref. [4]. The tap water coming from the network has an annual mean temperature of around 16^{o}C, while the maximum is 23.8^{o}C in August and the minimum is 8.3oC in January. The mean tap water temperature deviation per month is given in Table 25. The summary of the details referring to the DHW is given in Table 26.

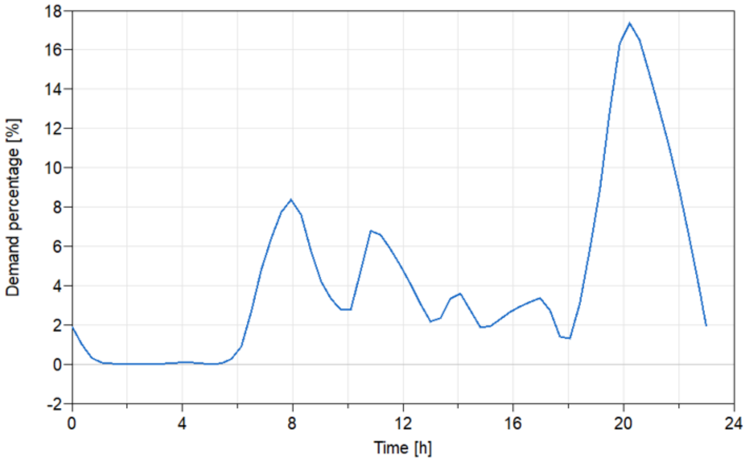


Figure 101. Daily dimensionless distribution of the hot water quantity demand [4]

Table 25. Grid mean monthly water temperature for the examined location [1]

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T(^{o}C)	8.3	8.4	9.7	12.8	16.6	20.4	22.8	23.8	22.6	19.7	15.3	11.0

Table 26. Parameters of the DHW system (Tank-2)

Parameter	Value
Storage tank capacity	2 m^3
Capacity of the electrical resistance	8 kW
Daily DHW specific demand	50 L/person
DHW desired temperature	45^{o}C
Number of residents	62
Mean yearly grid water temperature	16^{o}C

PV-battery system

The examined building has photovoltaic (PV) installed on its roof. A total area of 365 m^2 of PV cells is installed, oriented to the south with a tilt angle equal to the roof's angle (15^o). The PV module is the Suntech STP260-20Wd module [5] which has an area of 1.63 m^2 per panel with a nominal electrical efficiency of 16%. Moreover, there is an electrical storage system with Lead-acid batteries of 11.3 kAh pack nominal capacity [6]. The inverter of the system is the SMA Sunny Island with an efficiency of around 95% [7]. The PV-battery system is an off-grid system sufficient for the electrical load balancing of the building (self-consumption). More specifically, it balances lighting loads for the public spaces and heating loads for the DHW tank electrical resistance. According to previous studies [3], this system is slightly oversized in order to ensure that the battery is always charged and the aforementioned loads are 100% met. Table 27 summarizes the respective data.

Table 27. Parameters of the PV-batteries system

Parameter	Value
Total PV area	365 m^2
PV module area	1.63 m^2
Number of cells per module	60
PV tilt angle	15^o
PV azimuth angle	0^o (south)
Nominal electrical efficiency	16%
Temperature Coefficient of P_{max}	-0.43 %/°C
Temperature Coefficient of V_{oc}	-0.33 %/°C
Temperature Coefficient of I_{sc}	0.067 %/°C
Inverter efficiency	95%
Battery pack nominal capacity	11.3 kAh
Battery pack nominal voltage	48 V
Battery pack nominal energy capacity	542 kWh

6.2.1.1.1.2 BASELINE SCENARIO – SIMULATION RESULTS

The simulation of the baseline scenario is conducted by using the INTEMA.building tool. The simulation period is an entire year and the simulation time step is adjustable and variable using the Dassl solver with 10^{-4} tolerance. The layout of the energy system of the building for both space heating and DHW is depicted in Figure 102. More specifically, this system includes a solar thermal field with flat plate collectors coupled to a thermal storage tank (Tank-1), a biomass boiler, radiators for space heating production and a thermal storage tank (Tank-2) for DHW.

Firstly, it has also to be stated that the heating period was assumed to be from 15 October up to 15 April, which is the usual heating period in Greece. The hot water leaves the biomass boiler with a temperature of around 75^{o}C and then it is separated into two quantities, one for feeding the radiators and one for feeding the DHW tank. The first quantity is used in the radiators for covering the proper heating load into the building, while the second quantity feeds Tank-2 for keeping its temperature around 50^{o}C to cover the DHW needs. There is also an auxiliary electrical resistance, which is fed by the PV, which gives extra thermal energy in Tank-2 when it is needed. It is useful to state that the temperature at the radiators' inlet is lower, compared to 75^{o}C due to the thermal losses in the piping system (Pipe 2). Finally, the two water quantities are mixed before they return to Tank-1 through "Pipe 1".

The system is controlled with proper controllers in different locations in order to keep the temperature level inside the building and Tank-2 at the desired temperature levels. More specifically, the boiler operates according to the radiator’s operation schedule (7:00-9:00, 14:00-16:00, and 20:00-22:00) and only when the water outlet temperature of Tank-1 is lower than 75^{o}C. The goal is to achieve an indoor temperature of 20^{o}C during the heating period, when it is possible by taking into consideration the aforementioned operating restrictions due to the program. Tank-2 is fed with hot water when its temperature is lower than the limit of 50^{o}C. Also, the auxiliary electrical resistance operates with a time schedule for 3 hours in the morning (9:00 – 12:00) and for 3 hours in the afternoon (19:00 – 22:00). If the tank temperature is over the limit of 50^{o}C, then the electrical resistance is not activated. Table 28 includes the design parameters of the building’s energy system.

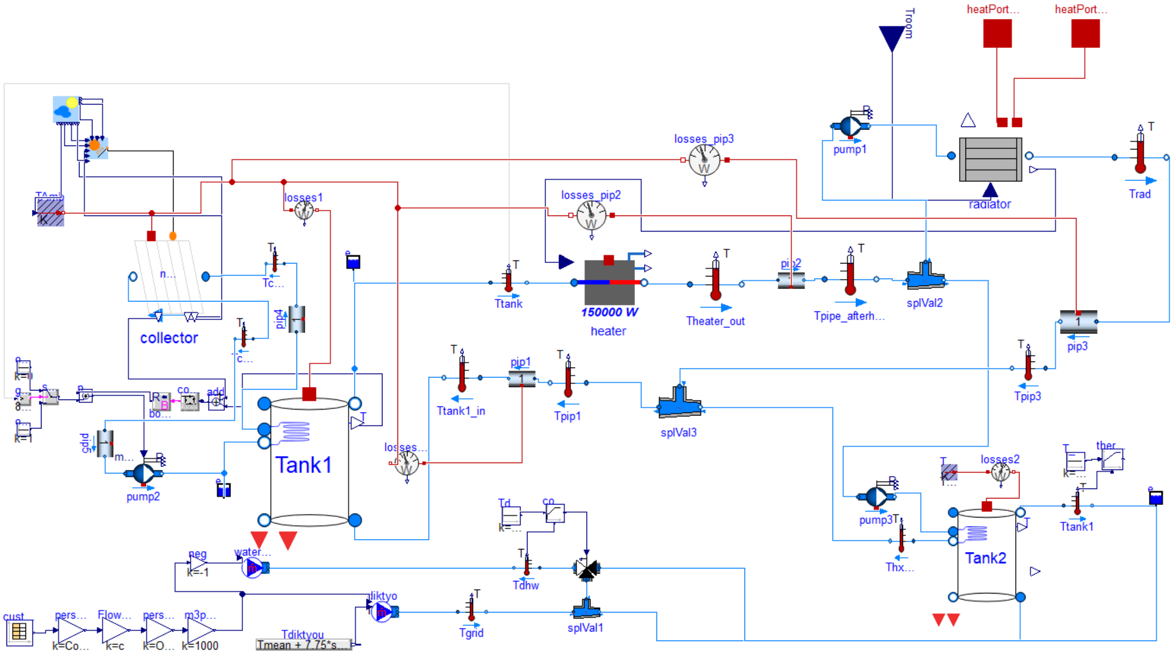


Figure 102. The energy system layout designed in the INTEMA.building tool

Table 28. Design parameters of the energy system

Parameter	Description	Value
$(UA)_{Tank1}$	Tank-1 total thermal conductance coefficient [kW/K]	10
$(UA)_{Tank2}$	Tank-2 total thermal conductance coefficient [kW/K]	2
$(UA)_{rad}$	Radiators' total thermal conductance coefficient [kW/K]	2
$\dot{m}_{col}$	Nominal mass flow rate of the working fluid in the solar thermal system [kg/s]	2.7
$\dot{m}_{rad}$	Mass flow rate of the hot water in the space heating system [kg/s]	1.0
$\dot{m}_{DHW}$	Nominal mass flow rate of the hot water in the heat exchanger in Tank-2 [kg/s]	1.0
$T_{set,DHW}$	Temperature setpoint of the water’s outlet in Tank-2 [^{o}C]	50
V_{Tank1}	Volume of Tank-1 [m^3]	5.2
V_{Tank2}	Volume of Tank-2 [m^3]	2
$P_{el,PV}$	Nominal power of the electrical resistance in Tank-2, powered by PV [kW]	8

Parameter	Description	Value
Q_{Boiler}	Nominal power of the boiler [kW]	250
Q_{rad}	Nominal power of the radiators [kW]	130
$L_{Pipelines}$	Length of the total pipeline system [m]	160

In Figure 103 the indoor temperature profile of the building's living zone is depicted. It is obvious that due to the daily operation schedule of the boiler, the indoor temperature of the building presents important declinations from the heating setpoint of 20°C; the building's heating loads are not satisfied and therefore the thermal comfort conditions are not acceptable. However, these results are reasonable due to the application of a specific operating program which makes the space-heating system operate only for 6 hours per day during the winter.

Following, the simulation results for the yearly heating load variation and total heating demand of the building, as well as the DHW load and the DHW total energy demand of the building, are illustrated in Figure 104a and Figure 104c, respectively. In addition, Figure 104b illustrates the building's thermal load from the 15th to the 20th of January. The maximum heating load is calculated at 156 kW on the 25th of January. Moreover, it was found that the DHW demand exists during the year and it is higher in the winter period compared to the summer period because of the lower temperature of the water in the grid. The maximum DHW water load was calculated at around 22.6 kW during the winter.

The boiler's power and energy demand, as well as the boiler's useful thermal power and energy production, are depicted in Figure 105a and Figure 105b. The boiler's power demand profile remains steady during the entire heating season due to the fact that the building heating system does not operate continuously and therefore the building heating load presents a similar profile during each day of the heating season. In Figure 105c the boiler useful power demand is presented for the period of 15th to 20th of January.

Figure 106 depicts the building's heating energy demand, the boiler's energy demand, the boiler's useful thermal production, and the DHW energy demand. Except for the DHW energy demand the other building's operational demands share a common behavior because the boiler is operating only during the periods when there is heating demand. On the contrary, the DHW energy demand is calculated to have an almost linear behavior, because even during the summer period there is a lower DHW load. It is obvious that the DHW demand is significantly lower compared to the other demands.

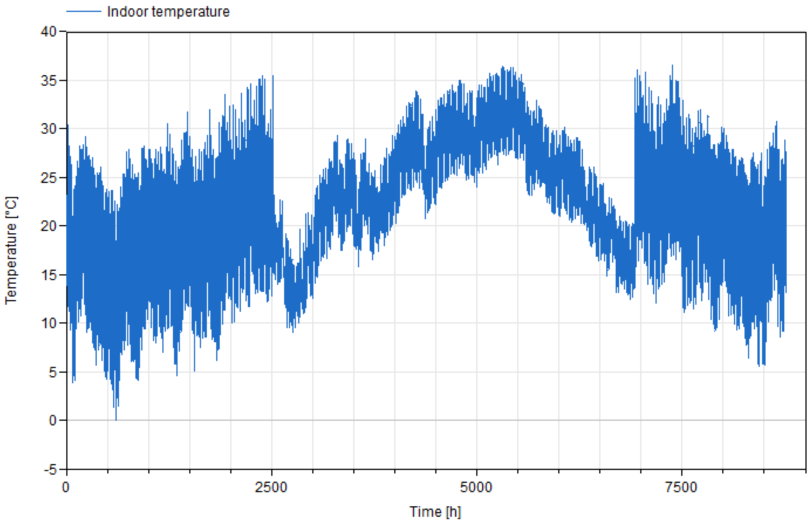
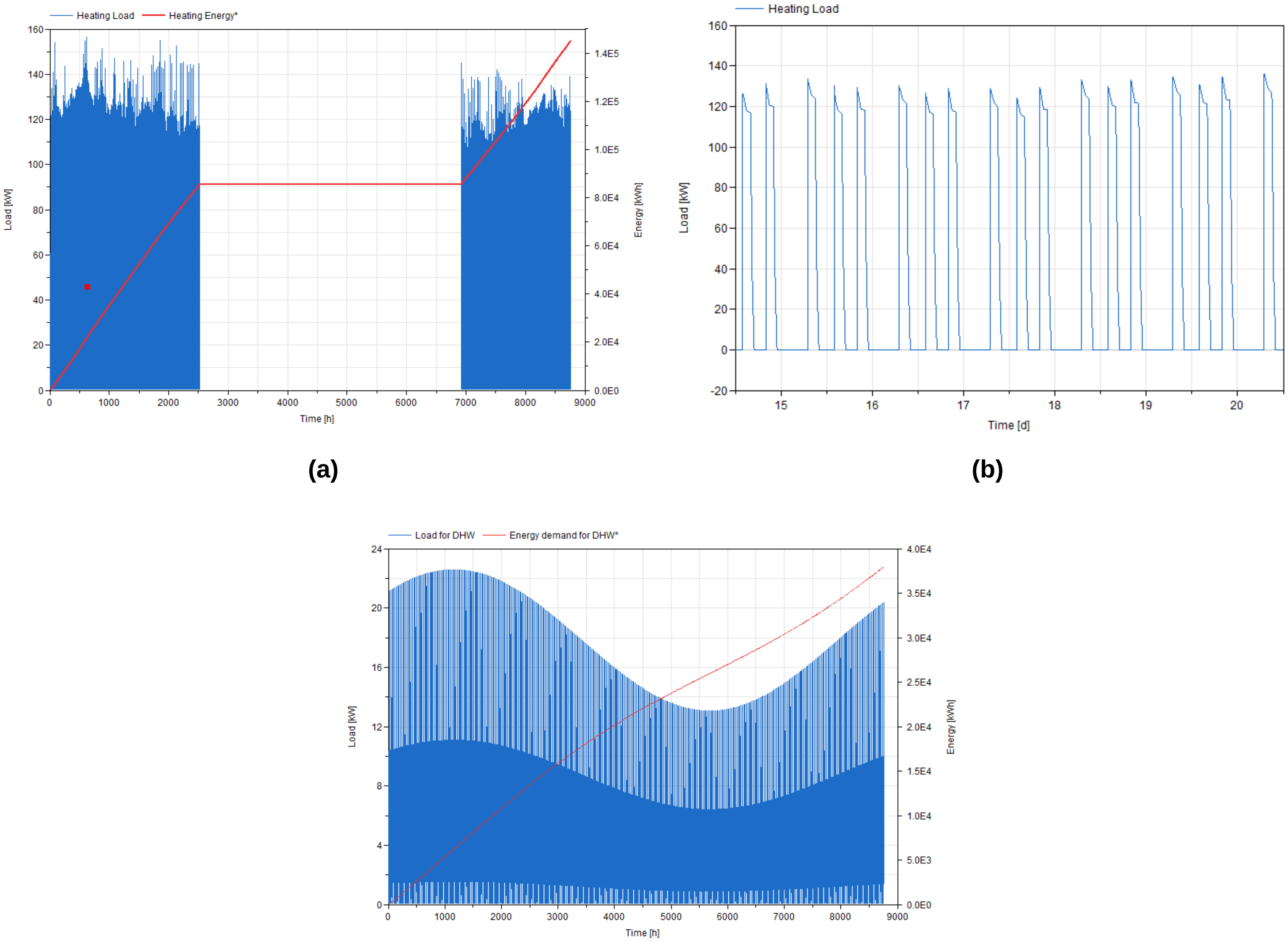


Figure 103. Indoor temperature

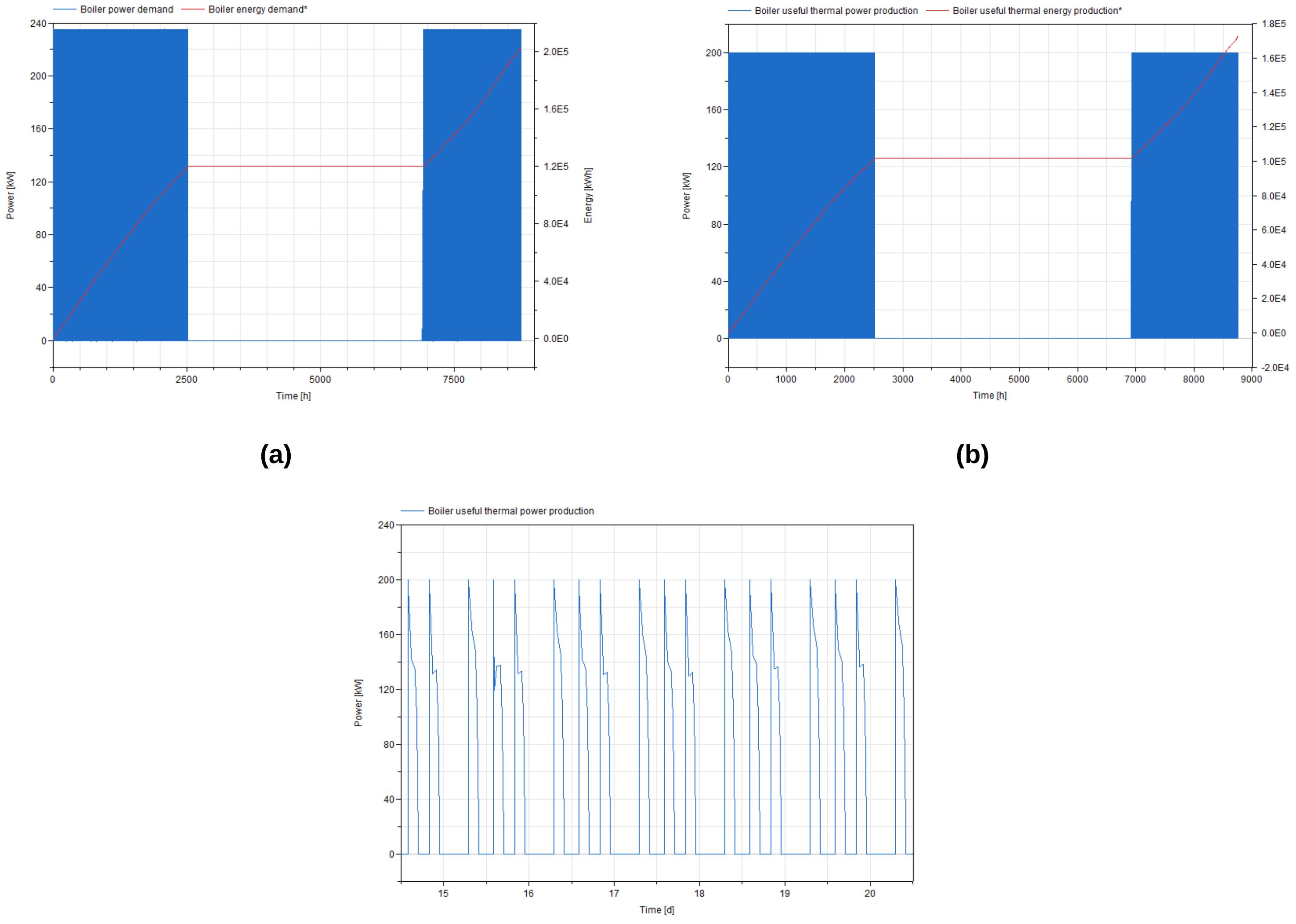


(a)

(b)

(c)

Figure 104. a) Heating load and heating energy load of the building, b) Heating load from the 15th – 20th of January, c) DHW load and DHW energy demand of the building's residents



(a)

(b)

(c)

Figure 105. a) Boiler's power and energy demand, b) Boiler's useful thermal power and energy production, (c) Boiler's useful thermal power demand from the 15th to 20th of January

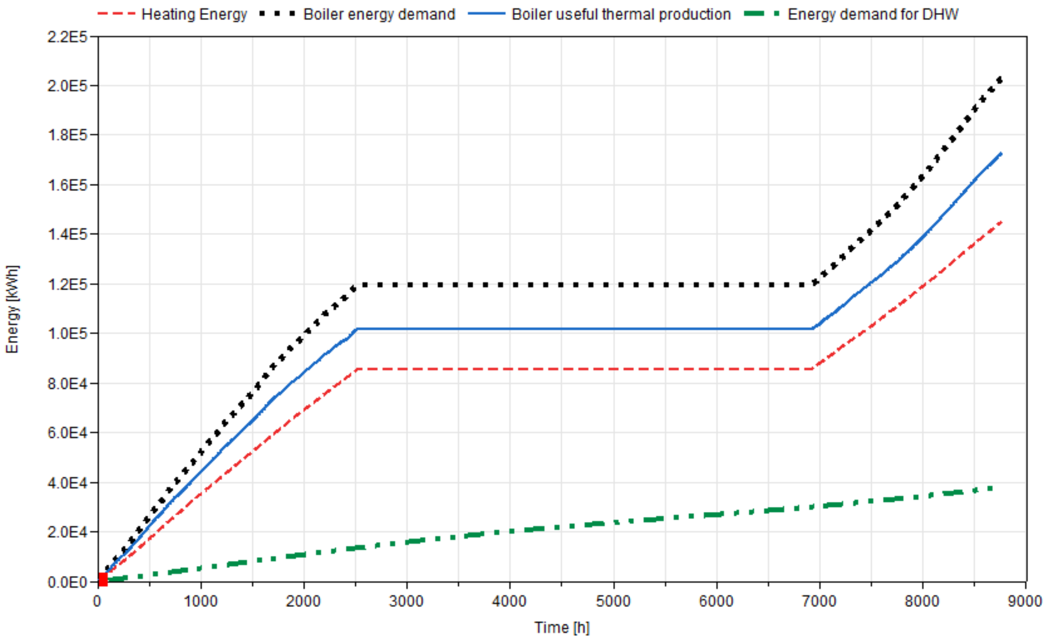


Figure 106. The cumulative energy demands for heating and DHW

The system of thermal collectors produces useful thermal energy which is stored in the thermal energy storage Tank-1 with a mean yearly thermal efficiency of 14.45%. This relatively low value is justified by the high operating temperature during the summer which reduces significantly the efficiency in the period with the highest potential. Figure 107, depicts the variation of the useful collector thermal power production, as well as the cumulative useful thermal energy produced yearly. During the winter period, the useful thermal energy production is lower in comparison with the summer period and the maximum thermal power produced is calculated at 123 kW during the end of March.

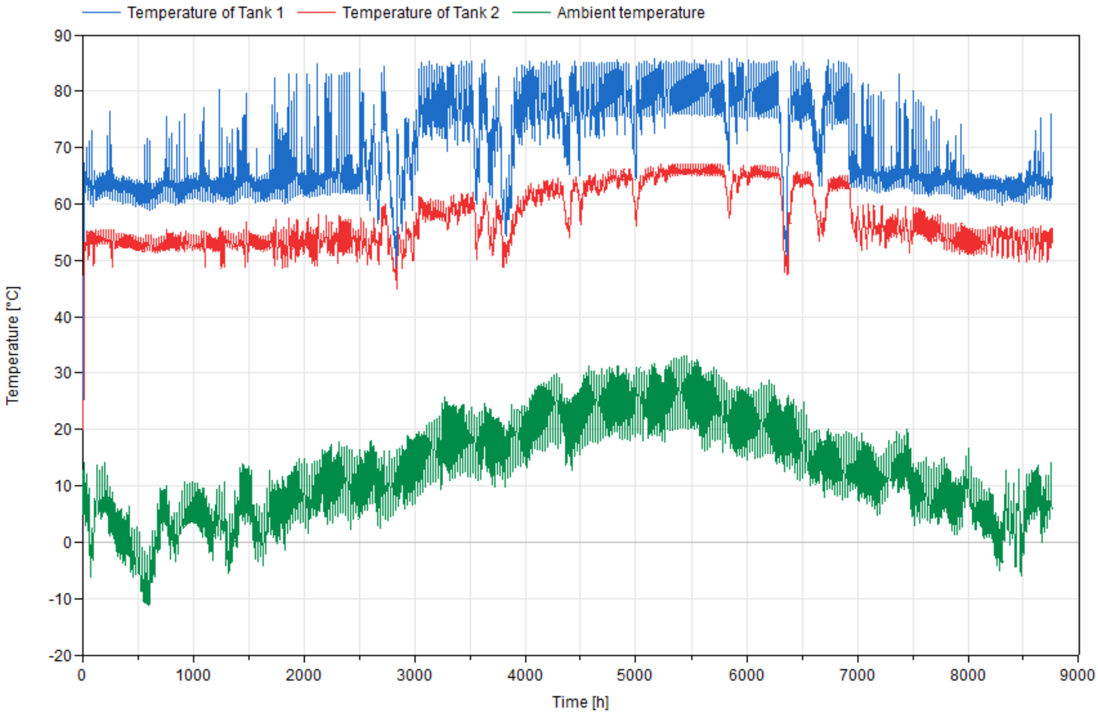


Figure 108, shows the temperature of the water outlet in both Tank-1 and Tank-2 and the ambient temperature. In Tank-1 the water's temperature during the summer period is higher by 15-20ºC, in comparison with the winter period. However, during summer it is calculated that water's temperature abruptly decreases by 25-35ºC, during days with low or no sunshine (Figure 107) because during the summer the boiler does not operate. On the contrary, in Tank-2, the water's temperature profile is relatively close to 55ºC, with slight temperature variations. Moreover, Figure 109 illustrates the auxiliary power in Tank-2 which is provided by the PV. The capacity of the electrical resistance is equal to 8 kW. Finally, it is calculated that the auxiliary thermal total energy input of the thermal resistance is equal to 7,266 kWh.

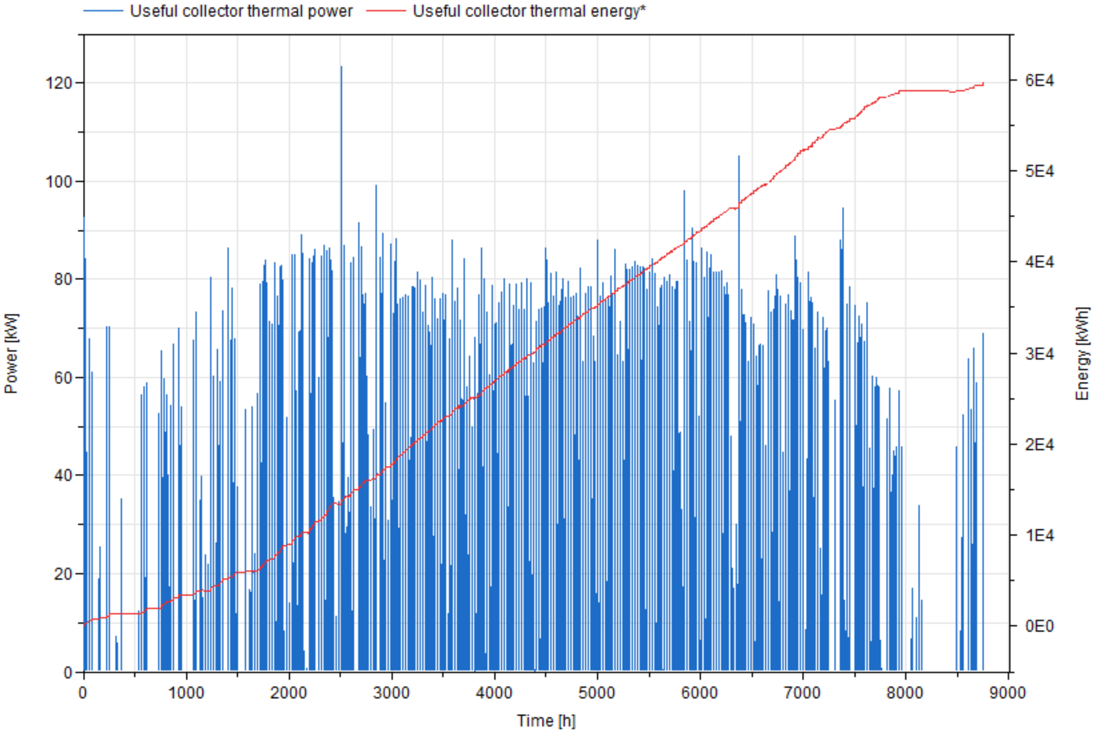


Figure 107. Useful collector thermal power and energy

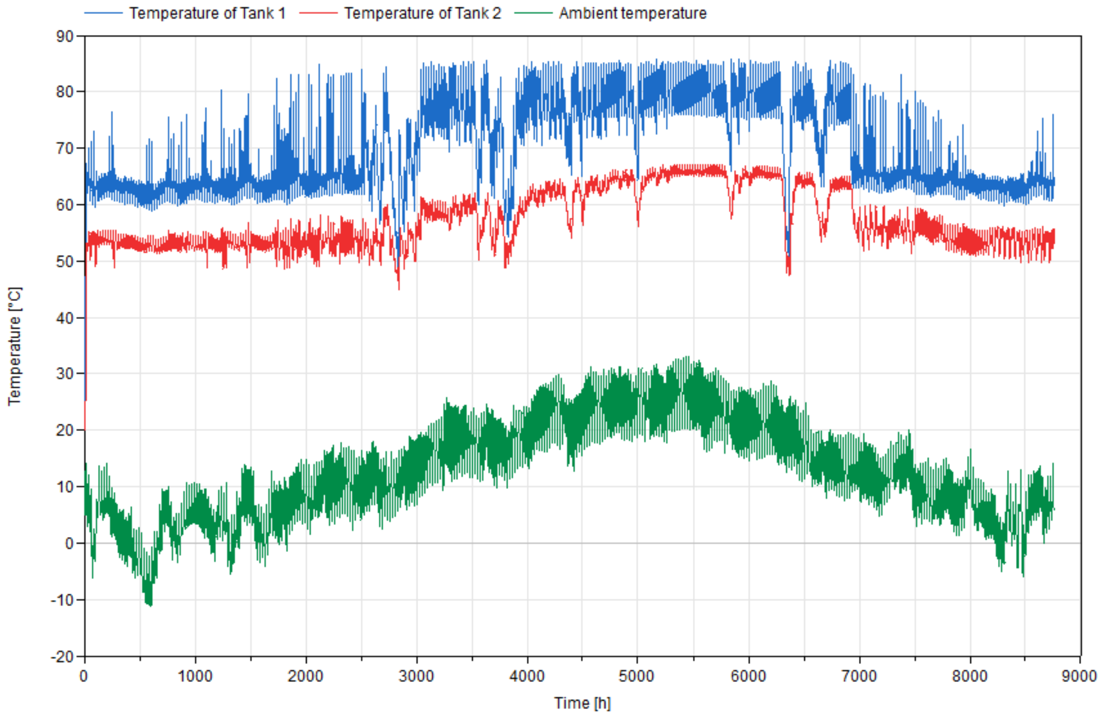


Figure 108. Yearly profiles of the ambient temperature, mean temperature of Tank-1 and mean temperature of the Tank-2

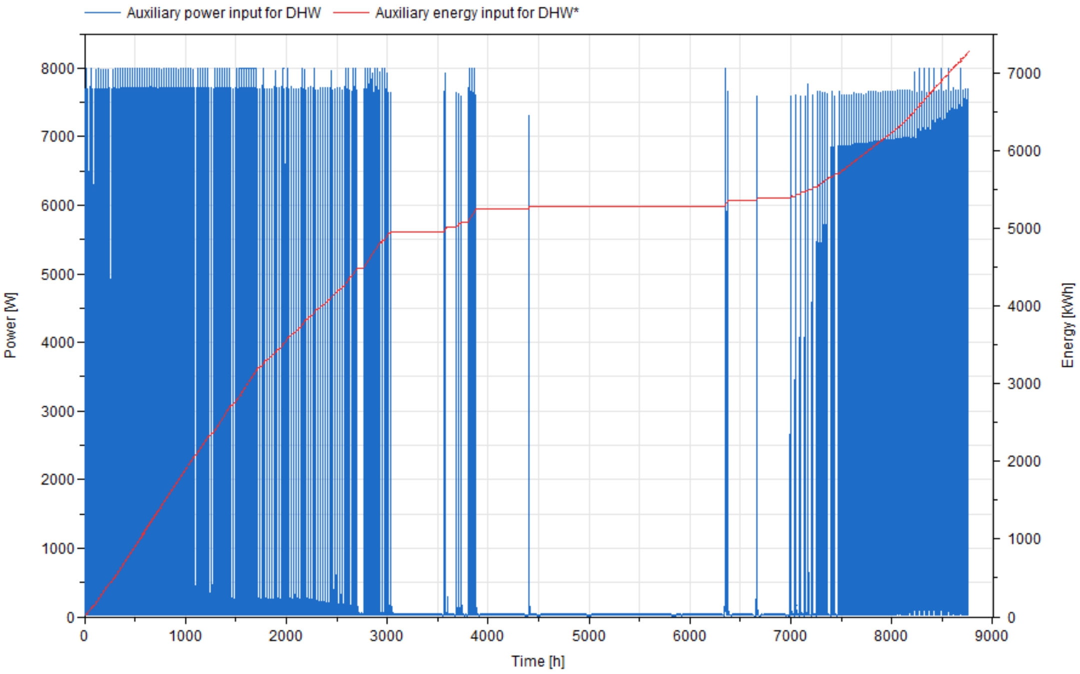


Figure 109. Auxiliary power and energy inputs from the PV for the DHW in the Tank-2

Figure 110 depicts the electrical power and electrical energy demand of the building. These calculations include the energy demand of appliances and lighting in correlation with the occupants’ presence and the calculation parameters are included in Table 22 and Figure 100. It is calculated that the building’s total electricity demand is 58,978 kWh.

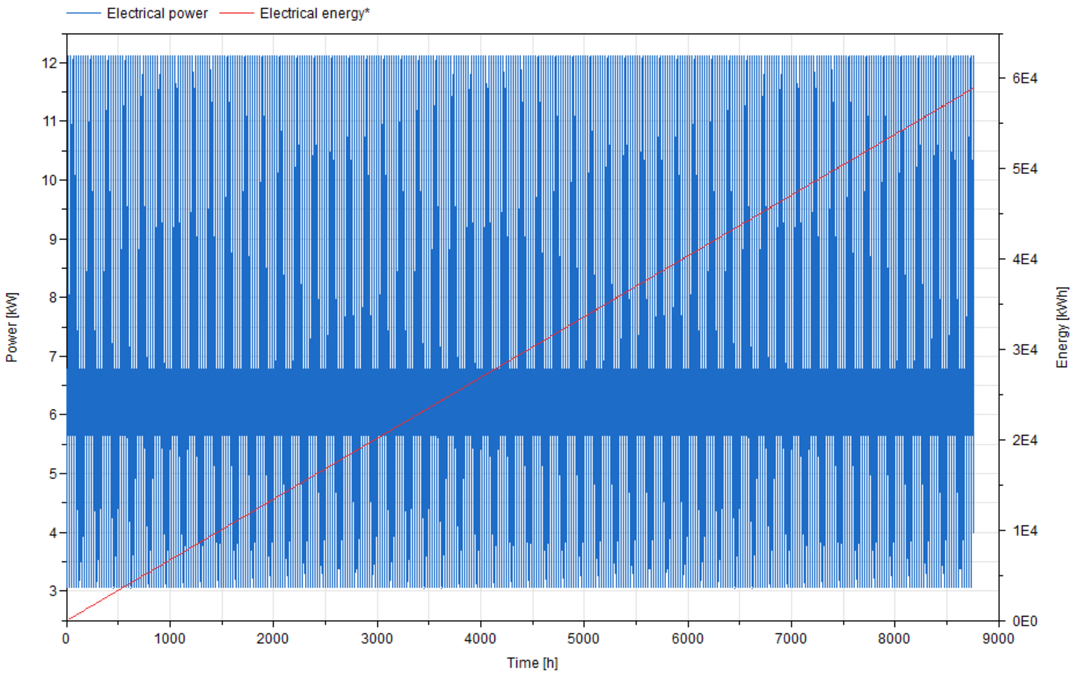


Figure 110. Electrical power and energy values for appliances and lighting purposes

Table 29 summarizes the building's yearly energy demands expressed in [kWh]. The heating demand was calculated at 145,213 kWh and the DHW demand at 38,020 kWh. The boiler energy demand in fuel was calculated at 203,245 kWh and the respective useful heat production from the boiler at 172,759 kWh. The solar thermal field produces 59,686 kWh which are stored in Tank-1 and are used as renewable energy assistance for covering both space-heating and DHW demands. The cumulative energy production from the PV system installed on the building's roof is calculated at 99,367 kWh. A part of this energy, namely the auxiliary energy from the PV is calculated at 7,266 kWh; a relatively low value that indicates that the FPC-Boiler system can produce the majority of the DHW demand. The remaining energy produced by the roof PV system is either exploited for the building's common areas' lighting, whereas a small quantity may not be properly exploited. Additionally, the thermal energy losses of the tanks and the pipelines are included in this table. The distribution losses through the pipeline system, are calculated at close to 17.8% of the building's heating and DHW energy demand which is a reasonable value.

Table 29. Summary of building's energy demands [kWh]

Parameters	Values
Basic demands	
Heating Energy Load	145,213
Energy demand for DHW	38,020
Electrical Energy for appliances and lighting	58,978
Boiler energy demand in fuel	203,245
Other important energy quantities	
Boiler useful thermal energy production	172,759
Useful collector thermal energy production	59,686
Auxiliary energy input for DHW by PV	7,266

Parameters	Values
Available solar energy on the solar field	413,166
Electricity production from roof PV system	99,367
Thermal losses	
Tank-1	6,710
Tank-2	2,728
Pipeline system	32,675

6.2.1.1.2 RENOVATION SCENARIO – DESCRIPTION OF THE RENOVATION ACTIONS

In this section, the renovation strategy that will be implemented regarding the case of the Greek Demo is analytically described and segmented into specific renovation actions. In this particular student's dormitory building, the renovation techniques that will be deployed are three REHOUSE renovation packages, namely the multisource heat pump, the ADBE and the SmartWall, in combination with standard renovation activities (out of REHOUSE Project) that concern the building's thermal insulation, the refurbishment of the baseline energy system through the installation of fan coil system. The building's thermal needs are satisfied by the parallel operation of two different energy systems. Therefore, in this section, the division of the building into two thermal zones is thoroughly explained. The DHW system and the PV battery system are not modified.

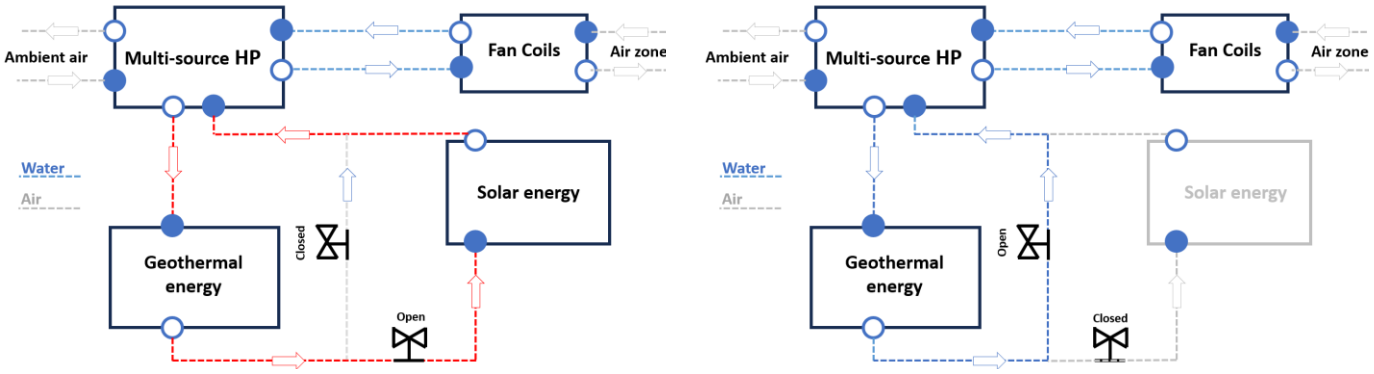
6.2.1.1.2.1 REHOUSE RENOVATION PACKAGES

i) RP#1: Multisource heat pump (Psyctotherm)

Description

The multisource heat pump is a technological solution that integrates thermal energy storage, thermal panels, and HFO (HydroFluoro-Olefins) refrigerants. This heat pump configuration can achieve high performance adjusted for the temperature ranges of modern heating appliances in both new and renovated buildings. More particularly, the multisource operation combines different natural heat sources such as ambient air, solar thermal energy, and geothermal energy and allows the integration with local thermal energy storage systems. Additionally, the advanced energy management and control system of the multisource solution optimizes operation according to resource availability, smart exploitation of buffer capacities, and demand response schemes, whereas the use of HFO refrigerant ensures suitability for future applications compliant with the F-gas regulation constraints.

The multisource heat pump is connected to a solar thermal system, geothermal energy system, and ambient air. The source selection and the operation of the technology are adjusted by a smart control system to ensure the most efficient operation of the system. The heat pump is designed to have two heat exchangers on the heat sources' side. More precisely, the heat pump configuration is equipped with one water-cooled heat exchanger to receive water from the geothermal source and the solar thermal system, and one air-cooled heat exchanger to utilize the environmental air. As far as the cooling mode is concerned, the heat pump system is designed to use the geothermal field as a sink for the condenser to achieve higher performance. The multisource heat pump uses both air and water as sources, according to an appropriate temperature criterion. In the case of water, after the heat pump's outlet, the water is driven through the geothermal field bypassing the solar thermal system in order to return to the heat pump's inlet, as it is depicted in Figure 111a. On the other hand, in the heating mode, and in the case of the water source, after the geothermal field water is driven toward the solar thermal system of collectors in order to return to the heat pump, according to Figure 111b. The water's flow into the geothermal field and the solar thermal system is controlled by two butterfly valves that remain open or closed according to the heat pump's mode.



(a) **(b)**

Figure 111. The water's flow in the geothermal field and solar thermal system according to the heat pump's mode, (a) heating mode, and (b) cooling mode

The main innovation of this system is its design to serve the simultaneous operation of the air and water-cooled heat exchangers (combined operation of the air-cooled and the water-cooled operation) when it can provide a better performance either for the heating or the cooling mode. This configuration demands a special refrigerant circuit and a specific control approach. The coefficient of performance of the multisource heat pump is described by a 2nd-order polynomial of the temperature at the evaporator for the case of heating mode and of the temperature at the condenser for the case of cooling mode. These polynomials have been created by performing simulations with the Dorin software which was suggested by Psyctotherm. Specifically, the working fluid was R407C, the compressor model H4000CC, the superheating in the compressor inlet 10 K, and the subcooling in the condenser outlet 2 K. These data and boundary conditions were provided by Psyctotherm. The polynomials use as parameters the evaporator temperature (TE) and the condenser temperature (TC). Table 30 includes basic data for the heat pump operation.

Table 30. Basic data of the multisource heat pump

Parameter	Value / Expression
Nominal COP (heating)*	4.17
COP (T_E)	$0.001257\ T_E^2 + 0.072\ T_E + 3.979143$
Nominal EER (cooling)**	3.17
EER (T_C)	$0.002057\ T_C^2 - 0.264171 T_C + 10.684571$
Nominal heating capacity	130.54 kW
Nominal cooling capacity	99.2 kW
Refrigerant	R407C

** For ambient air 5^{o}C and condensation at 45^{o}C*

*** For cold water at 7^{o}C and air-cooled condenser*

Application on the examined building

The REHOUSE project predicts the installation of 37 fan coil units, which are to be installed properly in the studied building. More specifically, the multisource heat pump of Psyctotherm is to be coupled with a fan coil system which serves the heating and cooling needs of some of the student rooms of 'C2 Building', as well as the thermal loads of the building's corridors and common spaces. Specifically, the multisource heat pump of Psyctotherm serves a fan coil system which totally consists of 33 terminal units that are divided as specified: 23 fan coil terminal units in students' rooms, 6 fan coil terminal units in the building's corridors, and 4 terminal units in the building's shared rooms serving as kitchens. The remaining 4 fan coil terminal units funded by the REHOUSE project will be coupled with the existing energy system of the biomass boiler of the building, as explained in the following section.

The solar feeding of the Psyctotherm multisource heat pump is satisfied by a part of the solar field area of the examined building is estimated at 243 m^2 and the respective thermal storage tank (Tank-1). More specifically, the 'C2 Building' is fed by 43 m^2 of solar field area (as an initial estimation), while the remaining 200 m^2 feeds the other thermal zone. The characteristics of the solar thermal collector, which is a selective flat plate collector, and the storage tank are given in Table 23. As far as geothermal energy is concerned, the Centre of Renewable Energy Sources (CRES) in Greece performed an analysis of the geothermal field of the area on behalf of the REHOUSE project for the integration of a vertical borehole system. The drawings of the proposed location of each borehole in front of the examined 'C2 Building' are presented in Figure 112. The number of total boreholes is 30 with 6 meters among them, creating an overall borefield of 34.8 x 24 m. The described geothermal field will serve the campus restaurant and a part of the borefields, specifically 10 out of the 30 boreholes, is exploited as a heat source for the 'C2 Building'.

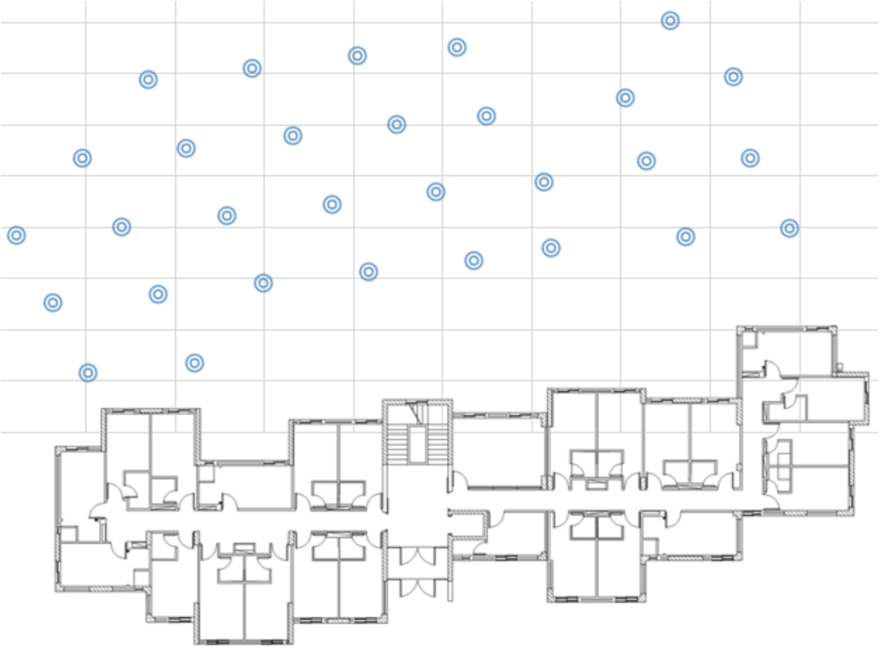


Figure 112. Typical scheme of the proposed borefield for the heating needs of the C2 Building.

The depth of each borehole is set at 90 m. Each borehole consists of a single-U piping system with 152.4 mm diameter, utilizing PVC pipes of 32 mm diameter and 3 mm thickness. Table 31 gives the overall geometrical characteristics of the boreholes and borefield respectively, as well as the thermal properties of Kimmeria's ground.

Table 31. Input parameters used by CRES report for the borefield model.

Parameter	Description	Value
nBor	Number of boreholes	30
hBor	Height of the borehole [m]	90
rBor	Borehole radius [mm]	76.2
DBor	Distance between boreholes [m]	6
xBorFie	Borefield length [m]	34.8
yBorFie	Borefield width [m]	24
Rb	Borehole thermal resistance [mK/W]	0.4259
dtube	Single-U pipe diameter [mm]	32
etube	Single-U pipe thickness [mm]	3
xC	Single-U pipe shank spacing [mm]	54
ktube	U-pipe thermal conductivity [W/mK]	0.420
dT/dZ	Vertical temperature gradient of undisturbed soil	0.01
T_0	Initial ground temperature from which the ground gradient starts [°C]	16.2
Z_0	Depth below which ground temperature gradient starts [m]	10
kSoi	Ground thermal conductivity [W/mK]	1.6
cSoi	Specific heat capacity of the ground material [J/kgK]	1.8
dSoi	Density of the soil material [m^3/kg]	1.3
kFil	Filling material thermal conductivity [W/mK]	1.5
cFil	Specific heat capacity of the filling material [J/kgK]	800
dFil	Density of the filling material [m^3/kg]	1,600

ii) RP#2: ADBE (Renel)

Description

The Adaptable Building Envelope (ADBE) is a technology that generally combines insulation, HVAC units, batteries, and photovoltaics. It enables adaptability to various geometry topologies thanks to its modular nature and high level of prefabrication and customization. It is based on a modular prefabricated structure made of recyclable materials (aluminium), contributing to the reduction of the building's carbon footprint and to the acceleration of the renovation time. All of the ADBE components are manufactured in the factory and delivered by truck to the installation site, where the installation crews installed them with the help of cranes. The installation procedure does not require expensive scaffolding or special training from the technicians.

The ADBE technology contributes to the improvement of a building’s sustainability due to its careful design, which is capable of allocating BIPV panels and battery storage for increased onsite RES production, HVAC ducts, and other technical facilities, as well as environment-friendly insulation materials. Figure 113 illustrates the unit-based ADBE façade elements that can be combined in order to create a holistic envelope product. Moreover, the controllability and smart energy operation of the building are also promoted through the embedment of the necessary sensors and actuators that allow users/owners to control the façade behavior for energy minimization and better quality of the indoor environment. Finally, the outer skin of the façade elements consists of weather-resistant panels, and the whole solution is proofed against major disruptive phenomena (e.g.: weather, fire, earthquake events, etc.).

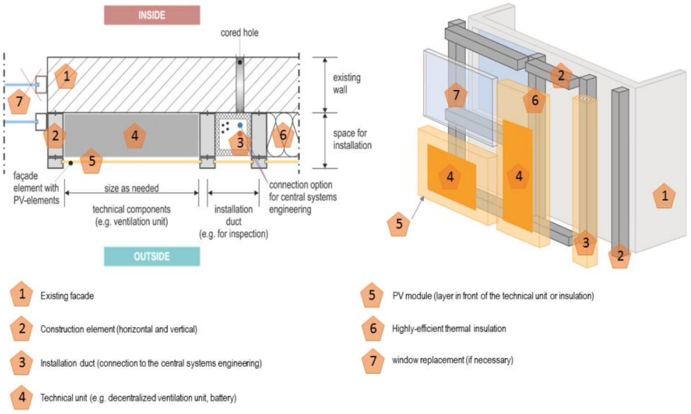


Figure 113. ADBE components and technical drawing (Legend: 1.- Existing façade 2.- Construction element 3.- Installation duct 4.- Technical unit (HVAC, battery) 5.- PV module 6.- High-efficient insulation 7.- Window replacement)

The Renel technology (BIPV) will be placed on scaffolding and in such a way that the adjacent panels are not shaded, due to the meandering form of the south wall of the building. Behind the BIPV panels, there will be space to lay insulation.

The ADBE prototype forms a structural ecosystem where an aluminium-glass façade design, based on modern construction standards and flexible specifications, enables its installation to almost any building's architectural design, both in residential and non-residential buildings, offering multiple additional functionalities to the existing building envelope. Because of the curtain wall, the construction is done outside of the existing building, which enables a refurbishment to be conducted without disrupting the operation of the building, eliminating the possibility of technical incidents. The aluminium-based profile ensures construction 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 according to the building's orientation, structural design, and illumination needs. Table 32 summarizes the main information of this design.

Table 32. Technical data of the ADBE technology

Parameter	Value
PV technology (Onyx Solar)	
Nominal total capacity [kW_p]	4.7
Dimensions [m x m]	1.6 x 1.6
Reference electrical efficiency [%]	5.76
Maximum Production Capacity [W_p/m^2]	57.6
Open Circuit Voltage [V]	125
Short Circuit Current [A]	1.93
Voltage at nominal power – V_{mpp} [V]	86
Current at nominal power – I_{mpp} [A]	1.72
Nominal Power [W]	147
Inverter efficiency [%]	94

Parameter	Value
Power temperature coefficient [%/°C]	-0.19
Voltage temperature coefficient [%/°C]	-0.28
Current temperature coefficient [%/°C]	0.09
Thickness [mm]	18.24
Material thermal properties	
U-value of the glass [W/m^{2}K]	5.2
U-value of ADBE façade with extra insulation layer [W/m^{2}K]	0.431
Total area in the renovated building [m^2]	82

Application on the examined building

The Renel ADBE technology will be placed on the south wall of the 'C2 Building', according to Figure 114, covering 82 m2 of wall area. The building's south and north walls are characterized by a meandering form. Therefore, in order for the BIPV panel not to be shaded, the ADBE technology will be mounted on scaffolding in such a way that the adjacent panels are not shaded. Simultaneously, this will allow the installation of insulation material behind the panels. The combination of the Renel ADBE technology and the standard insulation layer added will result in the enhancement of the external walls' thermal transmittance value. Specifically, the U-value of the external walls will be decreased from 1.05 W/m^{2}K at the baseline scenario to 0.3 W/m^{2}K (approximately) in the renovated scenario. Moreover, the electricity produced by the ADBE BIPVs is intended to provide for corridors and perimeter external lighting with the aim of an inverter battery located in the basement.

Figure 114. Installation of the ADBE technology on the building's south walls

iii) RP#3: SmartWall

Description

The SmartWall technology is a multifunctional wall system that can integrate various systems such as fan coils or other types of heating/cooling devices, windows or balcony doors, PV panels, and other electromechanical components. The SmartWall technology is versatile and adaptable to the needs of each project and therefore the components of its basic structure can be also modified, if needed, depending on the building and the country of installation. Figure 73 depicts a conceptual view of the SmartWall technology. The SmartWall technology is described by efficient environmental and thermal performance. A set of innovative technologies will contribute to new sophisticated SmartWall prototypes focusing on the use of recyclable mineral wool, a 60-min fire-retarding intumescent paint for improved thermal and fire performance, low-emission and IR-reflective coatings on the inner and outer surfaces of windows' glazing respectively, and a commercial certified system (BlazeCut T series) applied for active automatic protection of those components vulnerable to fire (e.g. batteries, fan-coil, inverter, motors, etc.).

(a) (b)

Figure 115. a) Basic description of examined technology, b) SmartWall conceptual view including BIPV, HVAC ducts, FCUs, batteries, and smart blinds

Application on the examined building

The SmartWall is a technology that can consist of various active or inactive elements, such as eco-friendly insulation, slim-type fan coil for heating and cooling, mechanical ventilation, IEQ control system consisting of filters, energy recovery system, batteries, PV panels, and windows. The generic blank version of the SmartWall technology includes the frame, the insulation, the gypsum or cement board, and the intumescent or multifunctional paint, as illustrated in Figure 115a. This version will be applied in the case of the 'C2 Building'. More specifically, the SmartWall technology will approximately cover 80 m2 of the north and south walls of the building at the basement level. Figure 116 depicts the exact location of the SmartWall façade, coloured in red. The application of the SmartWall technology will enhance the thermal transmittance value of the building's external walls. More specifically, the U-value of the external walls in the baseline scenario is calculated at 1.05 W/m^{2}K, whereas the application of the SmartWall façade will decrease the external walls' U-value at 0.386 W/m^{2}K. It is useful to state that in this analysis, the worst scenario is examined with 5 cm rockwool insulation with 0.033 W/mK thermal conductivity, while in some wall's VIP panels will be installed which leads to lower U-values. Table 12 summarizes the basic data of the SmartWall structure.

(a) (b)

Figure 116. The application of the SmartWall technology on the building's a) North and b) South walls

Table 33. Technical data of SmartWall technology

Parameter	Value	
Total area of the AMS façade [m^2]	80	
Installation walls	North and South walls on the Basement level	
Construction layers	**Thickness [cm]**	**Thermal conductivity [W/mK]**
Rubber	0.9	0.10
Rockwool insulation	5.0	0.033
Cement	1.25	0.35

6.2.1.1.2.2 DUTH RENOVATION ACTIONS (ACTIONS OUTSIDE OF REHOUSE PROJECT)

Except for the renovation actions planned to be conducted in terms of the REHOUSE project, Democritus University of Thrace is independently planning to realize energy efficiency interventions that do not belong in the REHOUSE project. This section is devoted to explaining these interventions.

i) Insulation of external walls

The entire area of the building's external walls is to be covered with the insulation material of EPS, characterized by a 7 cm thickness and a thermal conductance value of 0.031 W/mK. The only exception in this renovation activity will be the area of 80 m^2 of the south and north wall in the basement level on which the SmartWall façade will be mounted. The addition of the thermal insulation layer will enhance the external walls' thermal resistance and decrease the external walls' U-value to 0.311 W/m^{2}K, in comparison with the U-value of 1.05 W/m^{2}K in the baseline scenario.

ii) Replacement of Fan Coil system

The energy system described in the baseline scenario will be modified and upgraded. More specifically, instead of feeding the radiators that are distributed in the entire building with hot water, the modified energy system will be coupled with a fan coil system. In this configuration, the hot water temperature setpoint of the biomass boiler remains at 75°C. The fan coil system coupled with the biomass boiler consists of 39 terminal units which are to be installed in the remaining 39 out of the 62 student rooms of the building, covering the rooms' heating needs. Four of these fan coil terminal units belong to the REHOUSE project funding, as has been previously explained. From these 39 rooms, 4 will be covered by REHOUSE Fan coils, while the rest 35 will be installed with funding outside of this project. The water piping system necessary for distribution purposes of the system is predicted to be installed in the building's basement and ascend towards the building's floors and rooms.

6.2.1.1.2.3 DIVISION IN THERMAL ZONES

In the renovated state, the examined building will be served by two separate energy systems and therefore the building is divided into two thermal zones for performing a suitable simulation. Each thermal zone is characterized by the operation details of its energy system, the treated floor area, and the areas of external walls and windows as well as their orientation, the duration of the heating and the cooling season, the temperature setpoints, the number of occupants and the internal heat gained. Furthermore, it is essential to accurately describe the interfaces between the two thermal zones and therefore the heat transfer between them.

The first system refers to the upgraded energy system of the baseline scenario with the replacement of the radiators with fan coil units as terminal units. The refurbished energy system will consist of fan coil units which will be installed in 39 out of 62 student rooms, covering their heating needs. In total, the first energy system is responsible for 61% of the building's treated floor area, an area that corresponds to thermal zone 1. The second energy system refers to a fan coil system fed by the multisource heat pump (Psyctotherm technology provider) described in section 1.4.1. This system is predicted to serve the heating and cooling needs of the rest 23 out of 62 student rooms, as well as the thermal loads of the building's corridors and the common spaces serving as kitchens. In total, the second system is responsible for 39% of the building's treated floor area, an area which corresponds to thermal zone 2. In both thermal zones, the heating temperature setpoint is set at 20°C and the heating period starts on the 15th of October and ends on the 15th of April. In addition, the cooling temperature setpoint in thermal zone 2 is set at 26°C, while thermal zone 1 has no cooling system. The cooling period is typically considered from the 15th of May until the 30th of September Table 34 summarizes the basic information regarding the two thermal zones.

Table 35 gives the geometrical data and the thermal properties of each thermal zone as well as the geometrical data of the interfaces between the two thermal zones. In thermal zone 2 the areas of the external south and north walls are divided. That is because for this zone, a part of the south and north walls is covered with the SmartWall façade resulting in different thermal transmittance values of the wall elements.

Table 34. Basic description of thermal zones

Thermal Zone 1	
Parameters	**Values**
Heating operating program	7:00 – 9:00, 14:00 – 16:00, 20:00 – 22:00
Heating period	15th October – 15th April
Energy system	Thermal solar field and biomass boiler coupled with a fan coil system
Treated floor area [m^2]	836
Student rooms	M6, M7, M8, M9, M10, M11, M14, M16, M17, M18 (Ground floor)

Thermal Zone 1	
Parameters	**Values**
	M24, M25, M26, M27, M28, M30, M31, M32, M33, M34, M37, M39, M40, M41, M44, M47 (1st floor) M48, M49, M50, M51, M52, M53, M53, M54, M55, M56, M57, M60, M61 (2nd floor)
Occupants	39
Thermal Zone 2	
Parameters	**Values**
Heating temperature setpoint (°C)	20
Heating period	15 October – 15 April
Cooling temperature setpoint (°C)	26
Cooling period	15 May – 30 September
Energy system	Multi-source heat pump coupled with a fan coil system
Treated floor area [m^2]	535
Student rooms	M1, M2, M3, M4, M5, M12, M13, M15, M19, M20, M21, M22, M23 (Ground floor) M29, M35, M36, M38, M42, M43, M45, M46 (1st floor) M58, M59 (2nd floor)
Corridors & Common spaces	Basement, 1st floor and 2nd floor
Occupants	23

Table 35. Geometrical data of the thermal zones

Thermal Zone 1		
Parameters	**Values**	
-	**Area of opaque surfaces [m^2]**	**U-value [W/m^{2}K]**
North roof (slope=15°)	150	1.3
South roof (slope=15°)	233	1.3
Ground slab	247	3.1
North walls	230	0.311
South walls	288	0.311
East walls	122	0.311
West walls	165	0.311
-	**Area of windows [m^2]**	**U-value [W/m^{2}K]**

Thermal Zone 1		
Parameters	**Values**	
North windows	50	4.2
South windows	51	4.2
East windows	3	4.2
West windows	2	4.2
Thermal Zone 2		
Parameters	**Values**	
-	**Area of opaque surfaces [m^2]**	**U-value [W/m^{2}K]**
North roof (slope=15°)	86	1.3
South roof (slope=15°)	57	1.3
Ground slab	259	3.1
North walls	125	0.311
North walls with SmartWall	44	0.386
South walls	70	0.311
South walls with SmartWall	41	0.386
East walls	123	0.311
West walls	90	0.311
-	**Area of windows [m^2]**	**U-value [W/m^{2}K]**
North windows	18	4.2
South windows	12	4.2
East windows	7	4.2
West windows	2	4.2
Interfaces between thermal zones		
Parameters	**Values**	
-	**Area [m^2]**	**U-value [W/m^{2}K]**
Internal walls	788	3.1
Internal slabs	128	3.1

6.2.1.1.2.4 RENOVATION SCENARIO – SIMULATION RESULTS

The simulation of the baseline scenario is conducted by using the INTEMA.building tool. The simulation period is an entire year and the simulation time step is adjustable and variable using the Dassl solver with 10^{-}4 tolerance. The layout of the two thermal zones and their separate energy systems are depicted in Figure 117. Specifically, Figure 118 illustrates the energy system of thermal zone 2, namely the multisource heat pump coupled with a fan coil system, which covers both the heating and cooling demand of the zone. Additionally, Figure 119 depicts the configuration of the multisource heat pump and its coupling with the solar thermal system and the geothermal field. The energy system of thermal zone 1 operates only from the 15th of October until the 15th of April. The DWH demand of the building is satisfied according to the baseline scenario.

The simulation results for the yearly heating loads of thermal zone 1 are depicted in Figure 118 a. The maximum heating load is calculated at 91 kW during the 25th of January. The heating load demand of thermal zone 1 presents a repetitive daily profile, according to Figure 118b that is determined by the biomass boiler operation schedule (7:00-9:00, 14:00-16:00 and 20:00-22:00). On the 15th of October, the heating period begins again. The cumulative heating demand of thermal zone 1 is calculated at 80,640 kWh. Figure 118c illustrates the boiler power and cumulative energy demand for heating, regarding thermal zone 1, while Figure 118d illustrates the boiler's daily power demand profile. The boiler's cumulative energy demand is calculated at 142,059 kWh.

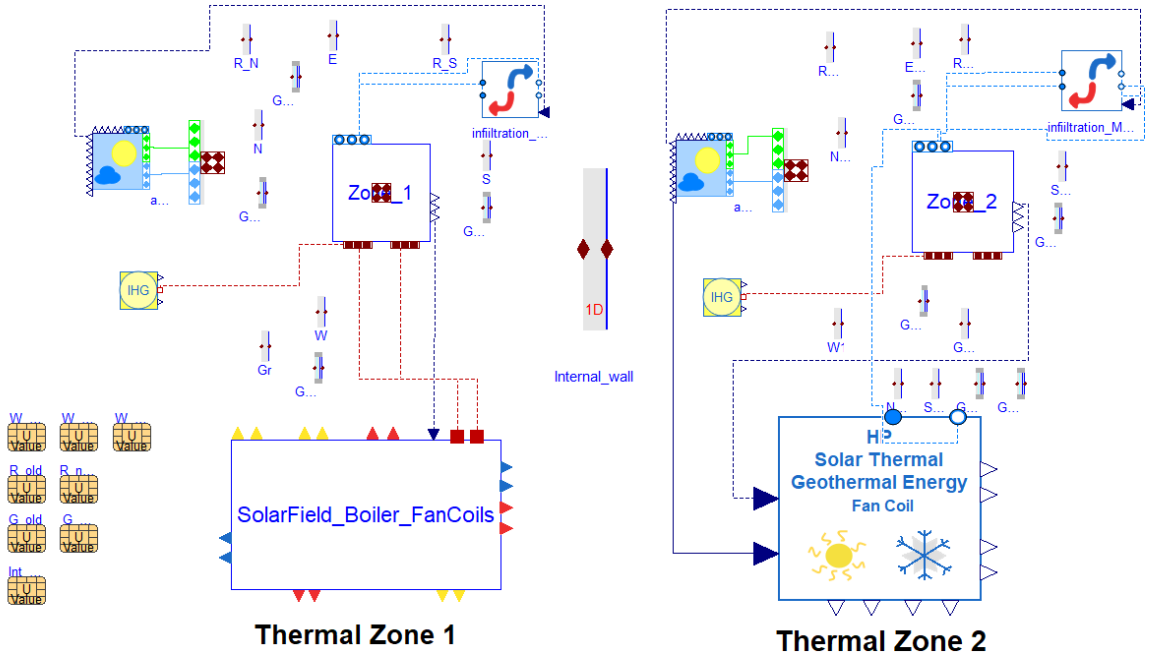


Figure 117. Configuration of the two thermal zones and their separate energy systems

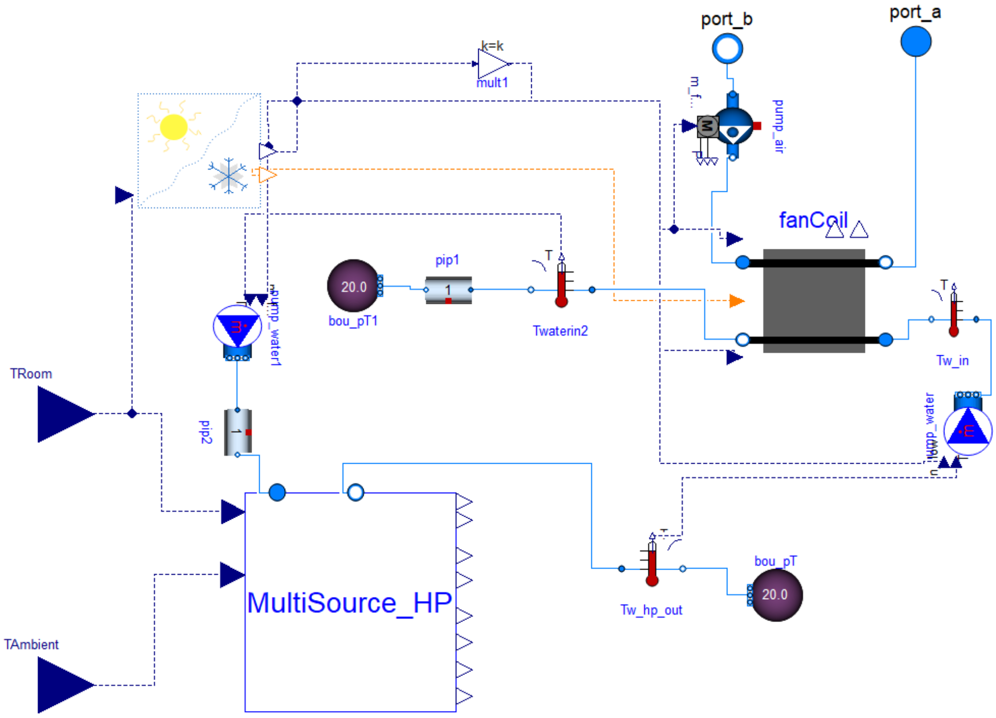


Figure 118. Configuration of the energy system of thermal zone 2

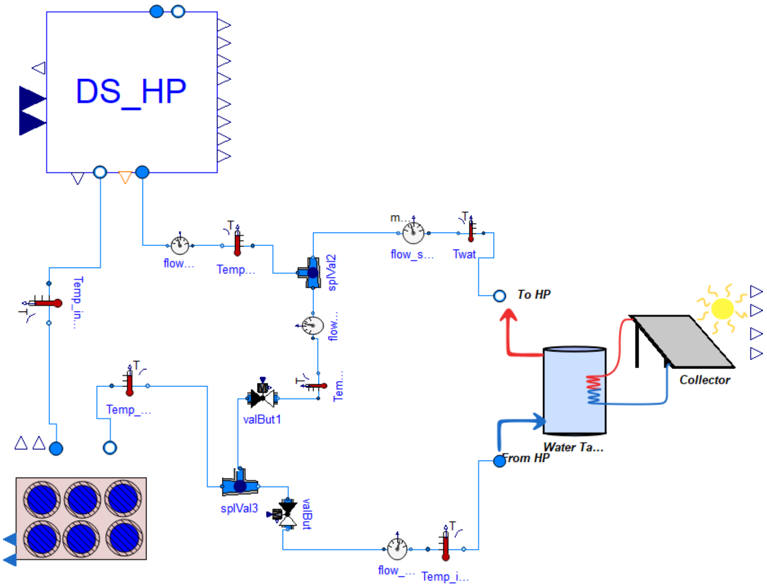
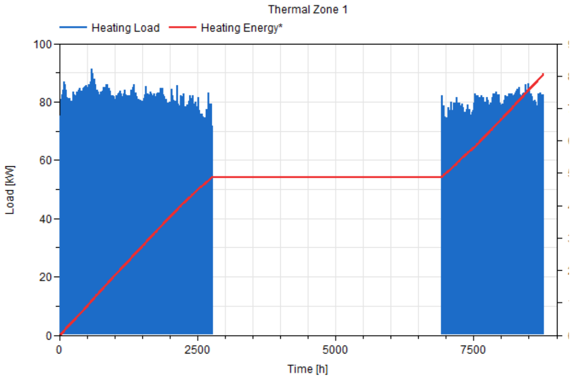
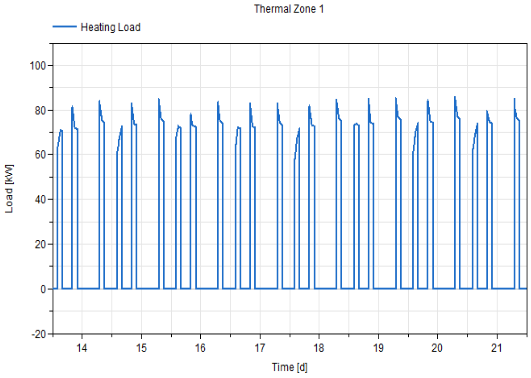
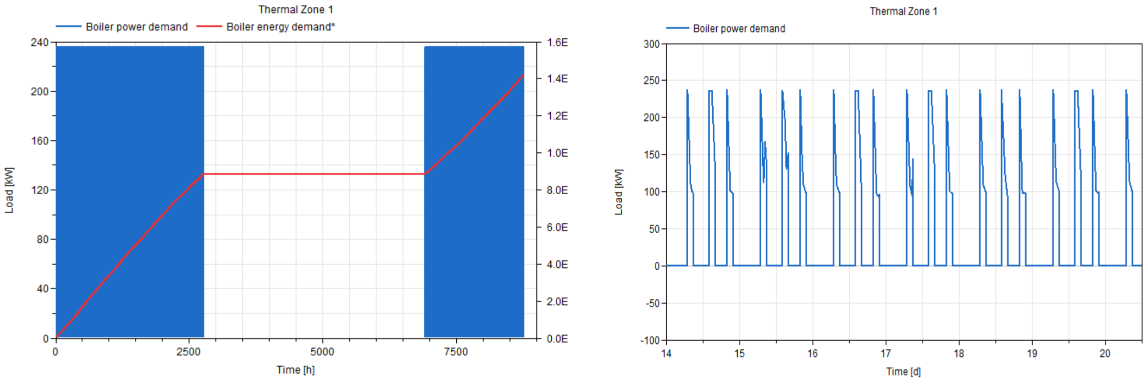


Figure 119. Configuration of the multisource heat pump





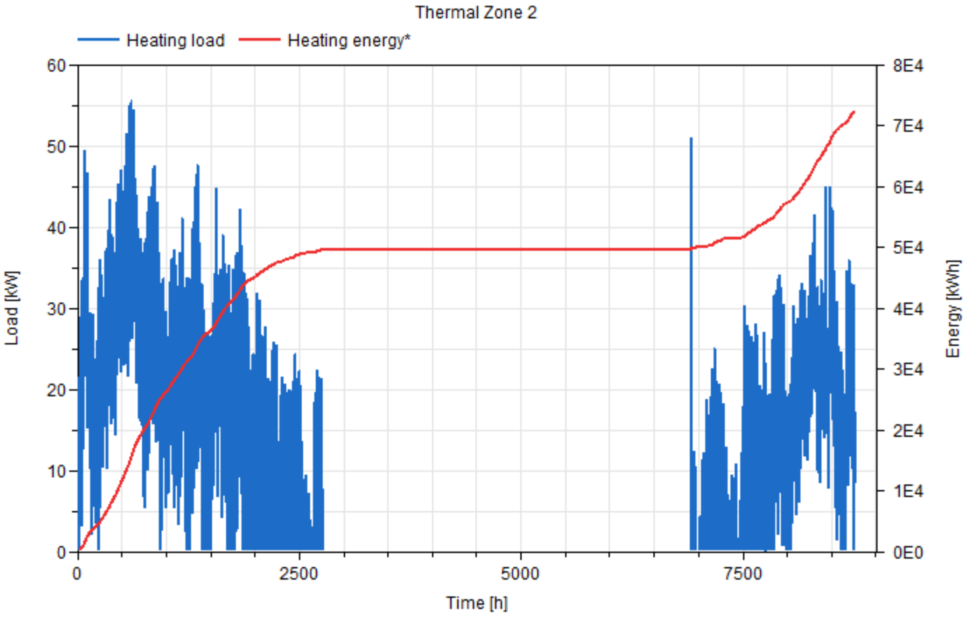
(a) (b)



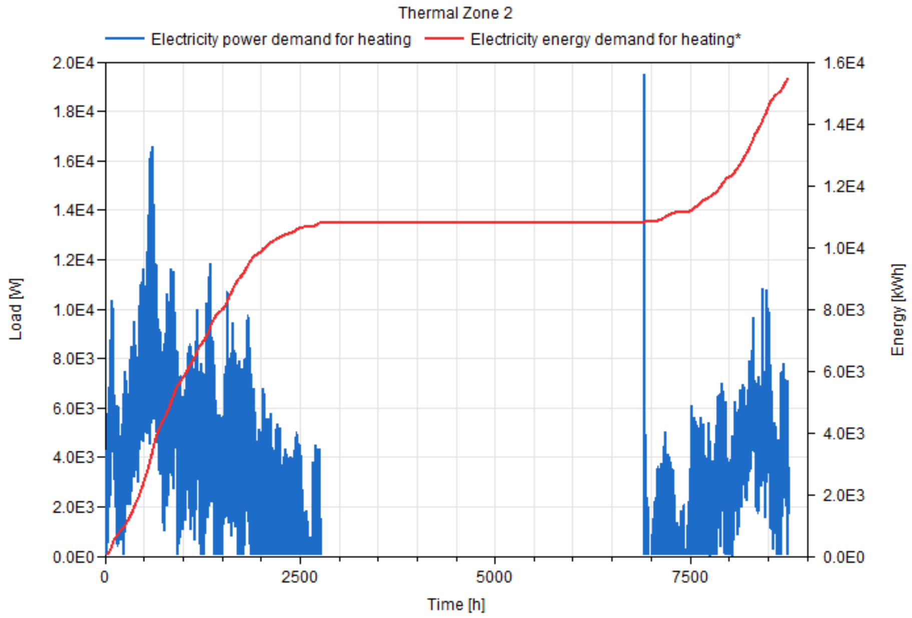
(c) (d)

Figure 120. Thermal zone 1 a) Heating load and cumulative energy load for the year period, (b) Heating load for a week in January, (c) Boiler power and cumulative energy demand for heating for the year period, and (d) Boiler power for a week in January

The next step is the presentation of the simulation results regarding the thermal loads of thermal zone 2. More specifically, according to Figure 121a, the maximum heating load of thermal zone 2 is calculated at 55.3 kW on the 25th of January. On the 15th of October when the heating period restarts, the heating load is abruptly high due to the unsatisfied accumulated heating loads until this date. The yearly heating energy demand of thermal zone 2 is calculated at 72,427 kWh. The electricity power and energy demand for heating are illustrated in Figure 121b. It is found that the electricity load of the multisource heat pump on the 25th of January is 16.5 kW, whereas on the 15th of October, the electricity load is calculated at 19.4 kW. The yearly electricity demand is calculated at 15,464 kWh.



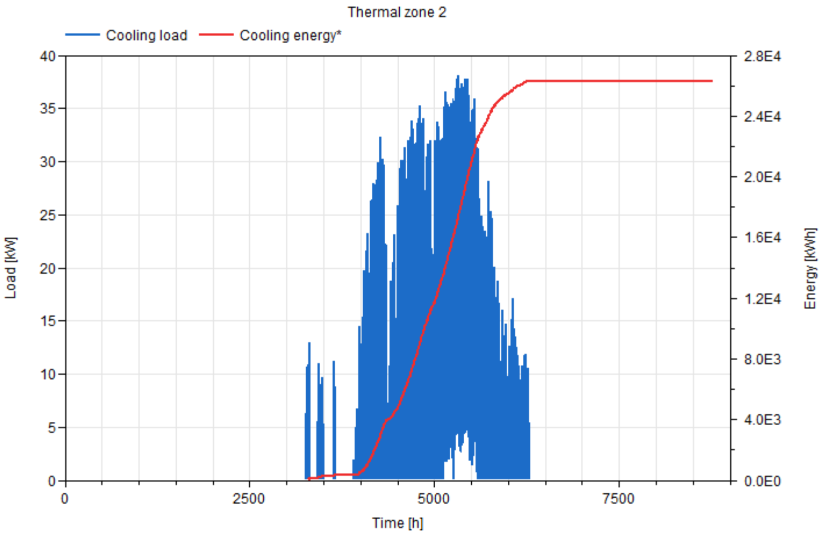
(a)



(b)

Figure 121. Thermal zone 2 a) Heating load and cumulative energy load, and (b) Electricity power and cumulative energy demand for heating

In contradiction with thermal zone 1, the energy system of thermal zone 2 covers the zone's cooling loads. Particularly, according to Figure 122a, the cumulative cooling energy demand of the zone is calculated at 26,353 kWh, while the maximum cooling load of the zone is presented on the 14th of August and is calculated at 37.9 kW. The electricity power and energy demand for cooling are illustrated in Figure 122b. It is found that the maximum electricity load of the multisource heat pump is 9.7 kW, while the yearly electricity demand is calculated at 5,549 kWh.



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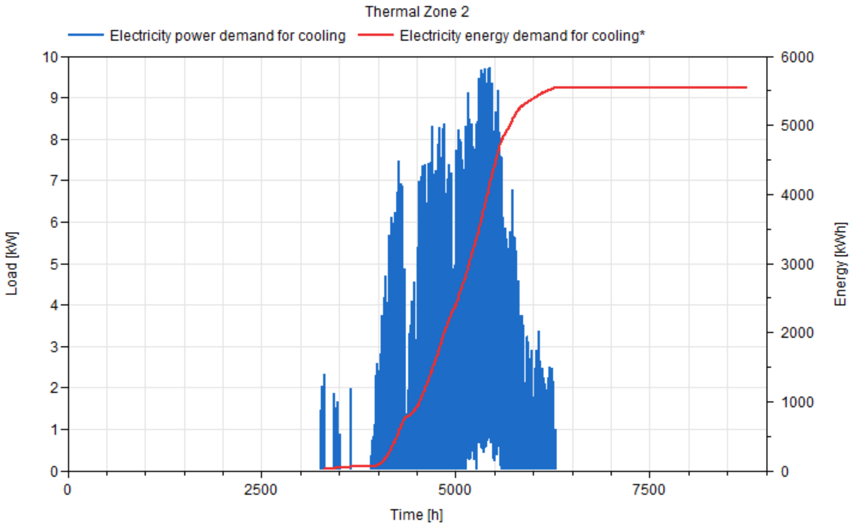
(a)



(b)

Figure 122. Thermal zone 2 a) Cooling load and cumulative energy load, and (b) Electricity power and cumulative energy demand for cooling

The coefficient of performance (COP) for heating and the energy efficiency ratio (EER) for cooling the multisource heat pump is illustrated in Figure 123 for the heating and cooling mode of the multisource heat pump. As far as the heating mode is concerned the COP value is fluctuating between 3.43, the coldest day of the year, and 9.71. The mean COP value is calculated at 4.68. On the contrary, in cooling mode, the EER value is in the range between 3.70, the hottest day of the year, and 7.33, whereas the mean value of EER is calculated at 4.75.

In Figure 124 the ambient temperature as well as the indoor temperature of thermal zone 1 and 2 are illustrated. For thermal zone 1 the indoor temperature intensely fluctuates between 14°C and 26°C due to the intermitting operating schedule of the zone’s heating system. On the contrary, in thermal zone 2 the indoor temperature presents a steady profile, with the temperature level being equal to, or higher than 20°C throughout the winter period. Thus, it is obvious that the renovated thermal zone 2 leads to better thermal comfort conditions inside the building. Also, it is observed that for both zones the indoor temperature drops below the temperature desired setpoint of 20°C for a few days after the 15th of April and a few days before the 15th of October, because during these days the heating loads of the zones are not equal to zero. Figure 125 illustrates the electricity load and energy demand for appliances and lighting in every thermal zone. The cumulative electricity demand for thermal zone 1 is calculated at 36,053 kWh and for thermal zone 2 at 23,050 kWh.

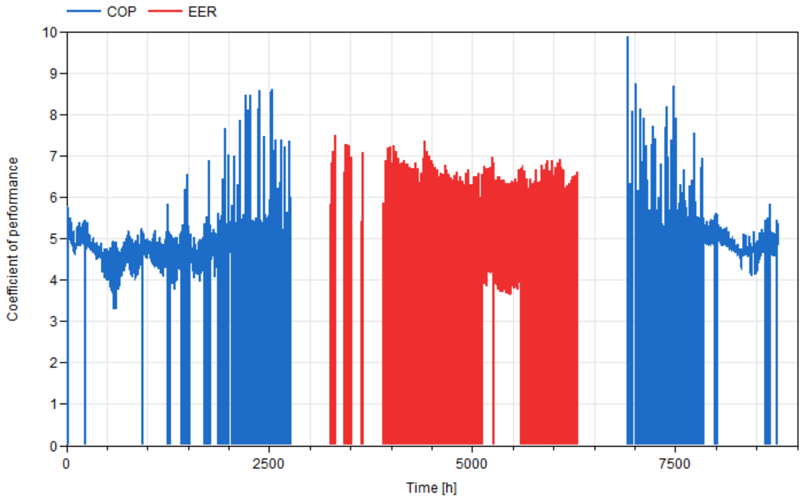


Figure 123. Coefficient of performance for heating and cooling mode of multisource heat pump

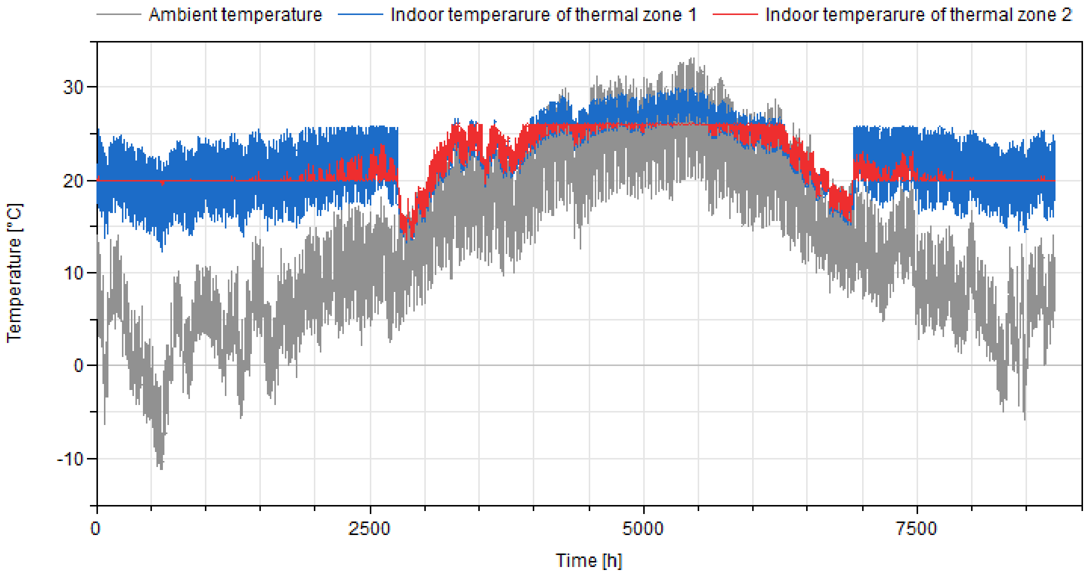


Figure 124. Ambient temperature and indoor temperature of thermal zones 1 &2

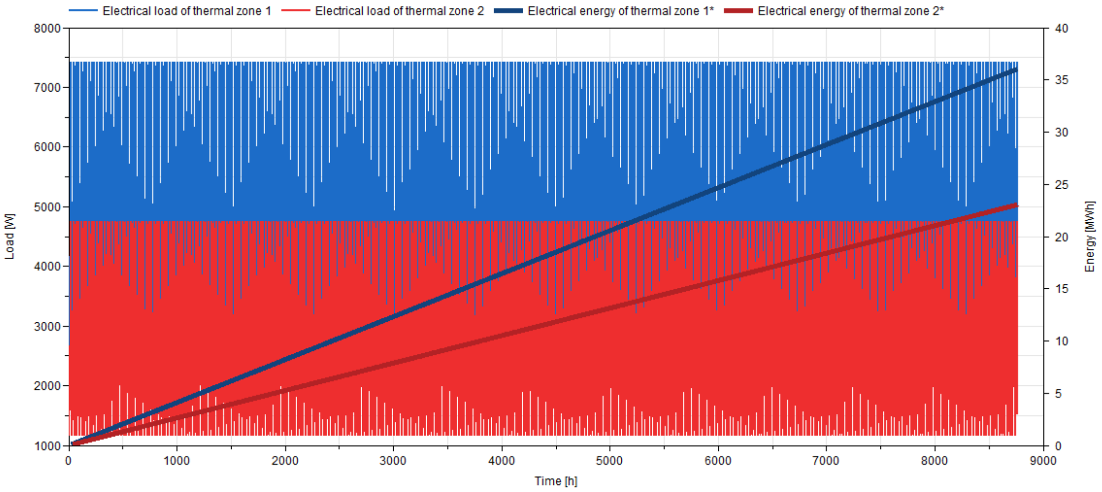


Figure 125. Electrical power and energy values for appliances and lighting purposes for thermal zones 1 & 2

The electrical load and yearly electrical energy produced by the ABDE BIPVs mounted on the building’s south walls are demonstrated in Figure 126. The BIPVs are more efficient during the sunny days of the winter period because of the sun’s relative angle to the building’s vertical walls.

Indicatively, during the months of January and February, the electrical load produced by the BIPVs is calculated to reach up to 4,710 W. On the contrary, during the summer period when there is greater solar potential, the maximum electrical load produced is calculated at 3,400 W in August. The cumulative electrical energy produced by the 32 ADBE BIPV panels is calculated at 6,053 kWh. This electricity production will be used for supplying lighting in the external outdoor area of the examined building.

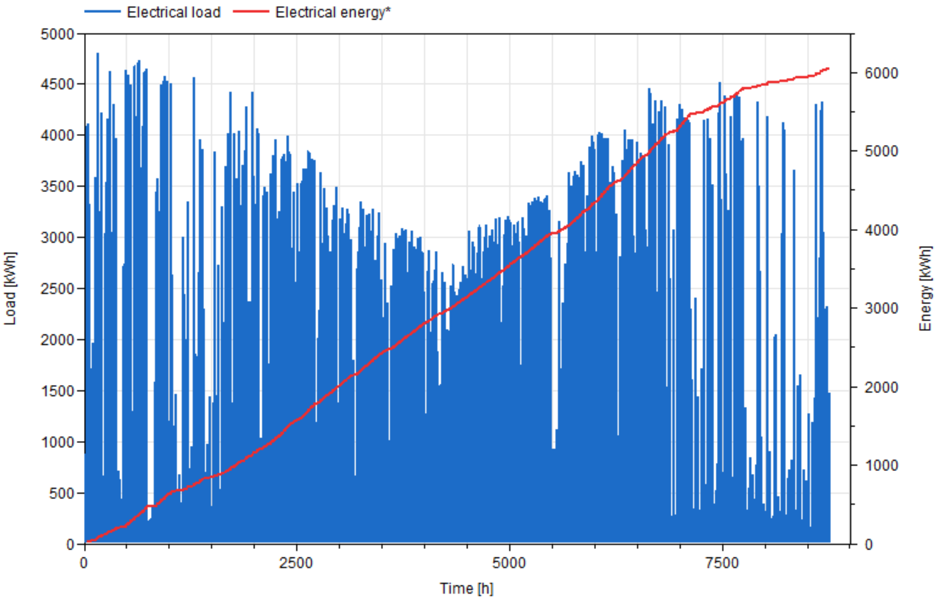


Figure 126. Electrical load and energy produced by ADBE BIPVs on the south walls

The multisource heat pump for its heating operation mode utilizes as energy sources the ambient, solar energy and geothermal energy, in order to serve a cumulative heating load demand of 72,427 kWh in thermal zone 2. In Figure 127, the geothermal heating load input of the borefield to the multisource heat pump is depicted. The yearly heating energy input of the ground source is calculated at 9,150 kWh. This figure practically depicts all the positive energy exchange of the heat pump with the geothermal field by taking into consideration the benefits both in heating period (input energy) and in cooling period (heat rejection), but with positive sign in both cases. Additionally, Figure 128 illustrates the temperature fluctuation of the water in the solar thermal inlet and outlet, whereas Figure 129 depicts the useful thermal energy produced by the solar thermal system. More specifically, the accumulated useful heating energy input of the solar thermal system coupled with the multisource heat pump is calculated at 10,802 kWh. Conclusively, the aggregated heating energy input of the ambient is calculated at 37,011 kWh, whereas the electricity demand is calculated at 15,464 and the seasonal COP at 4.68, as mentioned before. Table 36 summarizes the building’s thermal loads per zone and in total. The yearly water contribution to the heat input was found to be 35% (19,952 kWh) and the air contribution to be 65% (37,011 kWh) for the heating period. Finally, Figure 130 demonstrates the auxiliary power input for the DHW production by the PV system that pre-existed in the baseline scenario. The cumulative auxiliary energy input of the PV for the DHW production is calculated at 17,569 kWh. This quantity can be covered by the existing PV on the roof.

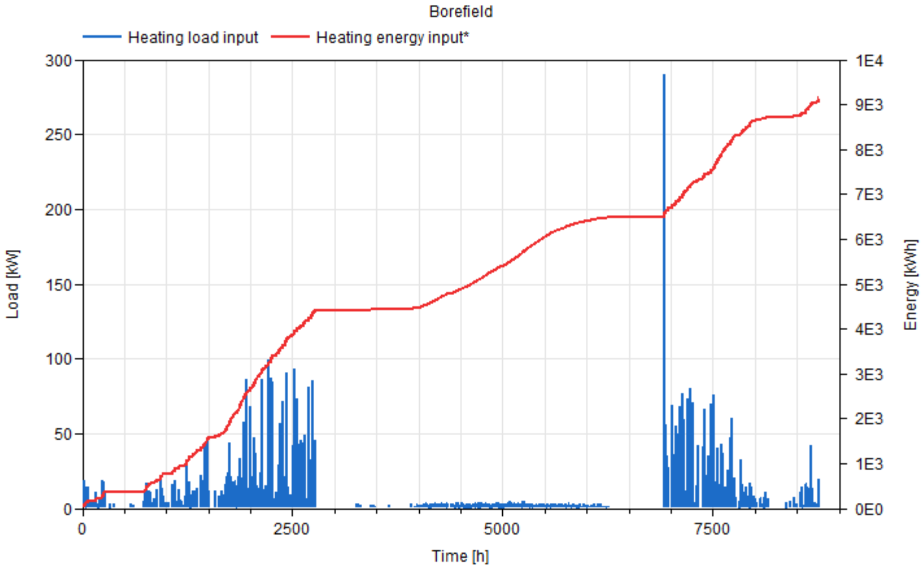


Figure 127. Exploited geothermal energy during the year for both heating and cooling (only positive values are given and thus the cumulative curve has an increasing trend during the year)

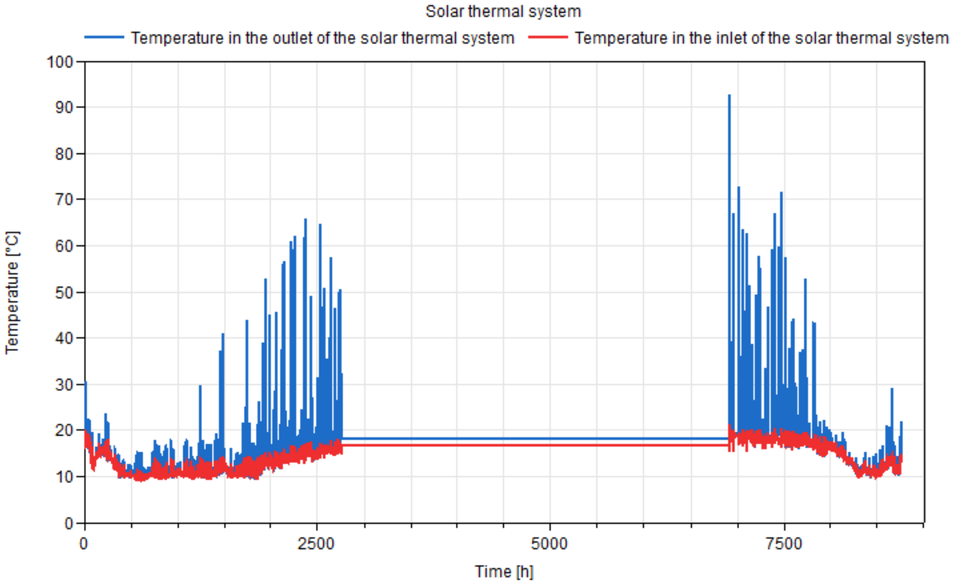


Figure 128. Temperature of water in the solar thermal system inlet and outlet

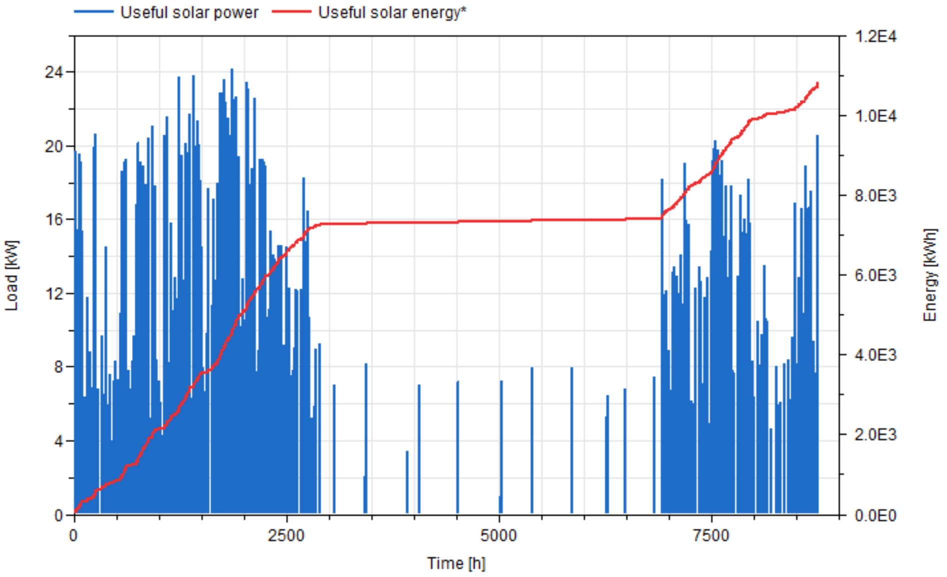


Figure 129. Useful solar power and energy produced by the solar thermal system coupled with the multisource heat pump

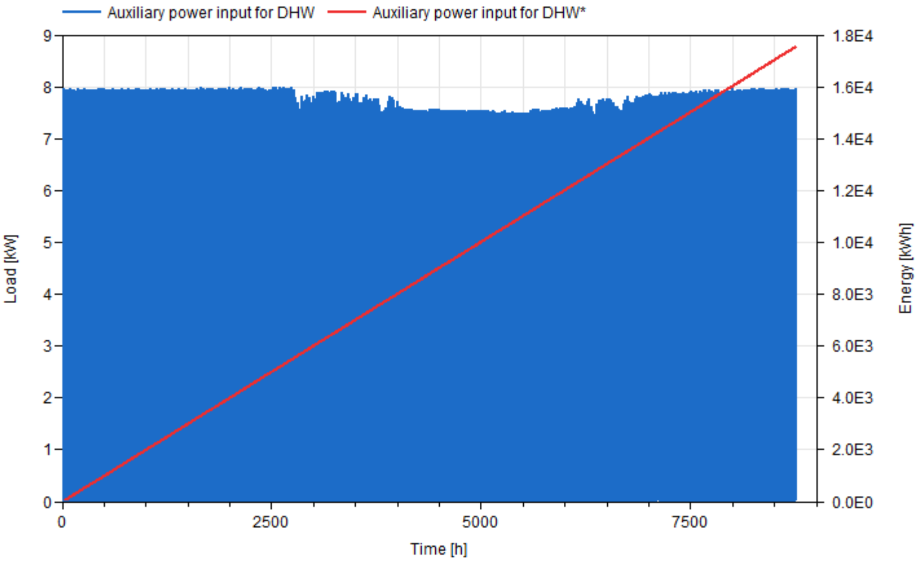


Figure 130. Auxiliary power and energy inputs from the PV system for the DHW

Table 36. Summary of building's energy demands [kWh]

Parameters	Values		
Basic demands	**Total**	**TZ-1**	**TZ-2**
Heating energy load	153,067	80,640	72,427
Cooling energy load	26,353	0	26,353
Electrical Energy for appliances and lighting	58,978	35,977	23,001
Boiler energy demand	142,059	142,059	0
Electricity demand for heating	15,464	0	15,464
Electricity demand for cooling	5,549	0	5,549
Energy load for DHW	38,020	23,916	14,104

6.2.1.1.3 COMPARISON OF THE RENOVATION AND BASELINE SCENARIOS

In this section, the simulation results regarding the baseline scenario and the renovation scenarios are compared and briefly discussed. In contradiction with the baseline scenario that the building was entirely served by a single energy system, covering its heating needs, in the renovated scenarios, the building is divided into two thermal zones and two separate energy systems are parallelly operating. In the first thermal zone, the refurbished energy system of the baseline scenario with fan coil units as terminal units, is covering its heating loads. The second thermal zone is also equipped with a fan coil system, but served by a multisource heat pump. The second thermal zone has both its heating and cooling needs satisfied. The first zone corresponds to 61% of the building's treated floor area and consists of 39 student rooms, while the second zone consists of the remaining 23 student rooms and the common spaces and corridors' area in each of the three floors of the building, corresponding to the 39% of the building's treated floor area. The purpose of the renovation strategy of the examined building is to decrease its thermal loads and improve the thermal comfort conditions of its residents. To achieve that various standards as well as technologically advanced solutions were implemented. The energy simulation analysis conducted in this report allows the comparison between the two states of the building and the prediction of the energy savings induced by the renovation actions. In Table 37, the basic energy demands of each examined scenario are given. In the baseline scenario, the heating energy demand is calculated at 145,213 kWh whereas in the renovated state the heating demand of the building is calculated at 153,067 kWh. The increase in the heating energy load of the building corresponds to the improvement of the living conditions of the students because the indoor temperature of the building better fulfils the thermal comfort requirements. In the renovated scenario, only thermal zone 1 is served by the biomass boiler and therefore the boiler energy demand is greatly decreased. More specifically, in the baseline scenario, the boiler energy demand is calculated at 203,245 kWh, while for the renovated scenario this value is equal to 142,059 kWh, indicating a decrease of 30.1%. Moreover, in the baseline scenario, the cooling demand of the building was not calculated, since there is no appropriate energy system available. In the renovated scenarios though, thermal zone 2 is equipped with an appropriate energy system and its cooling energy load is calculated at 26,353 kWh. The energy demand for DHW is the same in the two scenarios because the number of residents is considered stable. However, due to the change in the biomass boiler temperature setpoint, the PV contribution to the DHW production is modified. More specifically, in the baseline scenario, the yearly energy input of the PV system was calculated at 7,266 kWh, while for the renovated scenario the energy input was calculated at 17,569 kWh, indicating a significant increase. However, the existing PV on the building roof can supply this electricity amount; therefore, the new estimated value is an acceptable one. Finally, the electricity demand for lighting and appliances presents no alteration because no renovation actions were taken aiming at its decrease. Moreover, this table includes the total final and primary energy consumption. The primary energy conversion factor for electricity was selected at 2.9 and for biomass at 1.0, according to the Greek legislation. For the renovation Scenario 1, in which the electricity produced by the roof PV system is exploited only for the DHW production, in total, 17,569 kWh, the total primary energy consumption of the building is calculated at 374,033 kWh, indicating a slight decrease of 0.07% in comparison with the baseline scenario. Furthermore, in Scenario 2, the electricity production of the roof PV systems covers both the DHW energy demand, as well as the electricity demand of the heat pump operation, totally of 38,582 kWh of electricity. The total primary energy demand for Scenario 2 is calculated at 313,095 kWh, indicating a 16.35% enhancement relative to the baseline scenario. Finally, in Scenario 3the produced electricity from the roof PV systems covers the DHW energy demand, the electricity demand for the heat pump yearly operation, as well as the electricity demand for the building's appliances and lighting. In total, 97,560 kWh of PV-produced electricity is exploited, reducing the building's total primary energy demand by 62.04%, at 142,059 kWh.

Table 37. Comparison of basic energy demands between baseline and renovated scenario [kWh]

Energy Quantities	Baseline scenario	Renovation scenario		
	Total	Thermal Zone 1	Thermal Zone 2	Total
Heating energy load	145,213	80,640	72,427	153,067
Energy Load for DHW	38,020	23,916	14,104	38,020
Cooling energy load	No System	No System	26,353	26,353
Boiler energy demand	203,245	142,059	0	142,059
Electricity demand for heating	0	0	15,464	15,464
Electricity demand for cooling	No System	No System	5,549	5,549
Electricity demand for appliances and lighting	58,978	35,977	23,001	58,978
Total net electricity demand	58,978	35,977	44,014	79,991
Electricity production from roof PV system	99,367	-	-	99,367
Electricity production from BIPVs	-	-	6,053	6,053
Scenario 1: Evaluation of the results with PV exploitation for DHW				
Final energy demand	262,223	178,036	44,014	222,050
Primary energy demand	374,281	246,392	127,641	374,033
Scenario 2: Evaluation of the results with PV exploitation for DHW & heat pump				
Final energy demand	262,223	178,036	23,001	201,037
Primary energy demand	374,281	246,392	66,703	313,095
Scenario 3: Evaluation of the results with PV exploitation for DHW, heat pump, appliances & lighting				
Final energy demand	262,223	142,059	0	142,059
Primary energy demand	374,281	142,059	0	142,059

6.2.1.1.4 REFERENCES

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6.2.1.2LCA/LCC (VERIFY)

6.2.1.2.1 INTRODUCTION

The objective of this report is to conduct a thorough Lifecycle Assessment (LCA) and Lifecycle Costing (LCC) for the baseline and renovation scenario identified in the Greek Demo. The main focus of the calculations revolves around the building's energy consumption, energy production, and global warming impact.

To facilitate this analysis, VERIFY incorporates two specialized modules: the Environmental module and the Cost module. These modules are supported by an extensive database of components and technologies developed by CERTH/CPERI. The database encompasses a wide range of materials, building components/technologies, and energy systems, catering to the requirements of various renovation scenarios. It draws data from technology providers, internal studies, and public literature documents.

When utilizing the VERIFY platform for analysis, users create an "Electrical Plan" to define electricity production (preferably from renewable energy sources if available), consumption, energy storage technologies, and building operation. Additionally, a "Thermal Plan" is established to specify the building envelope, characteristics, and sizing of active systems (heating, cooling, ventilation), as well as passive systems (insulation, glazing, hot-water storage). Furthermore, an "Investment Plan" allows users to input information pertaining to applicable energy price mechanisms, funding details, and country-specific regulations, tailored to the building's location and user requirements. While this information is not mandatory for the core LCA and LCC analysis, it enhances the overall assessment.

VERIFY surpasses the provision of a static environmental and costing performance snapshot by enabling life cycle computations. It ultimately generates a comprehensive life cycle report, encompassing well-defined key performance indicators that can be further utilized for analysis and decision-making purposes [1].

6.2.1.2.2 BASELINE SCENARIO ASSESSMENT

In the initial phase of the REHOUSE assessment, the baseline scenario was chosen for the Greek Demo to conduct a comprehensive analysis of energy, environmental, and cost factors. In the subsequent paragraphs, a detailed description of this scenario and the analysis of its Lifecycle Assessment (LCA) and Lifecycle Costing (LCC) will be presented [2].

6.2.1.2.2.1 BASELINE SCENARIO – IMPACT ASSESSMENT

The environmental and economic analysis of the baseline scenario involves assessing the infrastructure and functional emissions and costs of the building. Additionally, the energy flows and exchanges within the building were taken into consideration. The CO_2 emissions, primary energy requirements, and costs related to the manufacturing phase of various building components were obtained from the relevant environmental and cost VERIFY databases.

On the other hand, the CO_2 emissions, primary energy requirements, and costs incurred during the analysis period (operational phase) were determined using the energy consumption time series derived from the energy analysis conducted in INTEMA.building.

To estimate the cost of building interventions, the VERIFY cost database, developed through an extensive literature review and market price analysis, was initially used. However, to ensure a more realistic cost estimation, given the recent volatility in building product prices, the costs were reviewed by i) conducting an updated review of market prices (where possible) and ii) consulting with demo leaders (where applicable).

Finally, the lifespan of our analysis was set to **50 years**.

Following this approach, presents the lifecycle environmental impact per component and the overall impact. The CO_2 emissions presented in the Table 38 include the emissions that were produced from the manufacture, transportation and installation of the components, the operation of the components and the replacement of the components during the 50 years of the analysis.

Table 38. Lifecycle Environmental impact per component – baseline scenario

Component Name	CO_2 (kg)
Glazing (South)	4,958.01
Glazing (West)	325.11
Glazing (East)	812.79
Glazing (North)	5,852.08
Hot Water Storage (2000lt)	7,254.82
Hot Water Storage (5200lt)	18,861.25
PV - System	92,856.56
Battery	37,940.11
Boiler biomass	24,963.15

6.2.1.2.2.2 BASELINE SCENARIO – LCA / LCC RESULTS

The LCA/LCC analysis results, are presented in Table 39 below. As mentioned earlier, the environmental and economic impact of the baseline scenario is assessed using the following Key Performance Indicators (KPIs). VERIFY analysis is centred around the energy performance of the building, i.e. the aspects of the building that consume electrical or thermal energy or prevent thermal losses. In addition, it is worth considering that the analysis commenced in August of the first year. Consequently, the data for the initial year is partial, accounting only for the period from August to December. Similarly, the data is partial for the last year, covering the period from January to July.

Table 39. LCA / LCC Results of the baseline scenario

KPI	RESULT
Lifetime CO_2 emissions	1,278,665.71 [$kgC0_2$]
Investment cost	0[€] **(no purchase of new component)**
Life cycle cost	2,070,722.11 [€]
Lifetime income	0[€] **(no exported energy to grid)**

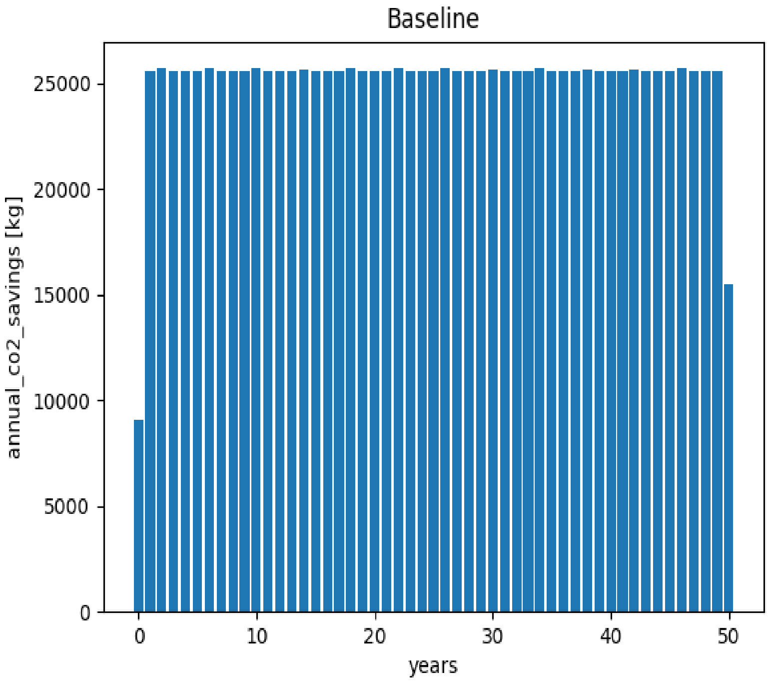

Figure 131. Annual Savings C02 [kg] – Baseline Scenario

Figure 131 shows a decline in annual CO_2 savings due to systems degradation.

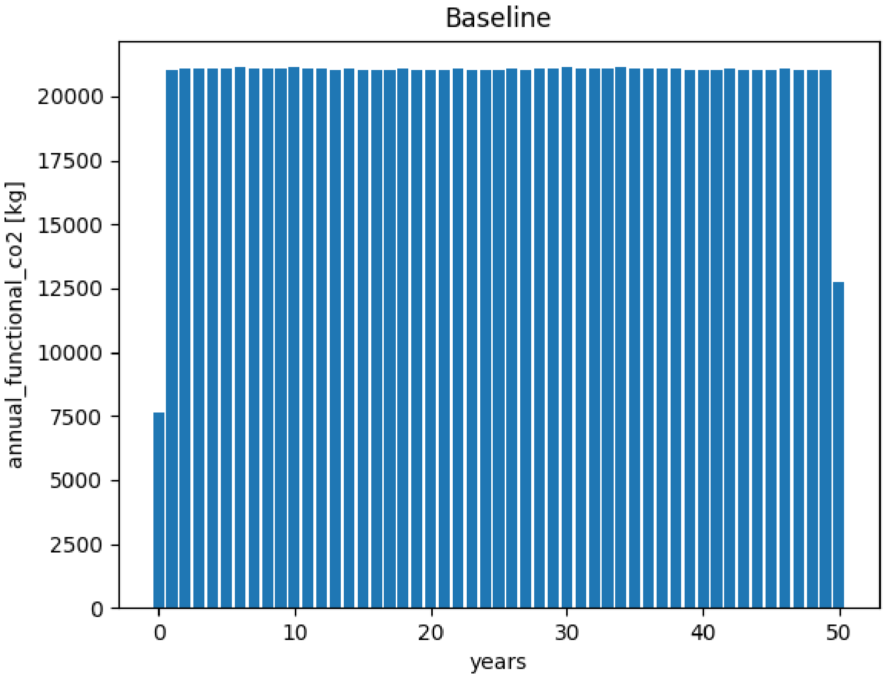

Figure 132. Annual Operational (Functional) C02 [kg] – Baseline Scenario

Figure 132 demonstrates an increase in annual CO_2 operating costs as a result of component degradation, leading to higher fuel consumption for achieving the same results. Upon replacing a component, an immediate improvement is observed, attributed to the new component being devoid of degradation.

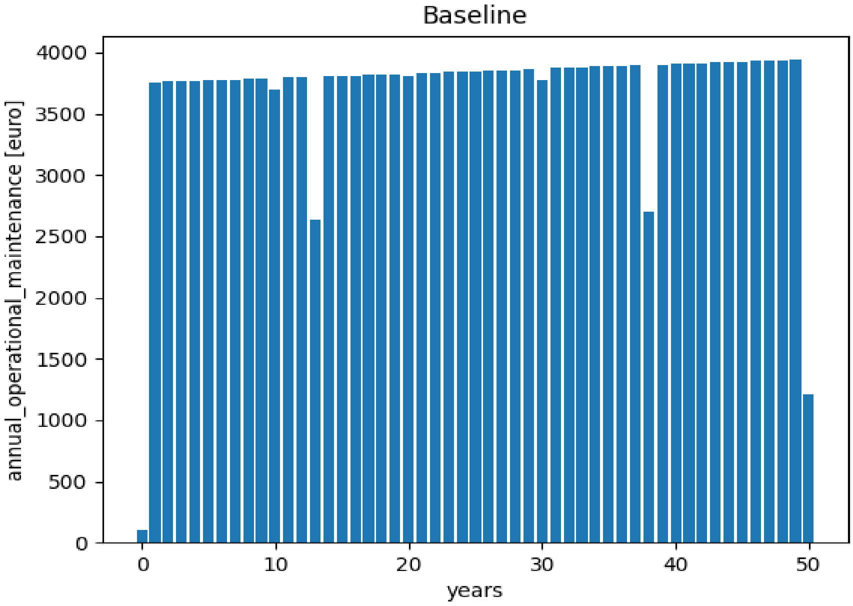

Figure 133. Annual Functional Operational Maintenance Cost (€)– Baseline Scenario

Figure 133 it is observed that whenever a component is replaced, there are no operational costs incurred for that year, as the new component requires no maintenance.

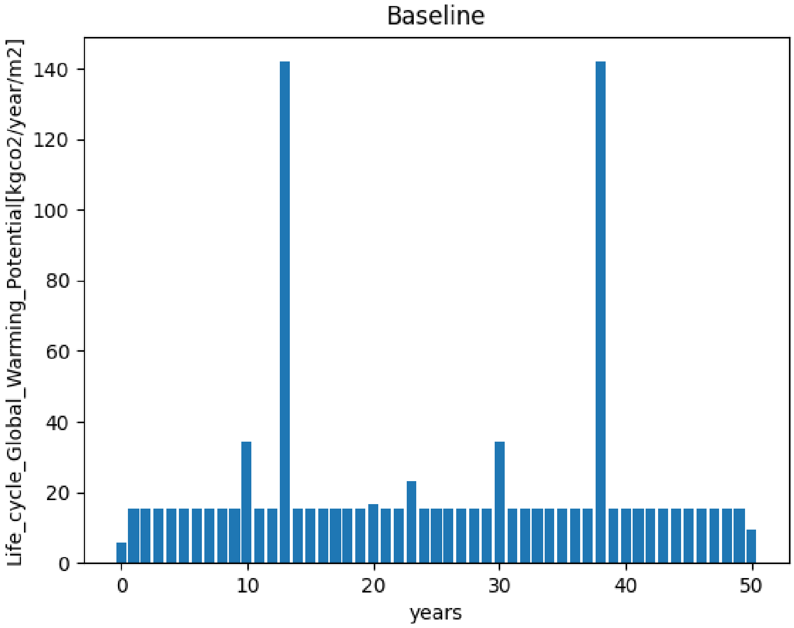

Figure 134. Lifecycle Global Warming – Baseline Scenario

The plot of Figure 134 is the result of the Annual Operational (Functional) CO_2 (figure 2) segmented based on the floor surface of the building and adding the infrastructure CO_2 of the different components. The peaks observed are depicted when a technology is going to be replaced, therefore additional CO_2 capex is paid.

6.2.1.2.3 RENOVATION SCENARIO

The next phase of the process entails establishing the renovation scenario, accompanied by a comprehensive report that outlines the renovation actions and their outcomes. The aim of this comparison is to conduct a comprehensive Lifecycle Assessment (LCA) and Lifecycle Costing

(LCC) analysis for the alternative scenarios proposed in the Greek Demo, while also calculating the relevant economic and environmental KPIs for the REHOUSE project.

6.2.1.2.3.1 DESCRIPTION OF THE RENOVATION ACTIONS

In this section, we provide a detailed description of the renovation strategy planned for the Greek Demo case, outlining specific actions for implementation. The chosen approach for revitalizing this student dormitory involves employing three REHOUSE renovation packages: the multisource heat pump, the ADBE and the SmartWall. Additionally, standard renovation activities, unrelated to the REHOUSE Project, will be carried out. These include enhancing thermal insulation and refurbishing the baseline energy system through the installation of a fan coil system.

6.2.1.2.3.2 DESCRIPTION AND ANALYSIS OF RP1

The multisource heat pump is a technological solution that integrates thermal energy storage, thermal panels, and HFO (HydroFluoro-Olefins) refrigerants. This heat pump configuration can achieve high performance adjusted for the temperature ranges of modern heating appliances in both new and renovated buildings. More particularly, the multisource operation combines different natural heat sources such as ambient air, solar thermal energy, and geothermal energy and allows the integration with local thermal energy storage systems. Additionally, the advanced energy management and control system of the multisource solution optimizes operation according to resource availability, smart exploitation of buffer capacities, and demand response schemes, whereas the use of HFO refrigerant ensures suitability for future applications compliant with the F-gas regulation constraints. Table 40 presents the technical specification of the product.

Table 40. Technical data- RP1

Parameter	Value
Nominal COP (heating)*	4.17
COP (TE)	0.001257 TE2 +0.072 TE +3.979143
Nominal EER (cooling)**	3.17
EER (TC)	0.002057 TC2 - 0.264171TC +10.684571
Nominal heating capacity	130.54 kW
Nominal cooling capacity	99.2 kW
Refrigerant	R407C

** For ambient air 5oC and condensation at 45oC*

*** For cold water at 7^{o}C and air-cooled condenser*

The life cycle phases which were included to model the environmental impact of the RP1 are the raw materials acquisition, components/ materials manufacturing & packaging, components/ materials transportation, RP manufacturing and RP transportation.

After conducting the life cycle analysis based on primary data (manufacturing data sheets for the examined technologies/components/energy systems) and secondary data (data sources from published articles/report and modules developed by CERTH) the embodied CO2eq [kg] for the RP1 is 12,064.

On Table 41 both the total acquisition cost and maintenance cost of the RP1 are presented:

Table 41. Acquisition and Maintenance Cost of RP1

Cost - Type	Value [€]
Total Acquisition Cost	58,800
Maintenance cost (annual)	800

6.2.1.2.3.3 DESCRIPTION AND ANALYSIS OF RP2

The Adaptable Building Envelope (ADBE) technology is a comprehensive solution that integrates insulation, batteries, and photovoltaics. It excels in adaptability to various building geometries, thanks to its modular construction and high degree of prefabrication and customization. ADBE is built around a modular prefabricated structure crafted from recyclable materials, such as aluminium, which not only reduces the building's carbon footprint but also speeds up the renovation process. All ADBE components are manufactured in a factory and transported to the installation site by truck, where installation crews can set them up with the aid of cranes, eliminating the need for expensive scaffolding or specialized technician training.

ADBE technology plays a significant role in enhancing a building's sustainability. Its thoughtful design allows for the incorporation of Building-Integrated Photovoltaic (BIPV) panels and battery storage, thereby boosting on-site renewable energy production. It also accommodates other technical facilities, along with eco-friendly insulation materials. Furthermore, the technology promotes smart energy management within the building by embedding essential sensors and actuators. Lastly, the exterior of the ADBE façade elements is fortified with weather-resistant panels, providing resilience against major disruptive events like severe weather, fire, earthquakes, and more. Bellow in Table 42 the technical data are given which summarizes the main properties and characteristics of this technology:

Table 42. Technical Data – RP2

Parameter	Value
PV technology (Onyx Solar)	
Nominal total capacity [kWp]	4.7
Dimensions [m x m]	1.6 x 1.6
Reference electrical efficiency [%]	5.76
Maximum Production Capacity [Wp/m^2]	57.6
Open Circuit Voltage [V]	125
Short Circuit Current [A]	1.93
Voltage at nominal power – Vmpp [V]	86
Current at nominal power – Impp [A]	1.72
Nominal Power [W]	147
Inverter efficiency [%]	94
Power temperature coefficient [%/°C]	-0.19
Voltage temperature coefficient [%/°C]	-0.28
Current temperature coefficient [%/°C]	0.09
Thickness [mm]	18.24
Material thermal properties	
U-value of the glass [W/m^{2}K]	5.2

Parameter	Value
U-value of ADBE façade with extra insulation layer [W/m^{2}K]	0.431
Area on the south-west wall [m^2]	18
Area on the south-west roof [m^2]	144
Total area in the renovated building [m^2]	82

The life cycle phases which were included to model the environmental impact of the RP2 are the raw materials acquisition, components/ materials manufacturing & packaging, components/ materials transportation, RP manufacturing and RP transportation.

After conducting the life cycle analysis based on primary data (manufacturing data sheets for the examined technologies/components/energy systems) and secondary data (data sources from published articles/report and modules developed by CERTH) the total embodied CO2eq [kg] of the RP2 in the demo is 3,084.02.

On Table 43 both the total acquisition cost and maintenance cost of the RP2 are presented:

Table 43. Acquisition and Maintenance cost of RP2

Cost- Type	Value [€]
Total Acquisition Cost	42,500
Maintenance cost (annual)	600

6.2.1.2.3.4 DESCRIPTION AND ANALYSIS OF RP3

The SmartWallSmartWall technology is a multifunctional wall system that can integrate various systems such as fan coils or other types of heating/cooling devices, windows or balcony doors, PV panels, and other electromechanical components. The SmartWallSmartWall technology is versatile and adaptable to the needs of each project and therefore the components of its basic structure can be also modified, if needed, depending on the building and the country of installation depicts a conceptual view of the SmartWallSmartWall technology. The SmartWallSmartWall technology is described by efficient environmental and thermal performance. A set of innovative technologies will contribute to new sophisticated SmartWall prototypes focusing on the use of recyclable mineral wool, a 60-min fire-retarding intumescent paint for improved thermal and fire performance, low-emission and IR-reflective coatings on the inner and outer surfaces of windows' glazing respectively, and a commercial certified system (BlazeCut T series) applied for active automatic protection of those components vulnerable to fire (e.g. batteries, fan-coil, inverter, motors, etc.).

The technical data of the configuration of the RP3 which was used in this analysis are presented in Table 44 below. It is important to note that it is possible different configurations of the RP3 to be installed in the GR demo and therefore modifications of this analysis might be needed in the future.

Table 44. Technical Data- RP3

Parameter	Value	
Total area of the AMS façade [m^2]	80	
Installation walls	North and South walls on the Basement level	
Construction layers	Thickness [cm]	Thermal conductivity [W/mK]

Parameter	Value	
Rubber	0.9	0.10
Rockwool insulation	5.0	0.033
Cement	1.25	0.35
Current at nominal power – Impp [A]	Thickness [cm]	Thermal conductivity [W/mK]

The life cycle phases which were included to model the environmental impact of the RP2 are the raw materials acquisition, components/ materials manufacturing & packaging, components/ materials transportation, RP manufacturing and RP transportation.

After conducting the life cycle analysis based on primary data (manufacturing data sheets for the examined technologies/components/energy systems) and secondary data (data sources from published articles/report and modules developed by CERTH) the embodied CO_2eq [kg] for RP3 is 32.60. On Table 45 both the total acquisition cost and maintenance cost of the RP3 are presented:

Table 45. Acquisition and Maintenance cost of RP2

Cost- Type	Value [€]
Total Acquisition Cost	2,745
Maintenance cost (annual)	100

6.2.1.2.3.5 DESCRIPTION AND ANALYSIS OF STANDARD RENOVATION ACTIONS (ACTIONS OUTSIDE OF REHOUSE PROJECT)

Except for the renovation actions planned to be conducted in terms of the REHOUSE project, Democritus University of Thrace is independently planning to realize energy efficiency interventions that do not belong in the REHOUSE project. This section is devoted to explaining these interventions.

Insulation of external walls

The entire area of the building's external walls is to be covered with the insulation material of EPS, characterized by a 7 cm thickness and a thermal conductance value of 0.031 W/mK. The only exception in this renovation activity will be the area of 80 m^2 of the south and north wall in the basement level on which the SmartWall façade will be mounted. The addition of the thermal insulation layer will enhance the external walls' thermal resistance and decrease the external walls' U-value to 0.311 W/m^2K, in comparison with the U-value of 1.05 W/m^2K in the baseline scenario

Replacement of fan coil system

Instead of feeding the radiators that are distributed in the entire building with hot water, the modified energy system will be coupled with a fan coil system. In this configuration, the hot water temperature setpoint of the biomass boiler remains at 75°C. In total, 66 fan coils will be installed in the demo where 37 will be funded from the REHOUSE project. The water piping system necessary for distribution purposes of the system is predicted to be installed in the building's basement and ascend towards the building's floors and rooms.

6.2.1.2.3.6 RENOVATION SCENARIO – RESULTS

Impact Assessment

It is of high importance to note in this chapter the fundamental scenario will be analysed in detail since it examines the GR demo as it most probably will be after the renovation (PV energy only for Domestic Hot Water Exploitation extracted from DUTh Panels). On chapter 5 there are comparative results for two other scenarios where more efficient PV energy exploitation for the building was considered.

The environmental and economic analysis of the renovation scenario involved assessing the infrastructure and functional emissions and costs of the building. Additionally, the energy flows and exchanges within the building were taken into consideration. The CO_2 emissions, primary energy requirements, and costs related to the manufacturing phase of various building components were obtained from the relevant environmental and cost VERIFY databases.

On the other hand, the CO_2 emissions, primary energy requirements, and costs incurred during the analysis period (operational phase) were determined using the energy consumption time series derived from the energy analysis conducted in INTEMA.building.

Following this approach, Table 46 presents the lifecycle environmental impact per component and the overall impact.

Table 46. Lifecycle Environmental impact per component- renovation scenario

Component Name	CO_2 (kg)
Glazing (South)	4,958.01
Glazing (West)	325.11
Glazing (East)	812.79
Glazing (North)	5,852.08
Hot Water Storage (2000lt)	7,254.82
Hot Water Storage (5200lt)	18,861.25
PV - System	92,856.56
Battery	37,940.11
Boiler biomass	24,963.15
Fan coils	3,305.00
Extra Insulation (outside of Rehouse Project)	30.1
RP#1	12,064.00
RP#2	3,084.00
RP#3	32,60

KPIS for LCA/LCC

The LCA/LCC findings, derived from the previously mentioned interventions, are showcased in Table 47 and the accompanying diagrams. The environmental and economic ramifications of the renovation scenario are evaluated through the utilization of the following Key Performance Indicators (KPIs). In addition, it is worth considering that the analysis commenced in August of the first year. Consequently, the data for the initial year is partial, accounting only for the period from August to December. Similarly, the data is partial for the last year, covering the period from January to July.

Table 47. LCA / LCC Results of the renovation scenario

KPI	RESULT
Investment cost	110,280.00[€]
Life cycle cost	1,564,316.17 [€]
Lifetime income	0 [€] **[no exported energy to grid]**

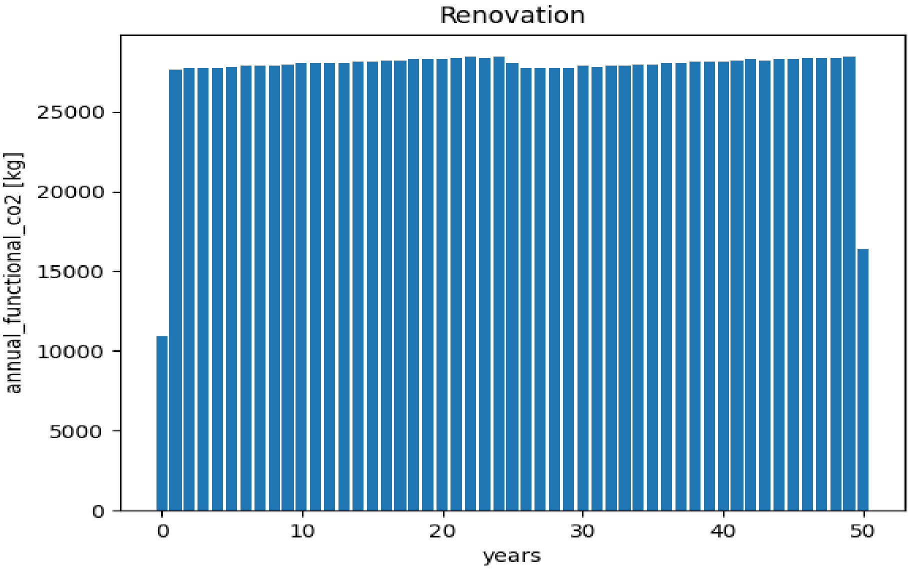

Figure 135. Annual Functional (Operational) CO2 [KG] -Renovation Scenario

Figure 135 illustrates a rise in annual CO_2 operating costs due to component degradation, leading to increased fuel consumption for achieving the same results. Every time a component is replaced, an instant decrease is noted, as the new component does not suffer from degradation.

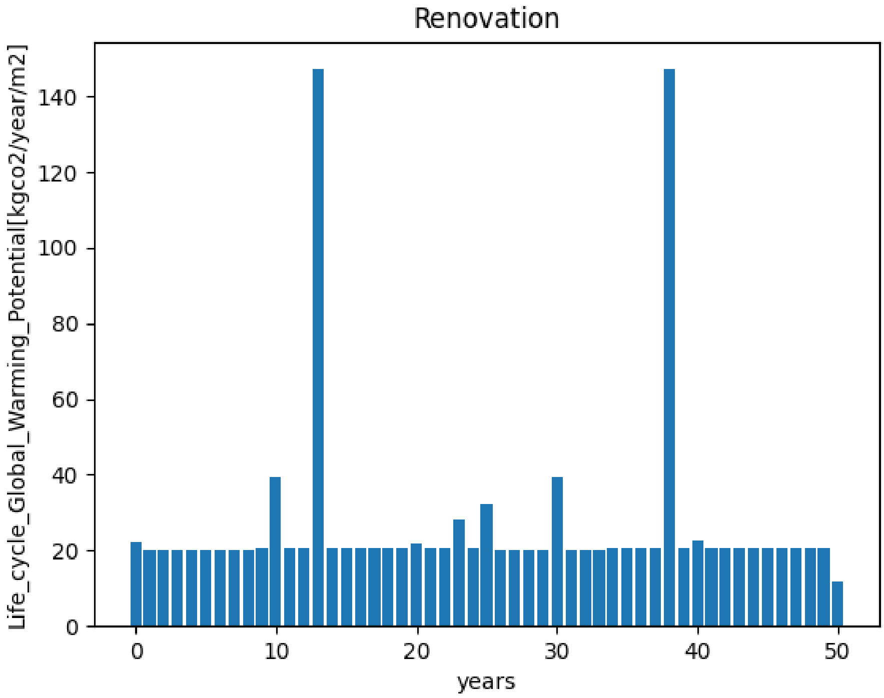

Figure 136. Global Warming Potential [KgCO2/year/m2] - Renovation Scenario

Figure 136 provides similar insights to those depicted in Figure 134. The plot of Figure 136 is the result of the Annual Operational (Functional) CO_2 segmented based on the floor surface of the building and adding the infrastructure CO_2 of the different components. The peaks observed are depicted when a new technology is going to be replaced, therefore additional CO_2 capex is paid.

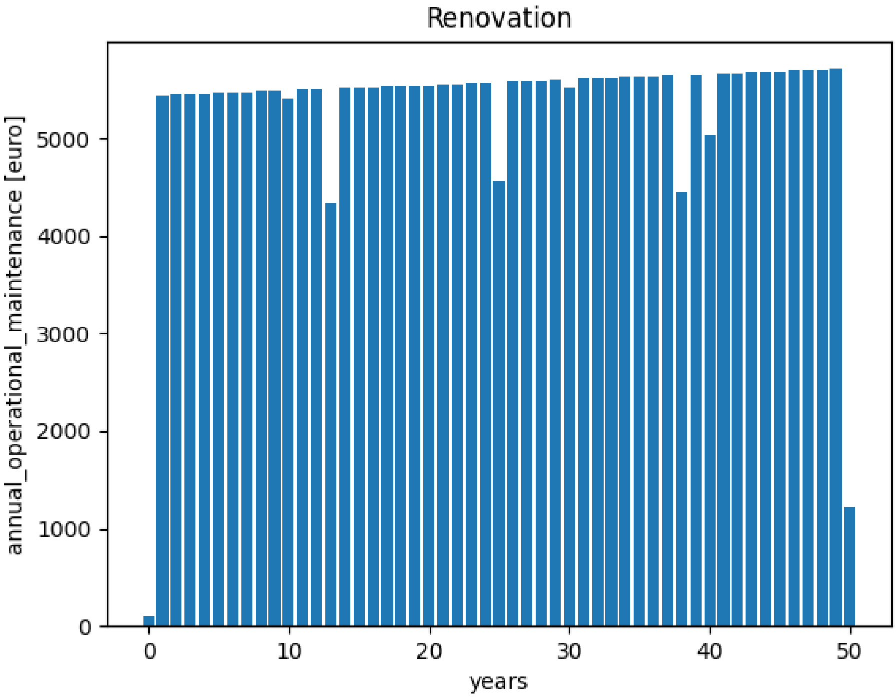

Figure 137. Annual Operational Maintenance Cost [€] – Renovation Scenario

Figure 137reveals that whenever a component is replaced, there are no operational costs incurred for that year, as the new component does not require maintenance.

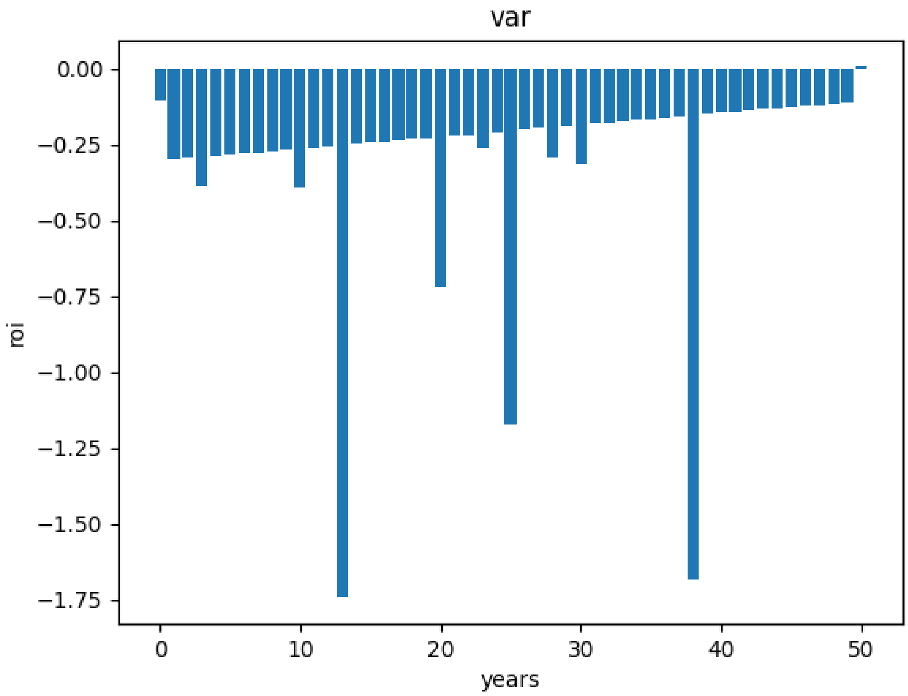

Figure 138. Annual Return of Investment

Annual ROI (Figure 138) is calculated as a ratio between the initial investment of the renovation and the annual cash flow of the renovation scenario. Negative annual ROI occurs when the annual cash flow is negative. A negative cash flow takes place when cash in-flows (incomes) are smaller than cash out-flows (costs) for the certain year.

6.2.1.2.4 COMPARISON OF THE RENOVATION AND THE BASELINE SCENARIOS

Three innovative technologies and other interventions were incorporated into the GR demo, each designed to achieve a dual objective: reduce the cooling and thermal requirements of the building while simultaneously generating electricity for self-consumption. In addition, the inclusion of geothermal technology supports the thermal system of the building. The table below presents significant KPIs for both the baseline and renovation scenarios, with a focus on two distinct cases within the Renovation scenario.

- In the first case, the renovation scenario is depicted in its fundamental state, where PV energy (DUTh PV) is exclusively employed for domestic hot water needs.
- The second scenario involves the PV (DUTh PV) system contributing energy to both domestic hot water and the heat pump.

Table 48. Comparison of LCA/LCC results between the baseline and the renovated scenarios

KPI	BASELINE	RENOVATION	
	Scenario: This Scenario is constant	**Scenario 1: Evaluation of the results with PV exploitation for DHW (fundamental state)**	**Scenario 2: Evaluation of the results with PV exploitation for DHW & heat pump**
Life cycle CO_2 Emissions [kgCO_2]	1,463,258	1,845,557	1,282,927
Life cycle CO_2 Savings [kgCO_2]	NOT APPLICABLE	NO SAVINGS	173,761
Carbon payback period [months]	NOT APPLICABLE	NO PAYBACK	21 months
Life cycle cost [€]	2,070,722	1,564,316.17	1,375,257
Monetary Investment Payback Period [months]	NOT APPLICABLE	123 months	59 months
Lifetime income [€]	0 (no exported energy to grid)	0 (no exported energy to grid)	0 (no exported energy to grid)

6.2.1.2.4.1 DISCUSSION

LCA

In scenario 1 (fundamental state) it is observed that there is an increase in the Life cycle CO_2 Emissions [kgCO_2] in comparison with the baseline scenario. This occurs due to the fact that a part of the biomass (considered CO_2 neutral) for heating usage decreases and RP1 which uses electrical energy from the Grid takes its place. However, an important positive outcome of this change is that the comfort zone of the building is increased since the RP1 is not only used for heating but also for cooling. In scenario 2, due to the increase of the PVs utilization a completely different CO_2 emission profile of the building is presented. Specifically, not only the Green Energy of the PVs is utilized and therefore a rise of the CO_2 savings of the building are achieved but also it is accomplished a CO_2 emission depletion since the building does not use the Grid Electrical Energy for a fraction of its electrical needs. As a main result it can be stated that when the utilization of photovoltaic energy expands, a proportional decrease in CO_2 emissions is achieved and therefore a carbon payback period is achieved.

LCC

In the Life Cycle Cost (€) KPI, a significant decrease is observed in all scenarios, primarily attributed to the judicious application of the PV panels. The 1st renovation scenario (fundamental state), where the PV is exclusively employed for Domestic Hot Water (DHW), demonstrates lower costs than the baseline scenario. This reduction can be attributed to the diminished cooling and thermal loads, along with the substantial replacement of biomass boiler consumption with the utilization of RP#1, contributing to overall cost efficiency. As far as the Monetary Payback period KPI is concerned, it is observed that the more PV energy utilization is accomplished (scenarios2), the earlier the Payback period is achieved.

6.2.1.2.5 REFERENCES

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[2] E.Bellos, P.Iliadis, C. Papalexis, R.Rotas, I.Mamounakis, V.Sougkakis, N.Nikolopoulos, E. Kosmatopoulos. Holistic renovation of a multi-family building in Greece based on dynamic simulation analysis. Journal of Cleaner Production. Volume 381, Part 1, 2022, 135202, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2022.135202

6.2.2 HUNGARIAN DEMO

The Hungarian Demo refers to a student’s dormitory building serving students from the nearby Paul the Saint University located in the Kőbánya district in Budapest, Hungary. The demo site’s exact location is at 47.4697580º latitude and 19.1463501º longitude, while the building’s orientation is northwest with an azimuth angle of approximately 35º. The original purpose of the building was as an industrial production facility but has been recently used as a student dormitory. Figure 139 depicts a satellite photo of the demo site taken from Google Maps of the examined building highlighted with a red polygon. Figure 140 depicts photographs of the examined demo side, one from the north-eastern entrance (after the interior renovation) and one from the southwestern side (before the interior renovation). The design drawings and construction plans of the building were used as a basis for the estimation of the building's geometrical dimensions. Drawings of the building in CAD are demonstrated in Figure 141. More specifically the northeast entrance and the Ground-floor top section view are illustrated.

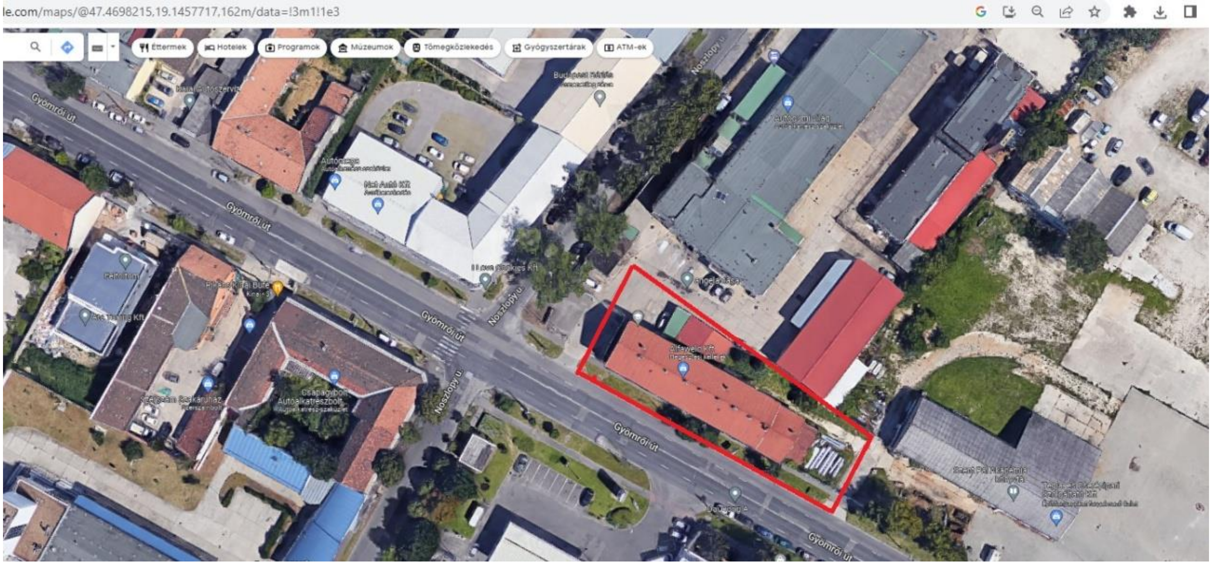
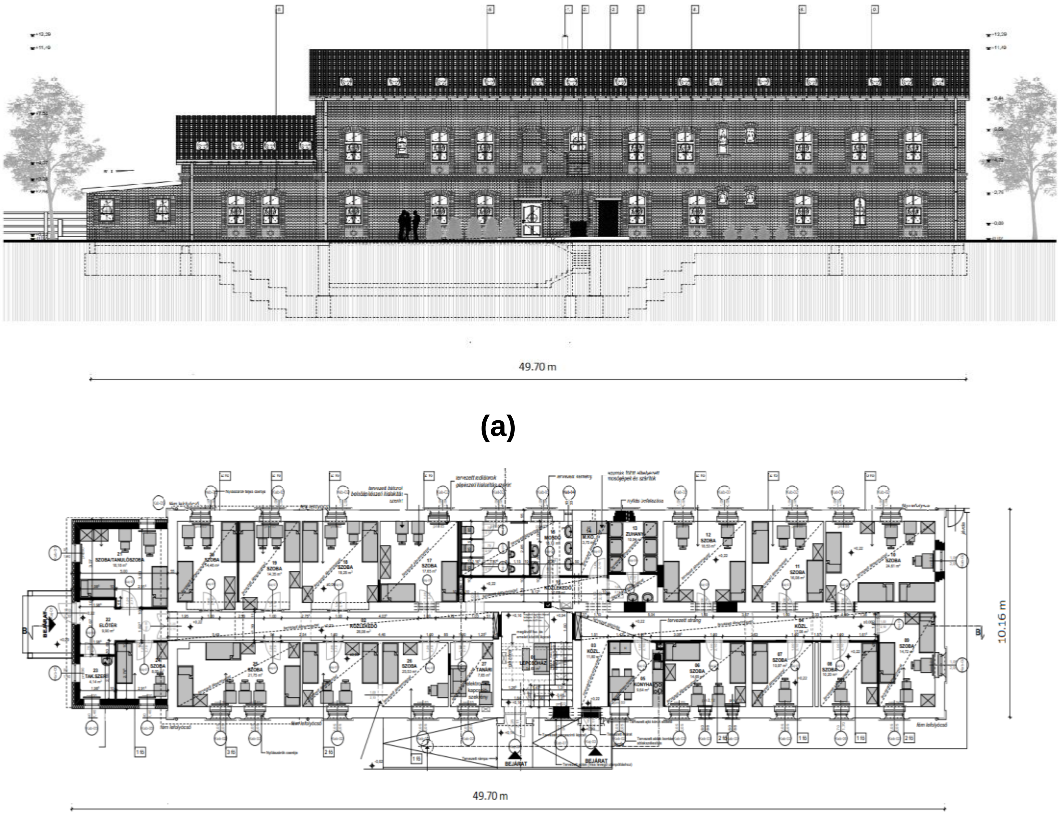


Figure 139. The examined demo at Kőbánya district, Hungary [Google Maps]

(a) (b)

Figure 140. Images of the examined building (a) Southeast entrance of the building, (b) Southwest side of the building



(a)

(b)

Figure 141. Cad drawings of the Hungarian demo (a) Front northeastern façade, (b) Top view of the Ground floor

6.2.2.1 ENERGY SIMULATION (INTEMA.BUILDING)

6.2.2.1.1 BASELINE SCENARIO ANALYSIS

The present building houses 78 residents living in 37 separate rooms of the dormitory block. All the rooms use radiators to cover their heating needs and the thermostat temperature is set to 22°C. Thus, all the rooms together can be assumed to be in the same thermal zone. This is a justified and reasonable assumption in accordance with [1]. The building's conditioned floor area was estimated at 1027 m^2 (including the Ground Floor, the First Floor, and the Attic), from which 425 m^2 refers to the net common area according to the drawings. The inclined roof has a slope of 27^o and is split into four parts, depending on the roof's elevation (4.5 m and 8.4 accordingly) and orientation (two in the southwest and two in the northeast).

Table 49 includes the basic structural components of the examined building and their thermal properties. The main construction of the ground floor is a vaulted slab with "I" beams. Vault with sand layer, 5/5 staples, and cladding. This component has a nominal U-value of 0.22 W/m^{2}K. In the present simulation, the basement is an unheated area and thus it is not taken into account. The external walls and the load-bearing structure of the existing building consist of 55 cm small brick masonry with a U-value=1.87 W/m^{2}K. As far as the roof is concerned, the total thermal transmittance is estimated at 0.218 W/m^{2}K a value which includes the effect of thermal bridges. The present building's glazing system consists of double-pane windows with a U-value of 1.20 W/m^{2}K including the glazing, frame and thermal bridge effect.

Table 49. Description of the basic structural components of the building

Structural elements	Materials	Thickness (mm)	U-value (W/m^{2}K)
Ground floor	porous glass vaulted slab with "I" beams	570	0.22
External walls	55 cm small brick masonry	550	1.87
Roof	Plasterboard, tiles, decking	350	0.218
Windows	Double-glazed with a wood frame	30	1.20

Table 50 includes basic information regarding the detailed description of the examined building. The absorbance of the opaque structural elements was estimated at 60% and the emittance at 80% which are typical values according to [1]. As far as the windows are concerned, the emittance value is estimated at 90% and the g-value at 75%. It is mentioned, that the present building has windows in all directions with the widest opening areas standing for the southeast and northwest oriented façades.

Table 50. Basic data for the description of the examined building

Parameters	Values
Gross total floor area (ground, 1st and attic)	1417 m^2
Net total floor area (ground, 1st and attic)	1027 m^2
Net total common area (ground, 1st and attic)	425 m^2
Area of the southwest wall	361 m^2
Area of the northwest wall	92 m^2
Area of the northeast wall	361 m^2
Area of the southeast wall	92 m^2
Area of the southwest roof	307 m^2

Parameters	Values
Area of the northeast roof	307 m^2
Slope of the south roof	27°
Slope of the north roof	27°
Area of the southwest windows	62 m^2
Area of the northwest windows	12 m^2
Area of the northeast windows	61 m^2
Area of the southeast windows	10 m^2
Opaque element absorbance	60%
Opaque element emittance	80%
Window g-value	75%
Window emittance	90%

The next step is the description of extra parameters that are correlated with the operation of the building and play a significant role in its thermal behaviour. Table 51 includes the parameters for the internal loads and for the infiltration/ventilation loads. It has to be commented that the specific loads are given per gross area which is 1417 m2. The mean operating factors were estimated according to the usual occupancy of the building. Moreover, it is useful to state that the daily operating profile of the building follows the profile of Figure 142 which has been taken by Ref. [2]. The infiltration and natural ventilation rates were selected at 0.3 and 0.9 air changes per hour (ACH) respectively.

Table 51. Operating parameters of the examined building

Parameter	Value
Number of occupants	78
Thermal load of the occupants	80 W/occupant
Mean operating fraction of the occupants (%)	90
Specific lighting electrical load (W/m^2)	6
Mean operating fraction of the lighting (%)	65
Specific appliances electrical load (W/m^2)	4
Mean operating fraction of the appliances (%)	60
Infiltration rate	0.3 ACH
Natural ventilation rate	0.8 ACH

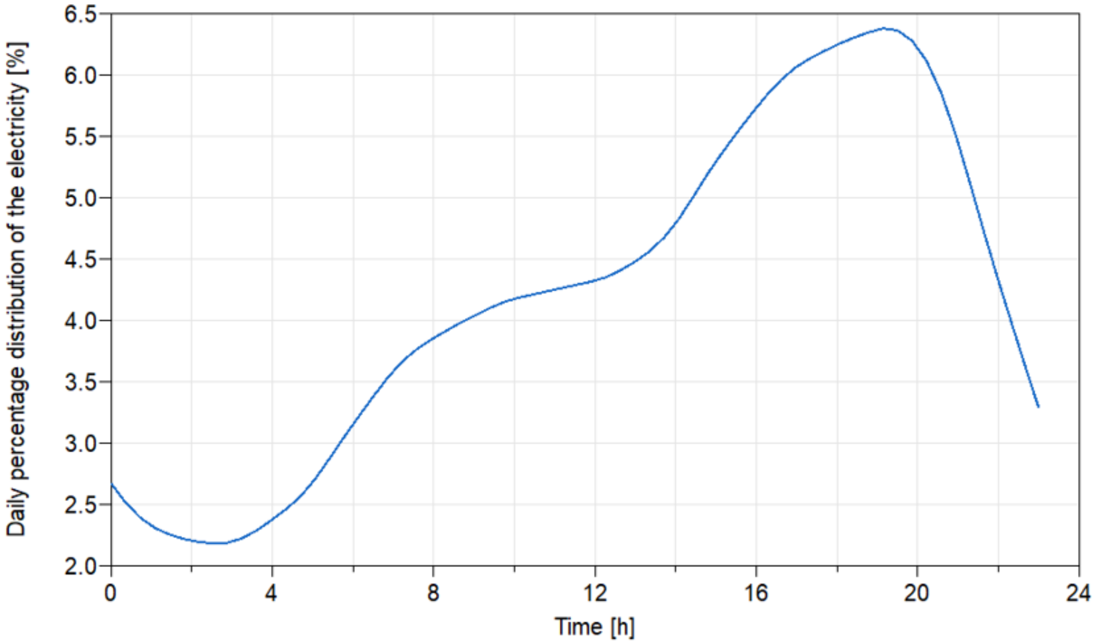


Figure 142. Daily distribution of the electrical energy consumption of the building [2]

6.2.2.1.1.1 DESCRIPTION OF THE ENERGY SYSTEMS

The heating and DHW needs are supplied by 2 x 45 kW natural gas furnaces, while currently no cooling is provided and no onsite RES are in place.

Space heating system (Natural gas boiler)

The space heating system of the building includes radiators which are fed but hot water of 80°C. The hot water is produced by an efficient natural gas boiler with 90 kW nominal capacity. Table 52 includes the basic data of the natural gas boiler system.

Table 52. Parameters of the natural gas boiler for space heating

Parameter	Value
Nominal capacity	90 kW
Boiler nominal efficiency	90%
Distribution thermal losses	15%
Water temperature at the boiler outlet	80ºC
Fuel type	Natural gas
Fuel lower heating value	50,000 kJ/kg

DHW system

The DHW temperature setpoint is estimated at 45ºC and the occupants' mean daily demand is approximately 80 L per person. A typical profile representing the daily hot water demand distribution is shown in Figure 143 in compliance with Ref. [3]. The tap water coming from the network has an annual mean temperature of around 14ºC, while a typical variation of the water temperature during the year was selected [4]. The DHW demand is covered by natural gas boilers with an efficiency of 90%. The summary of the details referring to the DHW is given in Table 53.

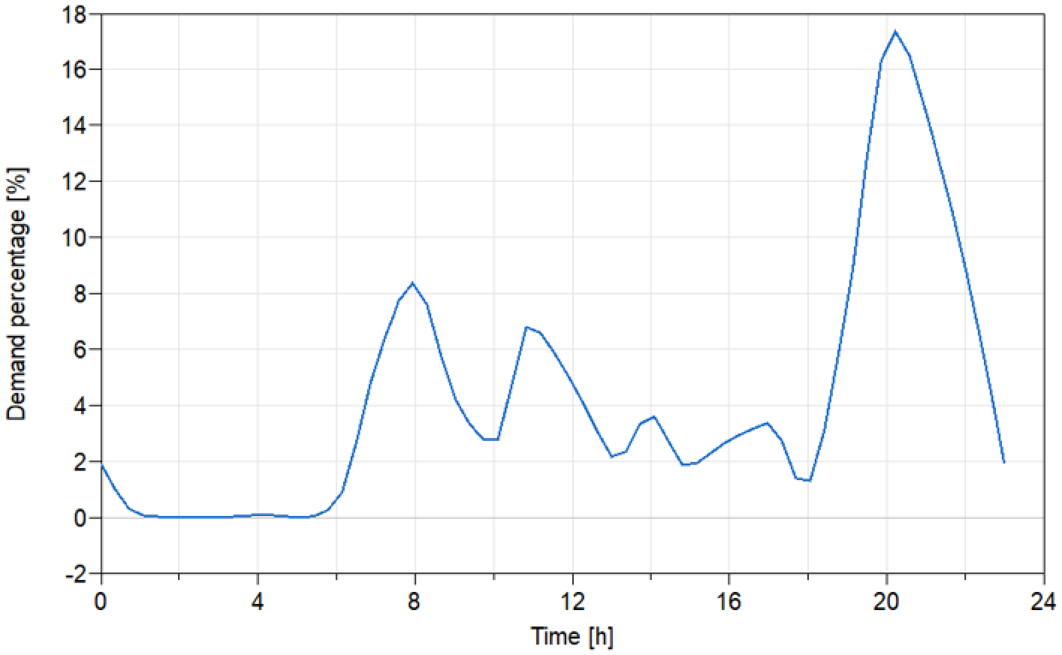


Figure 143. Daily dimensionless distribution of the hot water quantity demand [3]

Table 53. Parameters of the DHW system

Parameter	Value
Natural gas boiler efficiency for DHW	90%
Distribution thermal losses for DHW	40%
Daily DHW specific demand	80 L/person
DHW desired temperature	45ºC
Number of residents	78
Mean temperature of the cold tap water	14ºC

6.2.2.1.1.2 ENERGY SIMULATION RESULTS

The simulation of the baseline scenario is conducted using the INTEMA.building tool. The simulation period is an entire year and the simulation time step is adjustable and variable using the Dassl solver with 10-4 tolerance. The layout of the building with a space heating system and DHW system is depicted in Figure 144.

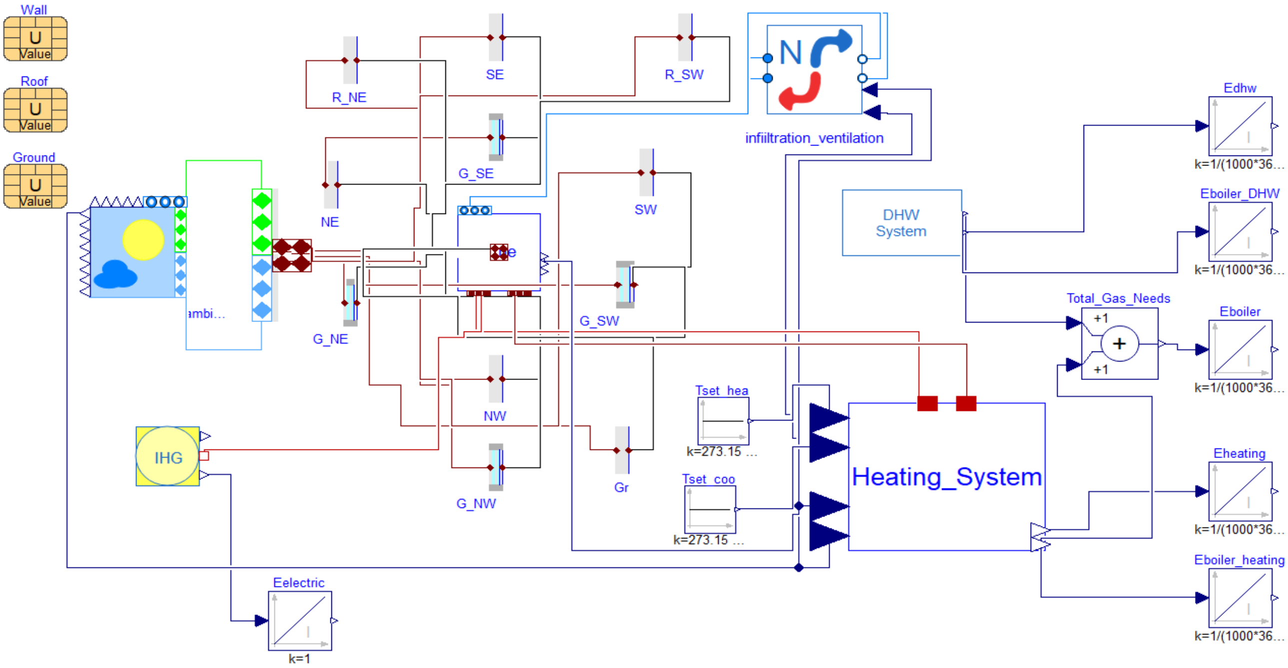
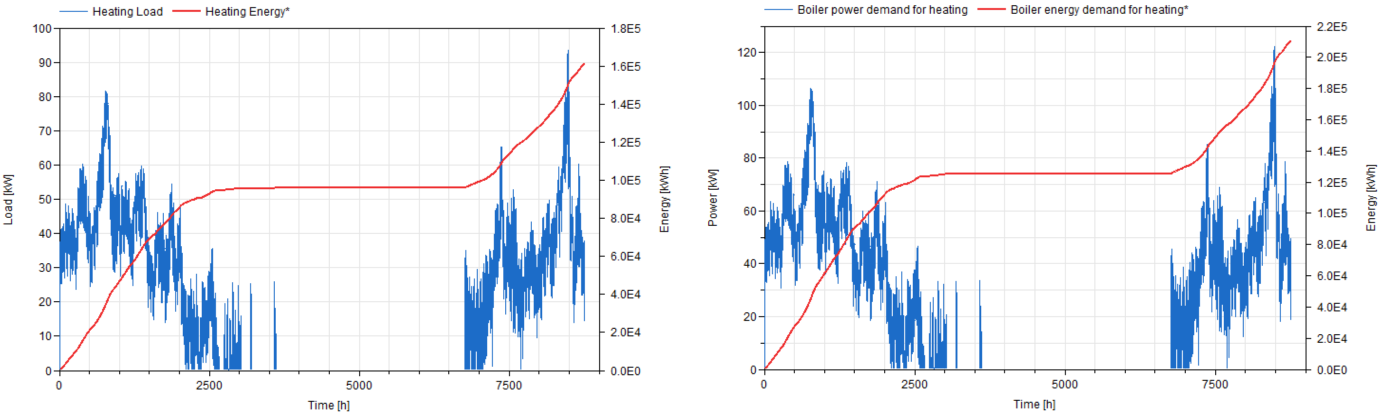


Figure 144. The developed model in the INTEMA.building for the heating and DHW system of the baseline scenario

Firstly, the results of the dynamic simulations for the heating loads and demands are presented. Figure 145a depicts the heating load and cumulative heating energy demand, while Figure 145b illustrates the boiler power and cumulative energy demand for heating. The baseline scenario heating system consists of a gas boiler of 90 kW nominal capacity and 90% efficiency. The distribution thermal losses of the heating system are set to 15%. In our simulation, the heating system was slightly oversized in order to meet the heating demand. According to the simulation, the yearly demand for fuel consumed by the gas boiler is calculated at 210,761 kWh covering the heating load of 161,232 kWh. The peak value of the heating load for the heating system is calculated at 93 kW on the 17th of December.

The DHW production system utilizes a similar natural gas Boiler of 90 kW nominal capacity and 90% efficiency. The distribution thermal losses of the heating system are set to 40%. Figure 146a depicts the DHW load and cumulative energy demand and Figure 146b illustrates the boiler power and cumulative energy demand for the DHW production. More specifically, the yearly boiler energy demand for DHW is calculated at 153,318 kWh, whereas the cumulative DHW load is calculated at 82,792 kWh. Moreover, the yearly consumption of DHW is equal to 2,287 m^3 of water.

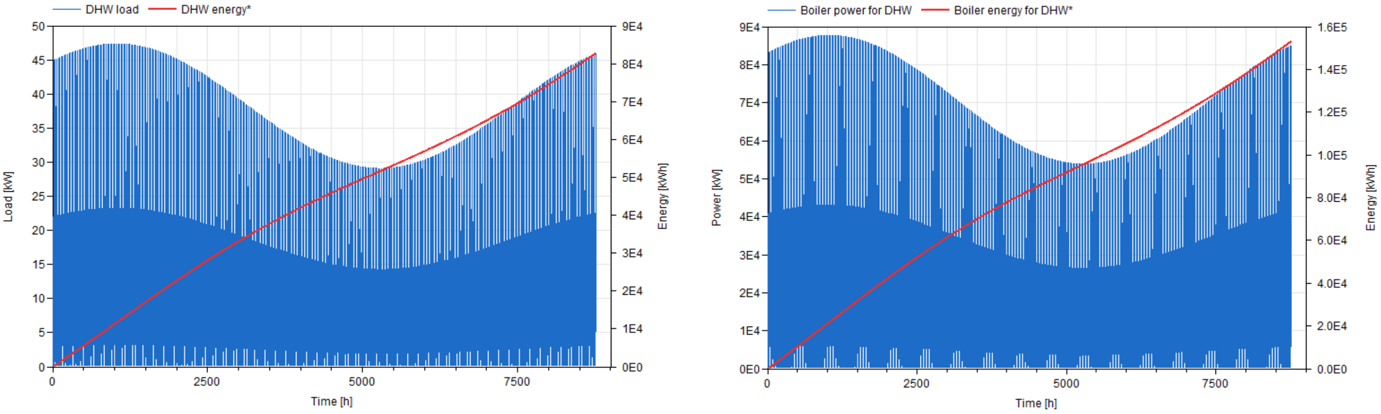
Additionally, Figure 147 illustrates and compares the cumulative energy demand for heating and DHW, the cumulative boiler energy demand for heating and DHW, as well as the total boilers' energy consumption for both heating and DHW. Finally, Figure 148 depicts the electricity power and yearly energy demand for appliances and lighting purposes.



(a)

(b)

Figure 145. a) Heating load and yearly energy demand, b) Boiler power and yearly energy demand for heating



(a)

(b)

Figure 146. a) DHW load and yearly energy demand, b) Boiler power and cumulative energy demand for DHW

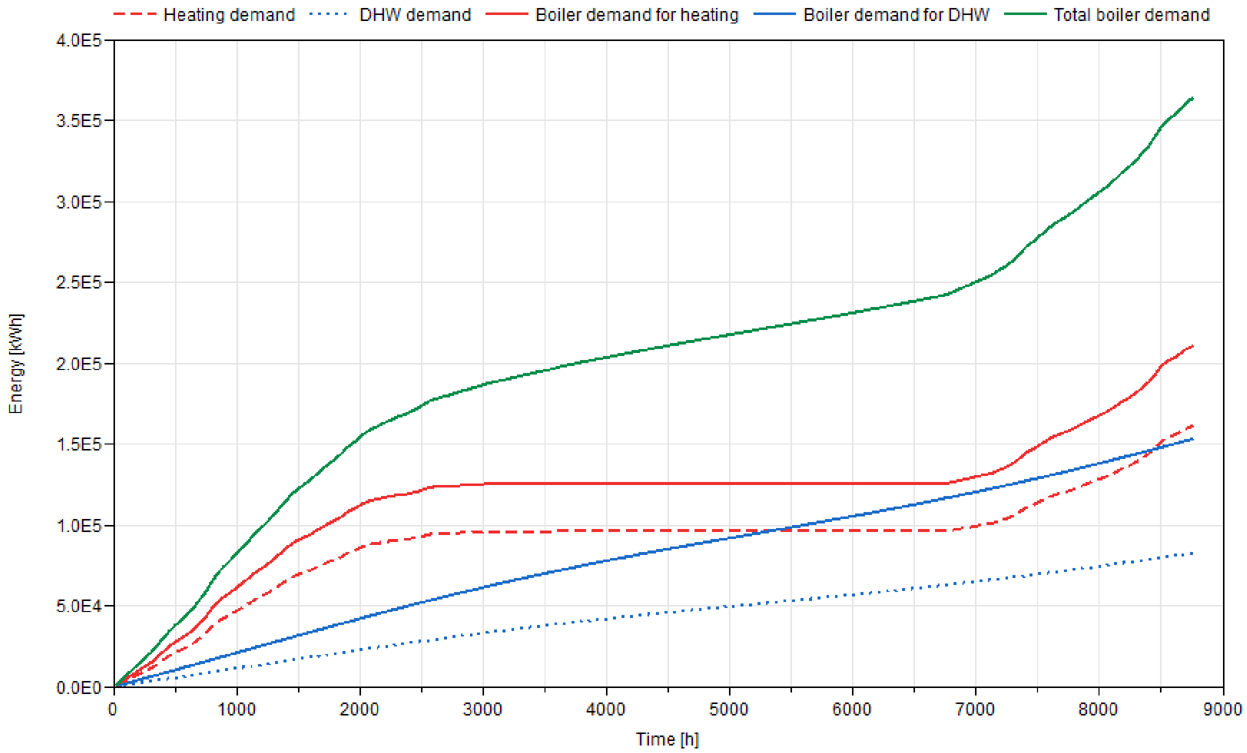


Figure 147. Yearly energy loads of heating and DHW, yearly boiler energy demand for heating and DHW, and total boilers' energy demand

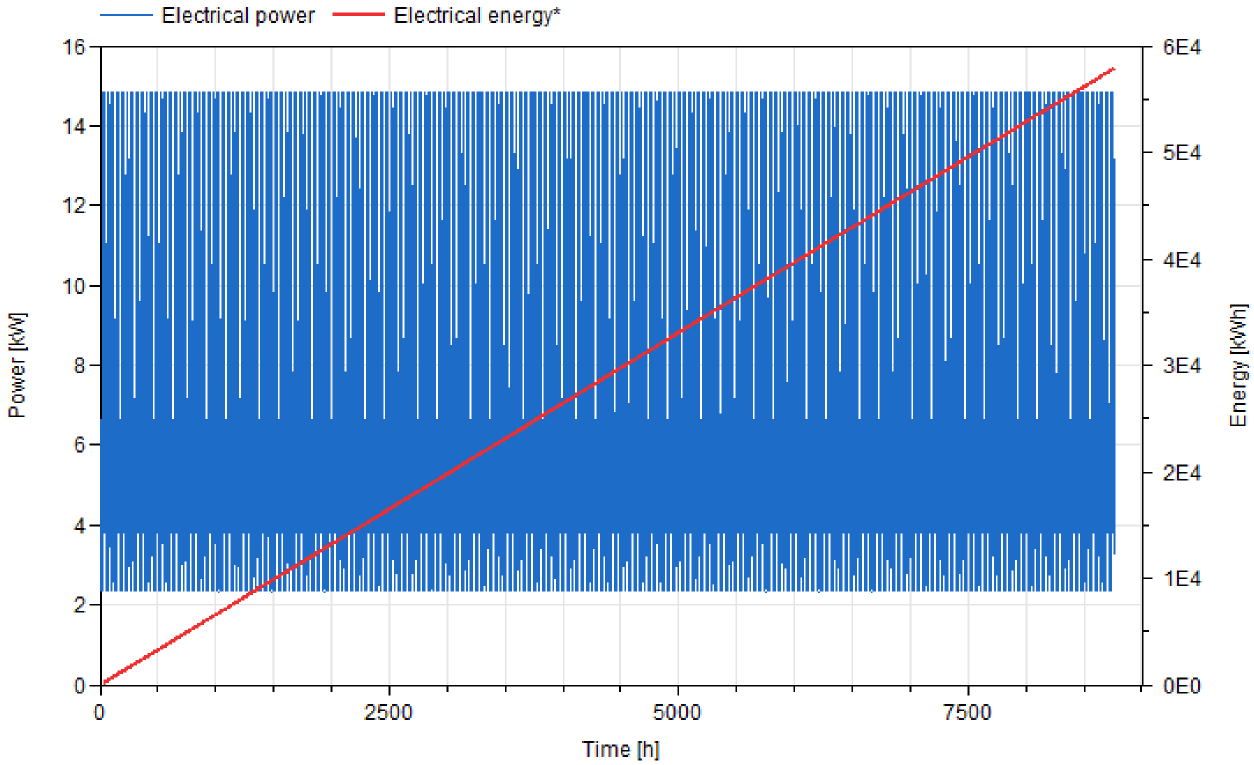


Figure 148. Electricity power and yearly energy demand for appliances and lighting purposes

Table 54 summarizes the building's yearly energy demands expressed in [kWh]. The calculation of the total primary energy demand is based on the selection of appropriate primary energy indexes according to the energy sources used. For Hungary, the primary energy factors are selected at 2.5 for electricity, at 1.0 for natural gas according to European regulations [5]. The total primary energy demand of the building is calculated at 508,894 kWh which is a significant amount and it is separated into 210,814 kWh for heating (41.42%), 153,318 kWh for DHW (30.14%) and 144,733 kWh for lighting and appliances electricity (28.44%). The natural gas demand is found at 364,161 kWh which is separated into 210,814 kWh for heating (57.88%) and 153,318 kWh for DHW (42.12%).

Table 54. Summary of building's energy demands [kWh]

Parameters	Values
Heating energy load	161,232
Energy demand for DHW	82,792
Electrical Energy for appliances and lighting	57,746
Boiler energy demand for heating	210,814
Boiler energy demand for DHW	153,318
Boiler energy demand	364,132
Total primary energy demand	508,877

6.2.2.1.2 RENOVATION SCENARIO

6.2.2.1.2.1 DESCRIPTION OF THE RENOVATION ACTIONS

In this section, the renovation strategy that will be implemented regarding the case of the Hungarian Demo is analytically described and segmented into specific renovation actions. In this student's dormitory building, the renovation techniques that will be deployed are three REHOUSE renovation packages, namely the Adaptable Dynamic Building Envelope (ADBE) technology, the activated cellulose thermal insulation, and the intelligent window system. The building's energy systems serve its heating and DHW needs are not modified.

i) RP#2: ADBE (Renel)

Description

The Adaptable Building Envelope (ADBE) is a technology that generally combines insulation, HVAC units, batteries, and photovoltaics. It enables adaptability to various geometry topologies thanks to its modular nature and high level of prefabrication and customization. It is based on a modular prefabricated structure made of recyclable materials (aluminium), contributing to the reduction of the building's carbon footprint and to the acceleration of the renovation time. All of the ADBE components are manufactured in the factory and delivered by truck to the installation site, where the installation crews installed them with the help of cranes. The installation procedure does not require expensive scaffolding or special training from the technicians.

The ADBE technology contributes to the improvement of a building's sustainability due to its careful design, which is capable of allocating BIPV panels and battery storage for increased onsite RES production, HVAC ducts, and other technical facilities, as well as environment-friendly insulation materials. Figure 149 illustrates the unit-based ADBE façade elements that can be combined in order to create a holistic envelope product. Moreover, the controllability and smart energy operation of the building are also promoted through the embedment of the necessary sensors and actuators that allow users/owners to control the façade behavior for energy minimization and better quality of the indoor environment. Finally, the outer skin of the façade elements consists of weather-resistant panels, and the whole solution is proofed against major disruptive phenomena (e.g.: weather, fire, earthquake events, etc.).

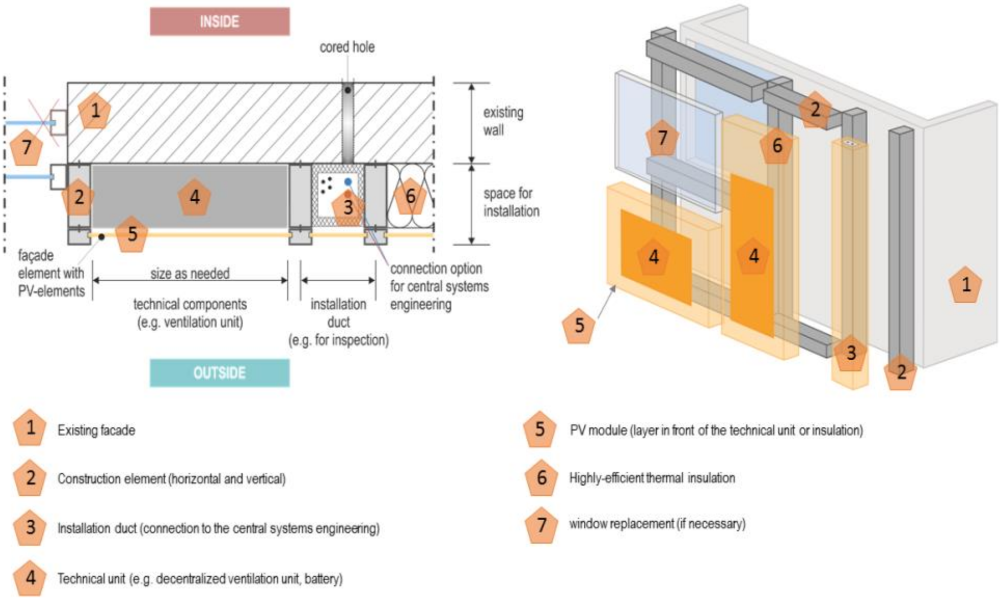


Figure 149. ADBE components and technical drawing (Legend: 1.- Existing façade 2.- Construction element 3.- Installation duct 4.- Technical unit (HVAC, battery) 5.- PV module 6.- High-efficient insulation 7.- Window replacement)

The ADBE prototype forms a structural ecosystem where an aluminium-glass façade design, based on modern construction standards and flexible specifications, enables its installation to almost any building's architectural design, both in residential and non-residential buildings, offering multiple additional functionalities to the existing building envelope. Because of the curtain wall, the construction is done outside of the existing building, which enables a refurbishment to be conducted without disrupting the operation of the building, eliminating the possibility of technical incidents. The aluminium-based profile ensures construction 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 according to the building's orientation, structural design, and illumination needs. Table 55 summarizes the main information of this design.

Table 55. Technical data of the ADBE technology

Parameter	Value
PV technology (Onyx Solar)	
Nominal total capacity [kW_p]	4.7
Dimensions [m x m]	1.0 x 1.8
Reference electrical efficiency [%]	5.76
Maximum Production Capacity [W_p/m^2]	57.6
Open Circuit Voltage [V]	125
Short Circuit Current [A]	1.93
Voltage at nominal power – V_{mpp} [V]	86
Current at nominal power – I_{mpp} [A]	1.72
Nominal Power [W]	147

Parameter	Value
Inverter efficiency [%]	94
Power temperature coefficient [%/°C]	-0.19
Voltage temperature coefficient [%/°C]	-0.28
Current temperature coefficient [%/°C]	0.09
Thickness [mm]	18.24
Material thermal properties	
U-value of the glass [W/m^{2}K]	5.2
U-value of ADBE façade with extra insulation layer [W/m^{2}K]	0.431
Area on the south-west wall [m^2]	18
Area on the south-west roof [m^2]	144
Total area in the renovated building [m^2]	162

Application on the examined building

The Renel ADBE technology will be placed on the southwest wall of the examined building, covering 18 m^2 of wall area, as well as on the southwest roof, covering an area of 144 m^2. It is important to state that the roof renovation regards only PV installation. Specifically, on the southwest wall, the Renel ADBE technology will be combined with the activated cellulose thermal insulation, namely the renovation package 7, resulting in the enhancement of the external walls' thermal transmittance value. Taking into consideration the building is a dormitory there are stricter fire safety regulations, which means there should be used only non-flammable insulation such as rock wool or similar. That is why the activated cellulose can be used only in restricted areas of the façade. Particularly, the U-value of the external walls will be decreased from 1.87 W/m^{2}K at the baseline scenario to 0.576 W/m^{2}K (approximately) in the renovated scenario. On the contrary, due to the fact that the building's roof is already renovated, the application of the ADBE technology on the roof will not the accompanied by the addition of thermal insulation. Moreover, the electricity produced by the ADBE BIPVs total surface of 162 m^2 is intended to provide for the building's electrical needs, with the aid of an inverter battery with 55.2 kWh nominal capacity. The capacity of the battery was selected according to the proposal's initial estimation and it was found to be a reasonable value after the conductance of a sensitivity analysis.

ii) RP#7: Activated cellulose thermal insulation (Woods)

Description

The activated cellulose thermal insulation made by WOODS is a bio-sourced – reused and recycled insulation material. It is a technological solution that is 100% fabricated with recycled and/or reused material. More specifically, it is constructed with activated cellulose made of sawdust (Figure 4), a technology that meets all the requirements of a circular economy and fits well into the green products standards. In particular, the main advantage lies in the fact that no adhesive is added to the product, making it a 100% chemical-free material. The key strengths of this new type of insulation material are environmental friendliness, high thermal performance, and easy recyclability.

Figure 150. Activated cellulose thermal insulation

The activated cellulose thermal insulation consists of a hard insulation material panel made of wood waste such as sawdust without adding any adhesive or bonding materials. The used sawdust is a wood waste and instead of burning this waste, it is used for producing thermal insulation panels. The insulation panel is a rigid solid material having higher compression strength and low thermal conductivity. One important advantage of this new material is its recyclability after the life cycle; thus, it fully meets the requirements of circular economy principles. The insulation material can be used alongside the ABDE façade system. Table 56 summarizes the main properties and characteristics of the present technology.

Table 56. Technical data of the insulation layer

Parameter	Value
Thickness [m]	0.06
Density [kg/m^3]	100-150
Specific heat capacity [J/(kg·K)]	700-1100
Thermal conductivity [W/mK]	0.055

Application on the examined building

The examined renovation package will be applied to the building’s entire southwest wall, resulting in the enhancement of its thermal properties. More specifically, the wall’s thermal transmittance will be decreased from 1.87 W/m^{2}K on the baseline scenario, to 0.576 W/m^{2}K. However, due to safety reasons and according to Hungarian regulations, a different material of thermal insulation with the same thermal properties and thickness may be used, for instance, rockwool.

iii) RP#8: Intelligent window system

Description

The Intelligent Window System (IWS) is a modular, low-cost solution that can be easily adapted to the outer skin of new or existing buildings and for any type of window, as depicted in Figure 151. A house renovation usually involves the replacement of the window installations and in this case, the old installations become waste. However, the solution of IWS allows the original windows to remain in place and fulfil their original function, but with smarter and adjustable thermal and optical properties. The IWS technology is applied as an adapter, fixed on the outer side of an existing window that incorporates a smart management system that determines the availability of solar gaining and simultaneously reduces the renovation disturbance to the building’s occupants to the minimum.

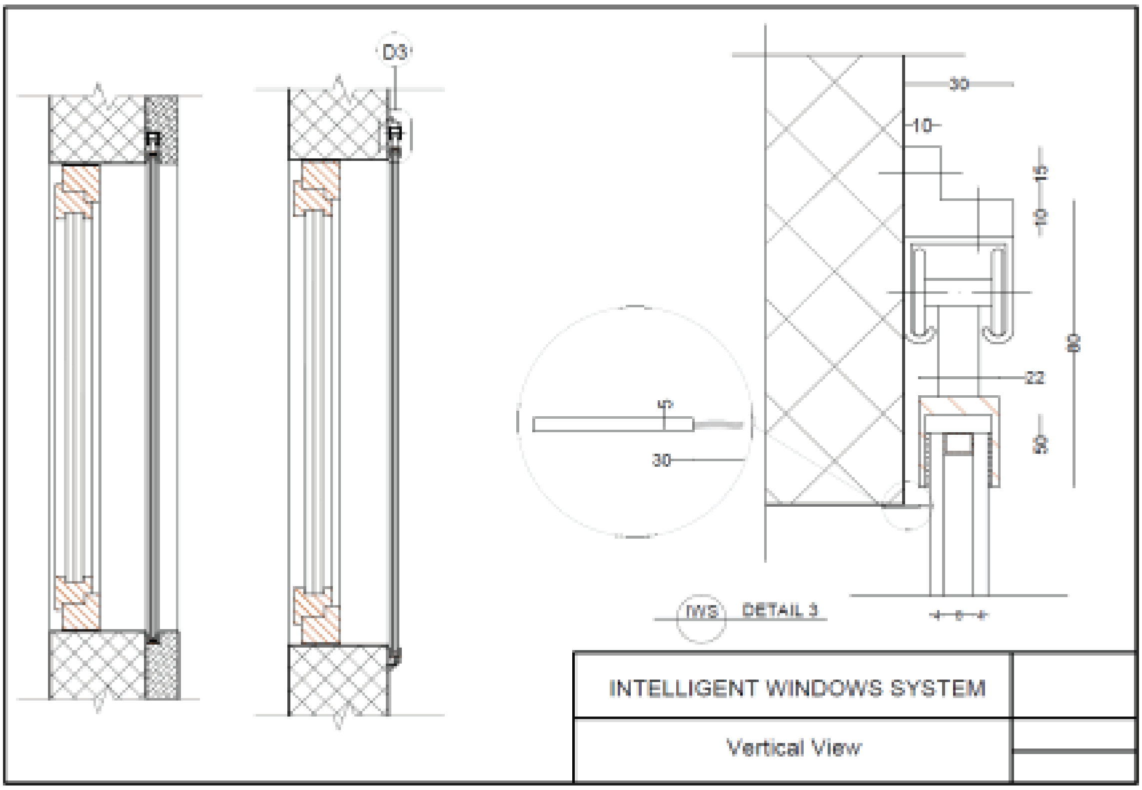


Figure 151. Intelligent window system

The IWS technology enhances the thermal comfort conditions of a building by altering its solar gain coefficient and thermal transmittance value. The IWS technology utilizes intelligent sensors and microcontrollers that determine the availability of solar gaining in winter, and according to the energy demand of the building decreases the thermal insulation of the window and increases the g-value of the windows glazing. When solar radiation is not available, the system automatically improves its thermal transmittance value, reducing heat losses. The IWS technology ultimately reduces HVAC energy consumption by protecting normal windows from solar radiation in summer without restricting the usage of the original windows.

The IWS technology is controlled automatically without offering the option for the user to force switching. If the window needs higher thermal resistance either in winter to protect heat or in summer to protect cold then the system will close automatically the additional double glassing IWS. The frame of the IWS will be designed so that the user cannot see a real frame just an edge to the glass connects to. The IWS is equipped with an oven-moving electric engine. Figure 152 depicts the IWS technology that consists of the passive element of the opening and the active element system of the moving solar thermal system mechanism. Also, Table 57 includes basic technical data of the examined technology.

(a) (b)

Figure 152. The IWS technology and its, (a) passive element (opening), (b) active element (solar thermal system)

Table 57. Technical data of IWS technology

Parameter	Value
Inactivated IWS (Existing case)	
Frame percentage [%]	20
U-value of the glazing [W/m^{2}K]	1.2
U-value of the frame [W/m^{2}K]	1.4
U-value of the window [W/m^{2}K]	0.9
g-value	0.75
Activated IWS (Renovated case)	
Frame percentage (%)	< 5
U-value of the glazing (W/m^{2}K)	0.7
g-value	0.65

6.2.2.1.2.2 RENOVATION SCENARIO – SIMULATION RESULTS

The simulation of the renovation scenario is conducted by using the INTEMA.building tool. The simulation period is an entire year and the simulation time step is adjustable and variable using the Dassl solver with 10^{-4} tolerance. Figure 153 illustrates the configuration of the Hungarian Demo, including its heating and DHW system, as well as the BIPVs modules and their coupling with the batterie and grid. The energy efficiency interventions of the renovated scenario do not concern the building’s heating and DHW system, therefore their inputs are not modified.

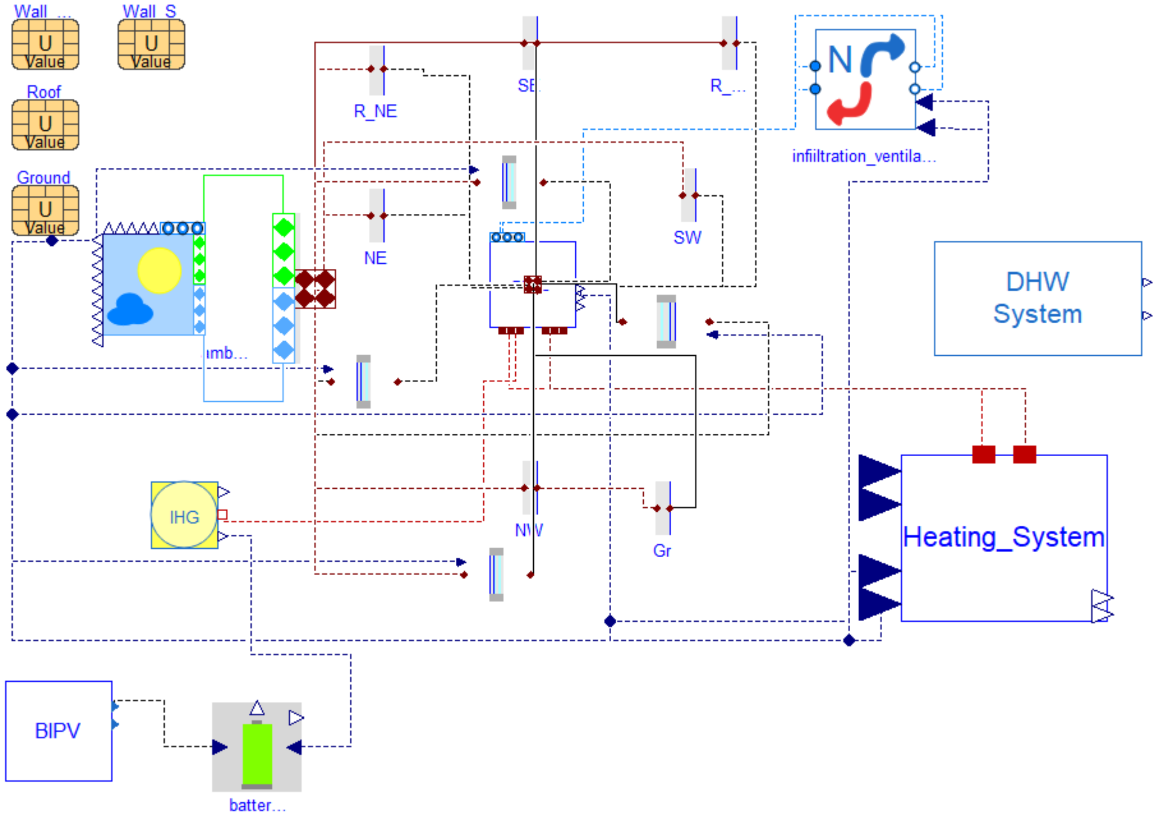


Figure 153. The developed model in the INTEMA.building of the Hungarian Demo for the renovated scenario

Firstly, the results of the dynamic simulations for the heating loads and demands are presented. Figure 154**¡Error! No se encuentra el origen de la referencia.** depicts the heating load and cumulative heating energy load of the building, while Figure 155 illustrates the boiler power and cumulative energy demand for heating. In the renovated scenario the heating system is not modified. The energy efficiency interventions resulted in a decreased cumulative heating energy load which is calculated at 43,959 kWh. Parallelly, the boiler's energy demand for heating is calculated at 57,557 kWh. The calculations that correspond to the building's DHW demand and the boiler's energy demand for DHW are the same as the baseline scenario.

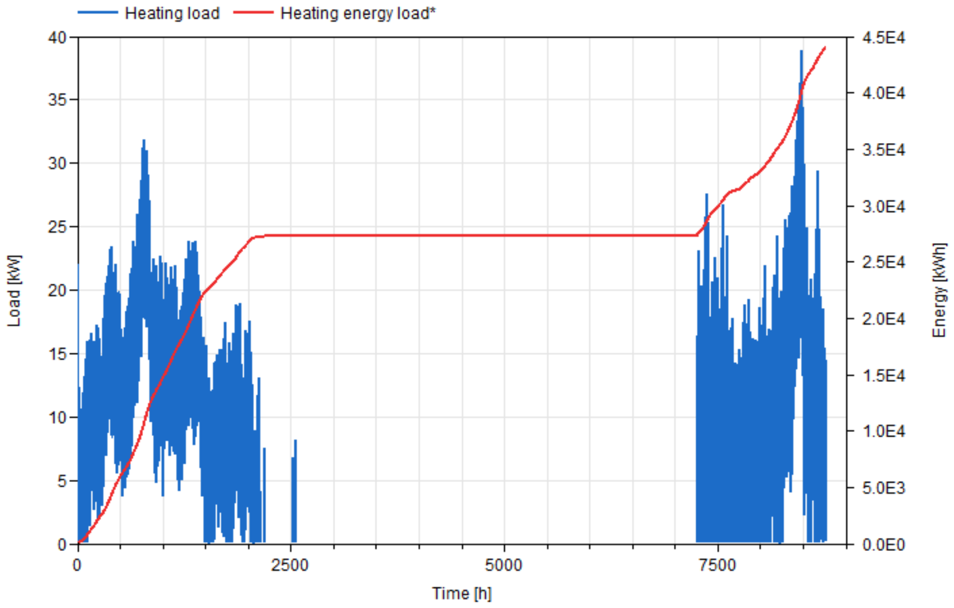


Figure 154. Heating load and yearly heating energy load

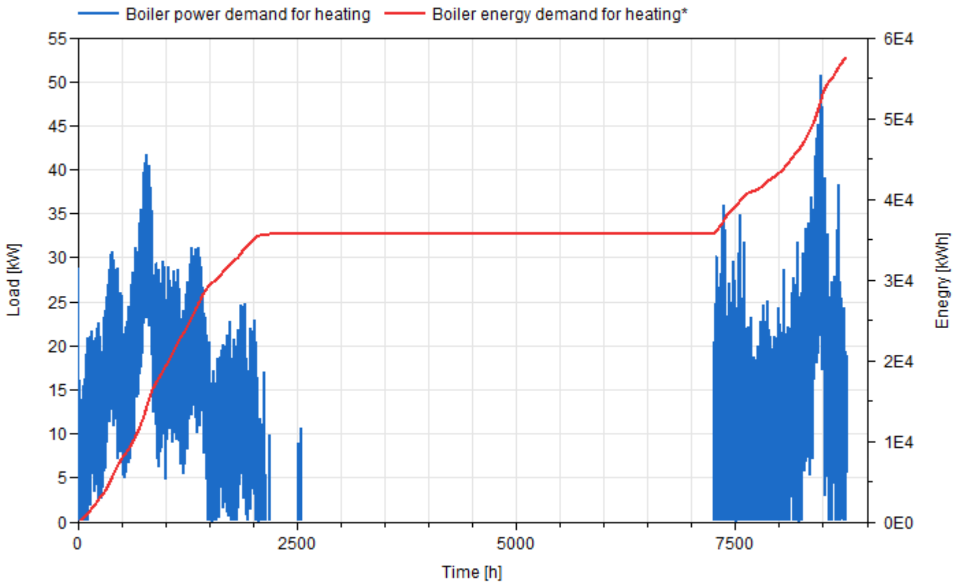


Figure 155. Boiler power and yearly energy demand for heating

Furthermore, Figure 156illustrates the electrical power and cumulative electricity produced by the 162 m^2 surface area of BIPVs installed in the building's southwest wall and roof. According to the calculations, the yearly electricity production of the BIPVs is equal to 24,860 kWh. In addition, Figure 157 depicts the electricity power demand from the grid. The cumulative electricity demand from the grid is calculated at 34,978 kWh. Figure 158 summarizes the building's cumulative electricity demand for lighting and appliances, which is equal to 57,746 kWh, the yearly electricity produced by BIPVs, which is equal to 24,860 kWh and the yearly electricity demand from the grid, which is equal to 34,978 kWh. According to these calculations, 2,092 kWh of the produced electricity corresponds to energy losses.

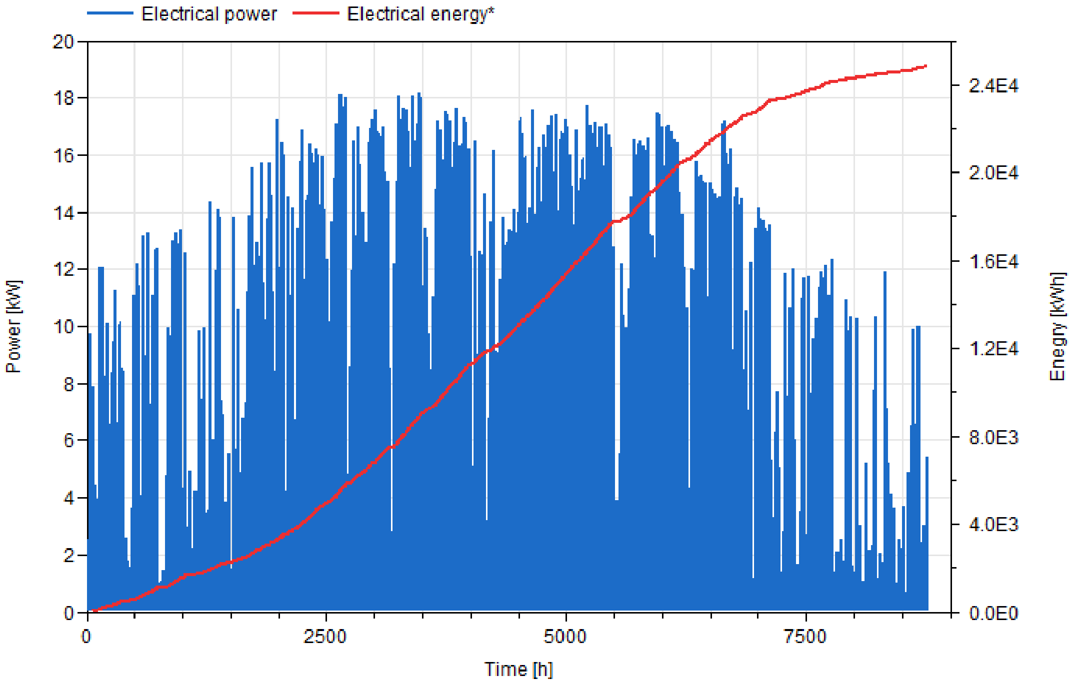


Figure 156. Electrical power and yearly electrical energy produced by the BIPVs

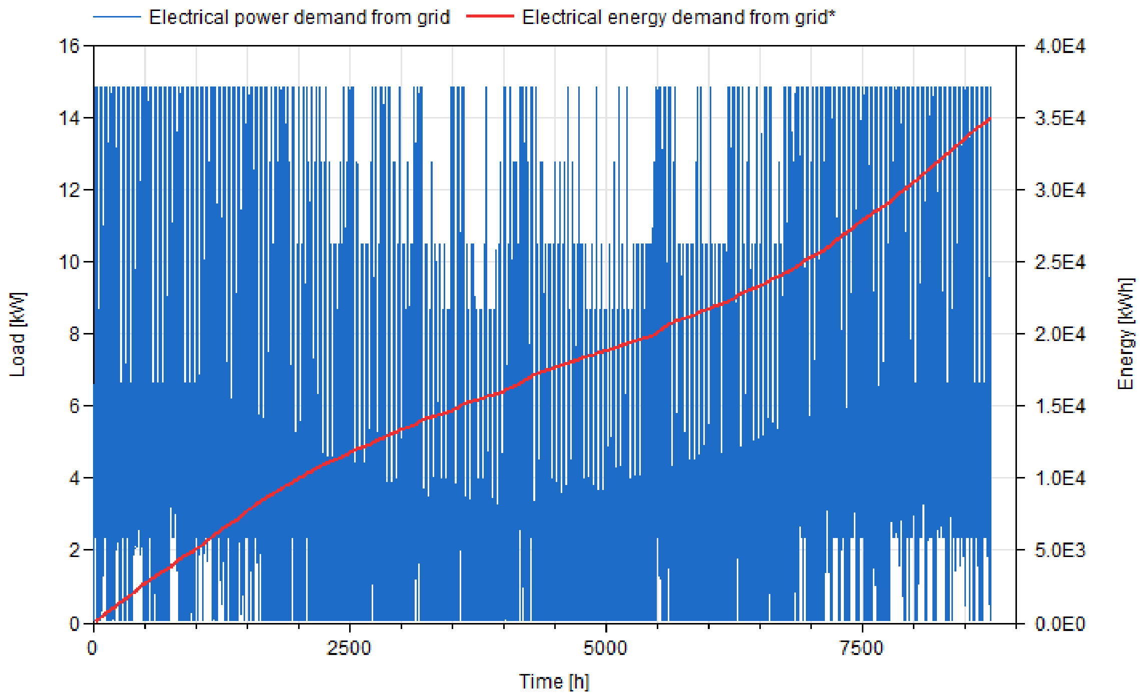


Figure 157. Electrical power and cumulative electrical energy from the grid

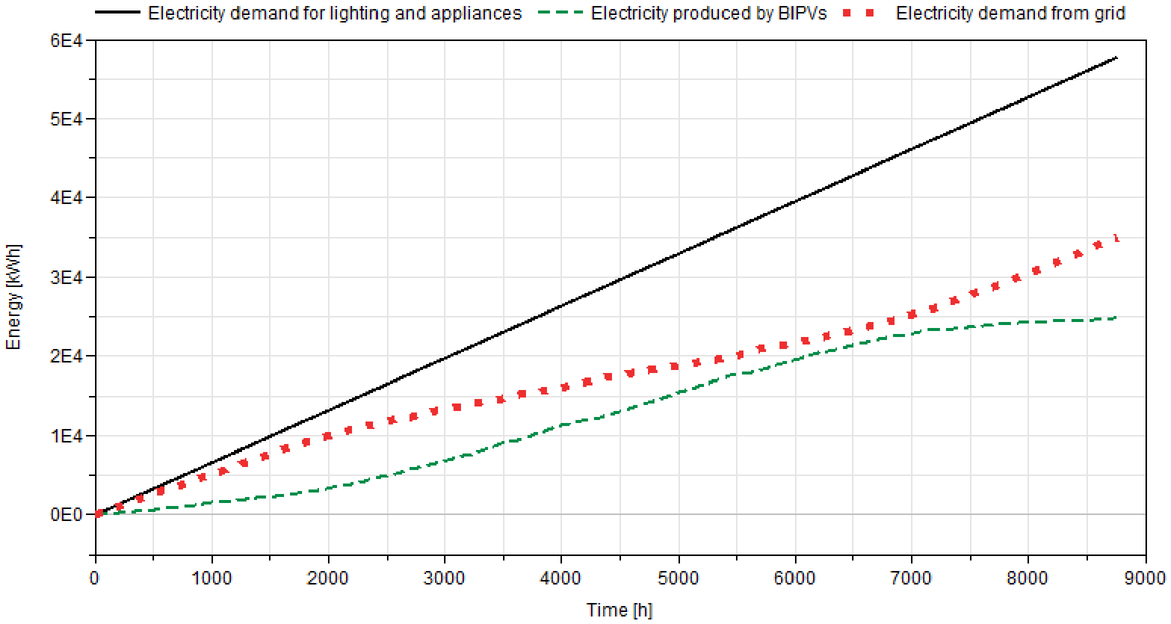


Figure 158. Cumulative electricity demand for lighting and appliances, electricity produced by BIPVs and electricity demand from the grid

Finally, Table 58 summarizes the building's yearly energy demands and electricity production.

Table 58. Summary of building's energy demands [kWh]

Parameter	Value
Heating energy load	43,959
DHW energy load	82,792
Electricity demand for appliances and lighting	57,746
Boiler energy demand for heating	57,557
Boiler energy demand for DHW	153,318

Parameter	Value
Electricity produced by BIPVs	24,860
Electricity demand from the grid	34,978
Total boiler energy demand	210,814
Total primary energy demand	298,320

6.2.2.1.3 COMPARISON OF THE RENOVATION AND BASELINE SCENARIOS

In this section, the simulation results regarding the baseline scenario and the renovation scenario are compared and briefly discussed. The purpose of the renovation strategy of the examined building is to decrease its thermal loads and improve the thermal comfort conditions of its residents. To achieve that various standards as well as technologically advanced solutions were implemented. The energy simulation analysis conducted in this report allows the comparison between the two states of the building and the prediction of the energy savings induced by the renovation actions. In Table 59 the basic energy demands of each examined scenario are given.

In the baseline scenario, the heating energy demand is calculated at 161,273 kWh whereas in the renovated state the heating demand of the building is calculated at 43,959 kWh. The decrease in the heating energy load of the building is combined with the improvement of the living conditions and is equal to 72.7%. In addition, the boiler energy demand for heating is greatly decreased. More specifically, in the baseline scenario, the boiler energy demand for heating is calculated at 210,814 kWh, while for the renovated scenario this value is equal to 57,557 kWh. Consequently, the building's boiler total energy demand is decreased by 153,257 kWh in comparison with the baseline scenario, and therefore the total boiler energy demand is calculated at 210,814 kWh.

Furthermore, in the renovated scenario the building is equipped with an area of 162 m^2 of BIPVs (100 panels) which leads to the yearly production of 24,860 kWh of electricity, reducing the building's electricity demand from the grid to 34,978 kWh from 57,746 kWh in the baseline scenario. This equals a 39.4% reduction in the building's electricity demand from the grid. Finally, as far as the total primary energy demand is concerned, in the baseline scenario the value is calculated at 508,877, whereas in the renovated scenario the value is equal to 298,320 kWh, indicating a decrease of 41.4%.

Table 59. Comparison of basic energy demands between baseline and renovated scenario [kWh]

Energy Quantities	Baseline Scenario	Renovated Scenario
Heating demand	161,273	43,959
DHW demand	82,792	82,792
Electricity demand for appliances and lighting	57,746	57,746
Boiler energy demand for heating	210,814	57,557
Boiler energy demand for DHW	153,318	153,318
Electricity produced by BIPVs	0	24,860
Electricity demand from the grid	57,746	34,978
Total boiler energy demand	364,132	210,875
Total final energy demand	421,878	245,136
Total primary energy demand	508,877	298,320

6.2.2.1.4 REFERENCES

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6.2.2.2LCA/LCC (VERIFY)

6.2.2.2.1 INTRODUCTION

The objective of this report is to conduct a thorough Lifecycle Assessment (LCA) and Lifecycle Costing (LCC) for the baseline and renovation scenario identified in the Hungarian Demo. The main focus of the calculations revolves around the building's energy consumption, energy production, and global warming impact. The target energy-related technologies/systems are divided into two key stages: manufacturing (including procurement and installation) and operation and maintenance.

To facilitate this analysis, VERIFY incorporates two specialized modules: the Environmental module and the Cost module. These modules are supported by an extensive database of components and technologies developed by CERTH/CPERI. The database encompasses a wide range of materials, building components/technologies, and energy systems, catering to the requirements of various renovation scenarios. It draws data from technology providers, internal studies, and public literature documents.

When utilizing the VERIFY platform for analysis, users create an "Electrical Plan" to define electricity production (preferably from renewable energy sources if available), consumption, energy storage technologies, and building operation. Additionally, a "Thermal Plan" is established to specify the building envelope, characteristics, and sizing of active systems (heating, cooling, ventilation), as well as passive systems (insulation, glazing, hot-water storage). Furthermore, an "Investment Plan" allows users to input information pertaining to applicable energy price mechanisms, funding details, and country-specific regulations, tailored to the building's location and user requirements. While this information is not mandatory for the core LCA and LCC analysis, it enhances the overall assessment.

VERIFY surpasses the provision of a static environmental and costing performance snapshot by enabling life cycle computations. It ultimately generates a comprehensive life cycle report, encompassing well-defined key performance indicators that can be further utilized for analysis and decision-making purposes [1].

6.2.2.2.2 BASELINE SCENARIO ASSESSMENT

In the initial phase of the REHOUSE assessment, the baseline scenario was chosen for the Hungarian Demo to conduct a comprehensive analysis of energy, environmental, and cost factors. In the subsequent paragraphs, a detailed description of this scenario and the analysis of its Lifecycle Assessment (LCA) and Lifecycle Costing (LCC) will be presented.

6.2.2.2.2.1 BASELINE SCENARIO – IMPACT ASSESSMENT

The environmental and economic analysis of the baseline scenario involved assessing the infrastructure and functional emissions and costs of the building. Additionally, the energy flows and exchanges within the building were taken into consideration. The CO_2 emissions, primary energy requirements, and costs related to the manufacturing phase of various building components were obtained from the relevant environmental and cost VERIFY databases.

On the other hand, the CO_2 emissions, primary energy requirements, and costs incurred during the analysis period (operational phase) were determined using the energy consumption time series derived from the energy analysis conducted in INTEMA building [2].

To estimate the cost of building interventions, the VERIFY cost database, developed through an extensive literature review and market price analysis, was initially used. However, to ensure a more realistic cost estimation, given the recent volatility in building product prices, the costs were reviewed by i) conducting an updated review of market prices (where possible) and ii) consulting with demo leaders (where applicable).

Following this approach, Table 60 presents the total initial embodied CO_2 per component.

Table 60. Initial Embodied C02 per component

Component Name	CO_2 (kg)
Aluminium Glazing (SW)	8,070.7
Aluminium Glazing (NW)	1,562.0
Aluminium Glazing (NE)	7,940.0
Aluminium Glazing (SE)	1,041.5
Hot Water Storage	2,333
Boiler gas	4,086

6.2.2.2.2.2 BASELINE SCENARIO – LCA / LCC RESULTS

The LCA/LCC analysis results, based on the aforementioned assumptions, are presented in Table 61 and at the diagrams below. As mentioned earlier, the environmental and economic impact of the baseline scenario is assessed using the following KPIs. In addition, it is worth considering that the analysis commenced in July of the first year. Consequently, the data for the initial year is partial, accounting only for the period from July to December. Similarly, the data is partial for the last year, covering the period from January to June.

Table 61. LCA / LCC Results of the baseline scenario

KPI	RESULT
Lifetime CO_2 emissions savings	0[$kgCO_2$]
Carbon payback period	NO PAYBACK
Payback Period	NO PAYBACK

KPI	RESULT
Investment cost	0[€] (no purchase of new component)
Life cycle cost	1,750,145 [€]
Lifetime income	0 [€]

Figure 159 shows the Annual Operational (functional) CO_2 [kg] of the Baseline Scenario and it reveals an increase in operational maintenance costs over time due to the degradation of the boiler. In the tenth year, a boiler replacement is performed, resulting in decreased costs, as the new boiler requires less fuel to produce the same thermal power.

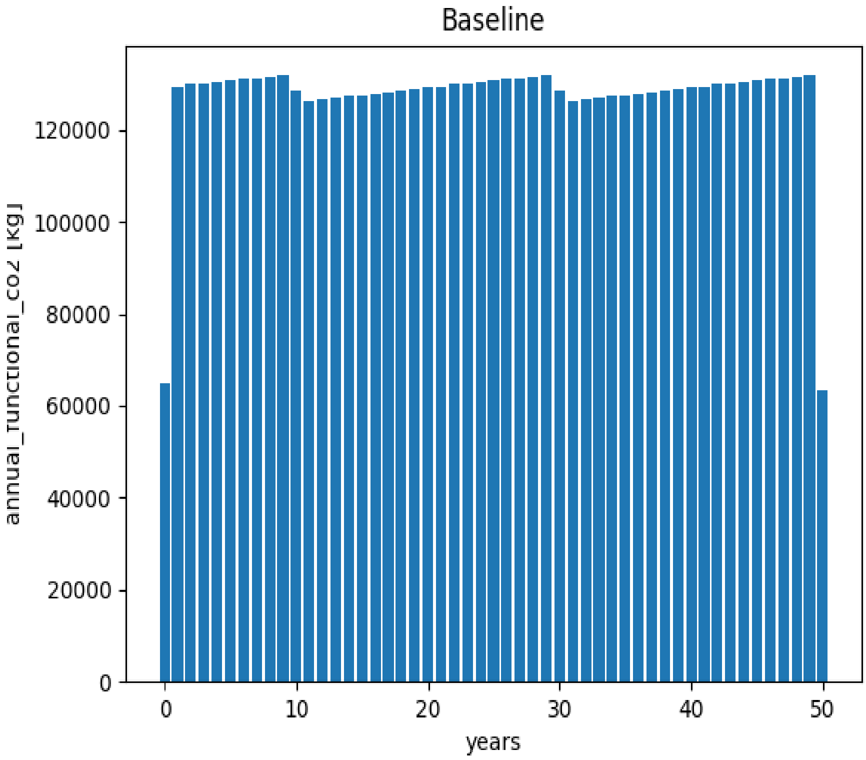


Figure 159. Annual Operational (functional) C02 [kg] - Baseline Scenario

In Figure 160, the operational and maintenance costs are depicted, showing a consistent increase over the years (mainly due to inflation). Year 10 and year 30 are the replacement years where the new components do not require maintenance.

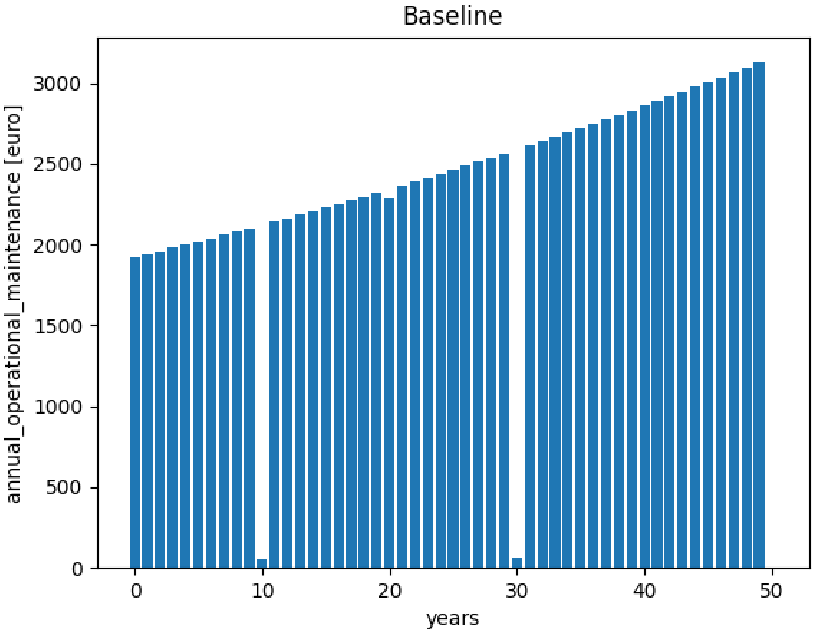


Figure 160. Annual Operational Maintenance Cost - Baseline Scenario

In Figure 161 the Life cycle Global Warming are presented. The operational and the infrastructure CO_2 emissions are included. The CO_2 are normalized per square meter of the demo.

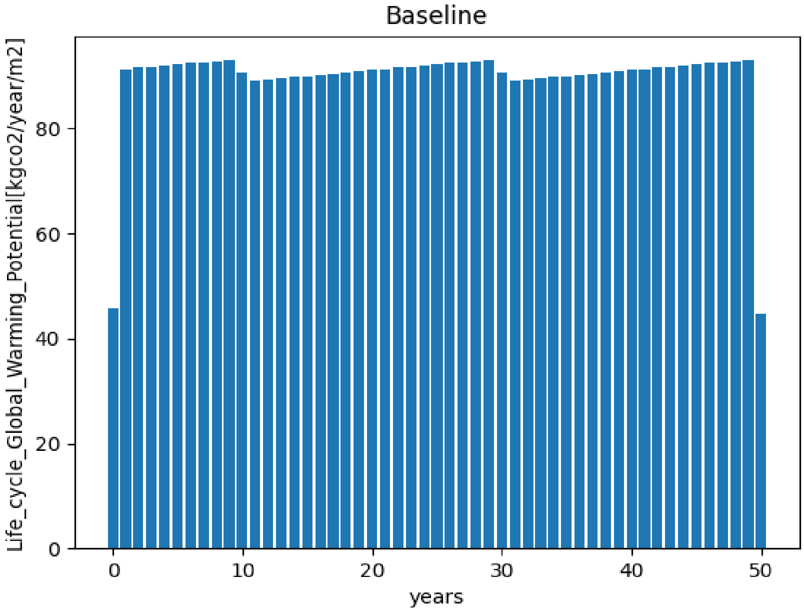


Figure 161. Lifecycle Global Warming - Baseline Scenario

6.2.2.2.3 RENOVATION SCENARIO

The next phase of the process entails establishing the renovation scenario, accompanied by a comprehensive report that outlines the renovation actions and their outcomes. The aim of this comparison is to conduct a comprehensive Lifecycle Assessment (LCA) and Lifecycle Costing (LCC) for the alternative scenarios identified in the Hungarian Demo, while also calculating the relevant economic and environmental KPIs for the REHOUSE project.

6.2.2.2.3.1 DESCRIPTION OF THE RENOVATION ACTIONS

In this scenario, three renovation actions have been carried out as outlined in the renovation packages. The primary objective of these renovations is not only to reduce the energy consumption of the building but also to generate power for self-consumption within the building. To achieve this goal, RP2 (ABDE), RP7 (Activated cellulose thermal insulation), and RP8 (Intelligent window system) have been implemented. The purpose of the subsequent analysis is to evaluate the impact on the energy efficiency and cost profile of the building after the installation of these renovation technologies.

6.2.2.2.3.2 DESCRIPTION AND ANALYSIS OF RP2

On the following table the composition of the RP2 and the functional unit are presented.

Table 62. Composition of RP2

Functional unit: 1 m^2		
	Quantity	Unit
Raw Materials *(The raw materials that are used for the production of the specific component)*		
Vidrio	30	kg/m^2
Front	7.9	kg/m^2
Encapsulant	2.79	kg/m^2
Junction box	0.053	kg/m^2
Reused/recycled materials. *(The amount of reused/recycled materials that are used in the production process. These data can be provided with a functional unit or as a percentage of the total material)*		
Vidrio	21	~~%~~
Encapsulant	30	~~%~~
Junction box	5	~~%~~
Electricity/Heat *(The electric and the thermal energy consumption during the production process)*		
	16,42	kw/h
Transportation *(The country of production, the country of installation or assembly for the final component and the mean of transportation)*		
Country of Production	Ávila (Spain)	
Country of Installation	Xanthi (Grecia)	3500 km

Functional unit: 1 m^2		
	Quantity	Unit
Mean of transportation (e.g. truck, plane, ship etc).	Truck	
Final Weight *(The weight of the component)*		
	41	kg/m^2

The life cycle phases which were included to model the environmental impact of the RP2 are the raw materials acquisition, components/ materials manufacturing & packaging, components/ materials transportation, RP manufacturing and RP transportation.

After conducting the life cycle analysis based on primary data (manufacturing data sheets for the examined technologies/components/energy systems) and secondary data (data sources from published articles/report and modules developed by CERTH) the embodied CO_2eq [kg] per 1 m2 for RP2 is 37.61. The total surface that the RP2 will be installed in the HU demo is 162 m2. Therefore, the total embodied CO_2eq [kg] of the RP2 in the demo is 6,092.82.

The following tables present the total acquisition cost, the yearly costs for operation and maintenance and the end-of-life costs of all the RP2 that will be used in the HU demo.

Table 63. Initial Investment- RP2

Cost	€
Total Acquisition Costs	42,525

Table 64. LCC- Operational Maintenance Costs- RP2

Cost	€
Inspection	200
General repair and maintenance	400
Equipment Insurance	-
Payroll	-
Employee Insurance	-
CO_2 Costs	-
TOTAL	**600**

Table 65. LCC End-of-Life Costs- RP2

Cost	€
Disassembly	200
Labour	200
Disposal (e.g. landfill, incineration)	100
Transportation costs	50
TOTAL	**550**

6.2.2.2.3.3 DESCRIPTION AND ANALYSIS OF RP7

On the following table the composition of the RP7 and the functional unit are presented.

Table 66. Composition of RP7

Functional unit: panel (1 m x 0.5 m x 0.05 m)		
	Quantity	**Unit**
Raw Materials *(The raw materials that are used for the production of the specific component)*		
Saw dust or other lignocellulose waste materials. One piece is a 1 m x 0.5 m x 5 cm panel	5	kg
Fire protection bore or other material	0.1	kg
Reused/recycled materials. *(The amount of reused/recycled materials that are used in the production process. These data can be provided with a functional unit or as a percentage of the total material)*		
Saw dust or other lignocellulose waste	2.5	kg
Electricity/Heat *(The electric and the thermal energy consumption during the production process)*		
Estimated electricity	3	kWh
Estimated heat	15	kWh
Transportation *(The country of production, the country of installation or assembly for the final component and the mean of transportation)*		
Country of Production	Hungary	
Country of Installation	Hungary	
Mean of transportation (e.g. truck, plane, ship etc).	truck	estimated distance 220 km
Waste Management *(The potential waste management of different materials)*		
No waste	all materials can be used either for product or for heat production	
Final Weight *(The weight of the component)*		
	2	kg

The life cycle phases which were included to model the environmental impact of the RP7 are the raw materials acquisition, components/ materials manufacturing & packaging, components/ materials transportation, RP manufacturing and RP transportation.

After conducting the life cycle analysis based on primary data (manufacturing data sheets for the examined technologies/components/energy systems) and secondary data (data sources from published articles/report and modules developed by CERTH) the embodied CO_2eq [kg] per panel (1 m x 0.5 m x 0.05 m) for RP7 is 7.81. The total surface that the RP7 will be installed in the HU demo is 361 m2 with thickness 0.06 m. Since the functional unit of the RP7 is 1 m*0.5 m*0.05 m the volume of the RP7 that will be used in the HU demo is 886.4 m3 [= 361*0.06/ (1*0.5*0.05)]. Therefore, the total embodied CO_2eq [kg] of the RP7 in the demo is 6,922 (= 886.4 * 7,81).

The following tables present the total acquisition cost, the yearly costs for operation and maintenance and the end-of-life costs of all the RP7 that will be used in the HU demo.

Table 67. Initial Investment – RP7

Cost	€
Total Acquisition Costs	1,575

Table 68. LCC- Operational Maintenance Costs- RP7

Cost	€
Inspection	0
General repair and maintenance	10
Equipment Insurance	0
Payroll	100
Employee Insurance	0
CO_2 Costs	0
TOTAL	110

Table 69. LCC End-of-Life Costs- RP7

Cost	€
Disassembly	200
Labour	200
Disposal (e.g. landfill, incineration)	100
Transportation costs	50
TOTAL	**550**

6.2.2.2.3.4 DESCRIPTION AND ANALYSIS OF RP8

On the following table the composition of the RP8 and the functional unit are presented.

It must be noticed that (Glass, Aluminium and Wood are referred to per m^2 of the RP and the other elements per the entire RP)

Table 70. Composition of RP8

Functional unit: *See above*		
	Quantity	unit
Raw Materials *(The raw materials that are used for the production of the specific component)*		
Glass	48	kg
Aluminium	2	kg
Wood	40	kg

Functional unit: *See above*		
	Quantity	unit
Electric circuit	0,3	kg
Battery Li-Ion	0,3	kg
Plastic	1,5	kg
Electricity/Heat *(The electric and the thermal energy consumption during the production process)*		
Mechanical manufacturing	3	kWh
Transportation *(The country of production, the country of installation or assembly for the final component and the mean of transportation)*		
Country of Production	Hungary	
Country of Installation	Hungary	
Mean of transportation (e.g. truck, plane, ship etc).	240	km
Final Weight *(The weight of the component)*		
	91	kg

The life cycle phases which were included to model the environmental impact of the RP7 are the raw materials acquisition, components/ materials manufacturing & packaging, components/ materials transportation, RP manufacturing and RP transportation.

After conducting the life cycle analysis based on primary data (manufacturing data sheets for the examined technologies/components/energy systems) and secondary data (data sources from published articles/report and modules developed by CERTH) the total embodied CO_2eq [kg] of the RP8 in the demo is 12,905.

The following tables present the total acquisition cost, the yearly costs for operation and maintenance and the end-of-life costs of all the RP8 that will be used in the HU demo.

Table 71. Initial Investment – RP8

Cost	€
Total Acquisition Costs	27,300

Table 72. LCC- Operational Maintenance Costs- RP8

Cost	€
Inspection	300
General repair and maintenance	1000
Equipment Insurance	0
Payroll	200
Employee Insurance	30
CO_2 Costs	0
TOTAL	1530

Table 73. LCC End-of-Life Costs- RP8

Cost	€
Disassembly	200
Labour	200
Disposal (e.g. landfill, incineration)	100
Transportation costs	50
TOTAL	550

6.2.2.2.3.5 RENOVATION SCENARIO – RESULTS

The table below illustrates the total initial embodied CO2 per component that considered in the renovation scenario analysis.

Component Name	CO2 (kg)
Aluminium Glazing (SW)	8,070.7
Aluminium Glazing (NW)	1,562.0
Aluminium Glazing (NE)	7,940.0
Aluminium Glazing (SE)	1,041.5
Hot Water Storage	2,333
Boiler gas	4,086
PR2	6,092
RP7	6,922
RP8	12,905

The LCA/LCC results, based on the aforementioned interventions, are presented in Table 74 and the diagrams below. The environmental and economic impact of the renovation scenario is assessed using the following KPIs. In addition, it is worth considering that the analysis commenced in July of the first year. Consequently, the data for the initial year is partial, accounting only for the period from July to December. Similarly, the data is partial for the last year, covering the period from January to June.

Table 74. LCA / LCC Results of the baseline scenario

KPI	RESULT
Lifetime CO_2 emissions savings	159,488 [kgco2]
Carbon payback period	NO PAYBACK
Payback Period	NO PAYBACK
Investment cost	71.400 [€]
Life cycle cost	1,290,946 [€]
Lifetime income	0 [€]

In Figure 162 the annual CO$_2$ savings are presented. It is noticeable that the initial year the CO$_2$ income is significant lower compared to subsequent years since the analysis does not commence at the start of the year. Over time, the annual CO$_2$ income decreases due to the degradation of the PV panels. However, a significant uptick in CO$_2$ income is observed in the fortieth (40) year when the PV panels are replaced.

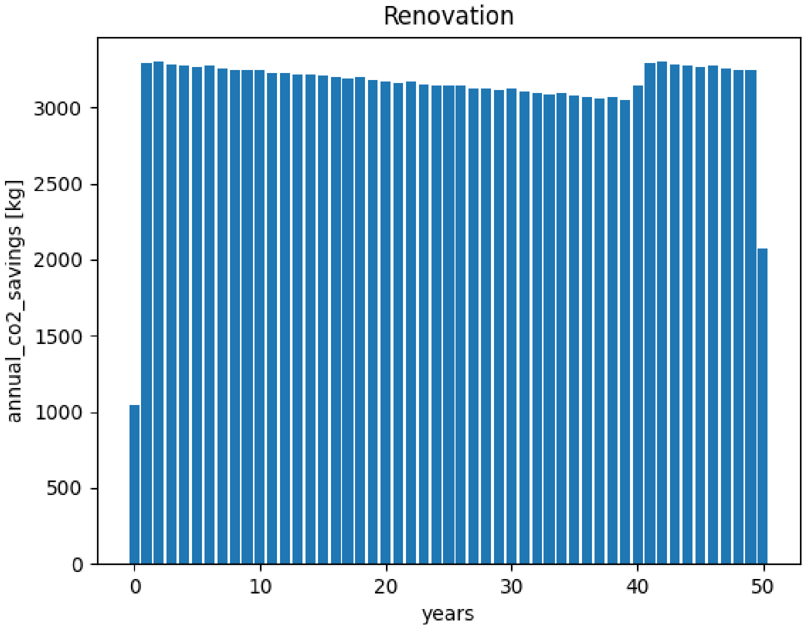


Figure 162. Annual C02 Savings [kg]- Renovation Scenario

Figure 163 (Annual Functional CO$_2$ [kg]) reveals an increase in functional CO$_2$ emissions over time due to the degradation of the boiler. In the tenth year, the boiler is replaced, resulting in decreasing costs, as the new boiler requires less fuel to produce the same thermal power.

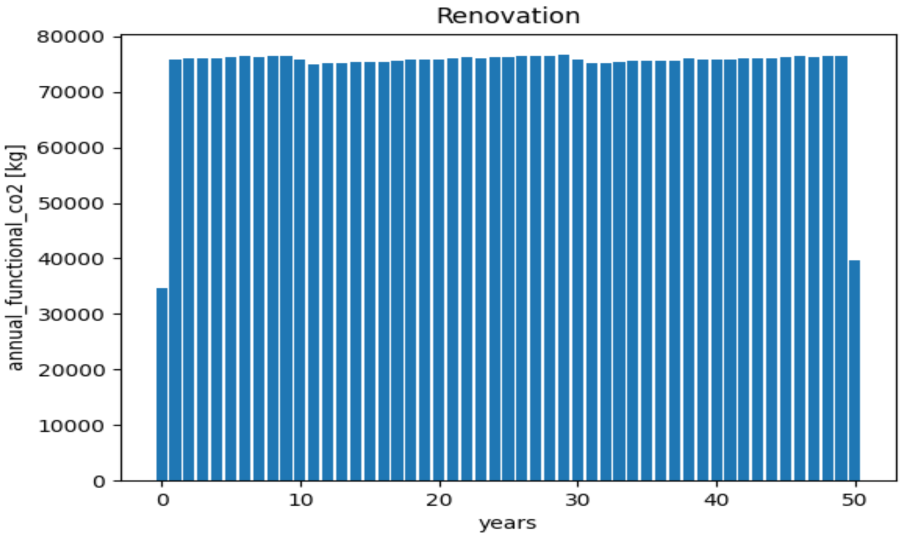


Figure 163. Annual Operational (Functional) C02 [kg]- Renovation Scenario

In Figure 164 the operational and maintenance costs are depicted, showing a consistent increase over the years (mainly due to inflation). Year 10, 30 and 40 are the replacement years where the new components do not require maintenance.

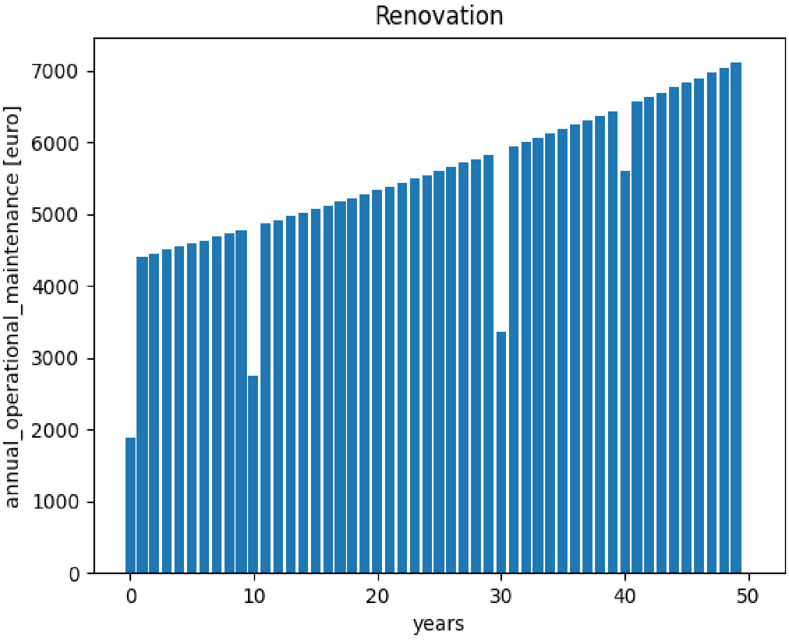


Figure 164. Annual Operational Maintenance Cost [€]- Renovation Scenario

Figure 165 illustrates the Global Warming Potential per year per square meter of the HU demo considering both operational and infrastructure CO_2 emissions.

Figure 165. Global Warming Potential [KgCO2/year/m2] - Renovation Scenario

Figure 166 illustrates the return of investment (ROI). The PV panels that will be installed are not generating sufficient energy and therefore the ROI cannot be achieved.

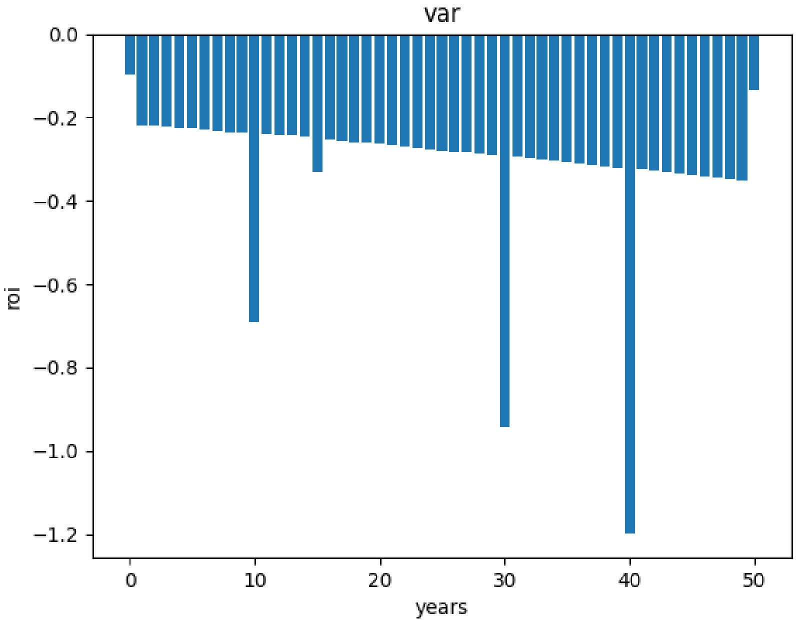


Figure 166. Return of Investment (Total) - Renovation Scenario

6.2.2.2.4 COMPARISON OF THE RENOVATION AND THE BASELINE SCENARIOS

Three innovative technologies were incorporated into the HU demo, with the dual aim of decreasing the cooling and thermal demands of the building while simultaneously generating electricity for self-consumption. The reduction in thermal demands has resulted in a notable decrease in CO_2 emissions from the natural gas boiler, which is clearly reflected in the operational (functional) costs diagrams of the renovation scenario. Similarly, a reduction in boiler usage has led to lower fuel consumption and subsequently reduction in financial costs.

However, it is important to note that even with reduced boiler use, the electricity generated from the solar panels may not provide an immediate CO_2 payback or return on investment (ROI). Nevertheless, the total investment costs over the fifty-year project duration are lower in the renovation scenario compared to the baseline scenario due to significant reductions in operating costs.

In Table 23 the LCA/LCC results between the baseline and the renovated scenarios are compared. The installation of the RPs has resulted in a substantial reduction in the project's CO_2 emissions. Additionally, the monetary costs of the project have decreased significantly, primarily due to lower fuel consumption and reduced reliance on grid-imported electricity.

Table 75. Comparison of LCA/LCC results between the baseline and the renovated scenarios.

Index	Baseline	Renovation
Life cycle cost [€]	1,750,145	1,290,946
Life cycle CO_2 Emissions [$kgCO_2$]	6,498,550	3,820,467
Life Cycle CO_2 Income [[$kgCO_2$]]	0	159,488

Index	Baseline	Renovation
Carbon payback period	NO PAYBACK	NO PAYBACK
Payback Period	NO PAYBACK	NO PAYBACK
Lifetime income [€]	0	0

6.2.2.2.5 REFERENCES

[1] V. Apostolopoulos, I. Mamounakis, A. Seitaridis, N. Tagkoulis, D.-S. Kourkoumpas, P. Iliadis, K. Angelakoglou, N. Nikolopoulos. An integrated life cycle assessment and life cycle costing approach towards sustainable building renovation via a dynamic online tool. Applied Energy, 334, (2023), 120710”

[2] E.Bellos, P.Iliadis, C. Papalexis, R.Rotas, I.Mamounakis, V.Sougkakis, N.Nikolopoulos, E. Kosmatopoulos. Holistic renovation of a multi-family building in Greece based on dynamic simulation analysis. Journal of Cleaner Production. Volume 381, Part 1, 2022, 135202, ISSN 0959-6526, **https://doi.org/10.1016/j.jclepro.2022.135202**.

6.2.3 ITALIAN DEMO

6.2.3.1ENERGY SIMULATION

6.2.3.1.1 BASELINE SITUATION

6.2.3.1.1.1 DESCRIPTION OF THE BUILDING ELEMENTS

The Italian demonstration site is situated in a peripheral area of Margherita di Savoia, an Adriatic coastal municipality within the Apulia region of Italy. As shown in the following figure, the specific demo building is part of a cluster of similar structures, all sharing common issues of physical degradation and social vulnerability. The assignees of this public housing stock are notably frail and vulnerable. Over the past two years, regional policies have been introduced for the requalification of poor areas. The demo building has a rectangular footprint with four floors and eight apartments and is built in a reinforced concrete frame with poor insulation.

6.2.3.1.1.2 DESCRIPTION OF THE ENERGY SYSTEM

The DEMO is a building of four floors above ground plus a floor on the roof dedicated to storage rooms. Each floor consists of two units of 80m^2 and 93m^2, respectively, for a total of 8 apartments.

The building, built in the mid-1980s, has a reinforced concrete structure with perforated brick closures and metal window frames without thermal break and with single glazing, except for three apartment units where the glazed surfaces have been replaced by PVC elements and double-glazing.

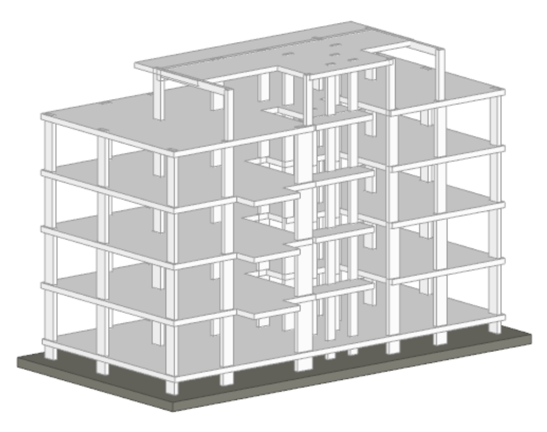


Figure 167. Modellazione 3D degli elementi strutturali

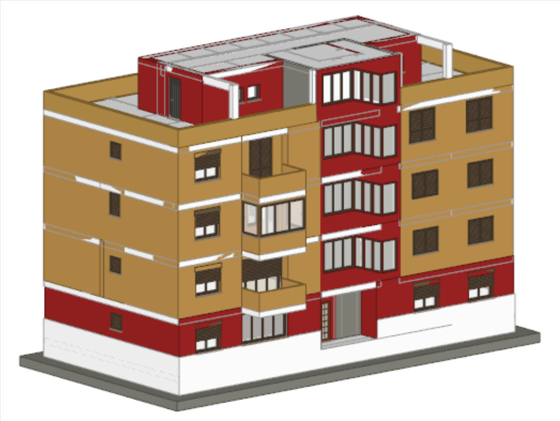
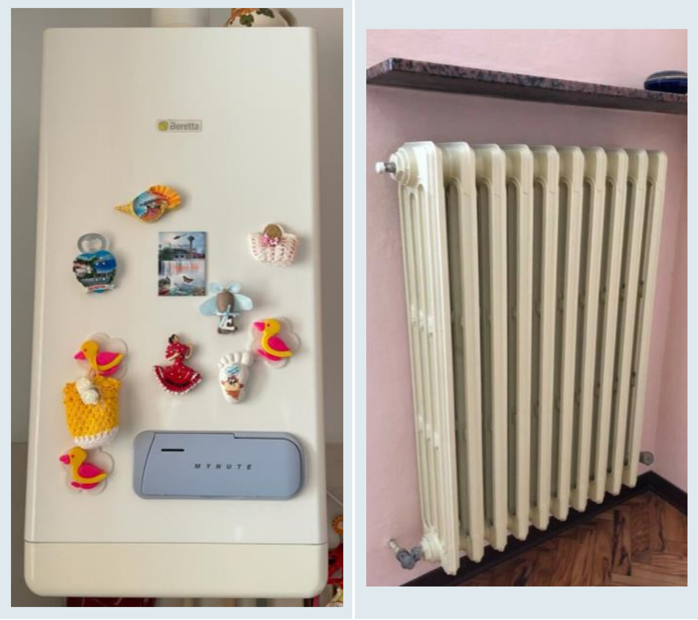


Figure 168. Modellazione 3D Termica/Architettonica

All apartments are equipped with independent natural gas heat generators for the production of domestic hot water and heating system with cast iron radiators as emission elements.



Caldaia autonoma

Radiatori in ghisa

Figure 169: Gas heat generators and heating system

In addition, there are air conditioners in only three housing units that are used for the summer season.

6.2.3.1.2 RENOVATION SCENARIO ANALYSIS

In Margherita di Savoia the renovation works include specific interventions using regional funds external to the project, that has been obtained in April 2023. Thanks to these funds, in Margherita di Savoia we have two types of interventions: standards renovation funded by Apulia Regional funds and innovative renovation (RP4 and RP5) funded by EU (REHOUSE). In the first year of the project, partners evaluated the installation of green Façades in those vertical walls not covered by the BIPV panels. These foreseen eco-friendly materials with positive impacts on the indoor and outdoor environments, thanks to the cooling effect in summer, and CO2 absorbing and air purification benefits from plants respectively. The possibility of installing a green wall was the main objective of two workshops with end users (tenants). In addition, ARCA, as owner of the building, evaluated the economic impact of the interventions. Finally, the costs of maintenance of the green wall were high and not sustainable for a social housing building. So, the vertical wall not covered by BIPV will be renovated according to the New European Bauhaus (NEB) strategy, following the co-design approach with end users as foreseen in WP1. In addition, a seismic risk analysis has been conducted to propose the best structural solution to face potential earthquakes.

Finally, thanks to the regional funds, global renovation actions will involve the neighbourhood. A neighbourhood renovation intervention will be initiated to improve the quality of life not only for the building users but for the entire neighbourhood. The strategy adopted in the diagnosis phase to create the baseline of the building was called “Rehouse methodology”, because the energy audit, the structural assessment and social analysis were integrated, saving costs and efforts and involving direct end users. Concerning the Italian DEMO site, in this deliverable the following information is not a final version” and it could be updated in later deliverables of the project (deliverables 4.2, 4.4 and 4.5).

6.2.3.1.2.1 DESCRIPTION OF THE RENOVATION ACTIONS

The renovation interventions address both the active and passive components of the building thanks to the integration of RP#4 and RP#5.

RP#5 will lead to the improvement of the envelope insulation level while locally producing RES electricity from the BIPV located in favourably oriented façades (295 m2) plus 120 m2 of fixed conventional PV on the rooftop. RP#5 aims to elevate the insulation level of the envelope and promote local electricity production from renewable sources. This will be achieved by incorporating coloured laminated glass photovoltaic (BIPV) modules into the facades, strategically placed as integral building components. The selected facades, including the three with optimal exposure and those of the technical rooms on the roof, will play a crucial role in meeting the project's key performance indicators (KPIs).

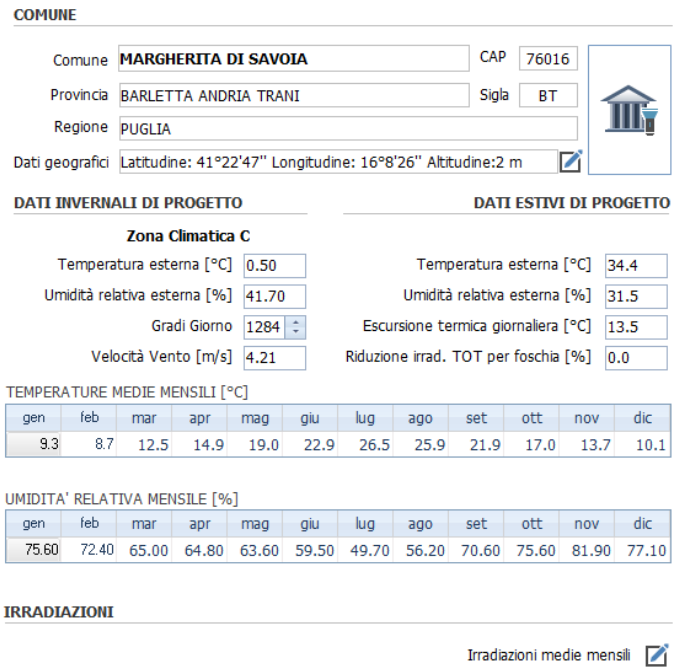
PV will be coupled to the renovated active energy supply (RP#4) based on the central heat pump, the PCM storage, as well as the smart energy distribution (based on the installation of the Smart rubber solution at 2 strategic points of each one of the 8 flats).

ARCA has applied for and been awarded additional regional funding from the Apulia Region to complete upgrades to the building, which include interventions to remove architectural barriers and energy upgrades to complete what was planned by REHOUSE project.

Following the New European Bauhaus movement, special attention is paid to delivering high-quality architecture design and combining aesthetic elements with functional standards and removal of barriers, while using naturally sourced materials.

6.2.3.1.2.2 SIMULATION OF THE ITALIAN DEMOSITE WITH RP4 AND RP5

The energy diagnosis of the building was done using the commercial software “Termus BIM” of ACCA software Spa. The model required the definition of the geographical location of the property necessary for the assignment of the thermo-hygrometric characteristics of the site.



COMUNE

Comune **MARGHERITA DI SAVOIA** CAP 76016
Provincia BARLETTA ANDRIA TRANI Sigla BT
Regione PUGLIA
Dati geografici Latitudine: 41°22'47" Longitudine: 16°8'26" Altitudine:2 m

DATI INVERNALI DI PROGETTO

Zona Climatica C

Temperatura esterna [°C] 0.50
Umidità relativa esterna [%] 41.70
Gradi Giorno 1284
Velocità Vento [m/s] 4.21

DATI ESTIVI DI PROGETTO

Temperatura esterna [°C] 34.4
Umidità relativa esterna [%] 31.5
Escursione termica giornaliera [°C] 13.5
Riduzione irrad. TOT per foschia [%] 0.0

TEMPERATURE MEDIE MENSILI [°C]

gen	feb	mar	apr	mag	giu	lug	ago	set	ott	nov	dic
9.3	8.7	12.5	14.9	19.0	22.9	26.5	25.9	21.9	17.0	13.7	10.1

UMIDITA' RELATIVA MENSILE [%]

gen	feb	mar	apr	mag	giu	lug	ago	set	ott	nov	dic
75.60	72.40	65.00	64.80	63.60	59.50	49.70	56.20	70.60	75.60	81.90	77.10

IRRADIAZIONI

Irradiazioni medie mensili

Figure 170: IT demo in Termus BIM

Thanks to the planimetric relief and the thermal characteristics of the building elements (envelope and systems), the modelling was carried out in the software library necessary for the correct three-dimensional modelling DEMO.

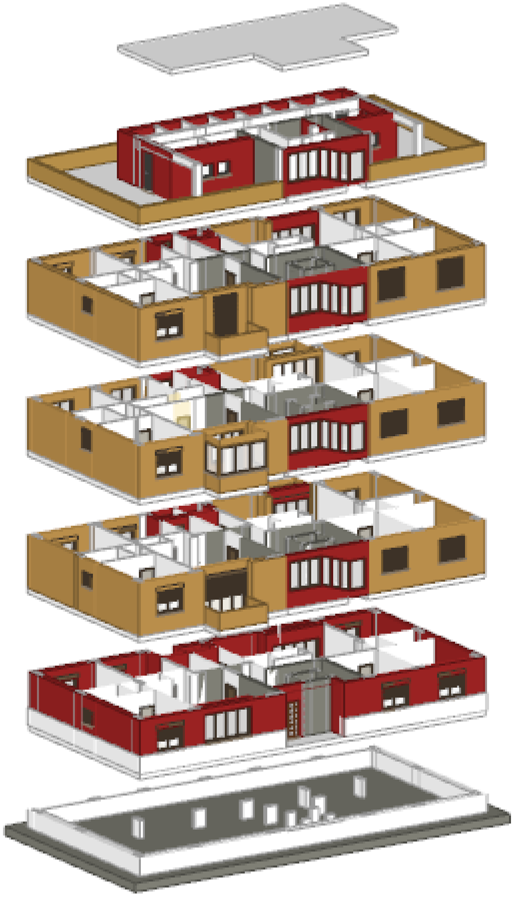


Figure 171: Creation of IT for the energy simulation

Schemes of different perimetral stratigraphy are presented in the following figures.

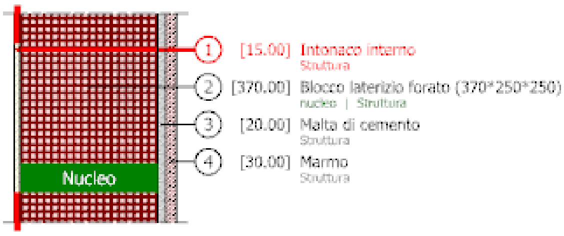


Figure 172: Perimeter perete with marble cladding

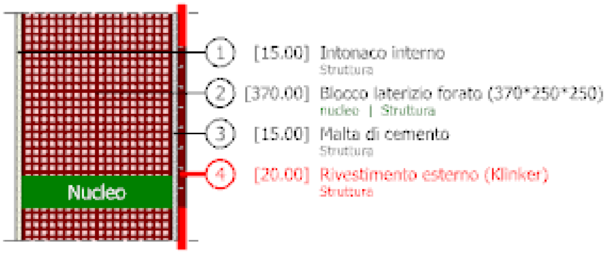


Figure 173: Perimeter wall with klinker cladding

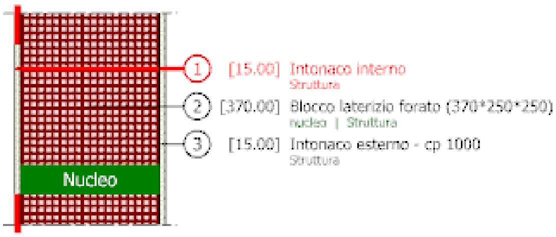
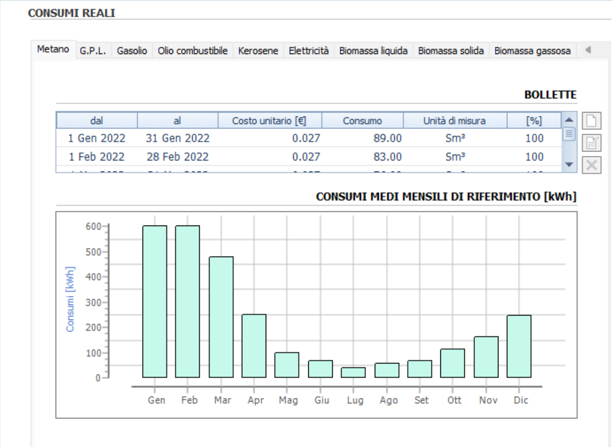


Figure 174: Perimeter wall plastered

The energy diagnosis requires an assessment of the building based on the actual consumption of energy flows for each individual building unit. So that, it was essential to include in the program the data made available by the local electricity and gas distributors.



CONSUMI REALI

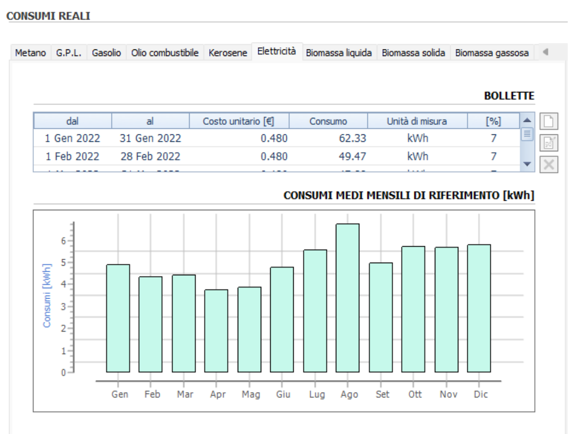
Metano | G.P.L. | Gasolio | Olio combustibile | Kerosene | Elettricità | Biomassa liquida | Biomassa solida | Biomassa gassosa

BOLLETTE

dal	al	Costo unitario [€]	Consumo	Unità di misura	[%]
1 Gen 2022	31 Gen 2022	0.027	89.00	Sm³	100
1 Feb 2022	28 Feb 2022	0.027	83.00	Sm³	100

CONSUMI MEDI MENSILI DI RIFERIMENTO [kWh]

Figure 175: Real consumption of natural gas



CONSUMI REALI

Metano | G.P.L. | Gasolio | Olio combustibile | Kerosene | Elettricità | Biomassa liquida | Biomassa solida | Biomassa gassosa

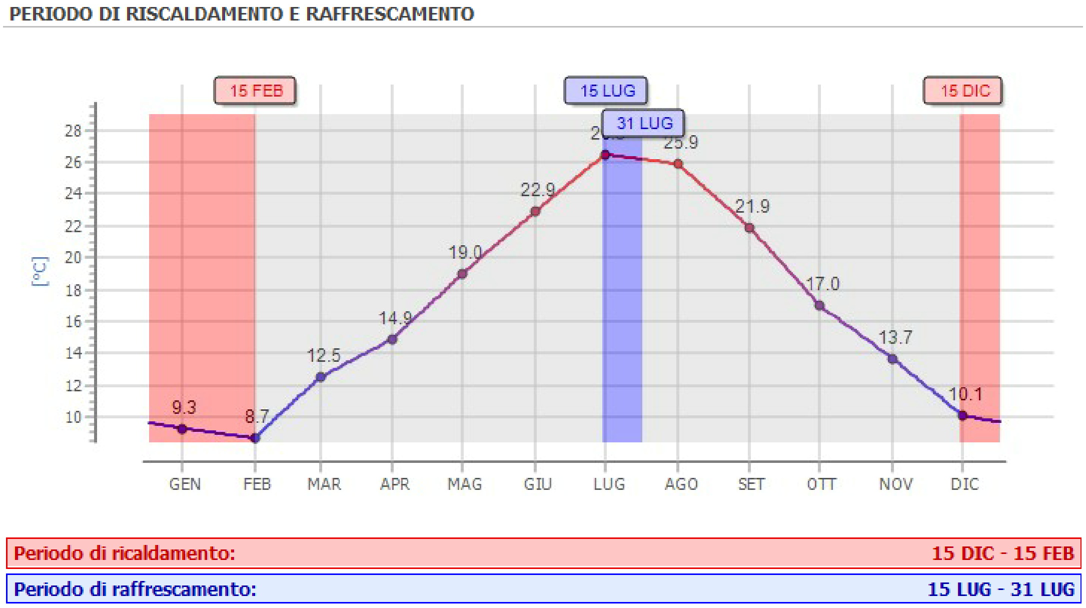
BOLLETTE

dal	al	Costo unitario [€]	Consumo	Unità di misura	[%]
1 Gen 2022	31 Gen 2022	0.480	62.33	kWh	7
1 Feb 2022	28 Feb 2022	0.480	49.47	kWh	7

CONSUMI MEDI MENSILI DI RIFERIMENTO [kWh]

Figure 176: Real consumption of electricity

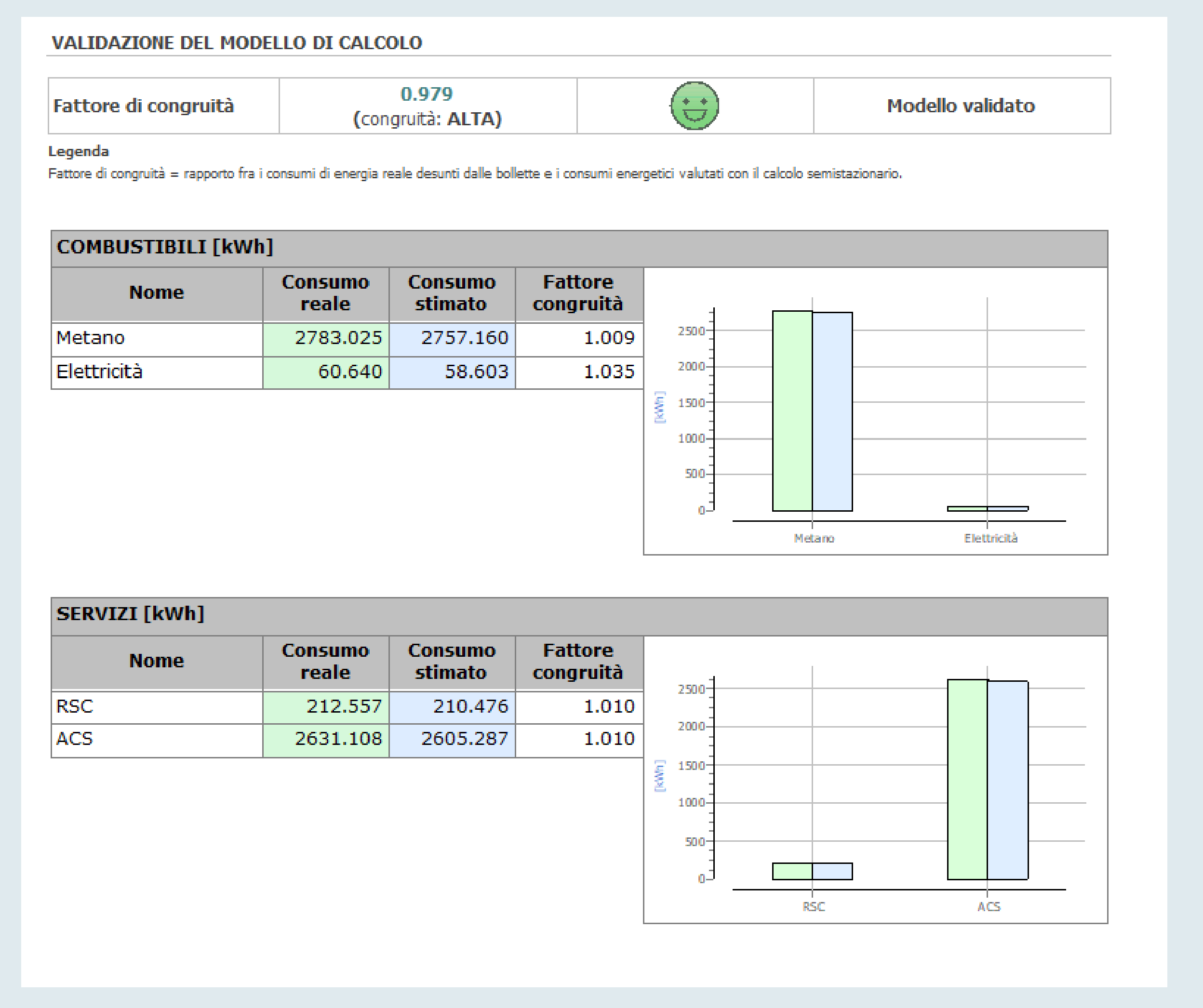
The construction of the simulation model of the building-plant system is followed by its validation by comparing operational and actual consumption. In this regard, building-plant system usage profiles were created based on information provided by residents.



PERIODO DI RISCALDAMENTO E RAFFRESCAMENTO

Periodo di ricaldamento:	**15 DIC - 15 FEB**
Periodo di raffrescamento:	**15 LUG - 31 LUG**

Figure 177: Analysis of consumption



VALIDAZIONE DEL MODELLO DI CALCOLO

Fattore di congruità	0.979 (congruità: **ALTA**)	☺	**Modello validato**

Legenda

Fattore di congruità = rapporto fra i consumi di energia reale desunti dalle bollette e i consumi energetici valutati con il calcolo semistazionario.

COMBUSTIBILI [kWh]

Nome	Consumo reale	Consumo stimato	Fattore congruità
Metano	2783.025	2757.160	1.009
Elettricità	60.640	58.603	1.035

SERVIZI [kWh]

Nome	Consumo reale	Consumo stimato	Fattore congruità
RSC	212.557	210.476	1.010
ACS	2631.108	2605.287	1.010

Figure 178: Validation of the model

6.2.3.1.3 COMPARISON OF THE RENOVATION SCENARIO AND THE BASELINE SITUATION

Starting from the initial model, innovative elements that will be implemented in the model will be defined in the library. Among them, the new stratigraphy of the perimeter walls will be defined, which include the installation of BIOCANAPANEL-type insulation material on the facade and the superimposition of vertical photovoltaic modules and decorative panels. In addition, the installation of insulation material is also planned on the roof.

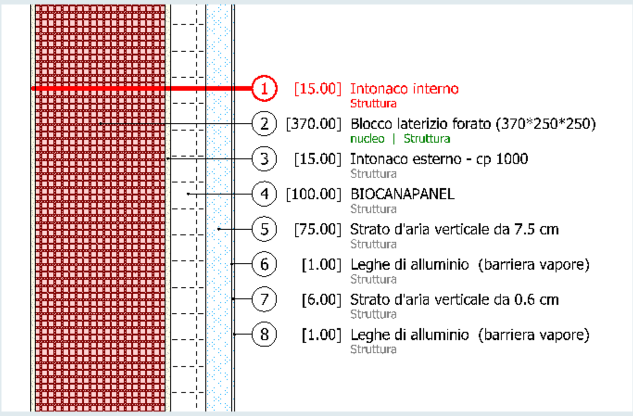


Figure 179: Perimeter wall area plastered PSAF + Alucore

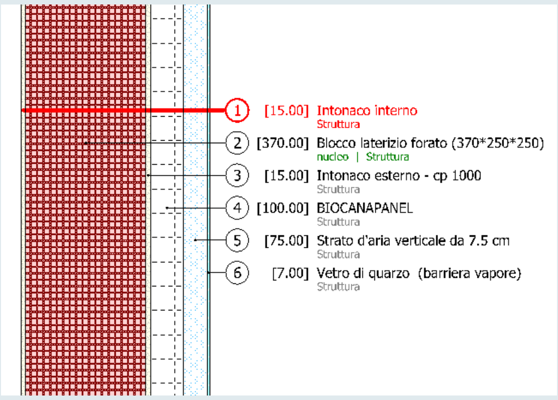
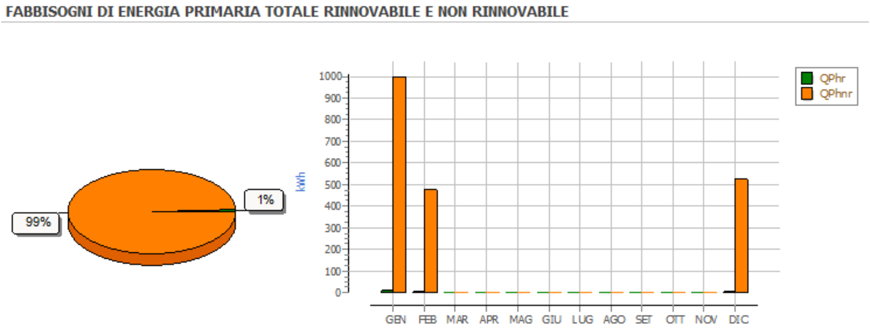
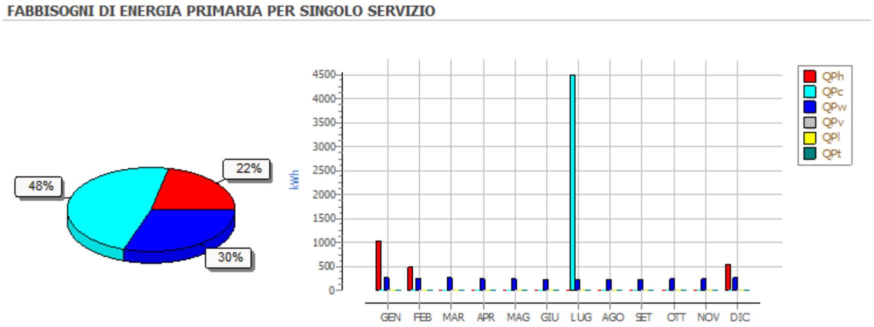
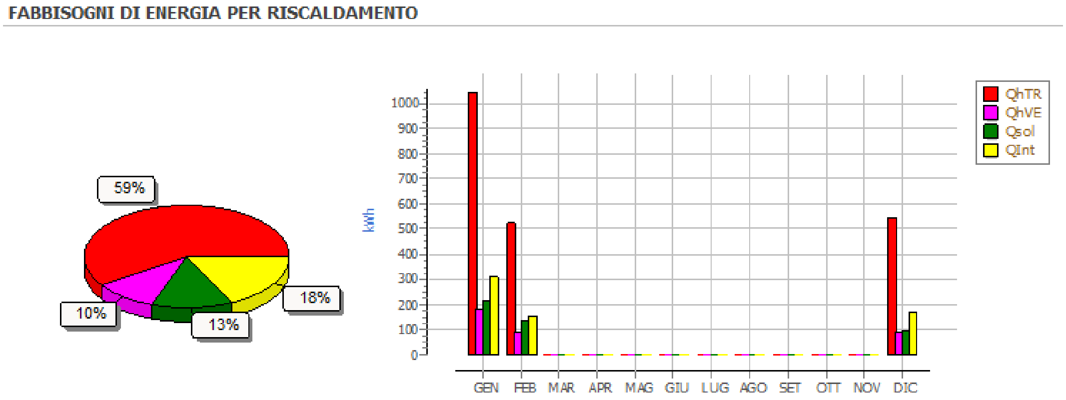


Figure 180: Perimeter wall area plastered PSAF + PV

All windows and shutters will be replaced using systems that will contain both heat loss and noise pollution. An innovative centralized heating/cooling system will also be modelled to replace the existing stand-alone generators and will be powered by electricity produced by the photovoltaic system. The insulation of the building, combined with the replacement of the windows and doors, will allow a significant decrease in the energy requirements of the heating and cooling services. In the following diagrams the results of heating and cooling demands are presented.







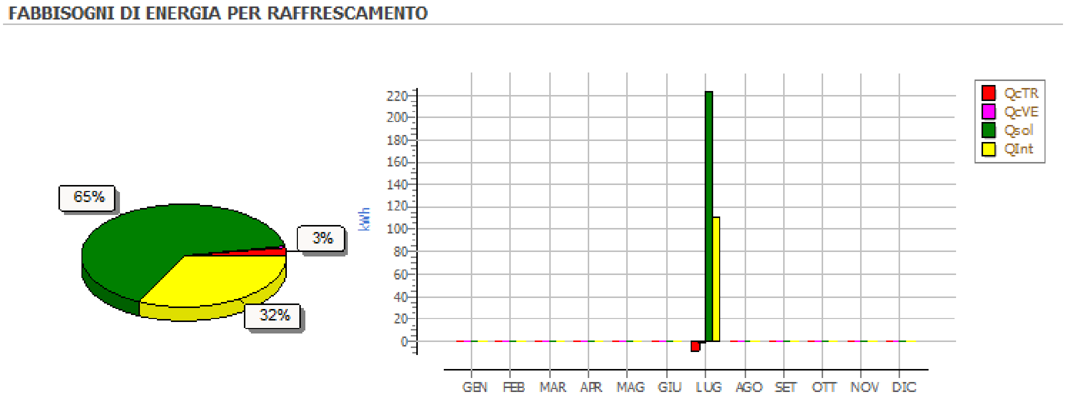


Table 76: Comparison of the baseline situation and the renovation scenario

Indexes	Existing state	Renovation with RP4 and RP5
Heating demands (kWh/ a)	31668.45	7937.14
Heating demands (kWh/m^2·a)	44.69	11.07
Heating demands reduction (%)	-	75.2%

As previously stated, in this deliverable these data are not the final version and they could be updated in later deliverables of the project (deliverables 4.2, 4.4 and 4.5).

6.2.4 FRENCH DEMO

6.2.4.1ENERGY SIMULATION

6.2.4.1.1 BASELINE SITUATION

6.2.4.1.1.1 DESCRIPTION OF THE BUILDING

The French Demosite is a social housing with an area[13] of 2260 m², located in the town of Saint-Dié-des-Vosges, in the North East of France. The building is composed of 20 apartments; 34

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[13] Corresponding to the Gross floor area – The net internal area is 1730 m² + 530 m² cellars

people live in, with an average age of 55-60 years old. It was built in 1959 and since its construction has only undergone an energy renovation with the replacement of the windows. The building has an East – West orientation and a rendered masonry façade.

Figure 181.General view and aerial view of the French Demosite

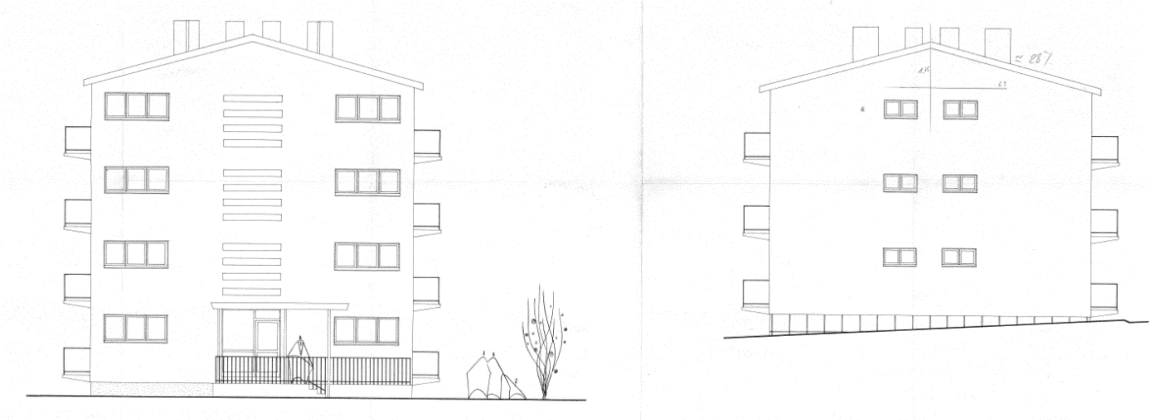

Figure 182.Façade cross section

Figure 183.East Facade

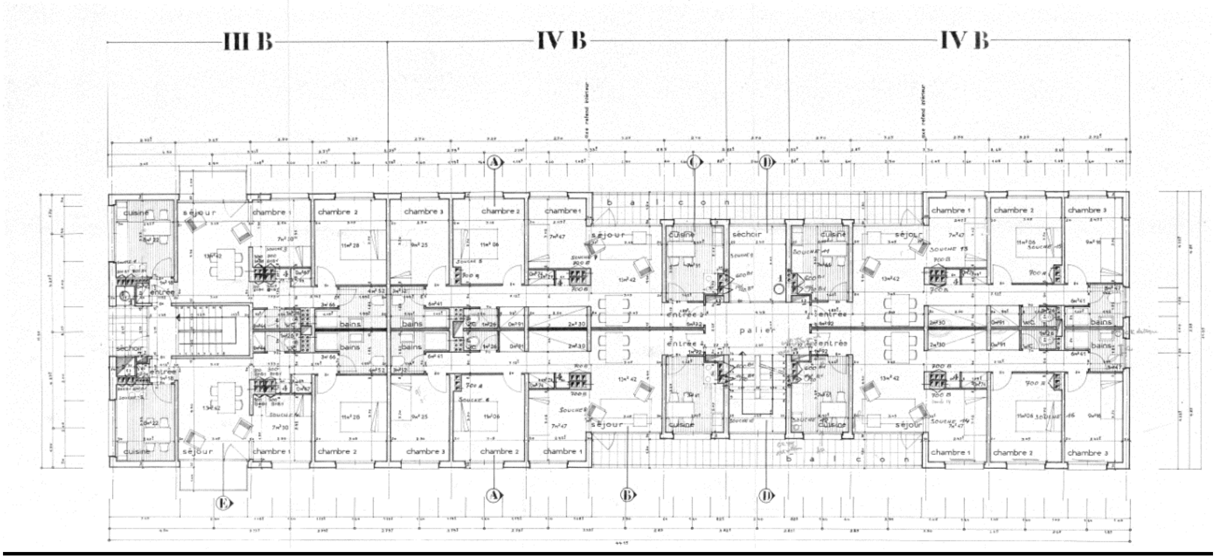

Figure 184.Current floor drawing

6.2.4.1.1.2 DESCRIPTION OF THE ENERGY SYSTEM

All the apartments have static ventilation (air ducts) but no mechanical ventilation system. As a result, people open the windows additionally, for very short periods in winter, longer in summer. All tenants have an individual gas boiler for the production of heating and DHW. Boilers are about 20 years old (no low-temperature, no condensation, 90% efficiency). A thermostat is available to set the temperature. The vast majority of tenants heat their homes to 19°C and are extremely careful to limit their energy consumption to reduce expenses. All households have LED lamps and appliances in class A. No air conditioning system (individual or collective) is present in the building. The energy and environmental performance rate of the French DPE[14] is a D rate; it means that the primary energy consumption value is between 151 and 230 kWh/m²/year.

6.2.4.1.1.3 AIRTIGHTNESS REPORT

The Airtightness report was conducted the 02/08/2023. Sampling was carried out in accordance with the FD P 50 784 supplementing the NF EN ISO 9972 standard, i.e. 3 dwellings, one on each level, selected according to tenants' availability.

Analysis and comments

The results obtained are already relatively good Q4 = 1.57 $m^3/h/m^2$. The main parasitic air inlets identified are in the following areas:

- PVC joinery, whose seals and closing systems are sometimes no longer sufficiently effective, and roller shutter boxes and their mechanical closing systems,
- Technical columns and their separation by light panels in WCs, or even bathrooms,
- Electrical feed-throughs in entrances, and, to a lesser extent, pipe feed-throughs between levels in ceilings, floors and service columns.

In addition, natural air intakes in wet rooms (kitchen (2), WC (2), bathroom (1)) must be sealed and their connections to the walls treated. The same applies to gas ducts in kitchens and old

---

[14] The Energy Performance Diagnosis (DPE) is a mandatory rating survey in France that provides information on the energy performance of a dwelling or building by assessing its energy consumption and its impact in terms of greenhouse gas emissions.

chimney flues in other rooms. Effective treatment of these main defects should make it possible to reduce leakage rates by a factor of at least 2.

6.2.4.1.1.4 SIMULATION MODEL

The building was modelled in the DesignBuilder software and was then simulated by the EnergyPlus software. Each apartment is modelled by a unique zone. Figure 6 shows the modelling of the building.

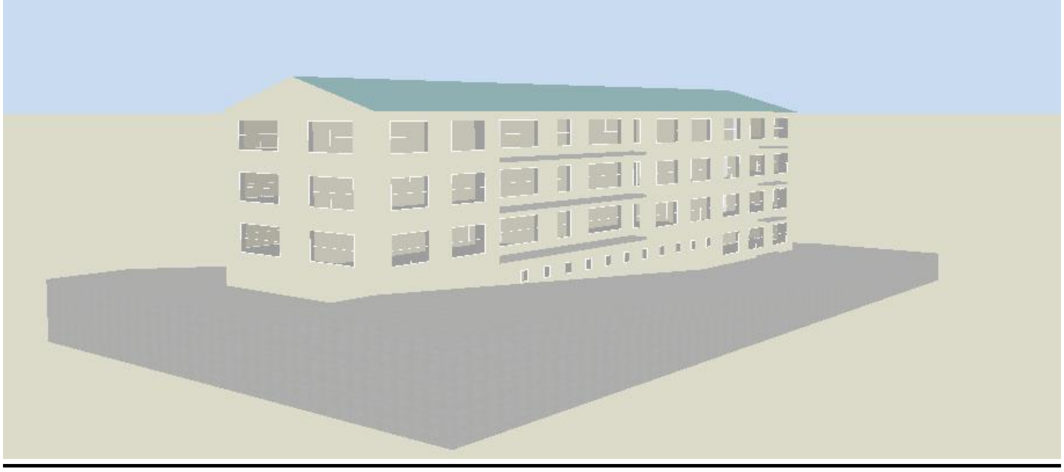

Figure 185.Modelling of the building

Modelling parameters

Table 77 presents the construction data for the different structural elements. Table 78 presents the systems, heating and DHW are alimented by a gas boiler. Table 78 presents the internal loads, the ventilation and the infiltration rate that are used in the model.

Table 77. Construction data

Structural elements	Materials	Thickness (m)	U-value (W/m²K)
Intermediate floor	Concrete, mortar, ceramic tiles	0,25	2,422
High floor	Cement plaster, Wooden joists, wool insulation	0,25	1,116
External walls	Cement plaster, Concrete	0,3	1,339
Roof	Steel		7,142
Load-bearing wall	Cement plaster, Concrete	0,24	1,413
Windows	Double-glazed	0,012	3,226

Table 78. Energy systems

Systems	Baseline situation
Heating system	Individual gas boiler
Cooling system	No
Domestic hot water production	Individual gas boiler
Ventilation system	Static Ventilation
RES system	No

In Table 79 (below), the occupancy density has been set from the number of people living in the building. The lighting density and power density are yearly averaged. The temperature heating setpoint is the average among residents. The infiltration rate is taken from the above section and the natural ventilation rate is applied when people open windows, in particular in long period in summer.

Table 79: Internal loads - ventilation and infiltration parameter

Parameter	Value
Occupancy density	0,0242 pers/m²
Lighting density	0,34 W/m²
Power density (equipment)	3,18 W/m²
Temperature Heating setpoint	19,5 °C
Low Temperature Heating setpoint	16°C
Infiltration rate Q4	1,57 m3/h.m²
Natural ventilation rate (during openings planning)	4 vol/h
DHW	56 L/pers. day 60°C hot water loop

Occupancy and heating schedule

There are thirty adults and four children. Retired people have generally lived in their homes for more than 10 years. Active or unemployed people are present and have lived there for less than 5 years. A third of tenants are retired and therefore spend a lot of time at home. Another third has a professional activity, finally, the last third is made up of children or students and unemployed people. The following planning occupancy is used: until 5:00 am 100%; Until 6:00 am 80%, until 8:00 am 75%, until 9:00 am 50%, until 3:00 Pm 43%, until 6:00 pm 50%, until 9:00 pm 75%, until 0:00 am 80%.

In winter, the following schedule is implemented: from 11:00 pm to 6:00 am, it is the low temperature Heating setpoint of 16°C and from 6:00 am to 11:00 pm it is the temperature heating setpoint of 19,5°C.

6.2.4.1.1.5 SIMULATION RESULTS

The EnergyPlus simulation of the baseline building gives a total primary energy consumption of 278, 319 kWh for one year; the primary energy consumption per occupied building area is 206 kWh/m² (see Table 80).

Table 80: Total Energy consumption of the building in a year

	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	**248,259**	**184**

	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Including heating consumption	170,293	-
Total Primary Energy	**301,018**	**223**

The Figure 186 presents different results for one apartment located in the west side of the first floor. The blue curve is the total heating rate in Watt, the red curve is the mean air temperature in °C, the green curve corresponds to the outdoor air temperature and the yellow curve shows the total transmitted solar radiation rate.

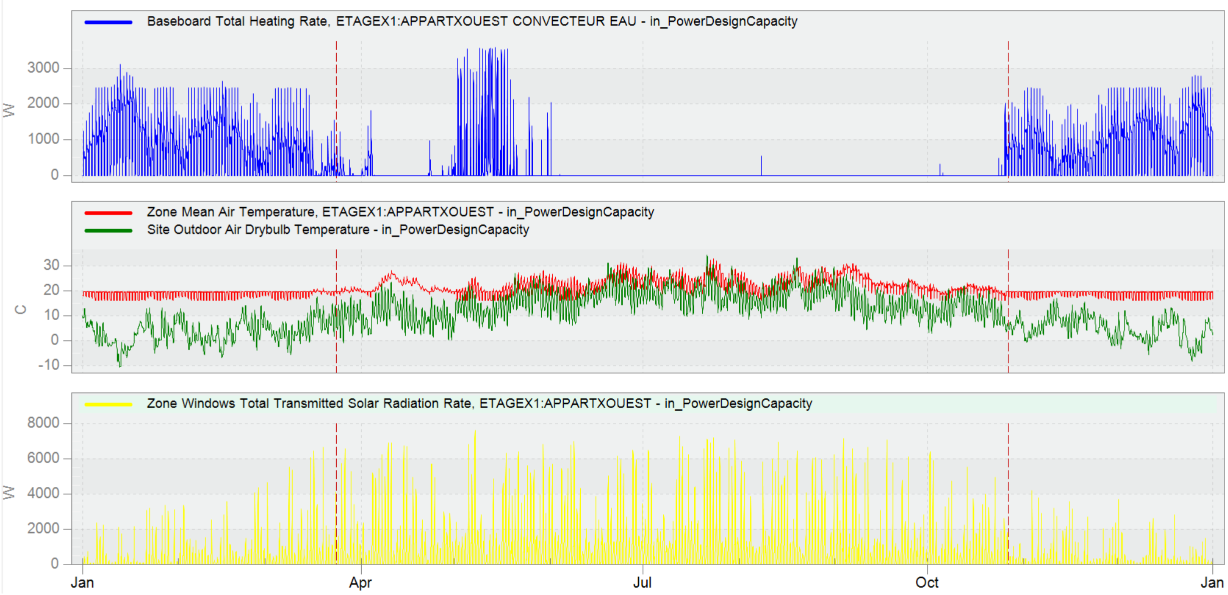

Figure 186.Total Heating rate, Mean Air Temperature and Windows total Transmitted Solar radiation rate for the West apartment of the first floor. The Site outdoor Air Drybulb Temperature is given as a comparison.

6.2.4.1.2 RENOVATION SCENARIO ANALYSIS

6.2.4.1.2.1 DESCRIPTION OF THE RENOVATION ACTIONS

Table 81: Difference of the systems before and after renovation

Systems	Before implementation of the RPs	After the implementation of the RPs
Heating system	Individual gas boiler	Heat pump
Cooling system	No	No
Domestic hot water production	Individual gas boiler	Heat pump
Ventilation system	Static Ventilation	Double flow mechanical ventilation
Building envelop	Concrete (1,339 W/m².K)	Concrete + PanoRen (0,18 W/m².K)
Windows	Double-glazed	Triple-glazed
RES system	No	Second-life PV module

Second-life PV module production

80 kWc of second-life PV module will be installed in two fields on the West and East side of the roof of 40 kWc each. The PV production has been estimated using the Autocalsol tool developed by INES. The results are presented below in *Figure 188*, *Figure 189*, *Figure 190*, *Figure 191*. *Figure 188*, and Figure 190 show the horizon mask for the East and West orientation. The annual solar irradiance for the East side is 1180 kWh/m² with an annual total production of 37,234 kWh. For the West side the annual solar irradiance is 1144 kWh/m² with an annual total production of 35,987 kWh. Thus, the total annual production is 73,221 kWh.

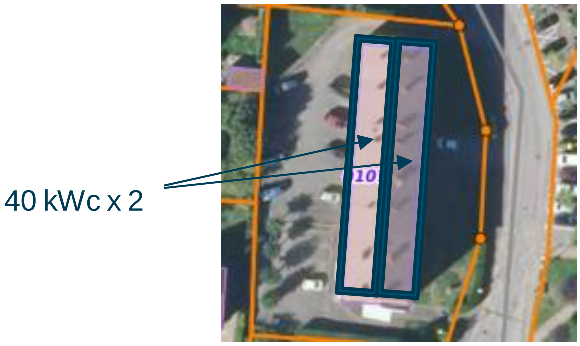

Figure 187. Aerial view of the PV installation

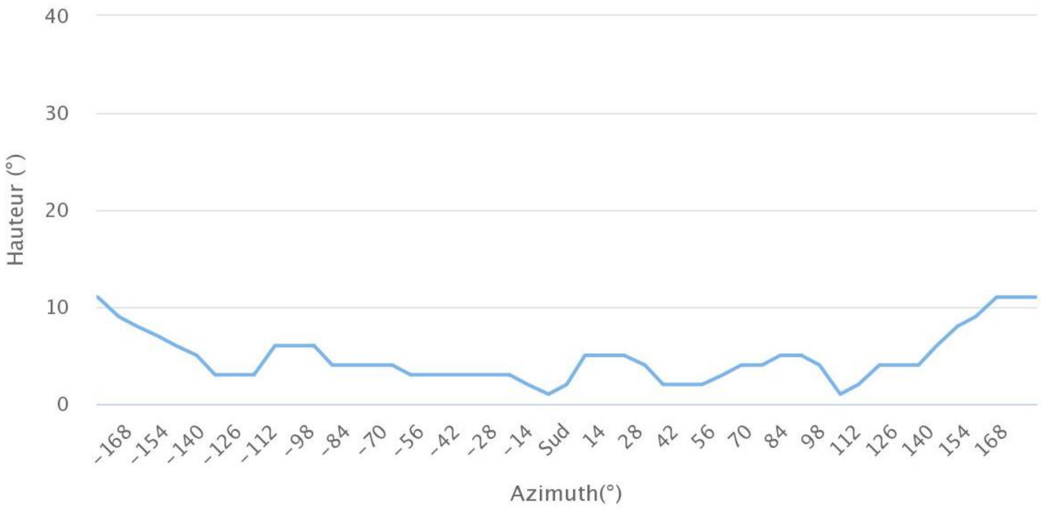

Figure 188.Horizon mask for the East side [PVGIS source]

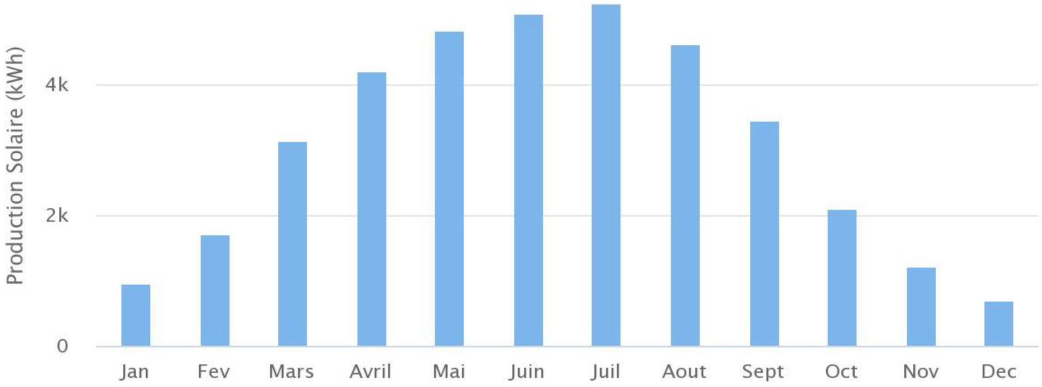

Figure 189.Monthly PV production for the East side (kWh) [PVGIS source]

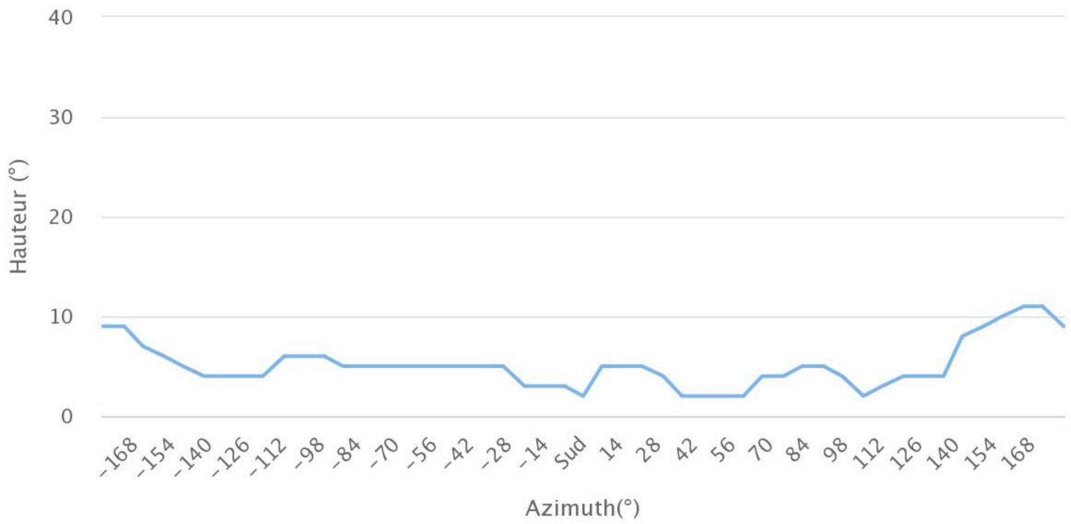

Figure 190.Horizon mask for the West side (PVGIS source)

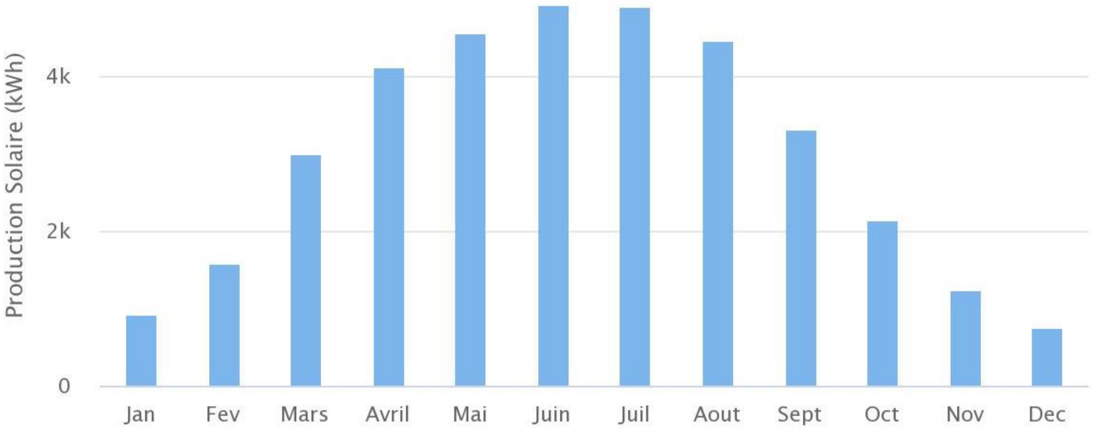

Figure 191.Monthly PV production for the West side (kWh) [PVGIS source]

6.2.4.1.2.2 SIMULATION MODEL

Modelling parameters

Table 82 presents the renovation action on the construction data for the different structural elements. The other structural elements as the intermediate floor, high floor, load-bearing wall are unchanged (see table 1 Construction Data). Different options that will be simulated are specified: double or triple glazed (option 1 and 2) with two configurations of Panoren with four or five layers (respectively 0.21 W/m²K or 0.18 W/m²K).

Table 82: Construction data renovation modification with different configuration that are going to be simulated

Structural elements	Materials	Thickness (m)	U-value (W/m²K)
Low Floor over cellars	Concrete, wood fibre	0.34	0.338
Roof	Steel, wood fibre, cellulose	0.36	0.116
Windows option 1	Double-glazed	0.012	1.407
Windows option 2	Triple-glazed	0.018	0.786

Structural elements	Materials	Thickness (m)	U-value (W/m²K)
External walls configuration 1	Cement plaster, Concrete, Panoren with 5 layers	0.5645	0.18
External walls configuration 2	Cement plaster, Concrete, Panoren with 4 layers	0.5089	0.21

Table 83 and Table 84 present the systems, heating and DHW are alimented by one heat pump of 40 kW, the internal loads, the ventilation, the infiltration rate, the DHW need that are used in the model.

Table 83: Energy systems

Systems	Renovation situation
Heating system	Heat Pump 40 kW
Cooling system	No
Domestic hot water production	Heat Pump 40 kW
Ventilation system	Double Flow mechanical ventilation
RES system	Second-life PV module

Table 84: internal loads – ventilation, infiltration, DHW parameter

Parameter	Value
Occupancy density	0.0242 pers/m²
Lighting density	0.34 W/m²
Power density (equipment)	3.18 W/m²
Temperature Heating setpoint	19.5 °C
Low Temperature Heating setpoint	16°C
Infiltration rate Q4	1 $m^3/h.m^2$
Mechanical ventilation rate (during occupancy)	0.5 vol/h
DHW	56 L/pers. Day 60°C hot water loop

As the aim of the simulation was to show the impact of the different Panoren and windows configuration, the other systems (DHW, heat pump, double-flow mechanical ventilation) has been simulated using a simplified model of Design Builder and Energy Plus. For the heat pump, the seasonal COP for DWH and heating was based on the Intuis ZePac of 40 kW (see Figure 192). For a hot water loop of 60°C (DHW) the 7°C exterior temperature nominal COP is 2.7.

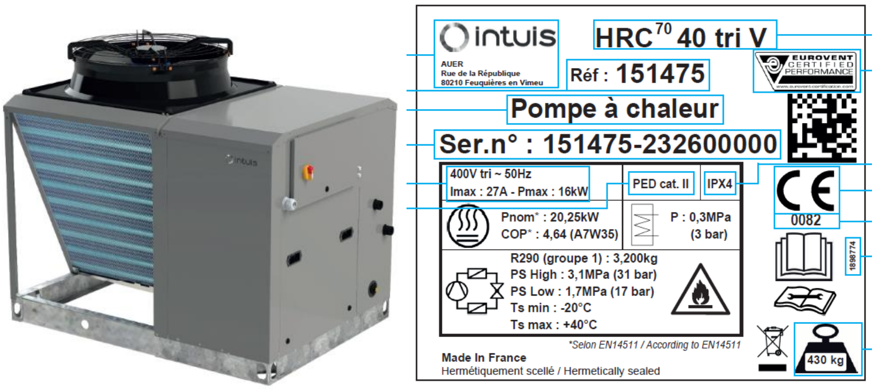

Figure 192.ZePac 40 kW

6.2.4.1.2.3 RENOVATION SCENARIOS AND RESULTS

Four EnergyPlus simulations with the different configurations of Table 85 were conducted and are the results are presented in the Table 86, Table *87*, Table 88 and Table 89. Theses tables indicate the total energy of the building in kWh, the energy per occupied building area in kWh/m².

Table 85. Configuration scenarios

Configuration 1	Panoren with 5 layers	Triple-glazed
Configuration 2	Panoren with 5 layers	Double-glazed
Configuration 3	Panoren with 4 layers	Triple-glazed
Configuration 4	Panoren with 4 layers	Double-glazed

Table 86: Configuration 1 results

Configuration 1	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	**87,158**	**65**
Including heating consumption	13,316	
Total On-Site Electric Sources	73,221	
Net Site Energy	**13,937**	**10**
Net Primary Energy[15]	**32,055**	**24**

Table 87: Configuration 2 results

Configuration 2	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	**91,224**	**68**
Including heating consumption	17,383	
Total On-Site Electric Sources	73,221	
Net Site Energy	**18,003**	**13**
Net Primary Energy[16]	**41,407**	**31**

Table 88: Configuration 3 results

Configuration 3	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	**88,297**	**65**
Including heating consumption	14,455	
Total On-Site Electric Sources	73,221	
Net Site Energy	**15,076**	**11**
Net Primary Energy[17]	**34,675**	**26**

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[15] With a conversion factor of 2,3 for electricity

[4] [17] [6] With a conversion factor of 2,3 for electricity

Table 89: Configuration 4 results

Configuration 4	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	**92,637**	**69**
Including heating consumption	18,795	-
Total On-Site Electric Sources	73,221	-
Net Site Energy	**19,416**	**14**
Net Primary Energy[18]	**44,657**	**33**

In Configuration 1 and 3, the gain of net primary energy due to the triple-glazed instead of the double-glazed is respectively 9,352 kWh and 9,982 kWh.

In Configuration 1 and 2, the gain of net Primary energy due to 5 layers instead of 4 layers for the Panoren is respectively 2,620 kWh and 3,250 kWh.

6.2.4.1.3 COMPARISON OF THE RENOVATION SCENARIO AND THE BASELINE SITUATION

The comparison of the energy consumption between the baseline and the renovation is presented in the Table 90 below. The energy gain is highly significant due to a global renovation scenario with second-life PV module system.

Table 90: Comparison of the baseline situation and the renovation scenario

	Baseline Scenario		Renovation scenario (Configuration 1)	
	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]	Total Energy [kWh]	Energy Per Occupied Building Area [kWh/m²]
Total Site Energy	**248,259**	**184**	**99,262**	**65**
Including heating consumption	170,293	-	25,421	-
Net Primary Energy	**301,018**	**223**	**59,894**	**24**
