H2020-NMBP-ST-IND-2018-2020- GA 958218

PLUG-AND-USE RENOVATION WITH ADAPTABLE LIGHTWEIGHT SYSTEMS

D2.7 Final stage complete design of PnU kits

Version: 1.0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958218

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Terms, definitions and abbreviated terms

GA	Grant agreement
EU	European Union
EC	European Commission
FP7	Seventh Framework Programme
H2020	Horizon 2020 Project
PLURAL	Plug-and-Use Renovation with Adaptable Lightweight systems
CZ	Czech Republic
ES	Espana
GR	Greece
PnU	Plug and Use
MODEST	Multi-objective Decision Support Tool
AMScope	AMS Control Panel
WP	Work Package
D	Deliverable

AMS	Advanced Management Solutions
NTUA	National Technical University of Athens
PA	Pich Architects
VVV	Voula – Vari - Vouliagmeni
CVUT	Ceske Vysoke Uceni Technicke V Praze
SPF	Institute Fur Solartechnik
AHC	Agencia de l'Habitatge
ZRS	ZRS Architekten GvA mb
DEN	Denvelops Textiles S.L.
RDR	RDR Rymarov s.r.o.
ATEX	Appareils destinés à être utilisés en ATmosphères EXplosives. - Devices intended for use in explosive
ATEX 114	Information for safeguarding the safety of devices intended for use in potentially explosive
ATEX 137	Minimum requirements for improving the health and safety protection of workers at risk from an
LVD	Low Voltage Directive
ETAG 029	European Technical Approval Guidelines for metal Injection anchors for use in masonry
IP54	Ingress Protection 54 – protection from ingress of dust, solid objects and water splashing from angle
EN 12165	European Standard specifies the composition, property requirements and dimensional tolerances for
ASTM	American Society for Testing and Materials
ASTM G21	Standard Practice for Resistance of Synthetic Polymeric Materials to Fungi
ASTM E2180	Test for Hydrophobic Antimicrobial Surfaces
EU 13501	Fire Classification of construction products and building elements
NOK 2012	New Greek Building Regulation 2012
TOTEE 20701-	Greek Technical Chamber Guidance toward energy efficiency of buildings and issue of Energy
ELOT	Hellenic Standardization Organization
ELOT HD843	Polyvinyl chloride insulated and sheathed power cables for rated voltage 600/1000 V
EGSA 85	Hellenic Geodetic Reference System 1985
EGSA 87	Hellenic Geodetic Reference System 1987
GOG 80/A/7-5-	Government Gazette 80 A '/ 7-5-2018 - Clarifications for the application of the Building Fire Protection
GOG	Government Gazette 1932 / B` 14.12.2010 - Replacement of the current Regulation of Internal Electrical
GOG 1222/B/5-	Government Gazette 1222 / B` 5.9.2006 - Security Issues of Internal Electrical Installations (UN).
NEAK 2003	Government Gazette 1154 / EAK 2003 - Amendment of provisions of the "Hellenic Seismic Regulation
GOK55 (ΓΟΚ55)	Government Gazette A '266: General Building Regulations of the State 1955
GOK73 (ΓΟΚ73)	Government Gazette 124A_1973: General Building Regulations of the State 1973
Law 4122/2013	LAW NO. 4122 Energy Efficiency of Buildings - Harmonization with Directive 2010/31 / EU of the

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EIDAP	Athenian's Water and Drainage Supply Company
KENAK	Greek Energy Efficiency Regulation of buildings
NDP	Nationally Determined Parameters
HVAC	Heating, Ventilation and Air Conditioning
DHW	Domestic Hot Water
RES	Renewable Energy Sources
CHP	Combined Heat and Power
ETICS	External Thermal Insulation Composite Systems
PV	Photovoltaic
PCM	Phase-Change Material
PVC	Polyvinyl Chloride
VIP	Vacuum Insulation Panel
CO	Carbon Oxide
CO_2	Carbon Dioxide
UV	Ultra Violet
IR	Infrared
NZEB	Near Zero Energy Building
SB	Semi-Basement
GF	Ground Floor
AC	Alternative Current
DC	Direct Current
E/M	Electro Magnetism
3D	Three-Dimension
PER or PE-X	cross-linked polyethylene
PROFIS	Engineering software for designing connections by HILTI
C-FIX	Design Software for steel and bonded anchor in concrete by FISCHER
T_r	Oscillation Periods (s)
T_c	Corner Periods (s)
β_p	Ground time response coefficient
A	Amplification factor
z	Height of the non-structural element (from building foundation level) (m)
H	Height of the building (from the building foundation level) (m)
T	Fundamental vibration period of the non-structural elements (s)
T_1	Fundamental vibration period of the building (in the direction concerned) (s)
Ψ	Coefficient of reduction of seismic effects
f_{ck}	Compressive strength
f_{ctm}	Tensile strength

f_{ct}	Bending Tensile strength
E	Elastic/Young Modules (MPa or GPa)
Kv	Quantity of water that flows through the fitting creating a drop in pressure of 1 bar
ΔP	Pressure Loss (bar or atm)
Q	Debit
Zeta	Hydraulic resistance of a fitting according to its shape
λ	Thermal Conductivity (W/mK)
U	Thermal Transmittance (W/m^2K)
ε	Emissivity (W/m^2)
m	Meters
cm	Centimetres
mm	Millimetres
μ	Micrometers
cm^2	Square centimetres
m^2	Square meters
m^3	Cubic meters
m^2a	Square meters per annum
kg	Kilograms
g	grammars
mg	milligrams
Pa	Pascal
MPa	Mega Pascal
GPa	Giga Pascal
sec	Seconds
W	Watt
kW	Kilo Watt
kWh	Kilo Watt Hours
V	Volt
N	Newton
kN	Kilo Newton
^oC	Celsius

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1. Executive summary

The deliverable *D2.7 Final stage complete design of PnU kits*, due in month 24 (end September 2022), presents the results of the task T2.6.2 PnU kit Final Design stage. This deliverable is public.

After the completion of the testing and optimisation of the PnU kit prototypes in WP4, the design and the industrial partners proceed to the final design of the PnU kits for the three real demonstration buildings by incorporating the suggestions, recommendations and optimisation results of WP4. Drawings, calculations and performance simulations validate the final design for each demo building.

The main objective of the related task *T2.6.2 PnU kit Final Design stage* is to finalize the actual design of the PnU kits, and the integration of all the technologies and partial developments within the PLURAL project. The technical details, production and installation strategies, usability and maintenance issues need to be already resolved at this point, given that they are all related and affect the details and the material selection. These issues are briefly discussed in this document.

2. Introduction

2.1 Introduction

The deliverable *D2.7 Final stage complete design of PnU kits*, due in month 24, presents the results of the task T2.6.2 PnU kit Final Design stage. This task was supposed to start in M22 and finish in M24, however, it was a natural continuation of the D2.6.1 that finished in M16, and the design development did not pause.

After the completion of the testing and optimisation of the PnU kit prototypes in WP4, the design and industrial partners proceed to the final design of the PnU kits for the real demos by incorporating the suggestions, recommendations and optimisation results of WP4. Drawings, calculations (PA, AMS) and performance simulations (SPF, NTUA, IREC) validate the final design for each demo building.

The task is led by PA. The following partners are involved: ZRS, SPF, CVUT, RECUAIR, NTUA, AMS, BGTC, DEN, RDR, ITeC and IREC.

This deliverable is public. It includes annexes with the detailed drawings of each solution.

The final design for the virtual demos will not be included in this deliverable, considering that the focus has been placed on the real demos and the virtual demos need to be developed further. These designs will be presented within the deliverable *D7.5 PLURAL systems installation at the virtual demo buildings.*

2.2Relation with other WPs

Inputs: This deliverable is based on deliverable *D2.6 First stage design of PnU kits (M16),* and the results of tasks mainly from WP2 that advanced since the mentioned deliverable D2.6:*, Task 2.2 Façade panel technologies selection (M9-M15), Task 2.3 Ventilation system selection (M10-M22), Task 2.4 Heating and cooling technology selection (M10-M22) and Task 2.5 Energy systems integration (harvesting & storage) – PLURAL toolbox (M10-M22)* that define the materials and technologies to be integrated in the PnU kits. Also there are inputs from the WP3: *Task 3.4. Adaptation of the Smart Energy Management (SEM) analytics (M13-M24)*, that defines the smart system to be implemented together with the PnU kits.

Outputs: The outcome of this deliverable is an important input for: a) WP3 for the development of the Smart Energy Management (SEM) system, b) WP5 for the development of MODEST-LYSIS tool, c) WP6 for the manufacturing – assembly of PnU kits and d) WP7 for the installation and monitoring of PnU kits in demo buildings.

Finally, the design and considerations resumed in this deliverable will affect the implementation within the WP7: *Task 7.2: Installation of PLURAL system in KASAVA (Czech Republic) real demo case (M30-M34), Task 7.3: Installation of PLURAL system in Terrassa-Barcelona (Spain) real demo case (M30-M34) and Task 7.4: Installation of PLURAL system in Voula-Athens (Greece) real demo case (M30-M34).*

In the *Task 1.7 PLURAL kits Standardization for different EU building typologies (M24 – M36)* the partners will identify, map, and analyze the types of the EU's building stock that PLURAL kits could be installed in, and will also use the outputs of the task T2.6.

This deliverable is related to the milestone MS4, due to month M24, *Documented full design of PnUs*, which is related to the completion of selection and validation of suitability of the energy production and storage systems (D2.4) and of the toolbox (D2.5).

2.3 Objectives

The main objective of the task *T2.6.2 PnU kit Final Design stage* is to finalize the actual design of the PnU kits, and the integration of all the technologies and partial developments within the PLURAL project. The technical details, production and installation strategies, usability and maintenance issues need to be already resolved at this point, given that they are all related and affect the details and the material selection. These issues are presented in this document.

Considering that each of the PnU kits is closely related to its demo site, and the demo conditions and characteristics were taken into account during the design process, the final PnU kits to be implemented on the respective pilot sites will be also presented here. The outputs of this deliverable in the practical sense will be also used for:

- Documents for the building licence
- Documents for tender processes
- Preparation of manufacturing documentation

2.4 Document structure

The first chapter of this document defines the main administrative characteristics of this deliverable, establishes the actual implementation time plan and proposed 3 budget scenarios to follow, considering the current uncertainty in the material costs and availability.

Following the introductory chapter, D2.7 is dived into 3 main parts, each dedicated to one of the PnU kits developed within the PLURAL project.

These cases and their architectural and structural design are detailed in the following chapters:

- Chapter 4: Czech demo: KASAVA
- Chapter 5: Spanish demo: TERRASSA
- Chapter 6: Greek demo: VOULA

Each of these chapters is then further sub-divided into 3 main sections. The first section (X.1) is dedicated in the description of the final architectural and structural design of the respective PnU kit.

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The second section (X.2) is dedicated to the HVAC and energy systems and refers to the corresponding deliverables T2.3, 2.4, & 2.5, as well as the smart control system as defined by T3.4.

The third section (X.3) is focused on the post-design life-cycle phases of the PnU kit implementation, such as manufacturing, transportation, installation, use phase and maintenance.

The architectural and structural designs are attached in the Annexes of this document. The annexes also include the 3D scanning and structural survey of the Kasava demo building, that were pending from the deliverable D7.1.

2.5Real demo cases

The three real demo buildings in this project are a) a double residential house located in a natural environment in Kasava, Czech Republic, b) a multifamily residential block forming part of a dense urban structure in Terrassa-Barcelona, Spain and c) a shelter for homeless or low waged families, self-standing and located in Voula municipality, Athens, Greece. The real demo building basic characteristics and the approach for implementation are summarized in the table below (Table 1).

TABLE 1: SUMMARY OF CHARACTERISTICS OF THE PLURAL THREE REAL DEMO CASES

Real demo cases	Czech demo (CZ)	Spanish demo (ES)	Greek demo (GR)
Location	Kašava, Prague	Terrassa, Barcelona	Voula, Athens
Year of construction	1962	2008	1971
Climate	Continental Warm-humid	Mediterranean–mild summer	Mediterranean–hot summer
Typology	Multiple- double dwelling house	Block of residential dwellings	Block of residential dwellings
Urban setting	Self-standing in natural environment	Within an urban block	Self-standing in urban environment
PLURAL solutions	eWHC concept. • Gas boiler heat source replaced by Heat Pump • Facade panels with air handling and heating/cooling system/installation • Windows • New control system, monitoring • Integration of BIPV system and/or solar thermal for DHW	The Al frame eAHC kit will integrate: • Insulation • PV panels • Ventilation units • Innovative windows • Folding blinds	"Smart Walls" including: • Innovative windows, • Fan coil, • PV panels, • Solar panels, • Heat pumps, • Control Toolbox, • Multifunctional coatings.
Other renovation	No (other building only,	Yes, renovation previous	Yes, renovation previous

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	could be used for comparison)	to the PLURAL renovation in 2021, to the 2006 standard	to the PLURAL renovation, started in 2020
Approach	Renovate and update to the contemporary needs, adapt volume given the unfavourable conditions of the current structure and the potential of the system. Renovate ground floor and first floor and their complete thermal envelope.	Follow up on the previous innovation. Improve the building by intervening partially, with the aim to affect positively the whole building. Reach nZEB standard in the apartments which are affected by the PLURAL renovation only.	Refurbish and upgrade each apartment with recyclable and eco-friendly materials. Upgrade all energy systems in order to reduce energy consumption.

3. Implementation time plan & budget scenarios

3.1 Implementation time plan

The implementation of the PnU kits in the three real demos is affected mainly by the following aspects:

- Readiness of the design
- Building permit
- Successful tender process
- Availability of material (both timewise and economically)

All these requirements have to be fulfilled before the PnU can be produced and installed.

Readiness of the design. Given that innovative solutions are being designed for all of the PnU kit types, significant amount of time is needed to develop, test, evaluate, redesign and further detail the solutions. Multiple components from different providers are to be assembled and optimized together. In case of the ConExWall and HybridWall, the teams are scattered in several countries and locations, which causes further complexity in the communication between the team. Therefore, the design in these two solutions only reached sufficient definition in Month 25 (October 2022). Originally it was considered to launch the tender and building processes earlier; however this was not feasible before the completion of the design.

Building permit. In all the demo cases, there has been collaboration with the local municipalities responsible for issuing the building permit to the projects, in order to assure that the PnU kit designs will comply with the urban planning requirements. Actually, these meetings resulted in several changes in the design, such as roof shape change in the Czech demo, or change of installation procedure in the Spanish demo. Therefore, the duration of the building permit process should not be prolonged compared to the expected 3 months.

Successful tender process. The material part of the PnU kits is assured by the project partners, which is a significant advantage. However, the installation of the kits has to be subcontracted by the pilot owners to third parties, which cannot be identified previously, as the pilot projects are owned by local administration partners who have to arrange a tender process. This process can last up to 6 months (e.g. in the Spanish case), and it also includes the risk that there won´t be any interested or suitable candidate. Therefore, efforts are being made to find potential installers to invite to the tender process and also to acquire needed feedback for the design of the PnU kits.

Availability of material. Finally, given the current conditions, another issue that can affect the implementation time of the PnU kits is the availability of some crucial materials. Materials such as glass or photovoltaic panels have long delivery times. The consortium takes measures to make these components available for when the production of the PnUs is expected. One of the measures is using the 3D scans of the buildings to determine the final dimensions of the openings, and allow the preparation for production of the windows, that will later be integrated in the prefabricated panels.

Considering all the above mentioned risks and limitations, the preview for the implementation of the PnU kits is as follows.

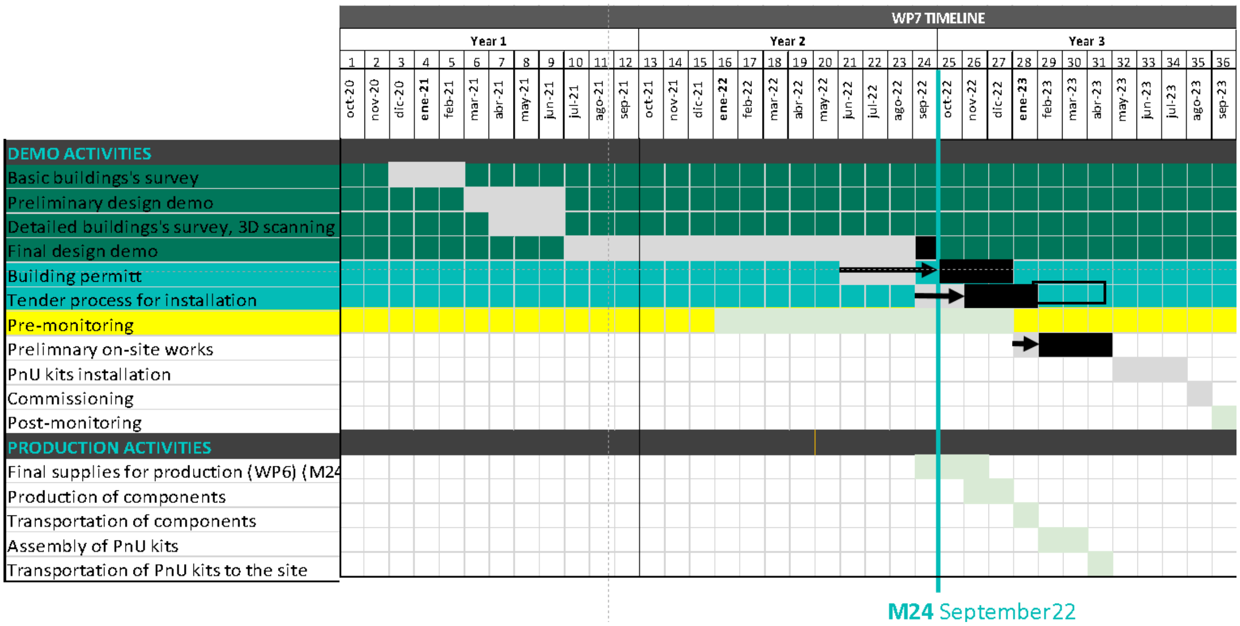

FIGURE 1 IMPLEMENTATION TIMELINE FOR THE PNU KITS

Compared to the original plan, the main changes introduced are that the building permit and the tender process were not initiated before the completion of the final PnU kits design, which was also postponed till October 2022. The estimate of the tender process was 3 months. However, in the Spanish demo it can last up to 6 months, which can also be seen on the figure above.

Given that there were certain buffer periods, and some of the processes can run in parallel, possibly the installation of the PnU kits will be executed as planned. However, there is no more buffer period for the initiation of the installation process. Therefore, if any complications arise with the tender process or building licence process, the implementation can be delayed.

3.2 Budget scenarios

Since the submission of the PLURAL project, when the project budget was set, significant historical events affected the construction products market. Starting with the Covid19 in 2019 and followed by the war in Ukraine in February 2022, we are currently facing rises of price of energy, lack of availability of materials and increases in their costs. Summarizing, the prices and delivery times of construction materials have risen in an unprecedented manner significantly affecting the planned budget of PLURAL for the demonstration activities.

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Considering these facts, the implementation of the PnU kits to the real demos might be put at risk. The envisaged budget might not be sufficient, especially considering material costs. The energy cost increase is not considered independently given that the assembly process of the PnU kits in not energy demanding.

Therefore, 3 scenarios will be created in order to see whether any changes have to be made to the design or to the size/extent of the demonstration projects. Also, these scenarios will serve to demonstrate to the European Commission how the demonstration budget is related to the reality now and at the beginning of the project and to justify the costs of the demonstrations. The 3 scenarios to be analyzed for each of the three demo sites of the PLURAL project are:

a) The original budget, based on the **original** renovation area, with the **material costs of 2020**
b) The actual budget, based on the **original** renovation area, with the **material costs of 2022**
c) The final budget estimate, with adjustment of the renovation area or design, with the **material costs of 2022**

The scenario c) will be only created in case that the scenario b) is not feasible.

In the case of the Greek and Spanish demos, AMS and Develops developed a budget based on scenario b) in September 2022. It has been confirmed that the original budget is sufficient to produce the PnU kits according to the original plan of the project for the demo sites in Voula and Terrassa respectively.

For the Czech demo, the forecast is that the project budget might also be sufficient, but the detailed budget still needs to be calculated by RDR.

However, in the next months, the energy, raw materials and transportation costs can increase, which can of course affect the project. Therefore it is important to remember that Task 6.2 is already going on and latest by next January or February 2023, all the raw materials should be ordered and bought if no other project delays had been produced.

The budget scenarios will be presented and submitted as part of the deliverables of WP6.

4. Czech demo: KASAVA

4.1Architectural and structural design

4.1.1 Resume of the renovation objectives and changes

Considering the implementation of the ConExWall in the Kasava demo case, there have been certain changes from the design presented in D2.1, where the whole implementation design can be found.

The changes, related to the demonstrations project as such, have been made based on continuous discussions within the team, and also based on further analysis and simulations.

Façade modulation. As described later in more detail, the modulation of the façade changed, based on the decision to produce a transport panels with larger height than the standard one, allowing the panels to reach height up to 3,5 m, which reduces the quantity of panels and therefore of anchors as well. The benefits include thermal performance.

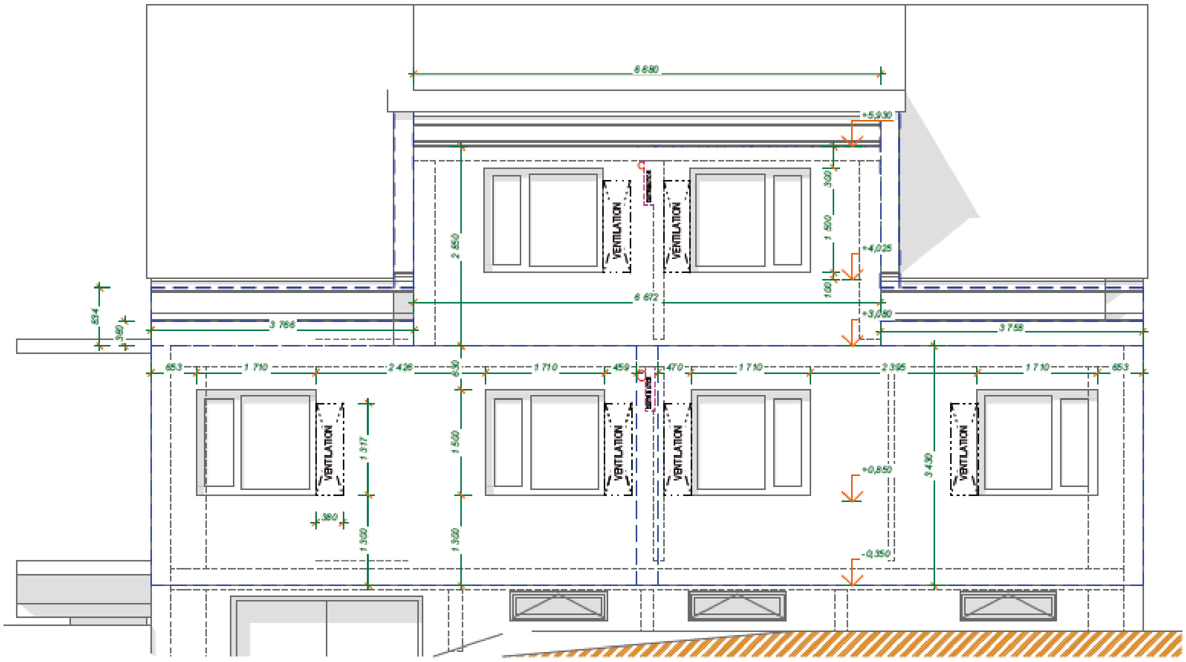

FIGURE 2 THE ACTUAL MODULATION OF THE FAÇADE, SOUTH ELEVATION

Decreased window surface. The simulations showed that with the original design, it was not possible to reach comfort in the rooms with the largest windows, although these were oriented to the South. Therefore, the size of the openings was decreased and the thermal comfort reached.

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External appearance. The wooden cladding was originally intended to be vertical, due to the structure of the panel. Finally, it was decided that the cladding will be horizontal for aesthetics reasons.

Roof shape and existing ceiling. The shape of the roof was adapted to the fact that the existing concrete ceiling above the first floor will be kept and eventually used for further heating, in a similar way as in the façade panels.

In the following table, updated information in regard to the extension of the renovation can be found.

Topic	Unit	Area	% of the total
Renovated façade	sqm	164,72	39
Renovated roof	sqm	0	0
New facade	sqm	54,3	13
New roof	sqm	163,6	38
Total area of new windows	sqm	43,1	10
TOTAL renovated/ new envelope	**sqm**	**425,8**	**100**
Terrace balcony - new wall	sqm	60,4	N/A

TABLE 1 : FINAL DEFINITION OF THE IMPLEMENTATION SCOPE

The final drawings can be found in the corresponding Annex.

4.1.2 Aesthetics and functional design criteria

In the overall design of the PnU kit, there are also several aspects that affected the final design of the PnU kit.

Integration of the ventilation unit. There are multiple ventilation units with heat recovery on the market. Many of them, including the ones selected for the ConExWall- Helty 40 and Helty 70, have significant depth, and therefore the façade needs to have at least the same depth. In the case of ConExWall, it was originally planned to include the ventilation unit in the prefabricated panel. However, given that its depth was decreased, and considering that the original wall is deep almost 500 mm, it was decided that the ventilation unit will be integrated in the original wall, using partially the original width of the window. This way, no significant demolition work is needed. In this design, only the channels of the ventilation unit need to reach the exterior, and therefore are integrated in the prefabricated panel. In case of the non-standard panel, when there is no existing wall behind, the ventilation unit is naturally integrated in the panel.

Vapor barrier and condensation. The location of the vapor barrier has been originally determined behind the layers of the heating system (between the flexible insulation and the gypsum board). This placement was ideal from the practical point of view, however it was causing a need to balance the thermal resistance at the interior side of the barrier by excessive amount of thermal insulation at the exterior side. The location of the vapor barrier has been changed to be at the connection between the existing wall and the prefabricated wall, which allowed to decrease the thickness of the thermal insulation at the exterior side by 60 mm. More details are described in the next chapter.

Installation channels. The original design was proposing to guide the vertical connection pipes within the prefabricated panels. In the final design, there will be two connection strategies. On the north and south façade, there is a vertical channel between the panels over the entire height of the ground floor (See **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**). On the first floor, however, as well as on the upper floor of the north and south façade, there is no channel, as here the modules can be delivered as a single unit. An installation opening is provided in the façade elements at the level of the wall duct (See Annex 9.2). The pipes end of the panels have to be long enough that they can be pulled through the wall opening and first connected to the pipes from the house via fittings on the inside. The opening and channels give space to bend the pipes and push them through the wall opening. The channels and openings will be filled by thermal insulation, similarly to the horizontal gaps between the prefabricated panels, where the anchors are located, and protected by the weathering membrane. (*see in 5.1.3 Final architectural design of the PnU kits*)

Level of industrialization. The objective of the PnU development is a full industrialization of the renovation kits. However, in the case of ConExWall, the installation process is more difficult as the panel has to be tightened to the existing façade, with special anchors that are due to the potentially difficult base to be placed roughly every 50 cm. These two facts cause that is not feasible to focus on a typical offsite joint between the panels. In any case, there are activities to be performed on site, and only then the joint can be finalized. Therefore, the horizontal joints where the anchors are to be tightened, will be completed on site. In order to improve the final aesthetic appearance, the final cladding with its substructure will be prefabricated separately, and added after the completion of the joints. The joints of the interior side of the panels will assure the water-tightness. Therefore, the final cladding is only a rainscreen and aesthetic layer.

The phases of installation will be a) installing the anchors, b) installing the interior part of the panels up to the exterior insulation and weathering membrane, by tightening them to the existing wall, c) filling the gap in the joints by thermal insulation and closing the weathering membrane, and finally d) adding the prefabricated cladding panel.

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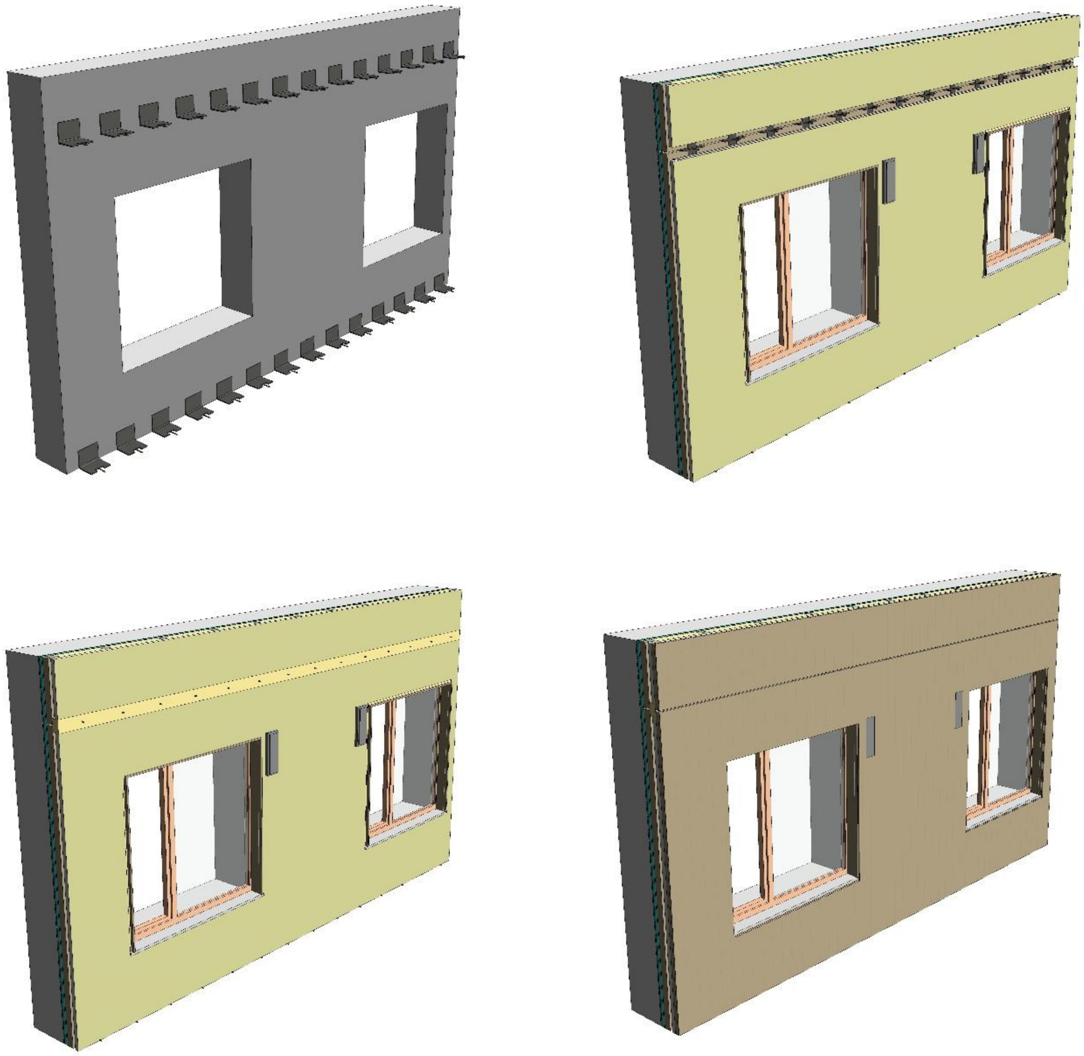

FIGURE 3 LEVELS OF INDUSTRIALIZATION

4.1.3 Final architectural design of the PnU kits

Compared to deliverable D2.6, some important changes in the PnU kit design were made. The new maximum height of the façade panels was found to be 3.5 m as for the transport, low loading lorries can be used. Due to this change, each large façade module can reach over one full floor of the building. This reduces the number of façade panels notably, which is beneficial with respect to the effort to produce and install the panels. The new division of the façade modules can be seen in the following figure, where the blue lines show the outlines of each façade panel.

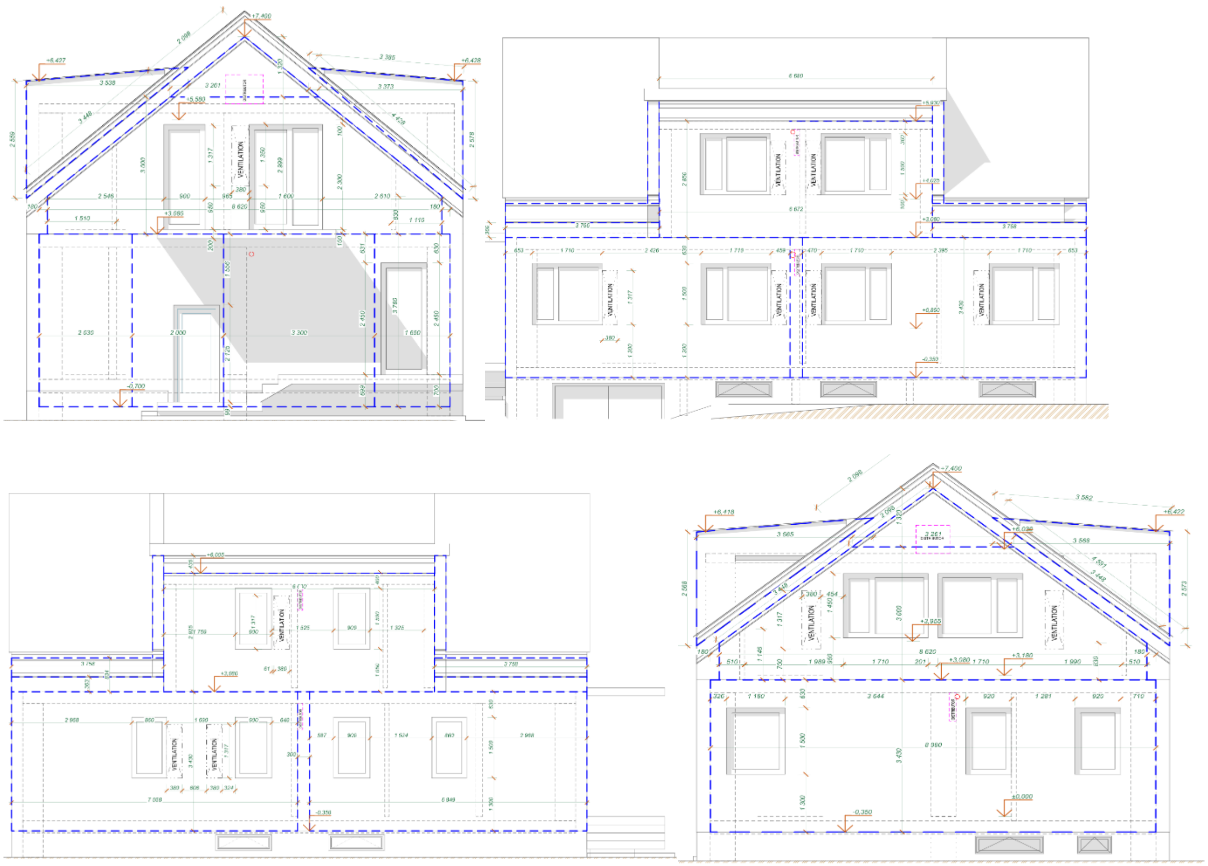

FIGURE 4 NEW DIVISION OF THE WALL PANELS OF THE KASAVA DEMO (BLUE OUTLINES) FOR THE FOUR FACADES INCLUDING NEW WINDOWS AND VENTILATION UNITS.

A second important change was the reduction of the thickness of the wooden frame which is the load-bearing structure of the PnU kit. The thickness was reduced from 180 mm to 120 mm, as with the reduced thickness the required thermal resistivity of the façade is still reached. The new calculated U-value of the renovated wall including the ConExWall is 0.18 W/m^2K.

Topic	Unit	Original building	Renovated building
Thermal properties			
U-value wall (incl. ConExWall)	W/m^2K	1.35	0.18
U-value window	W/m^2K	approx. 1.3	0.60
U-value roof	W/m^2K	0.99	0.10

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Solar shading type	-	Internal blinds	Windows-internal blinds
Shading factor			
Interior air quality			
Air-handling units with heat recovery		none	Decentral units in occupied rooms

Figure 5 Main characteristics of the renovation solution

The heat emission for space heating will be done via a heating pipe system commonly used in underfloor heating systems (drywall type). The pipes will be pre-mounted on the façade modules and will heat the building through the brick-wall (i.e., the old façade). An example of the distribution of the pipes for the south façade of the building is given in the following figure (heating meanders in colours). The rest can be found in the Annex.

As the height of the modules is no longer limited to 2.7 m, there are now some changes in the design in favour of easier and faster installation. In addition, the reduction of elements is to better tailor the meander to the individual rooms.

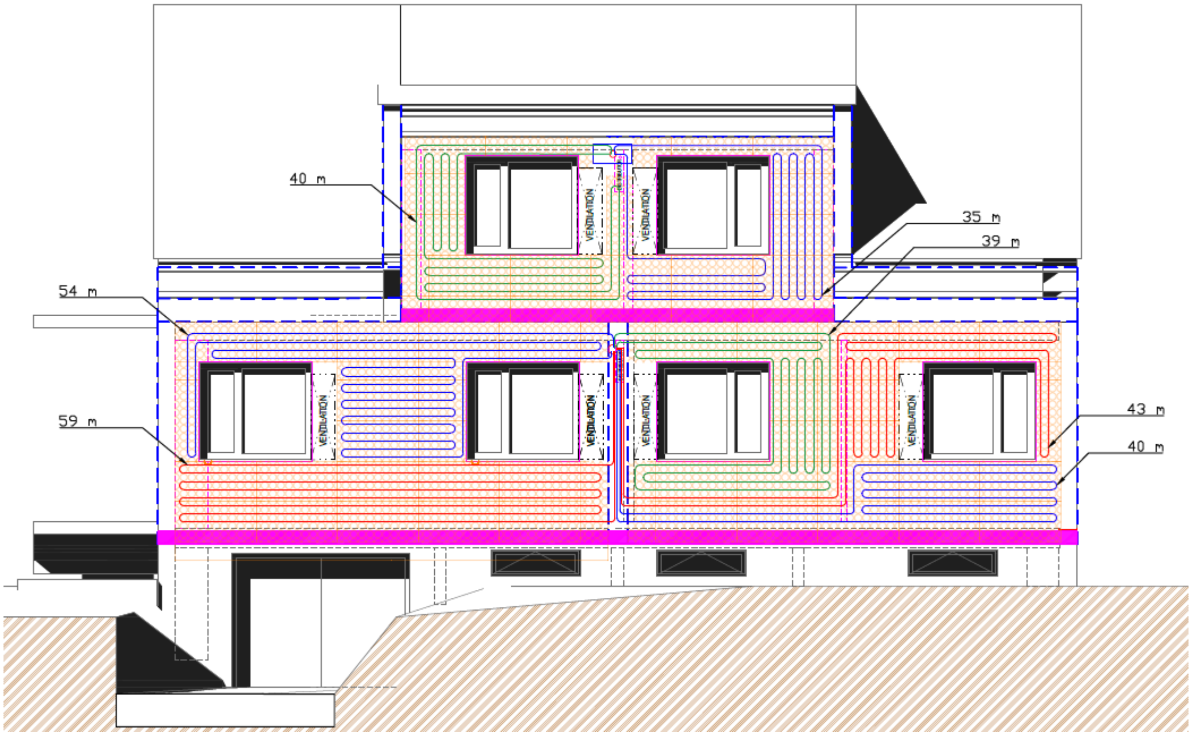

Figure 6 South façade of the Kasava demo as example with heating loop meanders that are located between old façade and new insulation. To better distinguish the loops, they have various colors. The pink bars indicate the space which is required for the L-profiles. The numbers show the length of each loop.

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On the ground floor, there is still a channel between the left and the right panel with a duct in the upper area. The panels on the top floor have now a duct in the middle below the ceiling. In the outdated version this duct was at the side of the dormer. Another difference is that the number of loops could be reduced so that the ducts in the wall have a smaller diameter and the circuit manifolds need less connections. As it can be seen in the Annex, the west side of the house now also has an own duct and will not be supplied anymore via the south side. This allows for better sealing of the house at its edges.

Details of the integration of the heating layer onto the wooden-frame façade module are shown in the following figure (update of D2.2). The heating layer of a module covers as much surface area of the module as possible. Areas that are left out are openings like for windows and air channels for ventilation, and the location where the L-profiles will touch the façade module after installation at the building (prevention of damaging the pipes by the L-profiles).

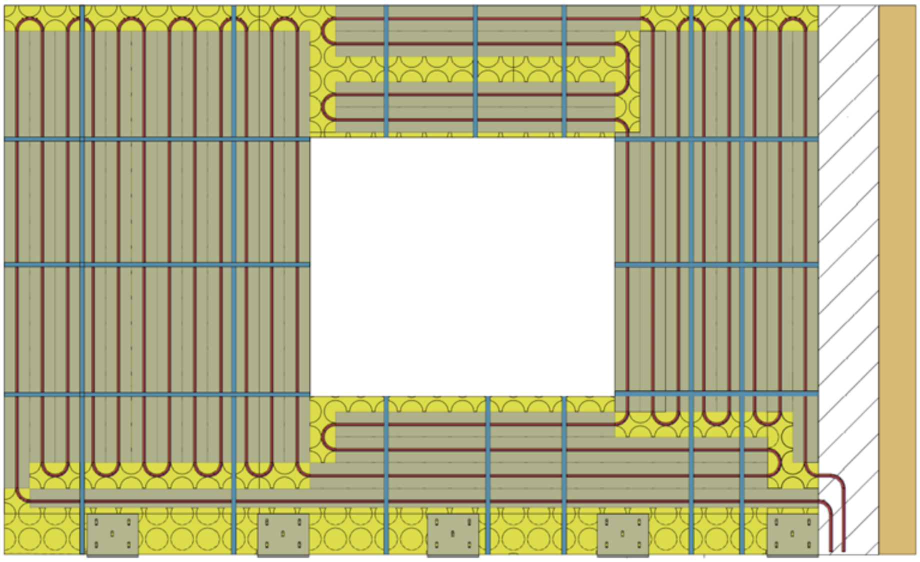

FIGURE 7 PREFABRICATED FAÇADE MODULE WITH HEATING LAYER ON TOP OF THE STANDARD STRUCTURE, AND WALL- MOUNTED ANCHORS AT THE BOTTOM (VIEW FROM THE BUILDING). VIA THE CHANNEL ON THE RIGHT SIDE, THE PIPES OF THE MODULE CAN BE CONNECTED TO THE HEATING SYSTEM. AFTER INSTALLING THE PIPES, THE CHANNEL IS INSULATED AND CLOSED. THE BROWN BAR ON THE RIGHT INDICATES THE FRAME OF A NEIGHBORING MODULE.

On the basis of the 3D scanning and final design of the façade panels, updated dimensions of the windows can be defined. Slight modifications does not affect final typology of the windows which complies with aesthetic, thermal and optic requirements described in deliverables 2.2 and 2.6.

The wooden construction of the window profiles with thickness of the frame 92mm, triple glazing and Venetian shading system integrated between the glass panes was selected.

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- Frame material: wood (finger joint)
- Frame thickness: 92mm

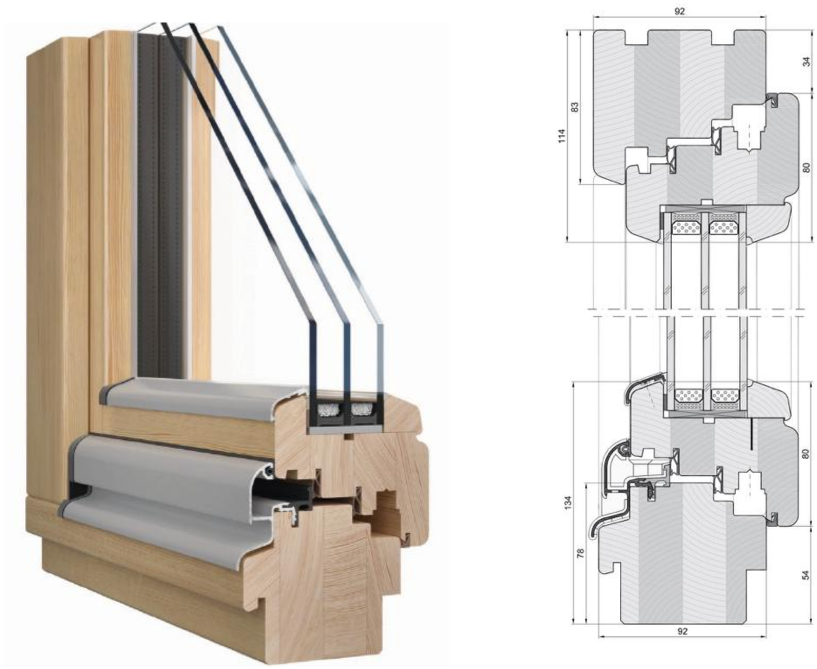

FIGURE 8 WOODEN WINDOW SECTIONS.

Triple glazing improving thermal performance of the unit and providing possibility of integration the shading system without affecting visual aesthetic of the building will be applied.

- Glazing type: triple glazing
- Thickness: 52,8mm
- Weight: 42 kg/m2
- Acoustic Rw=39dB

Integrated sun shading system is a prefabricated solution therefore time of installation and disturbance for the occupants are reduced. There is also no need of cleaning or further maintenance.

- Blinds: internal Venetian blinds
- system ScreenLine®, type SL20

This solution requires widening of the chamber between the glass panes which is enabled with enlarged sash profiles. Special glazing configuration is presented below. Venetian blinds will be installed in all windows except the small tilt ones on the ground floor with glass 4TP/18Ar TGI/4/18Ar TGI7035/4TP.

The proposed windows are in accordance with the requirements and classification.

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- Water tightness: 9A class
- Air permeability: 4 class

However while integrating the window into the timber structure it should be taken into consideration its weight due to the increased thickness of the profile and triple glazing with integrated blinds which is around 300kg of total weight for the biggest module.

FIGURE 9 GLAZING CONFIGURATION AND A SAMPLE OF THE GLASS WITH INTEGRATED SHADING SYSTEM.

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① Stratobel 33.1 (3 mm Planibel Clearlite + 0.38 mm PVB Clear + 3 mm iplus 1.1 pos.2) Ricotto ② 20 mm Argon 90% ③ 4 mm Planibel Clearvision Ricotto ④ 16 mm Argon 90% ⑤ Stratobel 33.1 (3 mm iplus 1.1 pos.5 + 0.38 mm PVB Clear + 3 mm Planibel Clearlite) Ricotto

Simulazione di dati sulle prestazioni in opera del vetro

Caratteristiche luminose - EN 410

Trasmissione luminosa : τv [%]	74
Riflessione luminosa : ρv [%]	16
Riflessione luminosa interna : ρvi [%]	16
Indice di resa dei colori : Ra [%]	97

Caratteristiche energetiche - EN 410

Fattore solare : g [%]	49
Riflessione energetica esterna : ρe [%]	28
Riflessione energetica interna : ρei [%]	28
Trasmissione diretta dell'energia : τe [%]	43
Assorbimento energetico vetro 1 : αe1 [%]	22
Assorbimento energetico vetro 2 : αe2 [%]	1
Assorbimento energetico vetro 3 : αe3 [%]	6
Assorbimento energetico totale : αe [%]	29
Coefficiente di shading : SC	0.56
Trasmissione dei raggi ultravioletti : τuv [%]	0
Selettività	1.51

Proprietà termiche - EN 673

Trasmittanza termica (vetri verticali) : U value [W/(m².K)]	0.5

Riduzione acustica

Direct airborne sound reduction - Interpolated : Rw (C;Ctr) [dB] 1	39 (-2;-7)

Caratteristiche di sicurezza

Resistenza al fuoco - EN 13501-2	NPD
Reazione al fuoco - EN 13501-1	NPD
Resistenza ai proiettili - EN 1063	NPD
Resistenza alle effrazioni - EN 356	NPD
Resistenza agli urti (Prova del pendolo) - EN 12600	2B2 / NPD / 2B2
Resistenza all'esplosione - EN 13541	NPD

Spessore e peso

Spessore nominale : [mm]	52.8
Peso : [kg/m²]	41

FIGURE 10 TRIPLE GLAZING SPECIFICATION WITH VENETIAN BLINDS

4.1.4 Final structural design of the PnU kits

Wall panel composition. As mentioned in chapter 5.1.3, the thickness of the wooden frame was changed from 180 mm to 120 mm. The following figure shows the new measures of the wall panel composition. The thickness of the flexible sub-layer of the external wall heating is 60 mm after manufacturing. After installing the panel at the building the thickness will be approx. 30 mm.

Statics and construction of the panel. The PLURAL project deals with the insulation and heating of older buildings that no longer meet the energy criteria of today. New insulation and heating is carried out without having to leave the house. The maximum amount of work takes place from the outside.
The brick building will be insulated using prefabricated wood-based panels from ecological materials. All materials used do not have a negative impact on the environment.
In our case, it is a perimeter wall in two versions - wall 1 (presses against the existing brick structure), wall 2 (forming a new wall - gable or over-slab) and a roof panel (forming a built-up panel of the new roof).
The dimensions of the elements are based on the basic module of 600 mm. The construction system of the panels is based on light prefabrication. The surface weight of the panels does not exceed 100 kg/m2. When designing dimensions, modular coordination and unification of building parts are used. The plan and height

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proportions of the panels subsequently follow from these rules. The connection is made with screw, clip or nail connections. Sealing materials create glued joints.
Attaching the panels to the existing structure will be done using steel anchors from rolled L-shaped profiles.

The building after modification will meet all applicable standards for building physics, acoustics, lighting, and sunlight. Survey work was carried out on the selected object in the form of measuring the geometry of the existing masonry structure from the outside (3D-scan) and strength survey work for the purpose of the necessary anchoring of the panels.
List of used documents, ČSN, technical regulations, professional literature:

- ČSN EN 1991
- ČSN EN 1995
- ČSN 73 4301
- ČSN 73 0802
- ČSN 73 0833
- ČSN 73 0532
- ČSN 73 0540
- IDA Nexis32, CADWORK, AUTOCAD

Wall panel 1. The designed perimeter wall panel 1 for insulation is designed as a structural element that must meet its own stiffness and cohesion. The statics of the building is made up of a brick structure. The insulation panel does not take over the static (vertical or horizontal) load from the masonry structure. Only its own weight and wind load act on the insulation panel and its anchoring to the wall, which is immediately transferred to the masonry structure. The proposed anchoring of the panel to the masonry structure must also meet the resistance to wind suction on the far side of the building.

The inherent rigidity of the panel is ensured by a closed frame tl. 120mm, which consists of uprights 60x120mm or 120x120mm (modularly spaced at a distance of 600mm), upper and lower waist. Stiffness is further created by the structural internal one-sided cladding with gypsum fiber boards of thickness 15 mm. 155/50 staples are used to connect the gypsum board and the frame (around the perimeter of the format at a spacing of 50 mm and inside the format at a spacing of 120 mm). The outer side of the wooden frame is reinforced with fiberboard/insulation tl. 50mm. Staples 155/100 or screws V6x80 or V6x100 directly into the wooden frame are also used for this. The ventilated gap is formed by a wooden batten thickness 40mm. The exterior facade is made of larch wood paneling.

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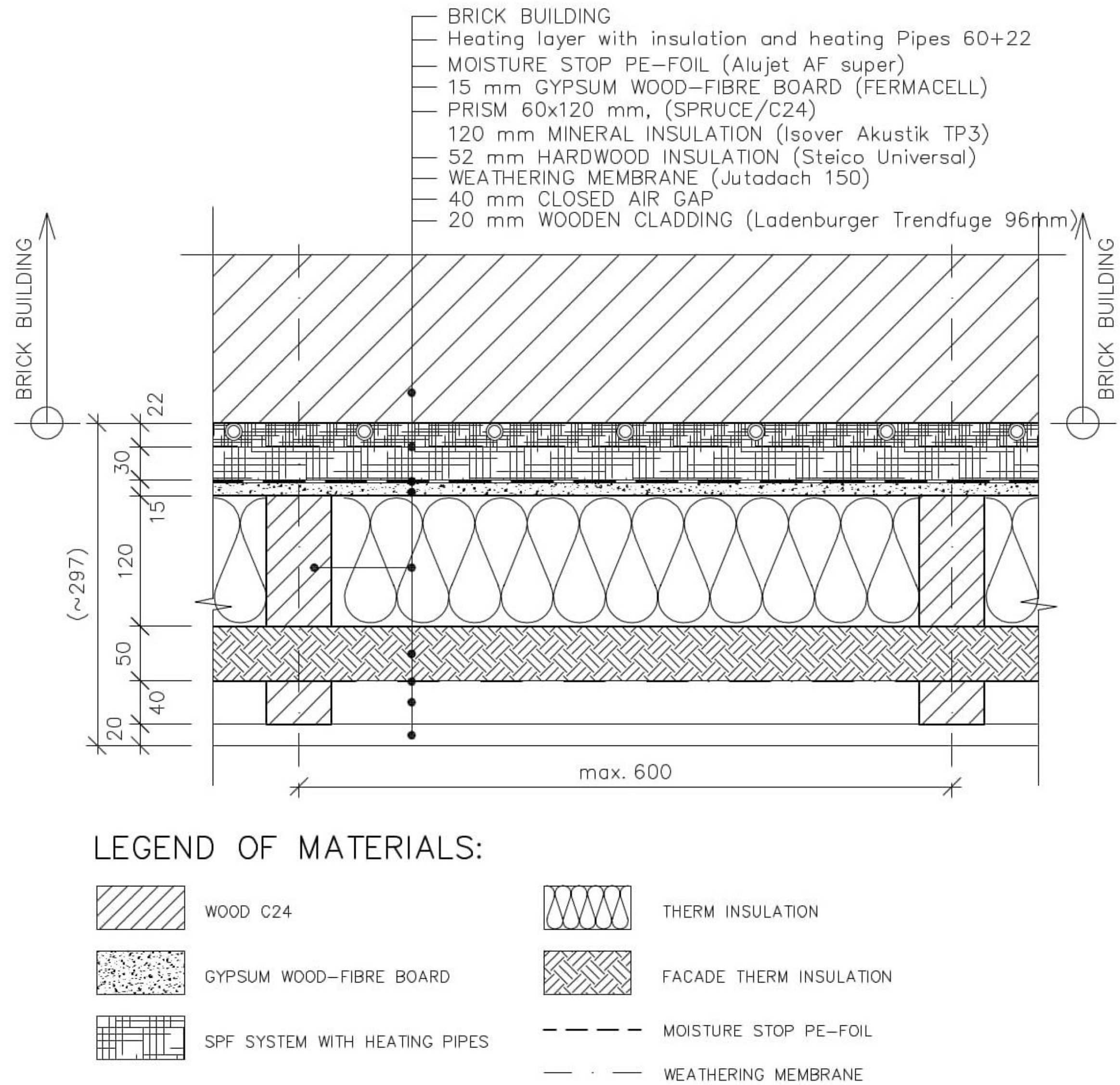

Figure 11 Wall panel 1: layers

Wall panel 2. The designed perimeter wall panel 2 for the attic floor is designed as a static and structural element. In addition to its own stiffness and cohesion, it must also meet static stress. It is necessary to place a column in the gable wall to support the top purlin. Shield and surfacing walls must also fulfill a stabilizing function. Overlaying gutter walls have posts for vertical support of the roof panels, which are saddled to the wall and top purlin. The walls are screwed together in the corners using Dual Drive D 12x220 screws. The perimeter wall panels are anchored to the brick ceiling from the inside using L100x100x6 angles, FAZ II 10x135 mechanical anchors (to the ceiling) and V5x60 screws to the lower waist. In all cases, the clearance distances of the connecting means to the wood and the concrete ring will be observed.

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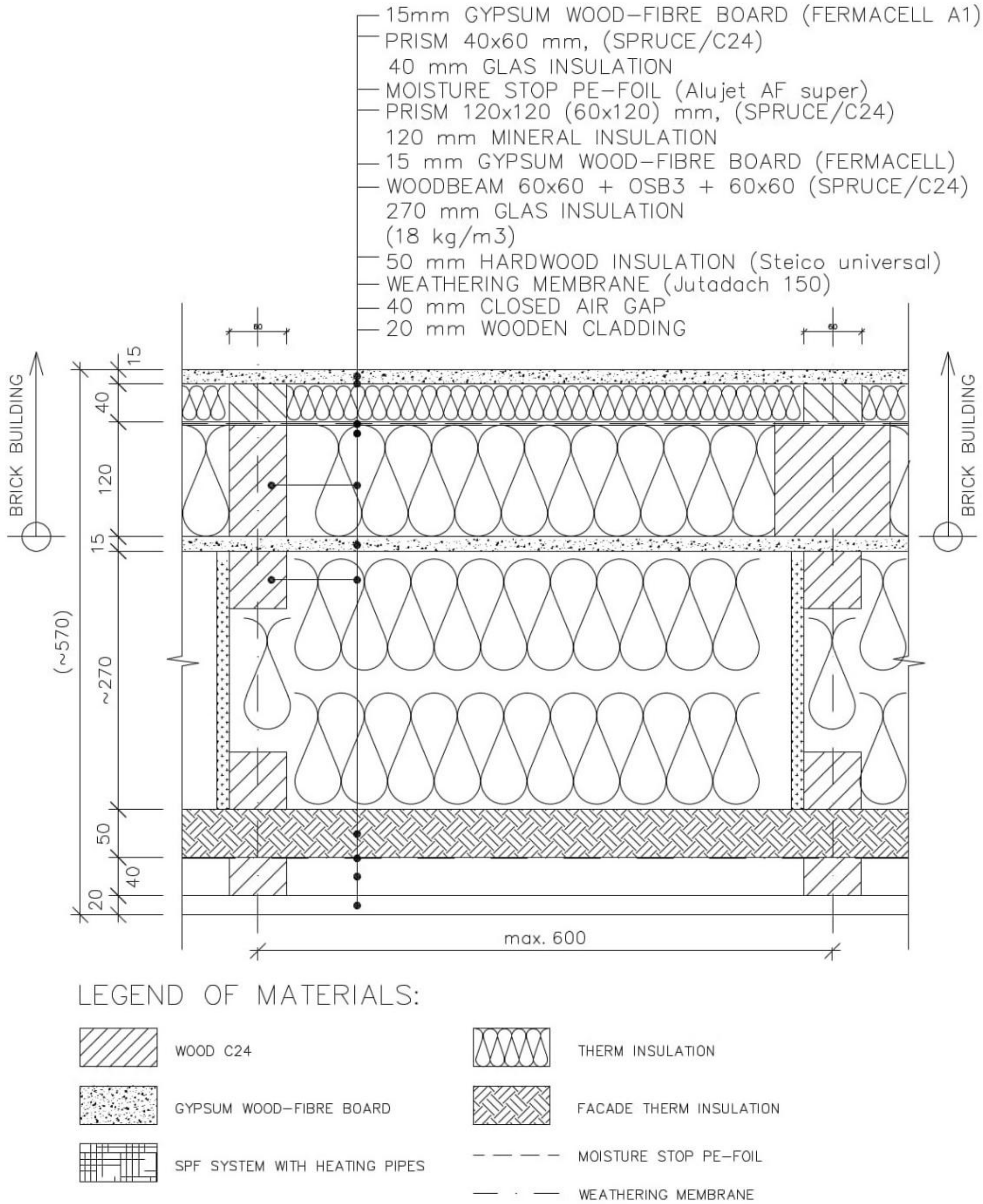

FIGURE 12 WALL PANEL 2: LAYERS

Roof panel. The designed roof panel is designed again as a prefabricated element. The load-bearing part of the truss is made up of an all-wooden system of rafters supported by a top purlin and a purlin wall. The connection at the saddle point is achieved using Rapid V8x300 screws. For the horizontal rigidity of the panel, the rafters will be fitted with a cover made of diffusion-open DHF plate thickness. 15 mm. From the bottom side, the panel will be reinforced with soffit battens thick. 60 mm and gypsum board. The entire panel is factory-insulated and equipped with a vapor barrier. The overhang of the roof from the side of the gable and the eaves is not considered for the building. The last rafter of the gable will be placed above the frame of the gable wall. The end of the rafters in the place of the eaves will be saddled to the frame of the lining wall and the header will be hidden in the insulation of the perimeter wall. The roof will be provided with metal roofing with a standing seam, dark in color.

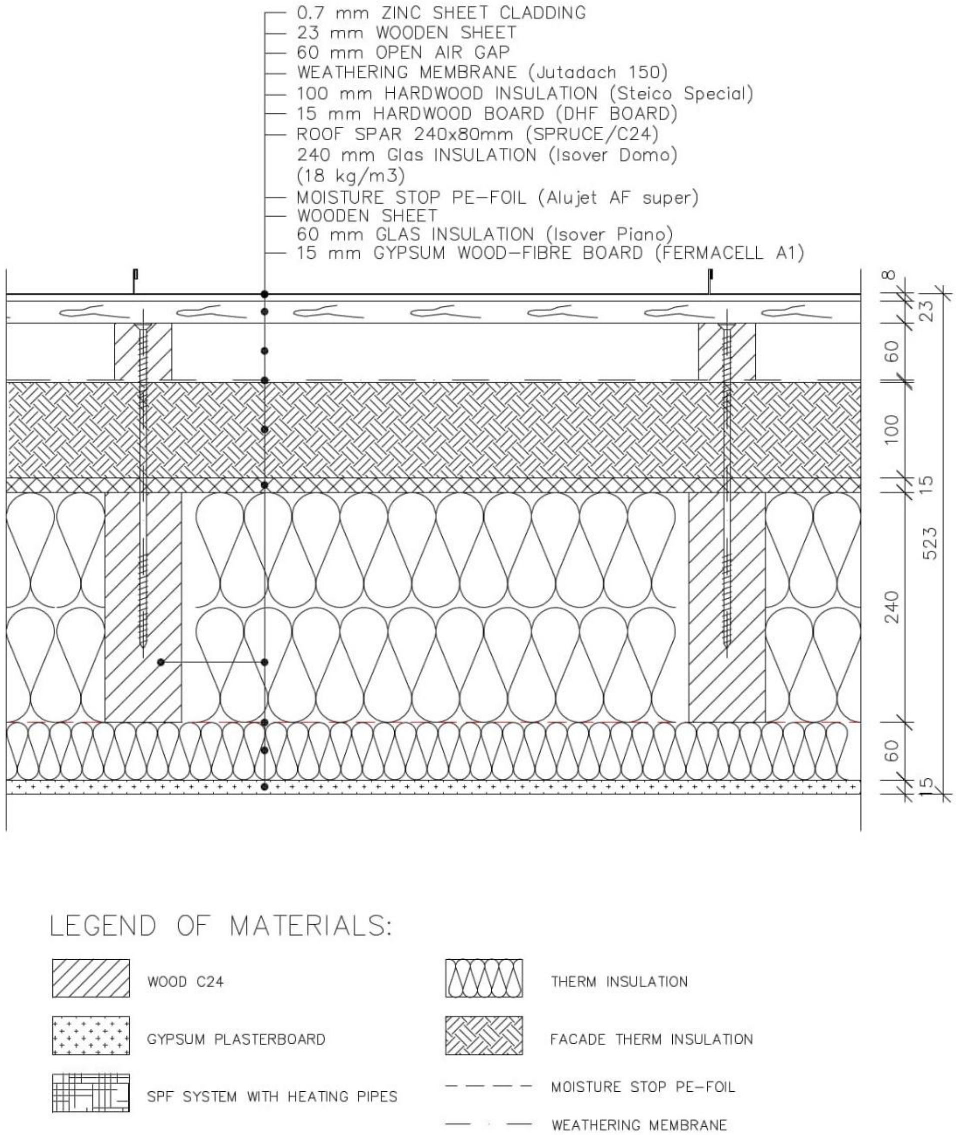

FIGURE 13 ROOF PANEL: LAYERS

Anchors. The basic profile for attaching the wall panels is made of a rolled L profile measuring 200x200x12. The length of the profile will be determined by the structural engineer and designer. The profile is attached to the masonry part using chemical anchors. The panel is attached to the masonry wall using threaded rods with a diameter of 12 mm, which are part of the L profile and are welded to it. For the possibility of pressing

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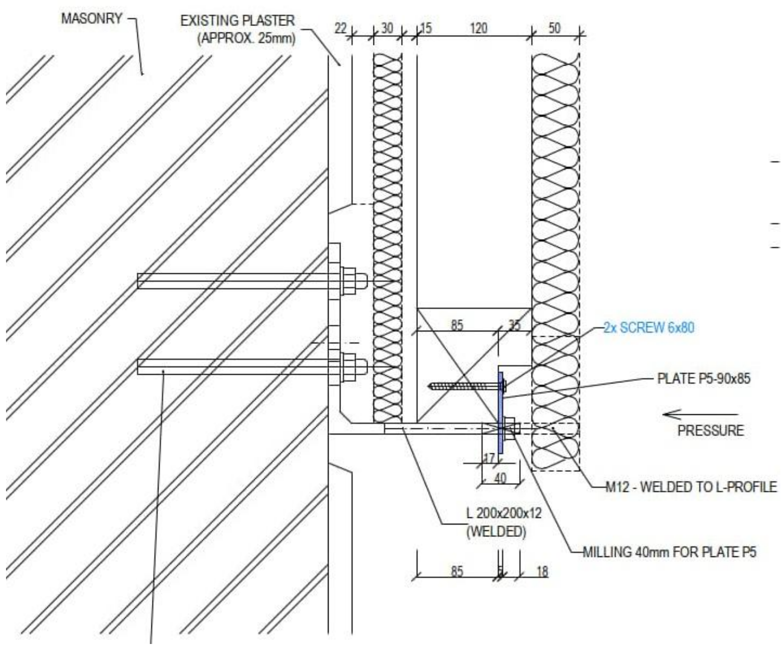
the panel, there is a milled groove for the M12 washer and nut in the bottom flange of the L profile. A half-groove is also milled in the lower waist of the wall of the wooden frame, to hide the same washer and nut. The remaining thickness of the bottom frame of 85mm is sufficient to carry the panel's own weight. The entire connection is covered with thermal insulation made of wood fiber board thickness of 50mm.

Two variants were discussed during the final design period - for a frame width of 180 mm and 120 mm. This is given by the definition of the hygro-thermal characteristics of the panel. Finally, the thickness of the structural layer of the panel was concluded as 120 mm.
The contact area of the anchor on which the panel rests is minimal in this case, and no further reduction is possible according to the static calculation. For this 120mm thick panel, 5mm-thick pressure pad is proposed, which would be the maximum void that would still be acceptable.
The final thickness of the anchor plate is 12 mm, and the diameter of the threaded rod welded to the plate which is also 12 mm. For the pressure pad to be added after the panel has been located, there is 20 mm void milled in the horizontal part of the anchor.
On the construction site, it has to be considered that the anchors will be embedded in the original plaster, which is at least 20mm thick, maybe more. In case the anchor was on the face of the plaster, then it would be set up outwards of by at least 20 mm more and it might create a barrier for the panel to be pushed closer to the original wall.



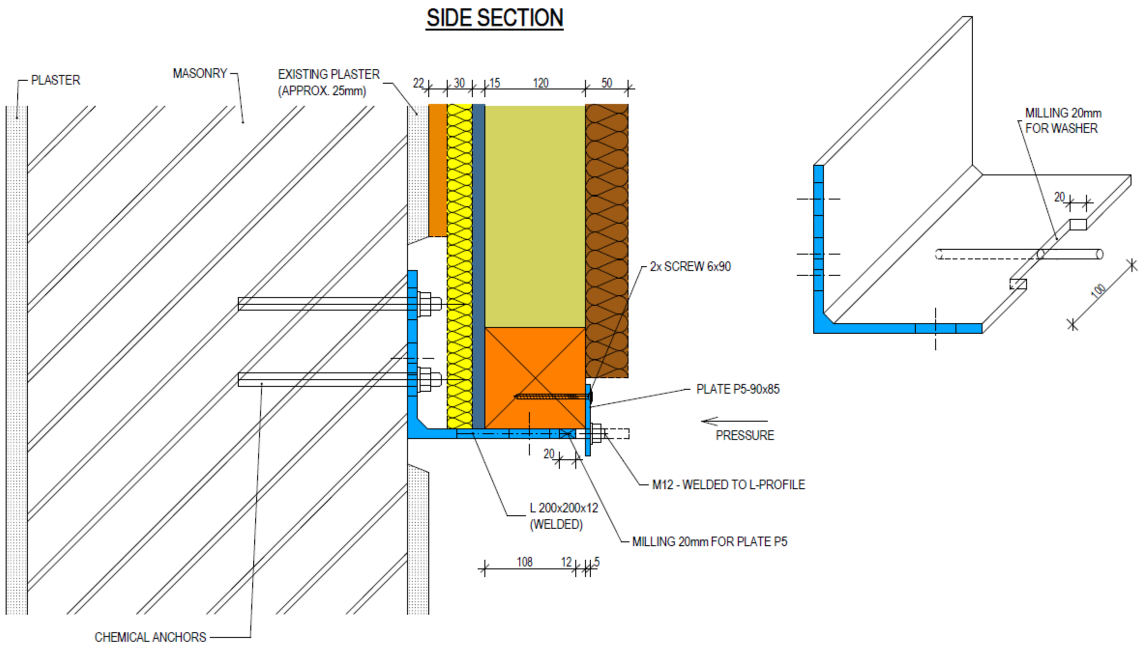


FIGURE 14 FINAL ANCHORAGE DESIGN

4.2 Final definition of the HVAC and energy systems

4.2.1 Energy efficiency of the building vs. NZEB

Due to the change of the thickness of the wooden frame from 180 mm to 120 mm, the thermal resistance of the façade panel is slightly decreased. As a consequence, the heating energy demand and the use of overall primary energy is increased. However, the adapted energy simulations show that the nZEB requirement is still met, in the following table.

Topic	Unit	Original building	Renovated building
Cooling energy demand		No active cooling	No active cooling
Heating energy demand	kWh/a	32’000	4’542
DHW production demand	kWh/a	4’266	4’266
Overall primary energy	kWh/a	69’402	302
Renewable energy production	kWh/a	-	11’187
nZEB standard reached?	Y/N	N	Y

Which document defines the nZEB standard?	N/A	"Act. No 406/2000 Coll." and "Decree No. 264/2020 Coll." define nZEB standard in Czech Republic

TABLE 2 : ENERGY EFFICIENCY

4.2.2 Passive strategies implemented

In the ConExWall, special attention was dedicated to the **hygrothermal properties** of the new wall. The fact that the wall layers include heating system, and that its location is not standard, created a specific situation that was to be studied, apart from the standard calculation of the condensation point. This point was studied by RDR and KAS.

In the design process, first, a rule of thumb was used for the definition of the thickness of the thermal insulation, necessary to avoid condensation in the wall. The rule of thumb suggested applying a triple thermal resistance at the exterior side of the vapor barrier, compared to the interior side. The vapor barrier was originally located behind the flexible thermal insulation, belonging to the heating system. Together with the existing wall, there was a substantial thermal resistance at the interior side, which caused the need to have 180 mm of mineral wool between the wooden structure and an additional 50 mm of rigid wood-fiber insulation at the exterior side. In the second step, it was considered that the overall thermal insulation and therefore the overall material use was excessive. Therefore, the following options of location of the vapor barrier were analysed:

a) Vapor barrier to be located between the flexible insulation later and the supporting board for the heating system
b) Vapor barrier in front of the heating system, connected to the panel
c) Vapor barrier located at the existing wall, previous to the panel installation

Based on the calculations of condensation and practical considerations, the option b) was selected. The following products have been identified by the local architect as suitable for this application: Daco KSD-R, BISTU-STICK VAP and VEDAGARD® FR.

The fact that the system contains a heating layer was considered positively from the condensation perspective, when the heating is on. In such case, the potential humidity would be dried out, and the surrounding layers would not achieve the dew point temperature, even at very unfavourable exterior conditions.

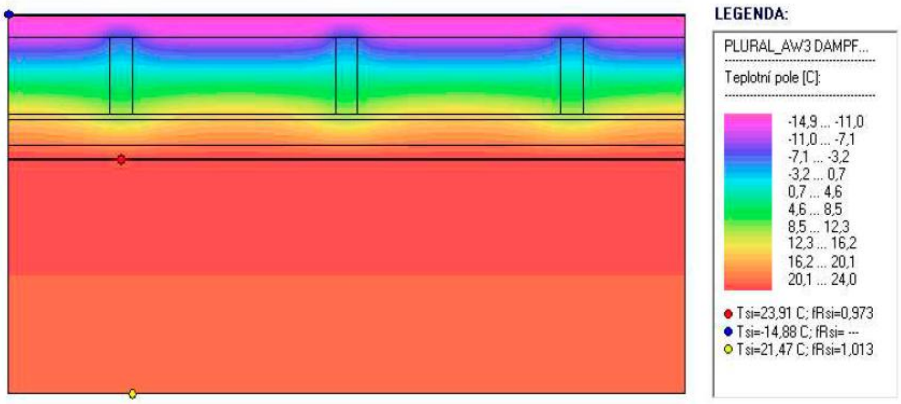


FIGURE 15 THERMAL DISTRIBUTION IN THE PANEL, CASE B)

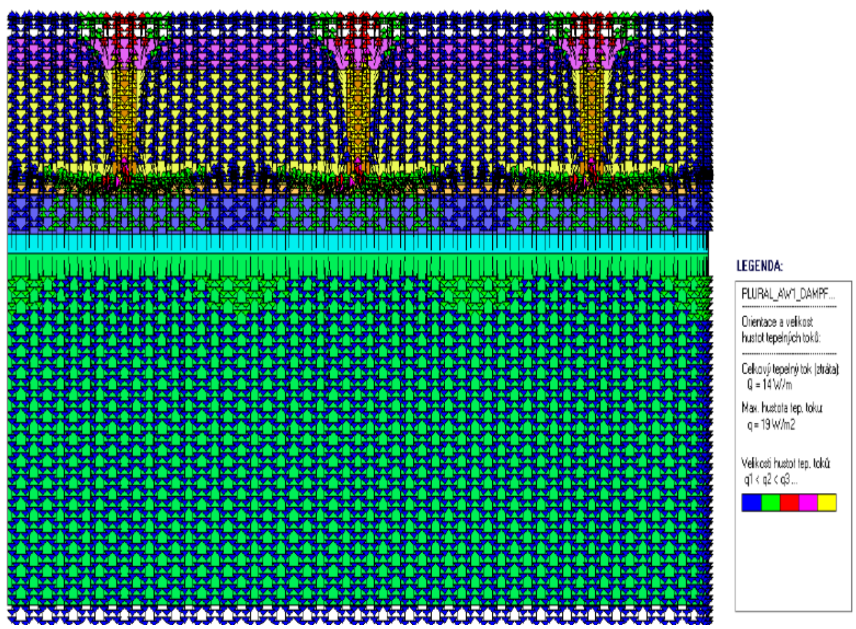


FIGURE 16 VAPOR DYNAMICS IN THE WALL, CASE B)

Furthermore, the assembly was also studied to identify any potential **thermal bridges**. The analyzed thermal performance is described below.

The study, developed by NTUA with assistance from SPF, aims to calculate the thermal transmittance of the eWHC PnU kit taking into account the thermal bridges caused by the wooden frame, the anchoring system and the presence of ventilation unit. The thermal transmittance of the eWHC is calculated, according to ISO

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10211, which is the most accurate method. The hygrothermal performance of the thermal bridges is also assessed by means of the temperature factor.

Methodology. The analysis of the building envelope, according to ISO 10211:200,7 is a steady-state approach aiming to calculate the equivalent thermal transmittance (U-value) taking into account all thermal bridges. The presence of the wooden structure, comprising of two wooden frames, along with the presence of ventilation units and the anchoring system (L-profiles) between the existing envelope and the eWHC PnU kit creates non-negligible thermal bridges. Concerning the water temperature, it is considered to be free, taking the temperature of the wall because the analysis is based on steady-state and passive conditions.

For the calculation of the equivalent thermal transmittance of eWHC, the whole PnU geometry is simulated by means of the commercial CFD package COMSOL in steady state conditions. The boundary conditions are summarized in Table 3.1, while the material thermal properties in Table 2

Boundary Condition	Value
Outdoor temperature	0°C
Indoor temperature	20°C
External heat transfer coefficient, h_{out}	25 W/(m²K)
Internal heat transfer coefficient for walls, h_{in}	7.69 W/(m²K)

TABLE 3 BOUNDARY CONDITIONS.

The hygrothermal behaviour of thermal bridges is assessed by means of the temperature factor, f_{Rsi}. The temperature factor at the internal surface, f_{Rsi} or f, is an indicator which is usually used for the thermal performance of thermal bridges. The f_{Rsi} expresses the relation of the thermal resistance of the envelope element (R_{tot}) to the thermal resistance of the element without the impact of the surface thermal resistance (R_{si}). Hence, it is defined as the difference between the internal surface temperature (T_{si}) and the outdoor temperature (T_{out}), divided by the difference between the indoor (T_{in}) and outdoor temperature. The temperature factor, f_{Rsi} (-), for a given surface resistance, R_{si}, is calculated by the following equation:

$$f_{R_{si}} = \frac{R_{tot} - R_{si}}{R_{tot}} = \frac{T_{si} - T_{out}}{T_{in} - T_{out}}$$

The temperature factor is also an indicator of the hygro-thermal performance of all types of thermal bridges. Mold growth is expected, when the relative humidity on a surface is higher than 80% for several days. The mold growth is avoided when the temperature factor is greater than a critical value depended on the building use and the consequent indoor relative humidity. The higher the desired indoor relative humidity, the higher the critical temperature factor will be in order to eliminate the likelihood of condensation and mold growth. For residential buildings, a typical value of the critical temperature factor is 0.7[1], however, national standards have set the lower limits for the temperature factor to be ranged between 0.65 to 0.75[2].

Geometry and materials. The eWHC geometry is constructed in COMSOL software, as depicted in Figure 1.

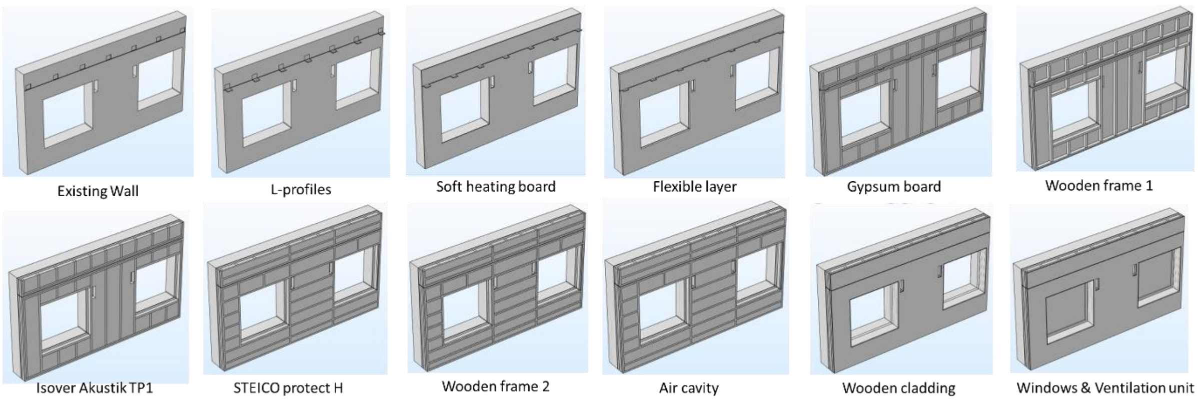

FIGURE 17 The construction of ewhc geometry in comsol software.

Material layer	Thickness [mm]	Thermal conductivity [W/(m·K)]	Density [kg/m^3]	Specific heat capacity [J/(kg·K)]
Existing Wall	500	0.810	1800	1000
Soft heating board - STEICObase	20	**0.050***	220	1450
Flexible layer - ISOVER Akustik TP 1	50	0.039	90	1400
Gypsum Fibreboard	15	0.350	1153	1000
Insulation - ISOVER Akustik TP 1	d=180 / 120	0.040	8	1030
Wooden frame - spruce		0.13	450	2300
Insulation - STEICOprotect H	50	0.048	266	1000
Non-ventilated layer in wooden frame	40	0.22**	1.1	1000
Wooden cladding - Profilholz	20	0.13	450	2300
Box of ventilation units & L-profiles - Steel	2	60.5	7854	434
Air inside the ventilation units		0.15**	1.1	1000
Window Glass Thermal transmittance - U_g	0.6 W/(m^{2}K) → k_g = 0.0294 W/(m^{2}K), d_g=44[mm]			
Window frame thermal transmittance - U_f	1.0 W/(m^{2}K) → k_g = 0.0134 W/(m^{2}K), d_f=100[mm]			

TABLE 4 MATERIAL THERMAL PROPERTIES USED IN THE ANALYSIS

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Heating layer. Due to the complexity of the geometry, the heating pipes are impossible to be simulated along with the rest eWHC geometry. For this reason, the contribution of heating pipes is calculated in the layer of soft heating board – STEICObase.

Geometry	Heat Flow [W/m^2]	Thermal conductivity [W/(m·K)]
Soft heating board without heating pipes	35.10	0.050
Soft heating board with heating pipes	37.87	0.056

TABLE 5 THE RESULTS OF HEATING LAYER ANALYSIS.

Results. The temperature contours of the eWHC kit are depicted in Figure 3 for both the external and internal side, for 120mm ISOVER Akustic TP 1. The internal and external surfaces of the eWHC kit seems to be quite uniform. For the external side, although the ventilation unit and the window (mainly the frame) provide significant thermal bridges, the temperature on the rest surface is relatively uniform. For the internal side, it is observed a significant temperature difference on the left side, due to the small distance between the window and the PnU edge. The L-profiles seem to not introduce a significant temperature gradient due to the large thickness of the existing wall (500mm).

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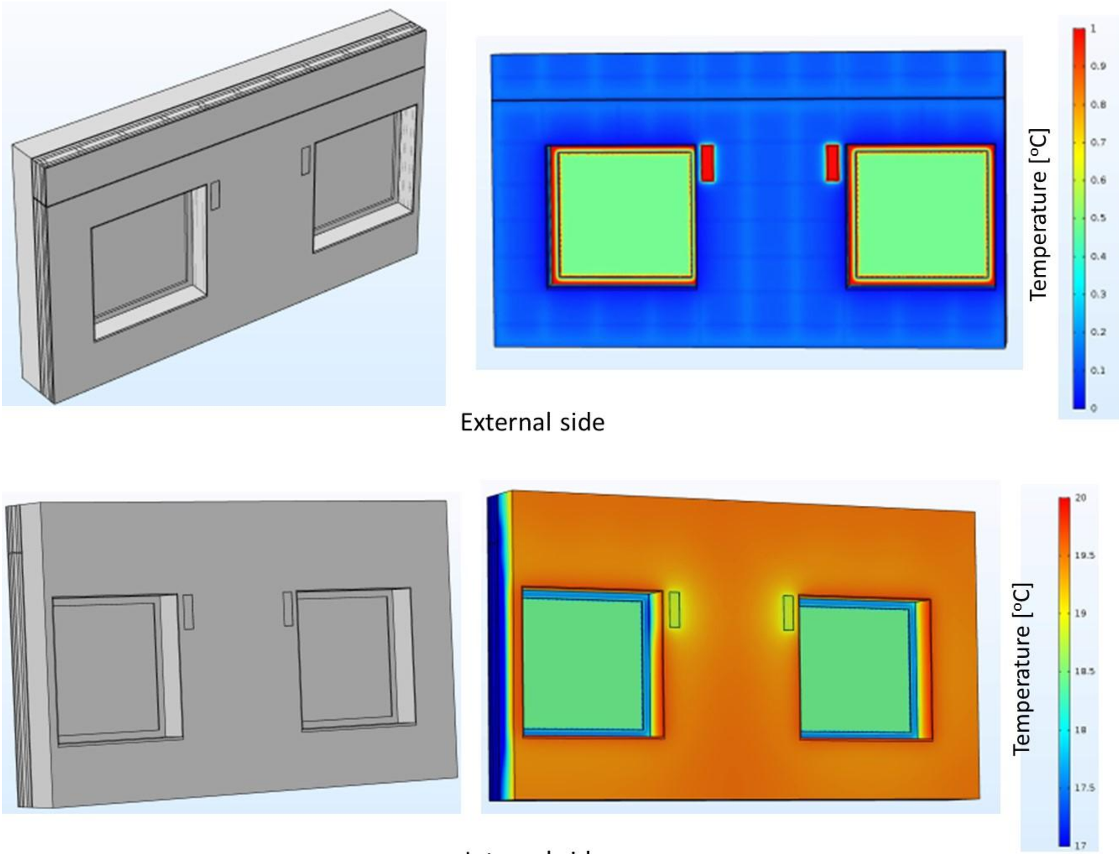

FIGURE 18 THE TEMPERATURE CONTOUR OF THE SIMULATED GEOMETRY AT THE EXTERNAL AND INTERNAL SIDE, FOR 120MM ISOVER AKUSTIC TP 1.

The following table summarizes the results of the equivalent U-value and the temperature factor for the two PnU alternatives (for 180 and 120 mm thick ISOVER Akustic TP 1). As it is observed, for 180mm insulation thick, the U-value of the opaque PnU is $U_{eq,wall}$=0.17 W/(m^{2}K), while the U-value of the whole PnU (taking into account the window) is $U_{eq,PnU}$=0.28 W/(m^{2}K). The reduction of insulation thickness from 180mm to 120 mm (33%) results an increase of the U-values by ca. 17.5%, resulting 0.20 W/(m^{2}K) and 0.33 W/(m^{2}K) for the $U_{eq,wall}$ and $U_{eq,PnU}$, respectively.

Insulation thickness (ISOVER Akustic TP 1)	$U_{eq,wall}$	$U_{eq,PnU}$	$f_{R,si,wall}$	$f_{R,si,PnU}$
180 mm	0.17 W/(m^{2}K)	0.28 W/(m^{2}K)	0.95	0.80
120 mm	0.20 W/(m^{2}K)	0.33 W/(m^{2}K)	0.93	0.80

TABLE 6 THE EQUIVALENT U-VALUES AND TEMPERATURE FACTORS OF THE TWO ALTERNATIVES OF THE EWHC PNU.

[1] DIN 4108-2:2013, Thermal protection and energy economy in buildings - Part 2: Minimum requirements to thermal insulation.

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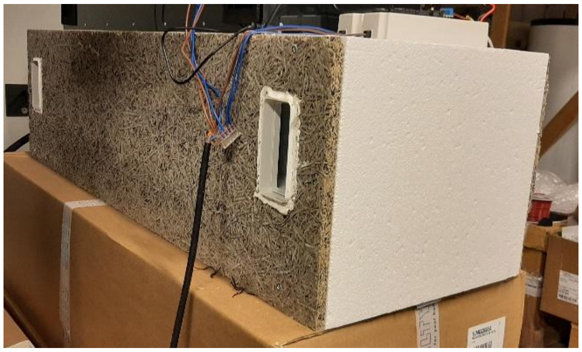
[2] T. Kalamees, Critical values for the temperature factor to assess thermal bridges Proceedings of the Estonian Academy of Sciences, 12 (3-1) (2006) 219-229

4.2.3 Ventilation system (as per T2.3)

Compact ventilation units Helty Flow 40 and 70 were selected for Kasava demonstration. The decision process is described in the Deliverable 2.3. Unit Helty Flow 40 has a maximum airflow rate of 42 m^3/h and unit Helty Flow 70 has a maximum airflow rate of 85 m^3/h. A local ventilation unit for each room is more preferable than a central system with ducts included in façade. Both units are equipped with efficient enthalpic heat recovery heat exchanger, fully controlled fans, filters (F7/G4+G2) and body with high outside noise attenuation. More preferred in installation is bigger unit Helty Flow 70 for the reason of lower acoustic noise. The Helty Flow 70 unit for day mode complies with national requirements at all four basic stages, but for night operation only in regime 1 (24,3 dB(A) < 25 dB(A) at 20 m^3/h).



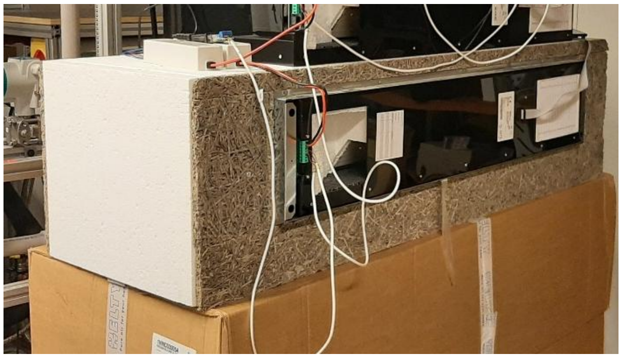


FIGURE 19 : VENTILATION UNIT HELTY FLOW 70 IN INSTALLATION BOX (EXTERIOR SIDE – LEFT PICTURE; INTERIOR SIDE WITHOUT PANEL– RIGHT PICTURE)

Both ventilation units need the 24 Vdc operating voltage. The enclosed 230V/24V (20 W resp. 100 W) transformer with rectifier can be used. Local ventilation units will be controlled by the central PLC (Programmable Logic Controller) that will get the data mainly from the Indoor Air Quality sensors. Each unit relate to one local sensor. Selected trim level has a RS485 interface with Modbus RTU standard implemented. Beside the IAQ sensors output information the status of the ventilation unit can be controlled via the Modbus register.

Possible locations of ventilation units in a room are beneath window in horizontal position or beside window in vertical position. Installation of the unit will use installation box provided by producer. This box is located during dirty works around walls and the unit comes later inside the box.

For more technical information please see the Deliverable 2.3.

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4.2.4 Heating and cooling system (as per T2.4)

A single air-to-water heat pump will be used to provide both apartments with space heat and domestic hot water. No function for cooling of rooms will be implemented into the system. The hydraulic scheme of the heating system and the choice of the main components of the heating system is already documented in deliverable D2.4. Some details of the integration of the heating system into the PnU kit eWHC are repeated hereinafter.

4.2.5 Energy system, PV installation (as per T2.5)

Energy system is designed in a way that there is single Heatpump unit for two dwellings. The PV system is connected to common consumptions circuits where there is also HeatPump. The photovoltaic systems covers local consumptions. The energy which is not consumed locally is fed in to the grid. The size of the systems is designed to cover the available roof areas in three sections of the roof. The size of the system will be selected with respect to valid regulation in 2023. For regulation from 2022 PV less then 10kWp is possible, if the new regulation is already valid the the design can be extended to 12,1 kWp. The inverter is considered to be GoodWe 12DT, (12kW, 3f, 2xMPPT) or similar with respect to product availability.

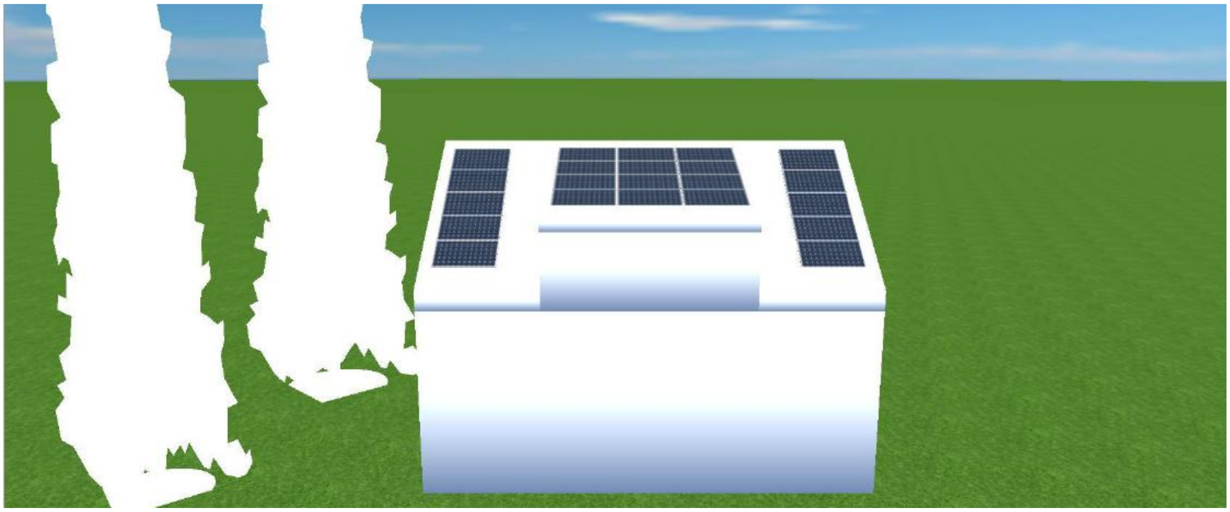

FIGURE 20: PV INSTALLATION IN KASAVA

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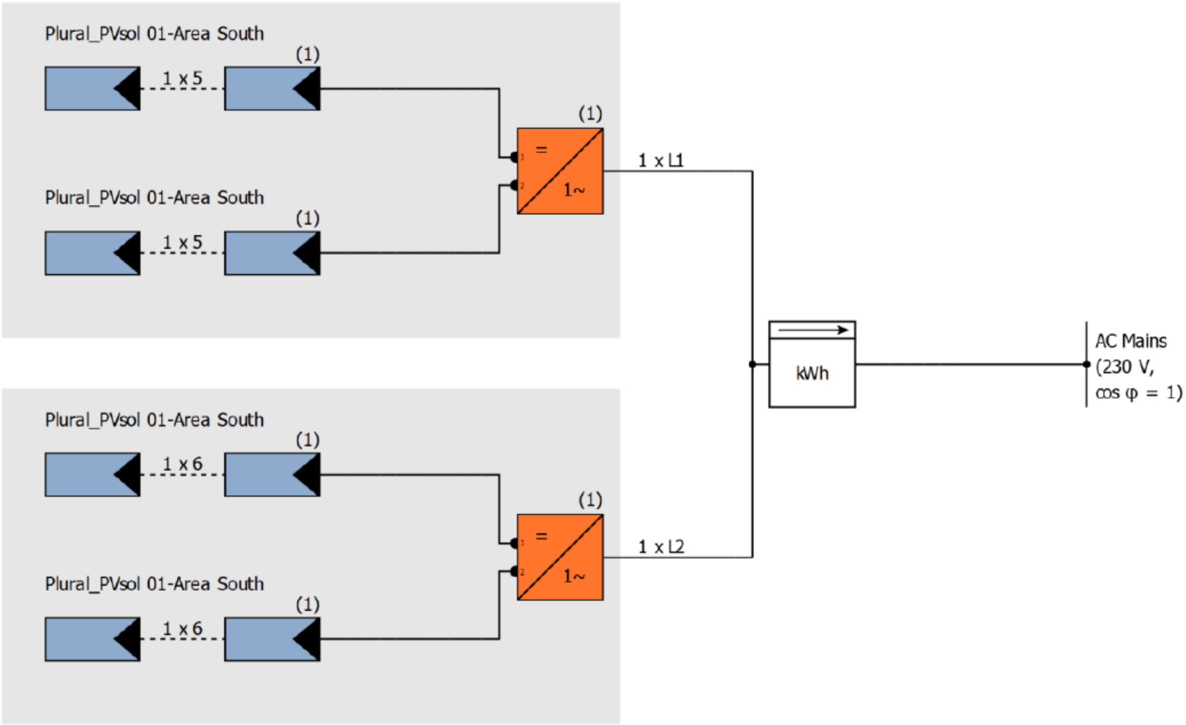

FIGURE 21: SYSTEM SCHEME

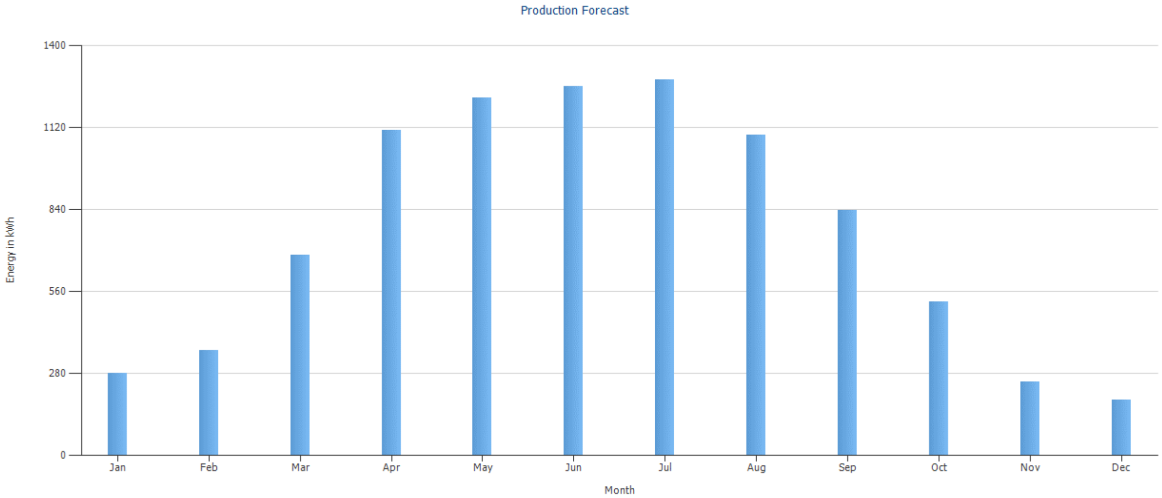

FIGURE 22: ANNUAL **PV** SYSTEM PRODUCTION

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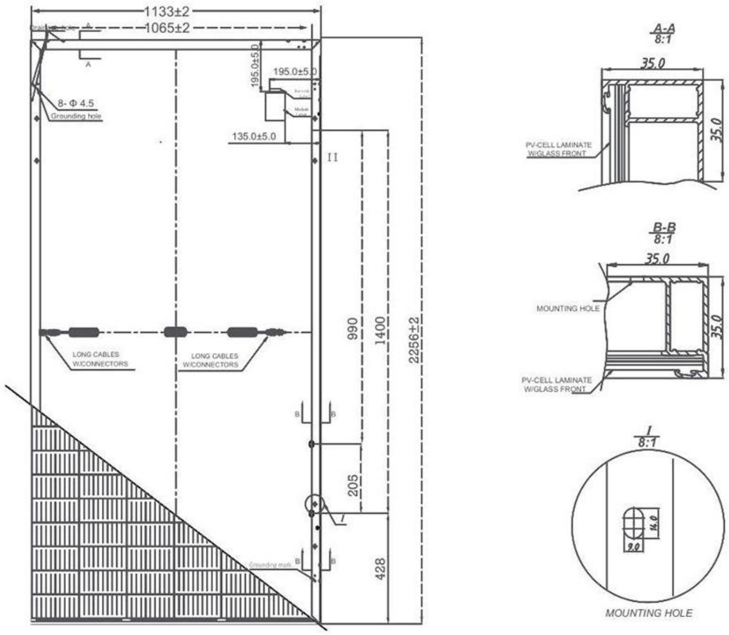

FIGURE 23: PV PANEL TECHNICAL DRAWING (SUNWAY SW550-M-144, FINAL PRODUCT MIGHT CHANGE WITH RESPECT TO AVAILABILITY)

Topic	Unit	Original building	Renovated building
PV panel type	N/A	none	Sunway SW550M or similar
PV panel size	mm	None	2279x1133x35 mm
PV panel peak power	Wp	None	550W
Nr. of panels: per orientation South / inclination 39°	units	N/A	10pcs
Nr. of panels: per orientation South / inclination 19°	units	N/A	12pcs
TOTAL installed PV peak power	Wp	N/A	12100 Wp (or 10kW if limitation is still valid)
TOTAL PV energy production	kWh/year	N/A	11.7 MWh
% of Total heating and cooling demand covered	%	0	TBC

TABLE 7: PV PRODUCTION

The type and number of panels is subject to change with respect to product availability.

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4.2.6 Smart system (as per T3.4)

There have been no changes in the smart system definition after the deliverable D3.4.

4.3 Post-design life-cycle phases

4.3.1 Manufacturing

The manufacturing of the façade and roof panels for the PnU kit will follow the common practice of the RDR company, with several particular changes due to the innovative design, developed within the PLURAL project.

The industrialization level. In the common practice of RDR, the finishing layers are done on site, once the panels are already installed. It was considered to include all the layers from the interior to the exterior cladding, as well as the roof finishing and the PV panels in the panels, however, considering the fact that several pipe connections need to be done on site, the industrialization level was slightly decreased.

In regard to the façade panels, for the typical panel (for the situations where there is an existing wall), the layers from the most interior layer- the heating, till the external thermal insulation will be manufactured and installed as a single panel. The insulation to cover the channels for HVAC pipes and their connections, and at the joint where the anchors are tightened, will be delivered separately. As a third component, the cladding with its substructure will be also industrialized as a 2D panel.

Integration of components. The windows will be integrated within the panels in the factory as part of the first assembly. The weight of the windows was considered as a potential problem, but with the heaviest window being calculated as 304 kg (2300*1600 mm), the structural integrity of the panel will not be affected, according to the structural engineer.

In regard to the ventilation units, the solution varies. The ventilation unit at the typical solution, where there is the existing wall behind the PnU panel, will be installed directly on site, given that the thickness of the existing wall allows for the installation of the unit, while the new panel is not deep enough, so the ventilation unit would not be protected during the transportation and the installation process would also be more complex. For the independent panel, where there is no existing wall, the ventilation unit will be integrated into the panel. This is also possible because these panels have more depth.

Façade modulation vs. production. During the design phase, the maximum standard panel size for the RDR production, being 2,7m, was considered for the façade modulation. However, considering that the number of panels would need to be doubled at least at the first floor level, it was agreed that the production will allow for special size of 3,5m max. This solution decreases the number of anchors needed as well as the joints, which are always the more sensitive spot.

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4.3.2 Transportation

Standardly used RDR transportation long vehicles will be used to transport panels from the manufacturing site in Rýmařov to location of demo building in in Kašava. The standard trucks will be able to load panels of maximal 3,5 x 2,7m. Panels are transported in vertical position. It is not recommended to install the PV panels before transportation since special care would have to be taken during manipulation and loading. The anchors for photovoltaic panels will be installed on the roof panels but the panels will be transported in this pilot case separately and mounted onsite to prepared anchors. The distance to travel between manufacturing and demonstration site is app 120 km. The transportation will assure panel protection against damage as well as against rain water.

The transportation of the PnU kits will be done using a special low-bed trucks, given the final height of the panels reaching 3,5 m.

FIGURE 24 EXAMPLE OF A LOW-BED TRAILER

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FIGURE 25 REFERENCE IMAGES FROM THE MORE-CONNECT PROJECT, COLLABORATION BETWEEN RDR AND CVUT

4.3.3 Installation (+Minimum occupant disturbance)

Before starting the assembly work, the construction manager personally checks the security of the construction site in terms of BaHP, the covering of penetrations. If +-0.000 is more than 1.5 m above the level of the surrounding terrain, scaffolding must first be erected around the entire structure, up to the level of the ceiling above the basement. The construction of scaffolding continues during construction so that it is possible to assemble additional floors from it. If for any reason there is no scaffolding around the entire house, or the scaffolding is not taken over, collective protection must be used. If work is started on any completed part of the scaffolding, a record of the inspection and acceptance of the scaffolding must be made in the construction logbook.

For correct and problem-free installation, comprehensive documentation for anchors, all installed wall and roof panels, details of individual connections and a description of fasteners, drawings of the wiring installed from the outside must be available. A laying scheme must be drawn up for exterior cladding.

In case of inclement weather, roofs must be available to cover the prefabricated panels.

The principal installation steps and possible disturbances when adding the ConExWall system to a building are as follows.

The façade panels, i.e. the ConExWall PnU-kits, will be installed at the existing façade from the outside with a crane (see scheme in the following figure). Before the installation of the façade panels, anchors must be mounted to the façade on which the panels will be put on and fixed. Further, core drillings have to be made through some of the walls of the building to be able to connect the heating loops of the façade panels with

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the heating system inside the building. Both, the mounting of the anchors and the drilling of the core drillings create disturbances for the inhabitants.

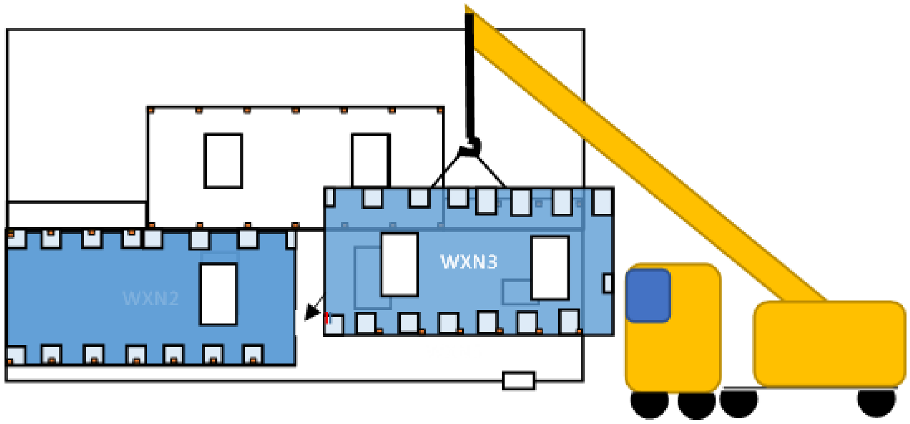

FIGURE 26 INSTALLATION OF THE FAÇADE PANELS WITH A CRANE.

Before or after the installation of the façade panels, the old windows will be demounted (the new windows are pre-mounted in the new façade panels). Within some of the window openings of the old brick wall, new ventilation units will be placed and connected to the air ducts within the façade panels. The new window boards will be mounted manually afterwards. If necessary, plaster work at the window and ventilation unit connections will be undertaken inside. The described work is associated with disturbances. However, the disturbance can occur per room and in each room, the room section at the outer wall where this work is carried out can be divided with a large and hermetic plastic foil to protect the rest of the room from pollution.

The connections of the heating loops of the façade panels to the heating system will be done at distribution boxes that are placed inside the building near the core drillings. Thermally insulated distribution pipes will be installed between the distribution boxes and the central heating system in the cellar. The installation of these connecting pipes will cause minor disturbances within each apartment.

In some of the rooms, the controllers of the Toolbox including temperature sensors will be installed and connected via Modbus wiring to the central controller. For this reason, some electric cables will be installed within the apartments.

Disturbances in the building in Kasava, however, are not an issue, as the building will be unoccupied during the renovation phase. This was decided by the owner, as the renovation should be used as opportunity to extend the living area of the first floor (which will be work outside the frame of the PLURAL project). This extension involves major interventions during the renovation that do not allow the building to remain inhabited.

The detailed description of the installation as described by the producer of the panels, RDR is as follows:

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1) Inspection of construction and acceptance of scaffolding, securing dangerous sections and places.
2) Knocking down the plaster in the places where the anchors will be installed, according to the anchor laying plan on the individual sides of the house, creating holes in the brick walls for the passage of the heating system, PV cables and other technologies.
3) Inspection of anchor locations and possible rehabilitation of damaged masonry.
4) Installation of all the anchors on the surface of the cleaned bricks and their comparison, filling the gaps between the brick and the anchor - technological break.
5) Installation of the first row of panels, installation of washers, nuts (roughly only) in the lower and upper part of the panels. Comparison of the bottom line to the string (level).
6) Installation of the second row of panels on the second floor (in place of the roof dormer), installation of washers, nuts (roughly) in the lower and upper part of the panels.
7) Overall comparison of all panels and even final tightening of all panels to flatness.
8) Connecting the panels of the 1st floor at the outside corners or between each other.
9) Installation of gable and surfacing walls of the second floor (placed on the ceiling of the 1st floor) - takes place only after leveling the already installed walls of the first and second floors (in the place of the roof dormer). The walls settle and align with the face from the outside. Then L100x100x6mm anchors are applied.
10) The shield and lining walls are leveled and connected at the corners with corner screws.
11) The top purlin is installed and secured with screws to the gable walls. It can be attached to a brick shield with a chemical anchor and besieged.
12) The roof panels are installed and the screws are screwed into the floors and top purlins.
13) Extension of heating and electrical wiring into the building and onto the roof. Filling and pressure testing of heating distribution systems, or venting the system. Sealing the passages of these technologies in place of vapor barriers, safety films and masonry. Before connecting the external connections of the panels, carry out an electrical test of the stretched PV cable line.
14) Additional insulation of assembly and technological gaps with thermal insulation, gluing of vapor barriers, further insulation with thermal insulation, gluing of insurance foils of walls and roof.
15) Adding ventilation battens to the walls and roof, installation of ventilation grilles against insects, wooden paneling, outdoor parapets, outdoor wooden cladding, roofing, sheeting, gutters, downspouts and other accessories (roof barriers, anti-tacks, lightning rod, etc.).
16) Installation of PV panels, connection of air conditioning units and commissioning of all technologies.
17) From the inside of the pasting of the vapor barrier when filling holes with existing masonry (it is necessary to carry out the BlowerDoor test).
18) Plastering or installation of gypsum board in the inner lining of filling holes. Installation of internal windowsills.
19) After finishing the work, perform thermal and hydro-insulation of the plinth part and sealing between the installed panels and the plinth insulation.

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4.3.4 Operation phase

Room temperature control. Each of the rooms that are normally occupied will be heated individually with a specific heating loop. A thermostat in each room which is connected to the Toolbox will control the thermal output of the specific loop. Further, the occupants can change the set-point temperature of each room in a certain range via the room thermostat. During e.g. holiday in the heating season, the temperature of all rooms of an apartment can be reduced jointly by entering a temperature reduction and the timespan of the absence. To consider the thermal mass of the facade and the interior, the effective time-span of temperature setback of the heating of the apartment will be shorter than the time of absence (by approx. two days).

Air quality. The ventilation units will be controlled from the main building controller. In rooms with longer duration of stay, the CO_2 concentration in the air is used for the regulation of the air exchange rate. In the other rooms (e.g. bathrooms and kitchens) the relative humidity is used instead. The inhabitants have the possibility to control each unit in manual mode (four manual power set points). To prevent long duration of manual mode, the user settings will remain only for a limited time (in main rooms until 6 am, in bathrooms for 20 minutes).

Shading. The windows will have internal venetian blinds (between two of the glass panes) which can be controlled manually.

4.3.5 Accessibility for maintenance and repair

Heating system. The only non-standard part of the energy system is the piping for space heat emission. As the piping is located between the façade modules and the old façade of the building and as the façade modules are fixed to the building, the piping is not accessible after the installation of the modules. To reduce the risk of leakages at the modules (due to e.g. damaged fittings), each heating loop consists of a single pipe without any fittings at the façade module. Any connections of that pipe are done with press-fittings within the installation channels or preferably inside the building. The channels are open during the installation and closed afterwards. However, principally they can be opened during the operation phase in case it is necessary.

As the heating loops are upright oriented and as their connecting pipes are guided downwards, air bubbles that commonly are present in the heating loops can accumulated in the loops. If too much air accumulates, this might block the respective loop. Hence, the loops have to be flushed from time to time. This can be done automatically with the aid of the circulation pump of the heating loop, and by opening only some of the loops to have a sufficiently high flow rate through the open loops. The air is flushed into the space heating storage tank where it accumulates. With a venting valve the air can be removed from the heating loop.

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All other parts of the energy system of the building like the heat pump, thermal storages, heating circuit distributors, valves and pumps, PV-panels, and PV-inverters are standard products and placed in or around the building such that they are accessible and can be maintained.

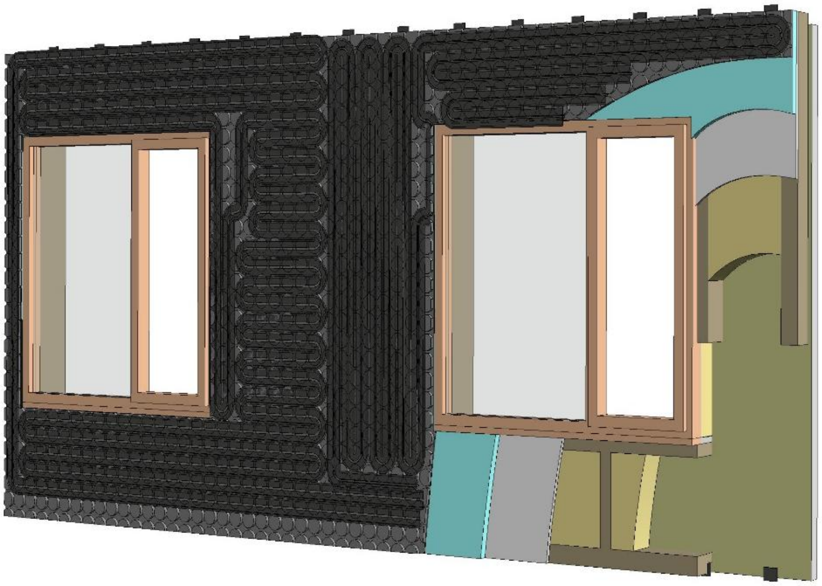

FIGURE 27 LAYERS OF THE CONEXWALL INTERIOR PANEL

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5. Spanish demo: TERRASSA

5.1 Architectural and structural design

5.1.1 Resume of the renovation objectives and changes

The renovation that takes place on the facade begins with the change of material above the ground floor and ends with the crowning of the walls of the attics. In addition, photovoltaic solar panels are added to the east and west roofs.

The building has been completed since the beginning of 2022, but according to the regulations in force before the actually valid CTE 2006. It has validated sanitary water and fire license. The electricity license and the first occupation license are being processed. It is expected that at the beginning of 2023, users will begin to settle in the homes. At the time of the completion of the PLURAL rehabilitation work, the homes will be rented and in use.

Topic	Unit	Area	% of the total
Renovated façade EAST (of total 355,25m2)	sqm	209,02 (179,61 only opaque)	58,9
Renovated façade WEST (of total 319,47m2)	sqm	207,49 (168,11 only opaque)	64,9
Total area of replaced windows	sqm	68,79	N/A
Renovated roof	sqm	0	0
New PV installation EAST ROOF	sqm	25,40 (36 panels)	N/A
New PV installation FLAT ROOF	sqm	21,17 (30 panels)	N/A
New PV installation WEST ROOF	sqm	8,47 (12 panels)	N/A
New facade		N/A	N/A
New roof		N/A	N/A
Total area of new windows		N/A	N/A
TOTAL renovated/ new envelope (of total 1697,9 sqm)	**sqm**	**416,51**	**24,5**

TABLE 8 : FINAL DEFINITION OF THE IMPLEMENTATION SCOPE

The renovation only has a scope of less than 25% of the surface of the total thermal envelope of the building. Therefore, according to the local regulation, CTE Catalan Technical norm, the overall renovation does not have to comply with the requirements for the actual building code. Even so, each point of the regulations that applies will be justified.

FIGURE 28: THERMAL ENVELOPE

The main objectives of the renovation project are:

- Complying with the nZEB standard for the renovated flats
- Improving the insulation and reduction of thermal bridges
- Improving the interior air quality
- Production of renewable energy via photovoltaic installation
- Improving the aesthetics of the building

5.1.2 Aesthetics and functional design criteria

The functional and design criteria in the HybridWall development are mostly coming from the requirements of the demonstration case, given that it is a social housing, managed and maintained by local administration, where the users might need more attention and the low-maintenance criteria gains more importance. These aspects are taken into the design of the system, considering that this way it would be suitable for the social housing application as one of the most stringent ones, while in the other applications the requirements might be more lose.

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Colors and patterns. The façade design has been changed, on one hand by the change of size of the PV panels to be integrated in the façade. From 1-module, the width of the PV panel changed to 2-modules, so the overall size of the façade PV panels is 390/ 1200mm. In order to integrate it, the pattern on the East façade, where the PV installation takes place, is adapted to the new size by creating double modules with the façade cladding as well, which dissolves as it continues to the bottom of the façade. The colors of the cladding panels were adjusted to further respect its surrounding and were initially approved by the town hall.

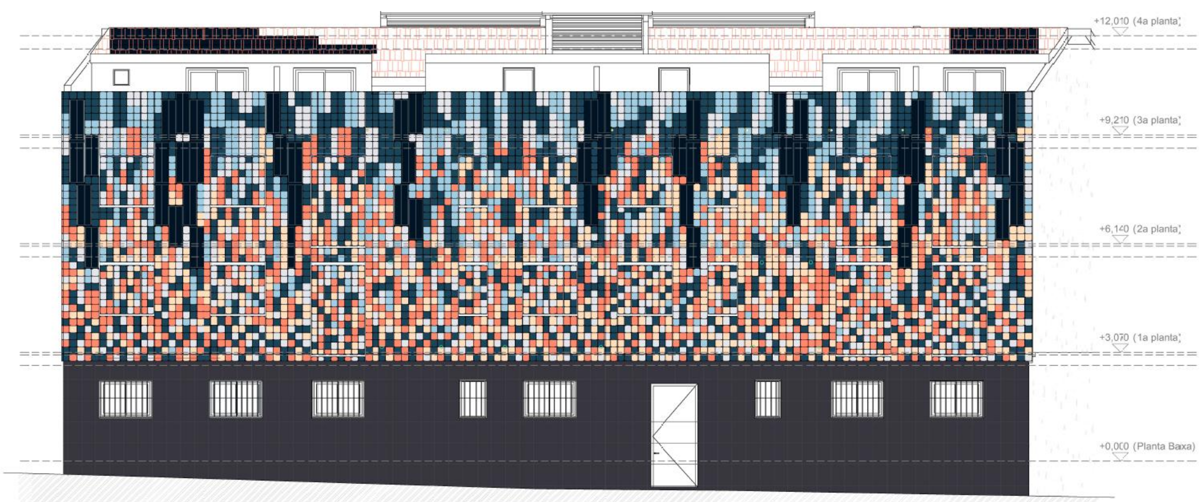

FIGURE 29: BUILDING FAÇADE, EAST ELEVATION, SHUTTERS CLOSED

Modular design. The division of the facades into sequences was finalized. The façade will be divided into vertical sequences based on the window widths. The sequences will be transported as 1 element, and hanged at the top of the façade by the main anchors. In order to facilitate the production, after defining the width of the panels, the widths of the cladding patterns were optimized to decrease the quantity of unique widths. This way, less different kinds of cladding panels and connectors will be needed. The optimization also counts with adjusting the tolerances between the sequences.

Also the new design of the solar shading system affected the modulation of the façade. Given the functionality of the solar shading shutters, that open to both sided of the window, the design has to by symmetrical and therefore the count of columns of the cladding tiles have to be an even number, ideally dividable by four, because the window shutters have 4 openable sequences. In order to simplify the modulation, but also for other practical reasons, the PV panels are only placed in the sequences that do not include windows and their shading systems. The other practical reasons are mainly related to leading the electrical cables at the opaque part of the façade.

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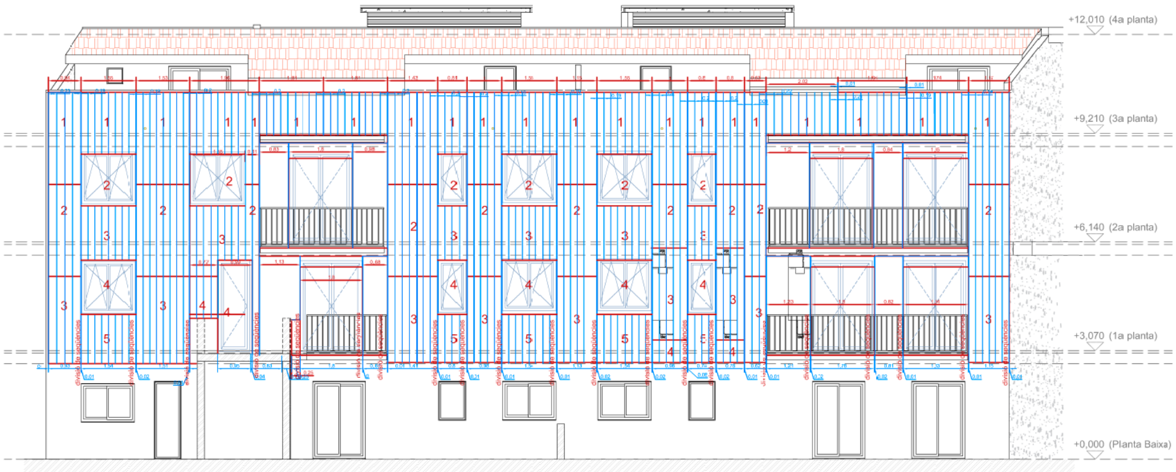

FIGURE 30: MODULAR DESIGN

Balconies. The four balconies at the West façade have all an eave- or another balcony, above their surface, which makes the installation of the HybridWall complicated, and does not take advantages of its off-site design. Therefore, it was decided that these areas of the façade will be renovated in more traditional way, applying ETICS to insulate the façade (no scaffolding is needed). Solar shading and the possibility to make the opening completely opaque, as requested by the building owner, will be assured via internal blinds, that are also easy to install and no maintenance.

It is still being discussed if the cladding pattern will be partially continued over the balconies, in order to provide shade to the interior also when the internal blinds are up, and to provide shade for the use of the balcony as well.

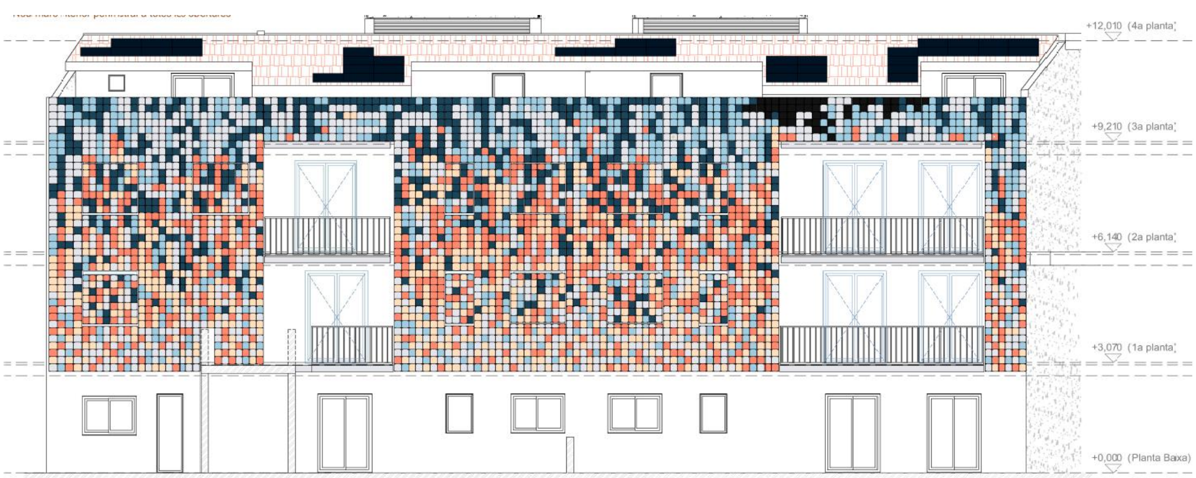

FIGURE 31: BUILDING FAÇADE, WEST ELEVATION

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Integration of the ventilation unit. Given that the building owner is interested in minimum maintenance, although the maintenance need of the ventilation unit are low and the exchange of filters and all the main interior equipment can be made and repaired from the interior of the building, the number of ventilation units eAHC has been decreased to 6. The ventilation units will be applied to 2 flats at the first floor, where the effects of it can be observed in a more controlled way, as the flat is completely located only on 1 floor, unlike the ones on the second floor. There is one ventilation unit located in each of the living areas- living room or bedroom, in total 3 units per flat. These 2 flats are also between the monitored ones. The ventilation units were located to only 1 of the facades also for maintenance issues. The East façade is has higher noise parameters, therefore the benefit of the ventilation units can be better observed.

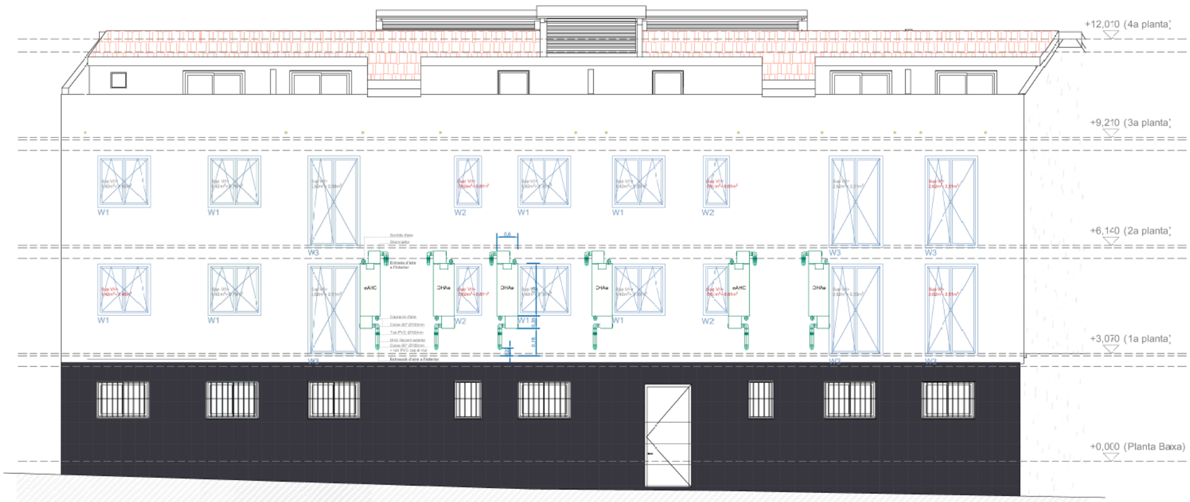

FIGURE 32: VENTILATION UNIT IN THE EAST ELEVATION

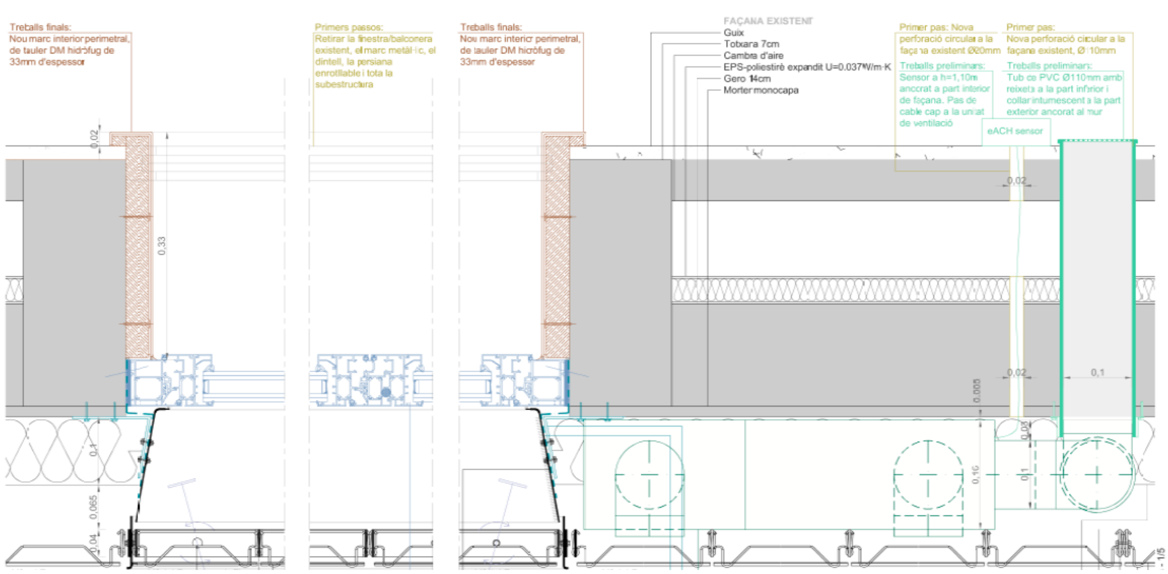

FIGURE 33: VENTILATION UNIT INTEGRATION, DETAIL

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5.1.3 Final architectural design of the PnU kits

Energy performance. The building is located in Terrassa, 286 m above sea level. The climate zone, which defines the nZEB requirements is D2. The transmittance of the thermal envelope of the walls in contact with the outside air is limited to have a maximum U of 0.19 W/m2K. Windowsin their entirety will have a maximum U of 1.16 W/m2K. The solar control parameter will not exceed the value of 0.80 kWh/m2.month. The air permeability of the windows will not exceed 5 m3/h.m2 The limit thermal transmittance of horizontal internal partitions, between units of the same use, will have one Ulim=0.43. The limit thermal transmittance of vertical internal partitions, between units of the same use, will have Ulim=1.83. The limit thermal transmittance of interior partitions, vertical and horizontal, between units of different use, they will have a Ulim= 0.69.

Protection against water and humidity. According to the technical code, as the building is located in rainfall zone III, in wind zone C, has a canopy less than 15 meters and is in an E1 environment class, the new solution guarantees a degree of impermeability 3. The moisture protection conditions of the new facade will also be guaranteed at those singular points where there are discontinuities related to the construction system used. The insulation used is waterproof and the finishing metal plates are superimposed on each other. With regard to the spouts of the balcony doors, the intermediate anchorages and the crowning of the facade, they will have a slope of at least 10º outwards and will be waterproof. They will protrude at least 2 cm from the facade, and at the bottom they will have a gutter. The spit of the balcony doors, in addition, will be extended by the jambs at least 2cm and with a slope of 10º, to act as flashings.

Acoustics. All the constructive solutions proposed in this project for the new facades will comply with the CTE DB-HR, technical regulation for the acoustic performance. Mainly, the present project considers the normative values for the sound insulation between houses and the street. The proof of compliance with the DB HR forms part of the project for building licence. On the main road- Martorell road a level of Ld =65dBA can be considered. For the interior facade, the one facing the courtyard, it could be considered a lower level. According to the local sound map, the limit value during the day is 65 dB, while during the night it is 55 dB.

Topic	Unit	Original building	Renovated building
Thermal properties			
U-value wall	W/m2K	0,48 / 0,52	0,19
U-value window	W/m2K	2,96	1,16
U-value roof	W/m2K	0,46	0,46
Solar shading type	-	Rolling shutters	Denvelops shutters
Solar shading control qsol:jul	KWh/m² month	0,73	0,80
Grade of waterproofing of the facade (CTE DB-HS)	-	none	3 (≤ 5)

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Airtightness of windows	m3/h.m2	none	5
Acoustic properties			
Sound resistance wall RAtr	dBA	unknown	55/ 58
Sound resistance window RA	dBA	unknown	32
Sound insulation to the areal noise D2m,nT,Atr	dBA	unknown	38
Lighting properties			
Minimum surface of window, natural light (D.141/2012)	m2	1/8 of the room surface	1/8 of the room surface
Fire protection			
Fire resistance of the walls (CTE DB-SI)	-	EI 60	EI 60
Fire class of the materials: walls (CTE DB-SI)	-	none	B-s3,d2 (facade cladding and interior of ventilated chamber)

TABLE 9 : MAIN CHARACTERISTICS OF THE RENOVATION SOLUTION

Thanks to the work realized in T*ask 4.4 PnU kit prototypes*, some changes in the design of the initial prototypes design were require. These changes are the following ones, and will be described in the next point:

- Attaching of the window to the façade.
- Need to install bigger PV tiles.
- Need to develop an easiest system to replace the UV
- Need to define a tolerance of installation and a system to absorb them.
- Change the opening system of the louvers.

In the next two images can be appreciated how these changes on the PnU AHC solution has not modified it is appearance beyond the dimension of the PV tiles (change od dimensions from 200x800 mm for a new one of 390x1190mm), and number of columns for the tiles for the sequences with louvers.

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FIGURE 34: FINAL DESIGN WITH CHANGES

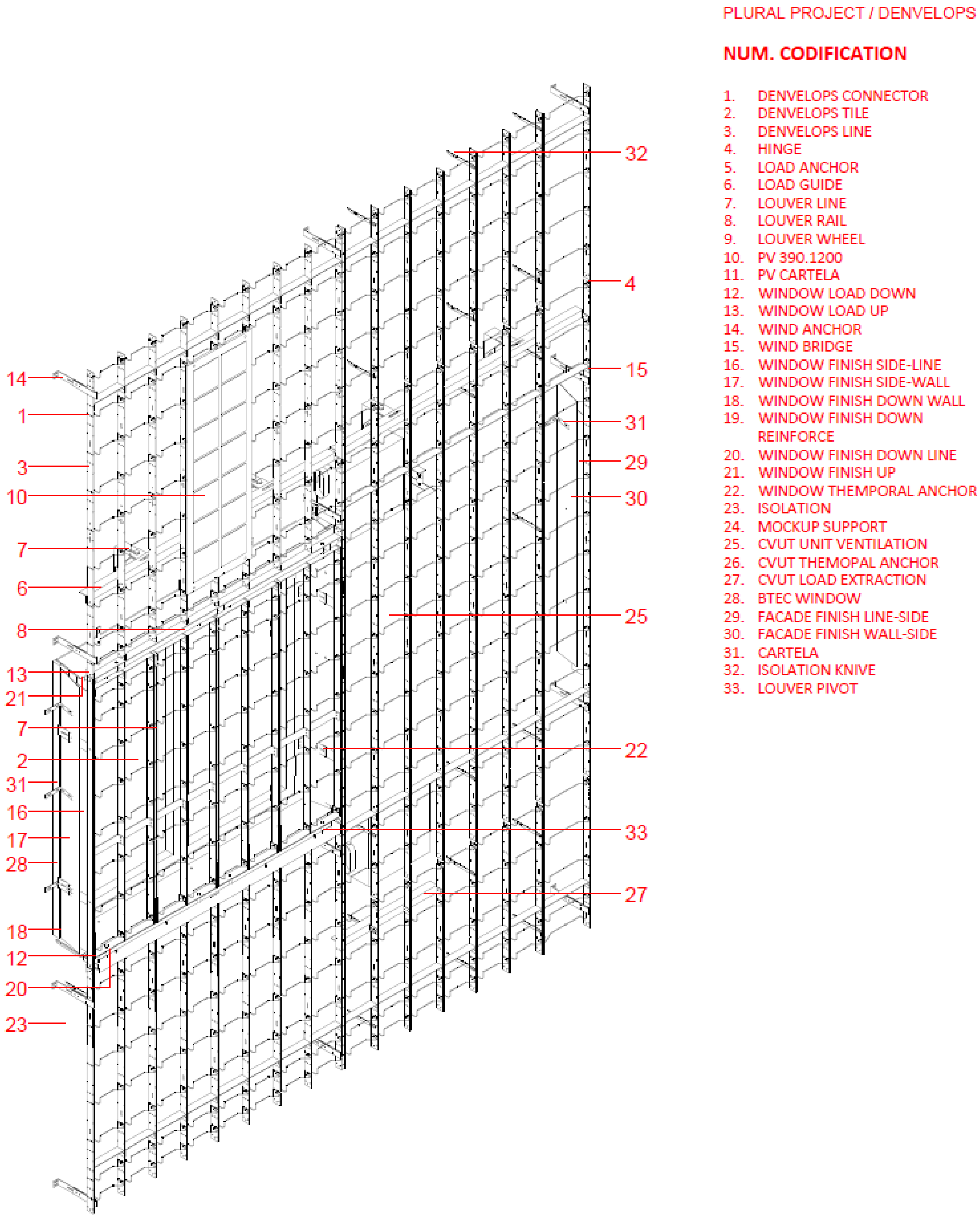

FIGURE 35: FINAL MOCK-UP COMPONENTS CHANGES

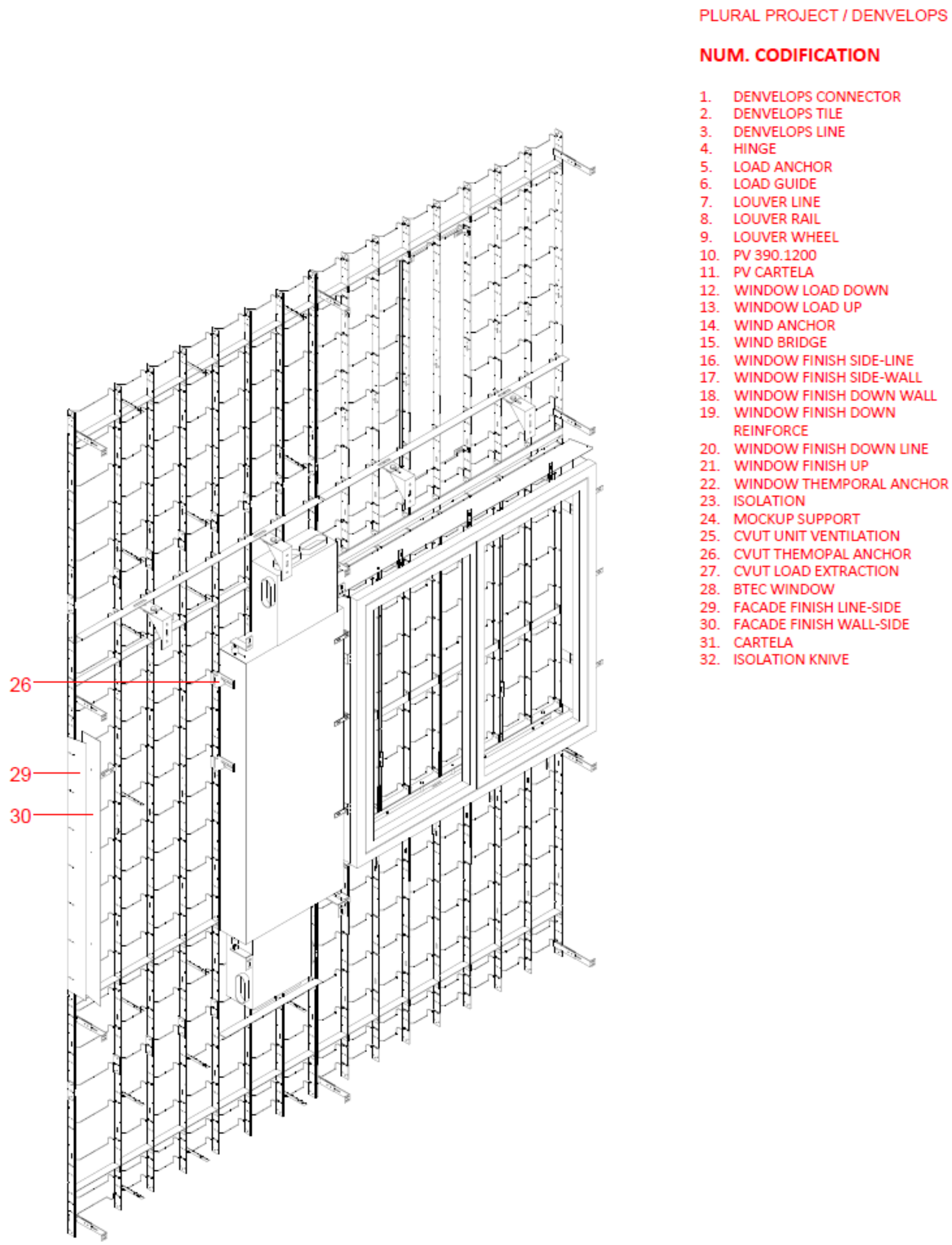

FIGURE 36: FINAL MOCK-UP COMPONENTS CHANGES

Attachment of the window to the façade. Component "Window Frame" nº 33 from initial mock-up components definition was removed for the next reasons:

- Weak design. It was supposed that together with the window the fitting of both components would be ok. But it was not.
- Thermal bridge: It was supposed it would be enough space in to add isolation seal to create a thermal bridge, but since it did not fit well it was not able.
- It was generating two times tolerances (tolerance of the window frame to the façade, and tolerance of the window frame to the window) which means having to lose light surface for the final window.
- Heavy weight: The window frame did not feel lighter and easy to move and install to the window.
- It was expensive to produce.

Instead of that is was realized that the window were really strong build, with heavy profiles, so that the window itself, was enough strong to be fixed to the Denvelops system, and later to the façade with no window frame.

So, the solution to improve the window frame was to eliminate it, earning the following advantages:

- Standard and quality installation: The window can be installed to the façade with standard procedures, so that all thermal benefits can be obtained.
- Lighter solution.
- Cheaper solution.
- Easy to integrate since there are less tolerances to keep.

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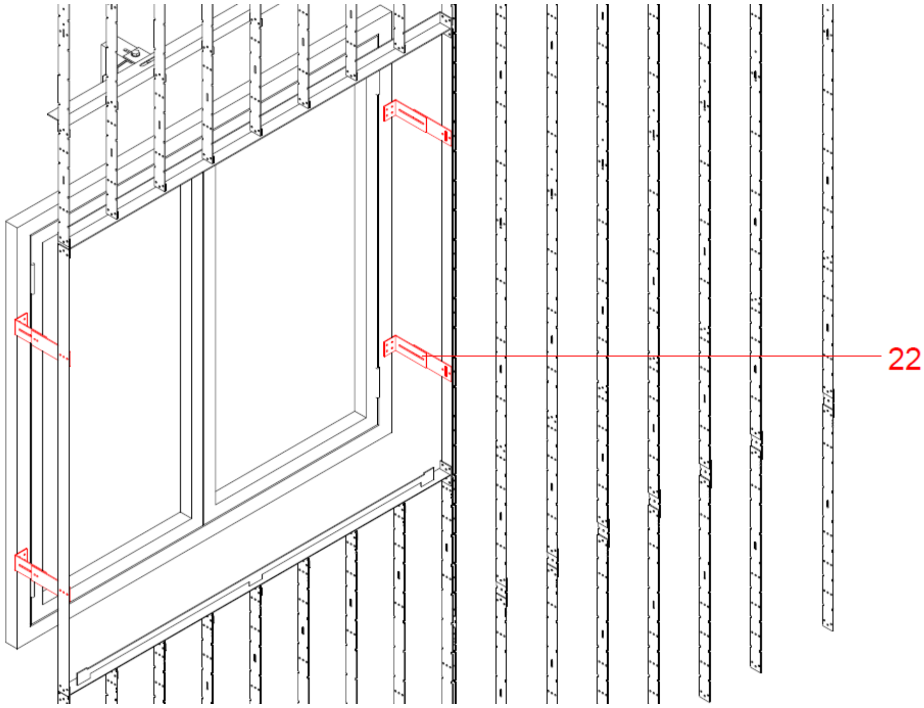

FIGURE 37: IMAGE OF WINDOW FRONT ATTACHED (N22) WITH NO WINDOW FRAME DIRECT TO DENVELOPS LINES

Need to define a tolerance of installation and a system to absorb them. The installation of the prototype realized to the team that tolerance design system maybe was not small. Despite the accuracy of the system, which ensure this would not be a problem, a new design detail for the finishing window were done to have installation tolerances of 5 cm.

Anyway, the attachment of the finishing windows components needed to be modified because of the elimination of the window frame. IN the initial prototype the window frame also were used to attach de window finishing components, but since it was removed, a new attachment detail was required.

The new solution, based on using gussets of 85 or 95 degrees, allow to fix the finishing windows in those degrees, and create two types tolerances for the installation process.

The first one, allow to adjust the window finishing to the window perimeter due to the large holes of the gussets. The second one, due to the orientated attachment of the window finishing, allows to create sort of space between the window and the Denvelops façade hole, that ensure that after installation both holes will be able to fit In an functional and aesthetic way.

Reinforce of the bottom component of the finishing window. During the analysis of the prototype, it was detected that the component sited in the bottom of the finishing window was a acoustic weak feeling in terms producing noise when it rains.

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To improve the reduction sound of these components a new layer has added under it. The designed solution consists in creating a two-layer sandwich solution, which means that under the original finishing piece made of stainless steel another layer of fiber cement board, that will eliminate that noise, and besides, the final solution has evolution to a stronger solution.

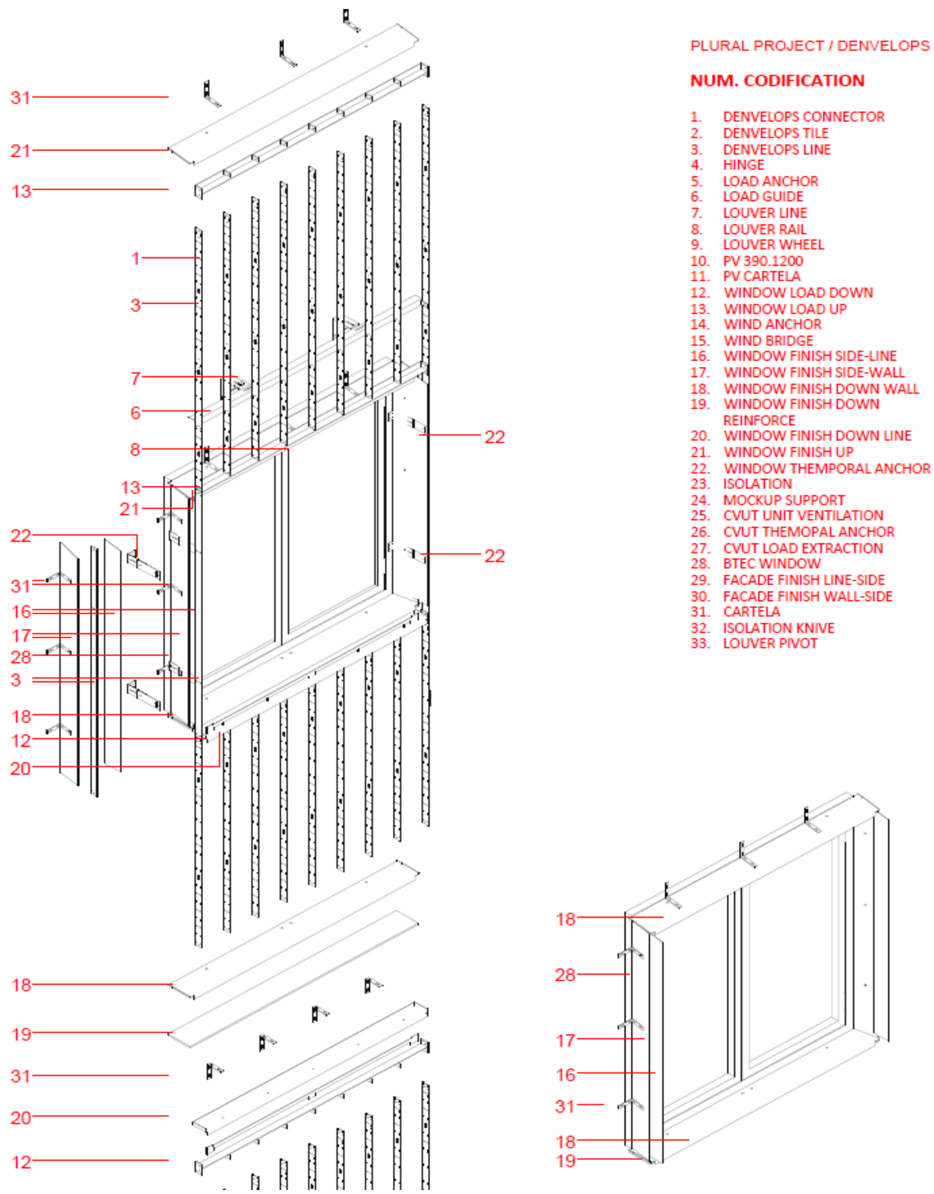

FIGURE 38: THE SPACE GENERATED BY COMPONENT N.17 AND N16. GENERATES THE TOLERANCE OF WINDOW AND FAÇADE INSTALLATION

Need to install bigger PV tiles. Due to the expensive cost of the initial proposed PV 200x800 mm tiles, a new dimension tile 390x1190mm was proposed to achieve the objectives of the project.

This requirement allowed to detect that the PV tiles attachment system had not been designed to be able to attach wider PV tiles.

IN the initial prototype design, PV were attached -always- between two lines, to leave them finished surface at the same level as the Standard tiles of the systems.

To install bigger PV, they may be attached in front of the Lines, which means that the solution increases 1 cm it thicknesses. Besides, in order to keep having the standard tiles at the same level of finishing PV tiles, the design of the connectors of the system, that attach the standard systems tiles was modified in order to move them 1 cm out, leaving in that way, all the Tiles of system, PV and standard at the same level.

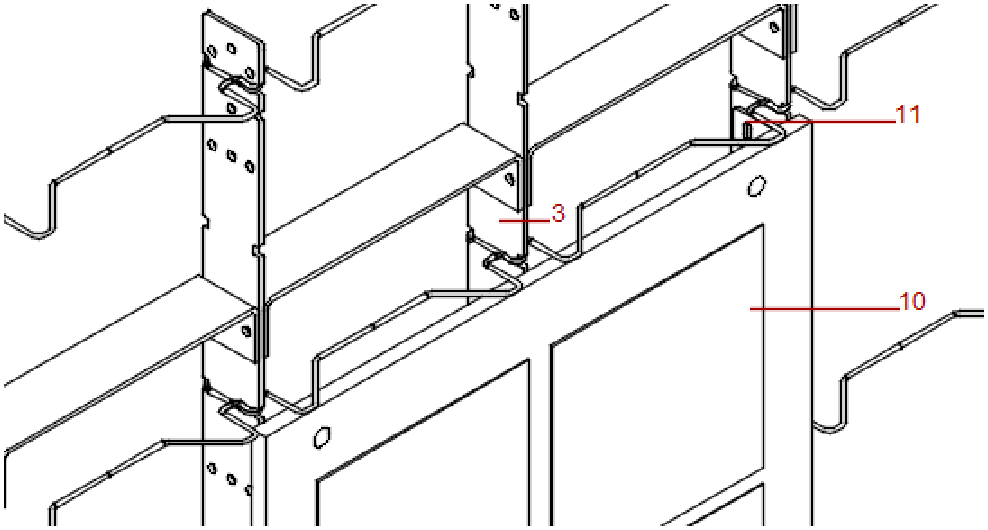

FIGURE 39: PV TILE DETAIL ATTACHED IN FRONT THE LINE POSITION (LEGEND N.3 LINE, N10. PV TILE, N11. PV TILE CARTELA)

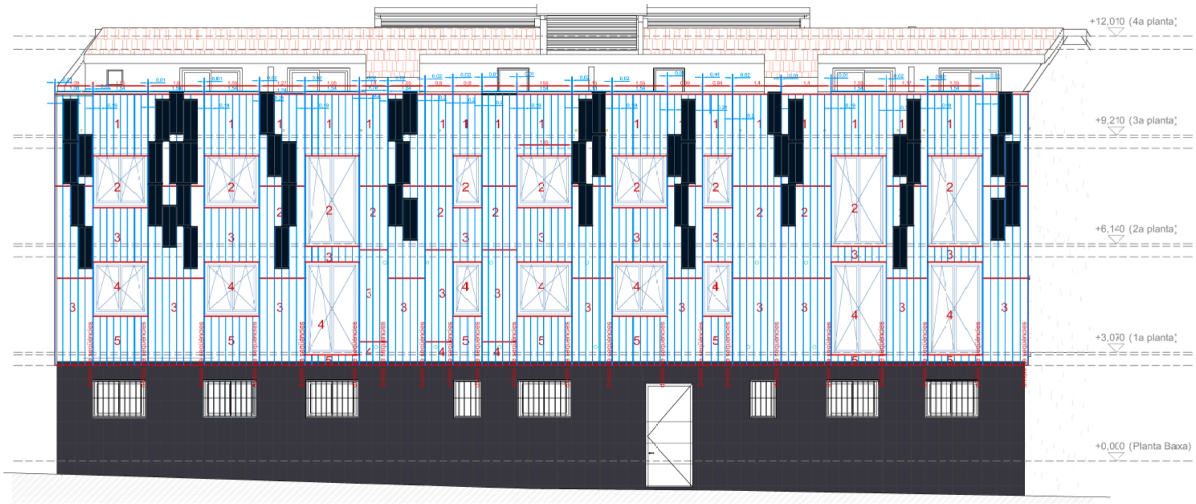

FIGURE 40: INTEGRATION OF PVS IN THE FACADE

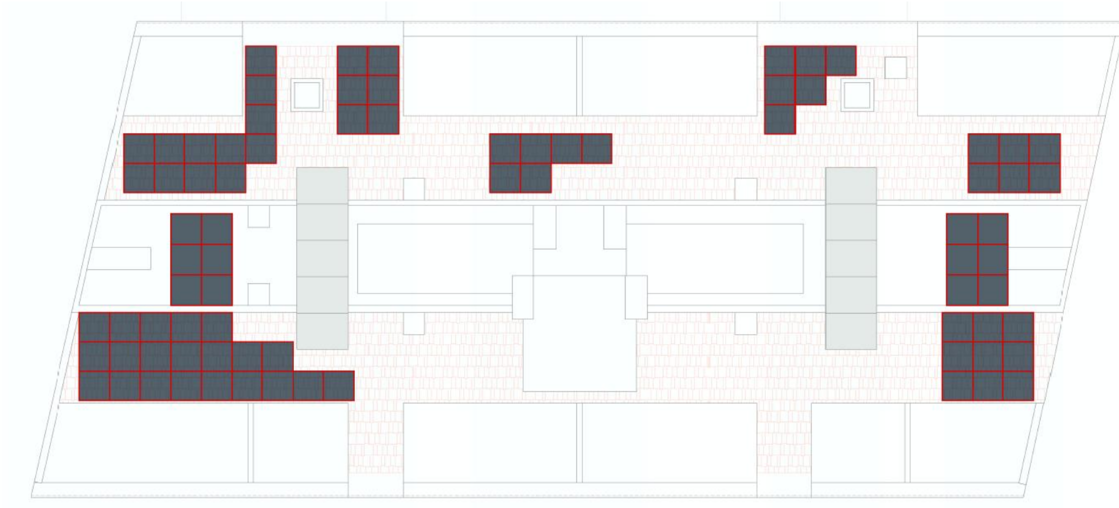

FIGURE 41: INTEGRATION OF PVS IN THE ROOF

Need to develop an easiest system to replace the UV. With the analysis of the first prototype, the Plural team for Terrassa Demo, realized that in case of having to take out the UV of the façade, it would be too much complicated and expensive, because to do that operation, one single sequence should be removed from the top de the bottom of the façade.

To improve this maintenance operation, a new component (called UV load extraction) was designed. It is a small load line that can be fixed temporally to the façade and create a little reinforcement to create a hole in the Denvelops system, just In front of the ventilation unit, with enough space to let the UV be taken off.

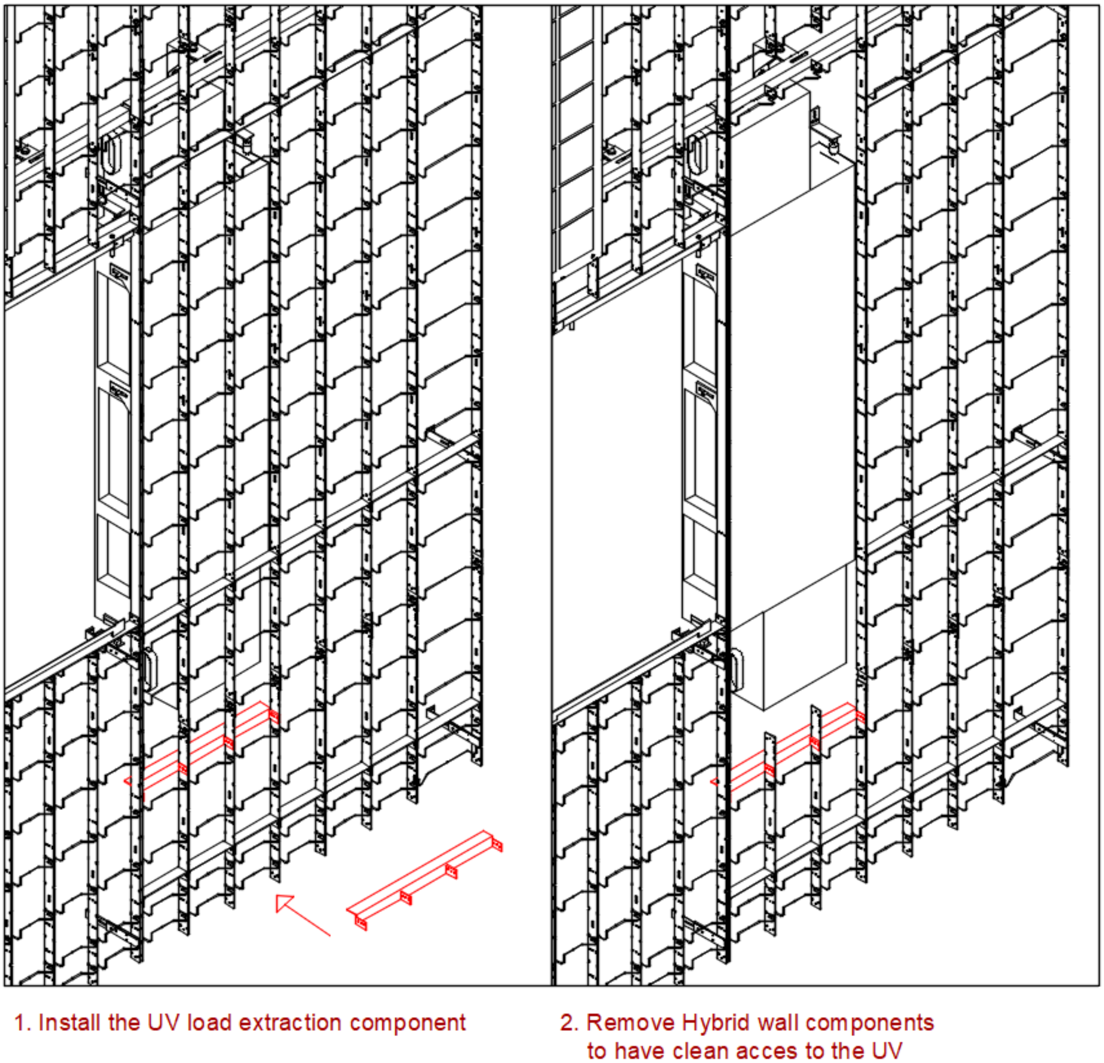

FIGURE 42: DETAIL OF THE INSTALLATION OF THE VENTILATION UNIT LOAD EXTRACTION

Change the opening system of the louvers. The Denvelops louvers systema and assembly was created and tested for the first time in the eAHC prototype. There were a lot of question to be known, special about the feeling and using commodity that the system would have. Beside it was also required to verify if the opening system of the louvers. Which in first time were designed to move by columns of tiles, in were every column could rotate over itself, and move to the sides.

Thanks to the prototype, it was realized that move all the columns one by one, was difficult and not practical. But allowed to the Plural team to define what type of louvers opening was the best for the project. This new opening was based on divide the louvers surface in 4 frames, which linked by hinges in groups of two frames, could be opened as a standard door or window, sliding, and rotating them to the window sides.

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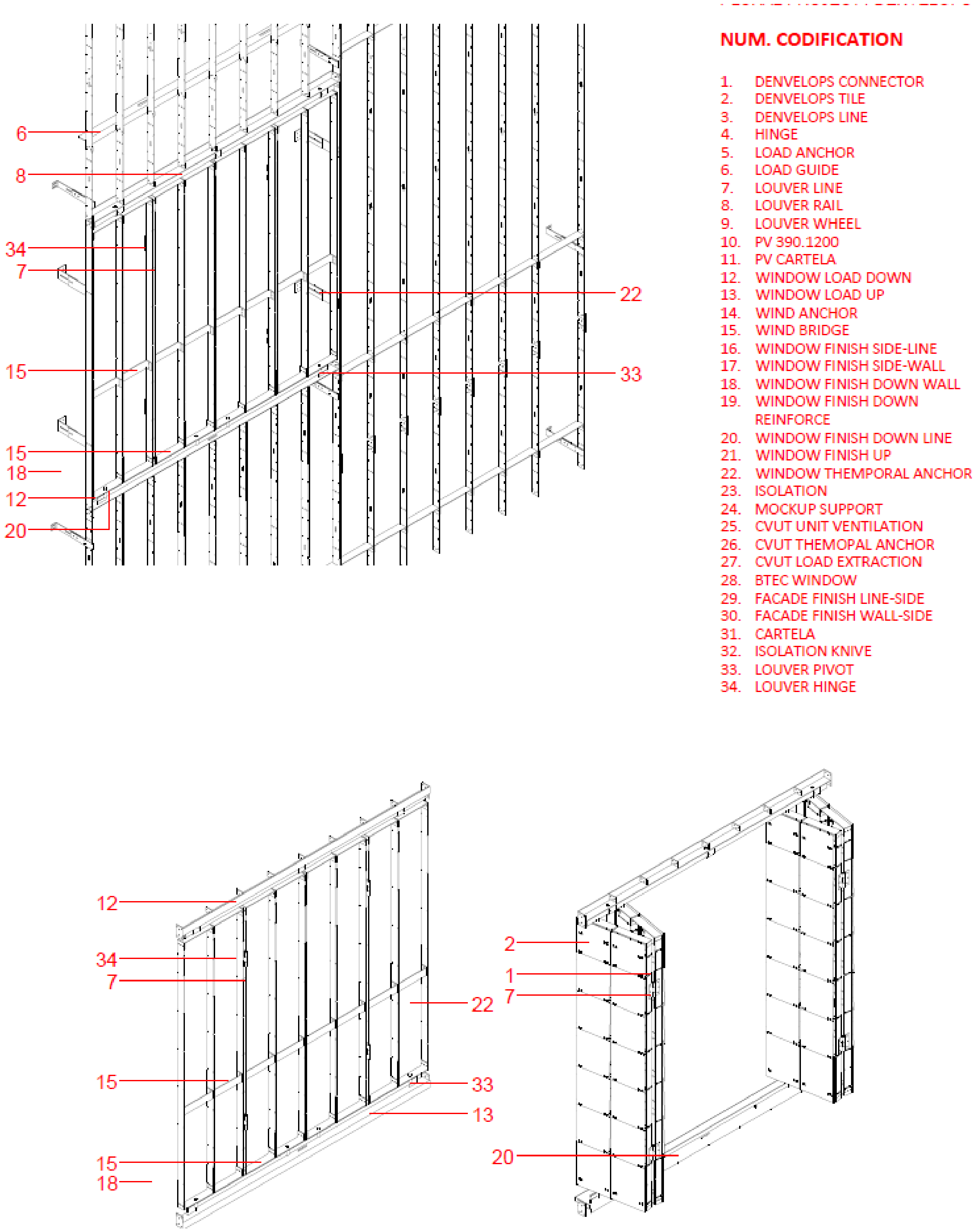

FIGURE 43: DETAIL IMAGE OF THE NEW LOVERS MOVEMENTS AND COMPONENTS

Window characteristics. Two types of aluminum windows aligned with the façade construction were selected for Spanish demo fulfilling thermal and acoustic building requirements.

Ponzio PE 68 aluminium frame with thermal break.

- Frame depth: 68 mm
- Sash depth: 76 mm
- Watertightness class: E1500
- Air-permeability: class 4
- Resistance to wind-load: class C5
- Thermal insulation: frame heat transfer coefficient Uf from 1,8W/m2K

In case of higher balcony doors Ponzio PE78N aluminum system will be applied providing better structural stability.

- Frame depth: 78 mm
- Sash depth: 86 mm
- Air-permeability: class 4
- Water-tightness class: E1650
- Thermal insulation: frame heat transfer coefficient Uf from 1,7W/m2K
- Resistance to wind-load: class C5

FIGURE 44 ALUMINIUM WINDOW SYSTEM PE 68

Two different glazing configuration fulfilling acoustic requirements are selected with specification as below.

In addition, micro-ventilation integrated in window closing mechanism will be applied due to the reduction of the ventilation units, providing possibility of the air exchange.
Windows will be installed to the aluminum façade by means of the special profiles without application of additional frame.

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① Stratophone Clearlite 44.2 Ricotto ② 16 mm Argon 90% ③ Stratophone 33.2 (3 mm iplus Top 1.0 on Clearlite pos.3 + 0.76 mm Acoustic PVB clear + 3 mm Planibel Clearlite) Ricotto

Simulazione di dati sulle prestazioni in opera del vetro

Caratteristiche luminose - EN 410	
Trasmissione luminosa : τv [%]	69
Riflessione luminosa : ρv [%]	20
Riflessione luminosa interna : ρvi [%]	22
Indice di resa dei colori : Ra [%]	95

Caratteristiche energetiche - EN 410	
Fattore solare : g [%]	46
Riflessione energetica esterna : ρe [%]	31
Riflessione energetica interna : ρei [%]	34
Trasmissione diretta dell'energia : τe [%]	38
Assorbimento energetico vetro 1 : αe1 [%]	23
Assorbimento energetico vetro 2 : αe2 [%]	8
Assorbimento energetico totale : αe [%]	31
Coefficiente di shading : SC	0.53
Trasmissione dei raggi ultravioletti : τuv [%]	0
Selettività	1.50

Proprietà termiche - EN 673	
Trasmittanza termica (vetri verticali) : U value [W/(m².K)]	1.0

Riduzione acustica	
Direct airborne sound reduction - Interpolated : Rw (C;Ctr) [dB] 1	44 (-2;-7)

Caratteristiche di sicurezza	
Resistenza al fuoco - EN 13501-2	NPD
Reazione al fuoco - EN 13501-1	NPD
Resistenza ai proiettili - EN 1063	NPD
Resistenza alle effrazioni - EN 356	P2A
Resistenza agli urti (Prova del pendolo) - EN 12600	1B1 / 1B1
Resistenza all'esplosione - EN 13541	NPD

Spessore e peso	
Spessore nominale : [mm]	31.5
Peso : [kg/m²]	37

FIGURE 45 GLAZING WITH ACOUSTIC RW = 44DB

① Stratophone Clearlite 66.2 Ricotto ② 20 mm Argon 90% ③ Stratophone 66.2 (6 mm iplus Top 1.0 on Clearlite pos.3 + 0.76 mm Acoustic PVB clear + 6 mm Planibel Clearlite) Ricotto

Simulazione di dati sulle prestazioni in opera del vetro

Caratteristiche luminose - EN 410	
Trasmissione luminosa : τv [%]	66
Riflessione luminosa : ρv [%]	19
Riflessione luminosa interna : ρvi [%]	21
Indice di resa dei colori : Ra [%]	93

Caratteristiche energetiche - EN 410	
Fattore solare : g [%]	45
Riflessione energetica esterna : ρe [%]	28
Riflessione energetica interna : ρei [%]	29
Trasmissione diretta dell'energia : τe [%]	35
Assorbimento energetico vetro 1 : αe1 [%]	28
Assorbimento energetico vetro 2 : αe2 [%]	9
Assorbimento energetico totale : αe [%]	37
Coefficiente di shading : SC	0.52
Trasmissione dei raggi ultravioletti : τuv [%]	0
Selettività	1.47

Proprietà termiche - EN 673	
Trasmittanza termica (vetri verticali) : U value [W/(m².K)]	1.0

Riduzione acustica	
Direct airborne sound reduction - Interpolated : Rw (C;Ctr) [dB] 1	51 (-2;-7)

Caratteristiche di sicurezza	
Resistenza al fuoco - EN 13501-2	NPD
Reazione al fuoco - EN 13501-1	NPD
Resistenza ai proiettili - EN 1063	NPD
Resistenza alle effrazioni - EN 356	P2A
Resistenza agli urti (Prova del pendolo) - EN 12600	1B1 / 1B1
Resistenza all'esplosione - EN 13541	NPD

Spessore e peso	
Spessore nominale : [mm]	45.5
Peso : [kg/m²]	62

FIGURE 46 GLAZING WITH ACOUSTIC RW = 51DB

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5.1.4 Final structural design of the PnU kits

The structural design of the Hybrid Wall PnU kits has not been changed from what was described in the Deliverable 2.1, Section 5.2.

The small changes, that have been introduced in the design of the detailed solution for the Demo Terrassa PnU kits, do not affect the basic calculation, or modify the required dimensions of the structural components defined in task 2.1.

5.2Final definition of the HVAC and energy systems

5.2.1 Energy efficiency of the building vs. Nzeb

To achieve nZEB status according to Spanish Regulation, the building must comply with the Building Techical Code (CTE), more specifically in the Basic Document for Energy Savings (DB-HE). This document limits the Primary Energy per conditioned area that the building can consume, according to the climatic zone where it is located, and depending on the fact it is a new or retrofitted building. The code sets the new building limits as a condition to achieve nZEB status. The Terrassa building is located in zone D2 in the division set by the code.

CTE regulation limits (ZD2)	Cons. EP nren [kWh/m2/year]	Cons. EP total [kWh/m2/year]
Primary Energy limit for new buildings	<38	<76
Primary Energy limit for existing buildings	<70	<105

TABLE 10: PRIMARY ENERGY LIMITS SET BY CTE

To calculate the Primary Energy Consumption, a detailed model of the building has been developed in TRNSYS, in the following figure, in the first place. The model reflected the behaviour of the whole building and its surroundings in terms of thermal influence and solar shading, but it was focused in the dwellings in floors 1st and 2nd+3rd, where the PLURAL solution will be installed. The model also reflected both states: pre-PLURAL and with PLURAL solutions installed.

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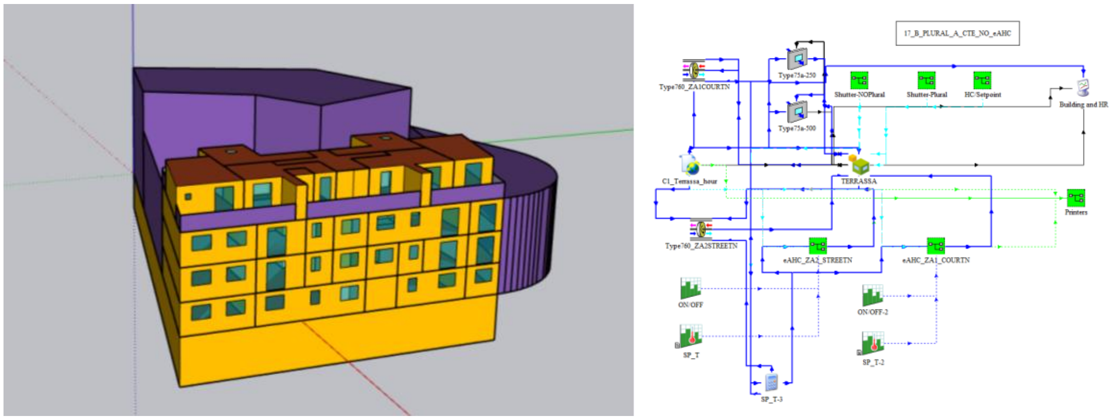

FIGURE 47: ON THE LEFT, THE GEOMETRY USED FOR THE TRNSYS MODEL. ON THE RIGHT THE TRNSYS MODEL.

The model allowed to calculated thermal demand and consumption for both heating and cooling. Domestic Hot Water demand was calculated as it is stablished in CTE, and the solar radiation contribution were estimated using monthly data radiation and the nominal performance of the thermal collectors already existing in the building.

The solar PV contribution was estimated in a first iteration, using PVGIS, in order to know the potential of the available surfaces in the building. This first analysis showed that it was possible to provide enough renewable energy to the PLURAL dwellings, in order to comply with the nZEB limits. It has to be taken into account, that the CTE sets a matching factor = 1 between renewable energy production and the building consumption using monthly values.

To calculate the Primary Energy the following pass factors were used:

Primary energy conversion factors				
		Fp_ren	Fp_nren	Fp_tot
Electricity	Grid	0.414	1.954	2.368
Electricity	PV	1	0	1
Environment heat	ENV	1	0	1

TABLE 11: PRIMARY ENERGY CONVERSION FACTORS

The results of energy demand and primary energy consumption appear in the following Table, and are compared to initial results of the building.

Topic	Unit	Original building	Renovated building
Cooling energy demand	kWh/m²	15.78	19.19
Heating energy demand	kWh/m²	26.52	12.96

DHW production demand	kWh/m²	26.84	24.96
Overall primary energy	kWh/m²	102.49	79.97
Renewable energy production	kWh/m²	10.83	89.73
nZEB standard reached?	Y/N	N	Y
Which document defines the nZEB standard?	N/A	Documento Básico HE Ahorro de energía	Documento Básico HE Ahorro de energía

TABLE 12: ENERGY EFFICIENCY FOR THE PLURAL DWELLINGS OF THE TERASSA BUILDING

Finally, in order to validate the whole process, the building underwent the Energy Certificate. It was performed using the approved tool for energy certification, CE3X, including a plug-in with integrated verification of the requirements of the local building code CTE HE0 and HE1. The process resulted favorable and the energy certification is annexed to this document.

5.2.2 Passive strategies implemented

The HybridWall renovation kit includes 2 important active technologies- the photovoltaic panels and the ventilation unit with heat recovery and additional heating and cooling, but also provides multiple benefits from the implemented passive strategies.

The integrated insulation. The base of the PLURAL HybridWall is the Denvelops system, providing the exterior cladding layer. Within this development, the thermal insulation was integrated in the prefabricated system. The insulation material-glass wool, is connected to the substructure of the system. This way, it does not have to be attached to the existing wall, so it does not create additional thermal bridge or potential for water penetration. The insulation is water-repellent so it does not need any additional waterproofing protection, which was confirmed by the producer. However, special details such as the integration of the ventilation unit or the window perimeter are protected with additional layer of a weathering membrane.

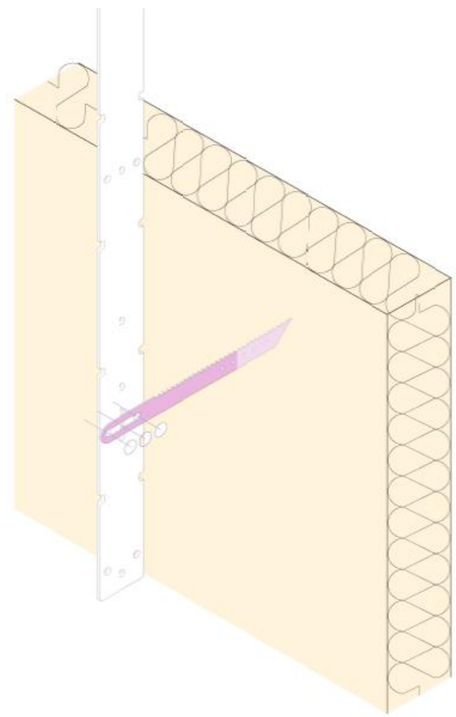

FIGURE 48: INTEGRATED INSULATION

The flexible solar shading. The possibility of allowing for visibility and solar shading at the same time is the main advantage of the proposed solar shading system- apart of the aesthetic advantages and logistic advantages of being part of the same system. Systems that do not allow this feature might compromise the overall energy efficiency, given that the users prefer the visibility over the shading. With the HybridWall system, the shutters can be either fully closed, open, or partially open. Given that the facades in question are oriented to the East and to the West, the system is even more appropriate, because the shutter in the open position if perpendicular to the façade acts as vertical solar shading, useful either during the early morning and late afternoon hours.

Exclusion of thermal bridges. The lightness of the HybridWall brings advantages also from the thermal point of view. Given that the whole façade is hanged from the top, it does not need multiple anchoring points, apart of the small wind anchors that are located at the perimeter of each vertical sequence of the system. The continuation of the thermal insulation between the modules is assured by keeping the insulation slightly wider than the module, so it can get condensed when 2 sequences are placed next to each other, and no air gap- linear thermal bridge occurs therefore. At the window detail, the perimeter of the window integration with the existing wall, if overlapped by the thermal insulation layer, guided by especially designed flashing.

The flashing assures that there is no gap between the elements leads any possible water collected within the façade layers to the exterior.

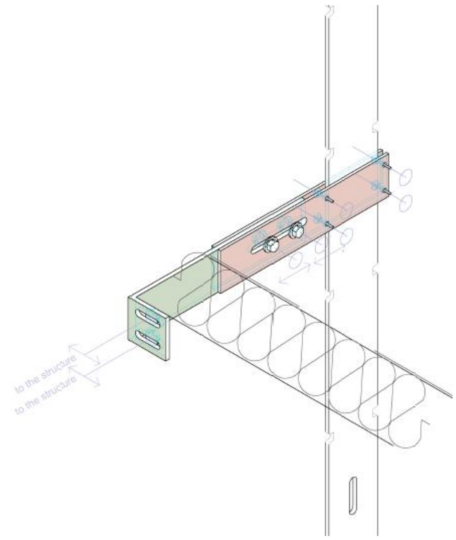

FIGURE 49: HYBRIDWALL WIND ANCHORS

5.2.3 Ventilation system (as per T2.3)

Ventilation unit for Denvelops HybridWall panel is built in PnU kit structure and serves for one room. This requires very specific dimensions respecting load bearing construction of façade panel. Especially the depth of ventilation unit is very low, up to 170 mm. For air supply and extraction from and to each ventilation unit is provided short PVC air channels. These channels are connected to silencing extensions of the unit and lead in thermal insulation to holes in the building wall. Channels are insulated.

The selected ventilation unit for Terrassa demonstration is a novel ventilation unit starting with CVUT IP. The air flow range is 20 to 90 m^3/h. The unit has two stages of heat recovery. The first stage is a counter flow enthalpic heat exchanger. The second stage of heat recovery is provided by an active module, which allows the fresh air to be heated in the winter and cooled in the summer. The active module works by means of thermoelectric cells (a heat pump principle). The conversion of electric energy into heat or cold therefore takes place directly in the device - no additional heat or cold source is needed. The thermoelectric modules then work with a COP and EER factor > 1 and thus the heat conversion is more efficient compared to an electric heater. Other typical components are two controlled fans, two filters of various classes from ePM Coarse to ePM2.5 for air filtration.

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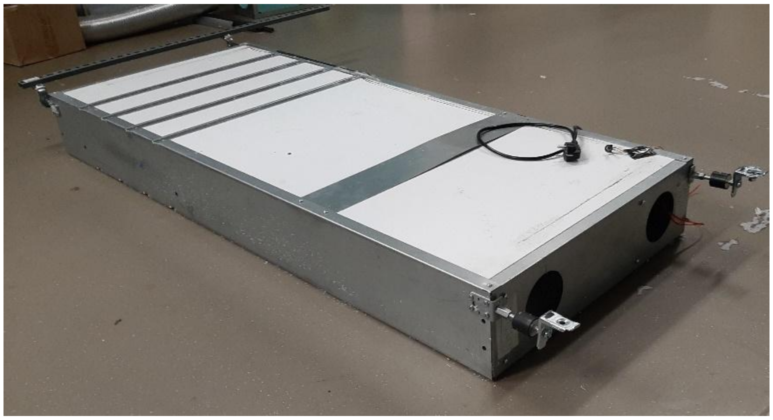

FIGURE 50: PROTOTYPE OF NO. 2 OF CVUT VENTILATION UNIT

Hanging system support the unit on wall surface. It use at each corner of the unit two L shaped anchors separated by a silenblock. One L shaped anchor is mounted to the unit body, the other to C rail. This rail is fixed to wall by two plugs.

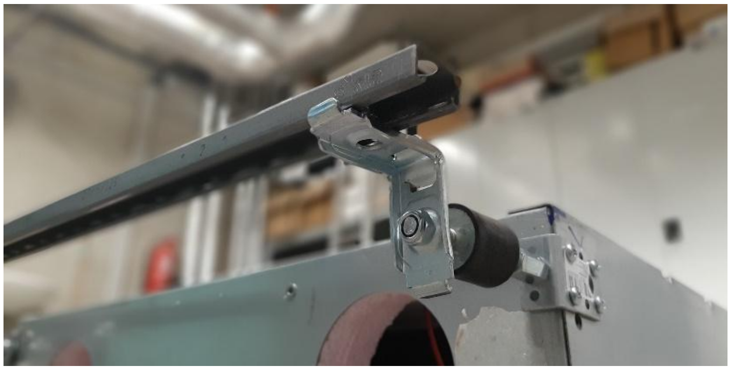

FIGURE 51: ANCHOR OF VENTILATION UNIT WITH SILENBLOCK

Each ventilation unit needs the 230 V/50 Hz electric supply with 6 A short-circuit protection and individual electrical circuit. The ventilation unit is autonomously controlled by the internal microcontroller that obtain the data mainly from the Indoor Air Quality sensors. The control algorithm is rule-based that control the fan speed and power of TEMs according to the actual concentration of CO_2.

For more technical information please see the *Deliverable 2.3. Ventilation systems selected for each demo site.*

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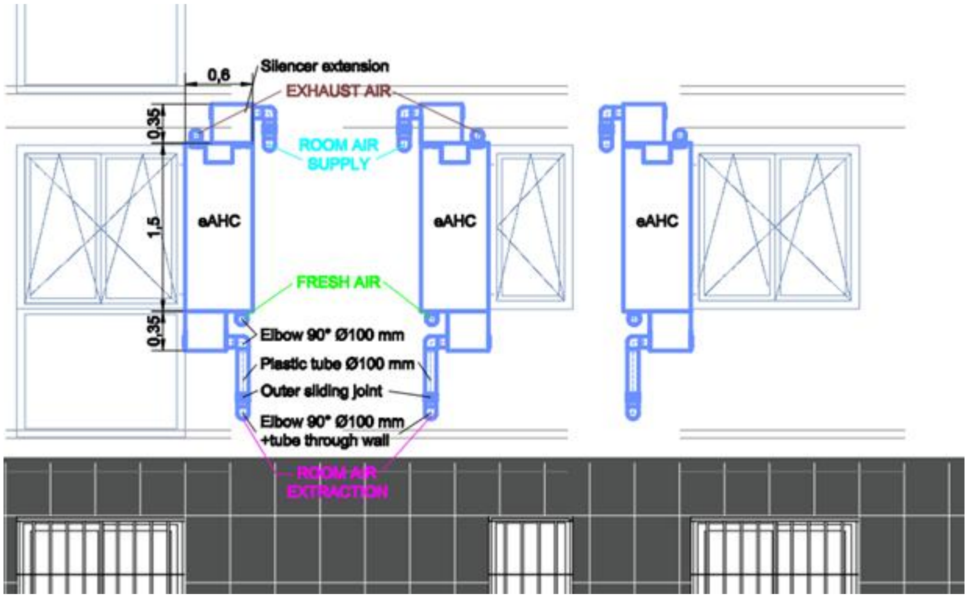

FIGURE 52: FRONT VIEW OF POSITIONS OF VENTILATION UNITS FOR ONE APARTMENT OF DEMO BUILDIND IN TERASSA

The ventilation unit is connected to the interior via short air channels for air supply and air extraction. These channels are pre insulated PE/PVC 100 mm tubes located in the layer of the thermal insulation, so the air temperature is not affected by the exterior temperature. Each tube penetrates outside wall through a drilled hole. Every supply is designed beneath the ceiling while extract over the floor. Path of air channels and holes location allows flexible positions. End of tube use a simple air diffuser for air distribution. Also the IAQ sensor will be connected to the unit via a cable lead through a little hole near (or behind) the unit. Suction of fresh air into each unit and exhaust from the unit is done directly through a grill in the façade cladding.

5.2.4 Heating and cooling system (as per T2.4)

It is not part of the PLURAL project to select and size heating and cooling systems. Instead, the pre-existing installation will be kept. For the heating demand, each dwelling is equipped with electric radiators from 4 to 7 units depending on the dwelling, and with 1.500 W of power each. The building has no cooling equipment.

5.2.5 Energy system, PV installation (as per T2.5)

After the first iteration from the building energy simulation, a detailed estimation of the PV production was carried out. In the first place, the solar radiation was calculated with DesignBuilder for each available surface, in the following figure.

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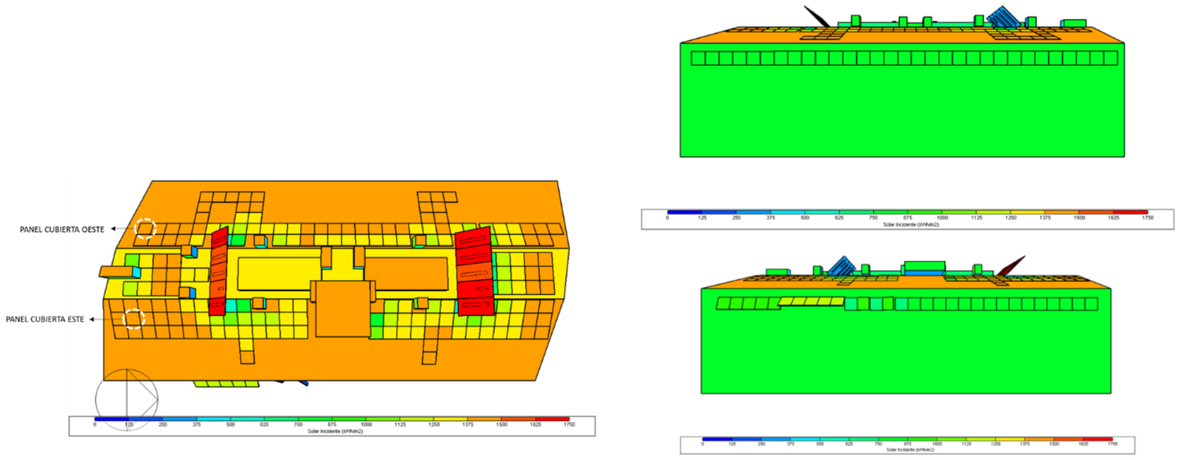

FIGURE 53: DETAILS ESTIMATION THE ANNUAL INCIDENT SOLAR RADIATION FOR THE DIFFERENT AVAILABLE SURFACES OF THE BUILDING. IT WAS CARRIED USING DESIGNBUILDER

After the technology and the models of the PV panels was selected, the final calculation of the PV production is presented in the following Table.

Cons. EP nren [kWh/m²/year]	Cons. EP total [kWh/m²/year]	Surface	Irradiation (kWh/m2·year)	Area (m2)	PV eff.	Production (kWh/year)	Productivity (kWh/ M2·year)
37.96 < 38	75.88 < 76	East roof	1404.2	19.8	18.00%	5005	252.76
		West roof	1409.6	28.2	18.00%	7155	253.73
		Horizontal roof	1409.6	8.5	18.00%	2157	253.73
		East Facade	799.8	11	16.03%	1410	128.21
		West Facade	804.5	10.7	16.03%	13.85	129.44
		TOTAL		**78.2**		**17111.7**	

TABLE 13: ENERGY EFFICIENCY FOR THE PLURAL DWELLINGS OF THE TERRASSA BUILDING

Topic	Unit	Original building	Renovated building
PV panel type	N/A	-	Monocrystalline silicone

PV panel size (Length x Width x Thickness)	mm	-	1.200 x 390 x 9,93	840 x 840 x 9,93
PV panel peak power	Wp/u.	-	75 +-3 Wp	127 +-3 Wp
Location	-	-	Façade (East)	Rooftop
Nr. of panels /Orientation /Inclination	Units / º / º	-	50 / East (-81) / 90	A → 30 / East (-81) / 20 B → 12 / South (0) / 5 C → 36 / West (99) / 20
TOTAL installed PV peak power	Wp	-	3.750	A→ 3.810 B → 1.524 C→ 4.572
			TOTAL = 13.656	
TOTAL PV energy production	kWh/year	-	3.027	A→ 4.901 B→ 2.038 C→ 5.454
			TOTAL = 15.420	
% of Total electricity demand covered	%	-	28,04%	

TABLE 14: PV PRODUCTION

Topic	Unit	Original building	Renovated building
Solar collector type	N/A	Helioconcept SRV 2.3 SAUNIER DUVAL	-
Solar collector surface	m^2/u.	2,35	-
Solar collector peak power	Wp/u.	1.860	-
Nr. of panels /Orientation /Inclination	Units / º / º	10 / South (0) / 37	-
TOTAL installed peak power	Wp	18.600	-
TOTAL energy production	kWh/year	13.787	-

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% of Energy demand for DHW production covered	%	45,78	-

TABLE 15: SOLAR COLLECTORS

The photovoltaic installation that is the object of this project is a type of shared photovoltaic self-consumption installation with grid support. The photovoltaic installation will be connected to the centralization of community meters as a further supply. Self-consumption will take place among the 18 existing homes in the building and the respective common areas. The distribution will be made among all the neighbors through previously established distribution coefficients. The surpluses that occur when there is more energy production than consumption will be injected into the network, although they will not have the consideration of energy incorporated in the electric power system and will be treated through an administrative mechanism of simplified compensation as a surplus recoverable in a deferred manner over time according to the regulation developed in this respect.

The photovoltaic generator will be distributed in two areas of the building:

Zone 1 - East prefabricated facade: The modules of the prefabricated facade, which will be attached to the east facade of the building, will incorporate 50 photovoltaic panels, with amorphous silicon cells, of a single type and with a unitary power of 75 W. The total power of this field of panels will be 3,750 W. The orientation of the panels will be east (-81º) and the inclination will be vertical (90º). The panels have been made to measure for this project.
The photovoltaic panels on the east facade of block A will be installed integrated in the facade and connected to each other as part of the same installation process. The cables of the different strings will be left at the top of the facade, on the roof, properly protected and signaled.

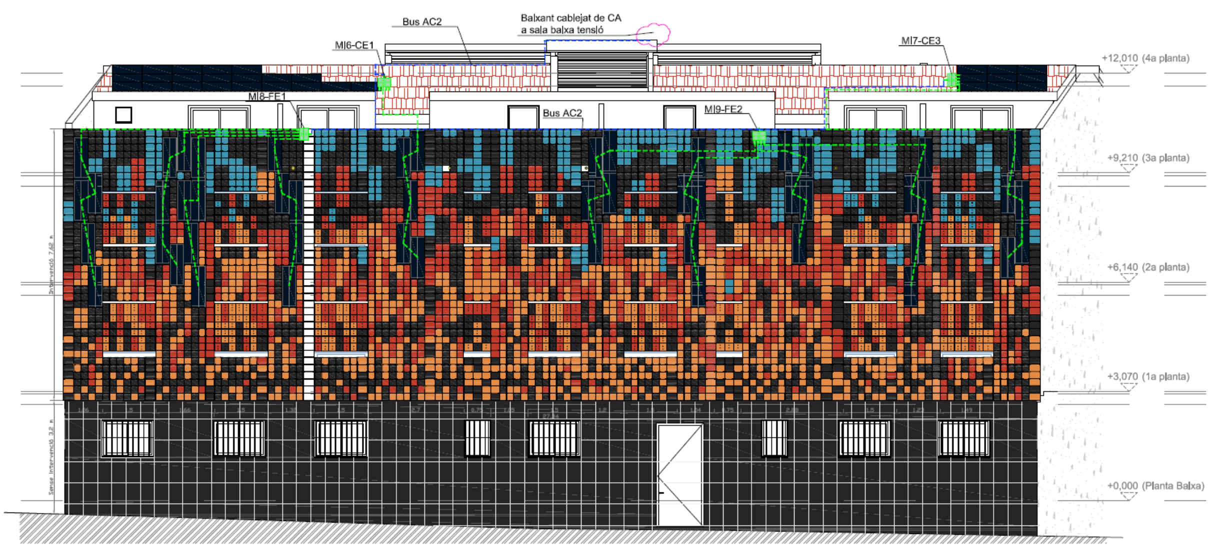

FIGURE 54: EAST FACADE

Zones 2 – Roof: It is a gable roof, with one side oriented to the east and the other to the west, in addition to a horizontal section (flat) in the highest part of the roof located between the two sides. Photovoltaic panels will be placed both on the two slopes and on the horizontal part. In total, 78 photovoltaic panels of 127 W will be installed, adding up to a total power of 9,906 W. The panels will be of PERC monocrystalline silicon and with an aluminum frame. Like the facade panels, these have also been made to measure.

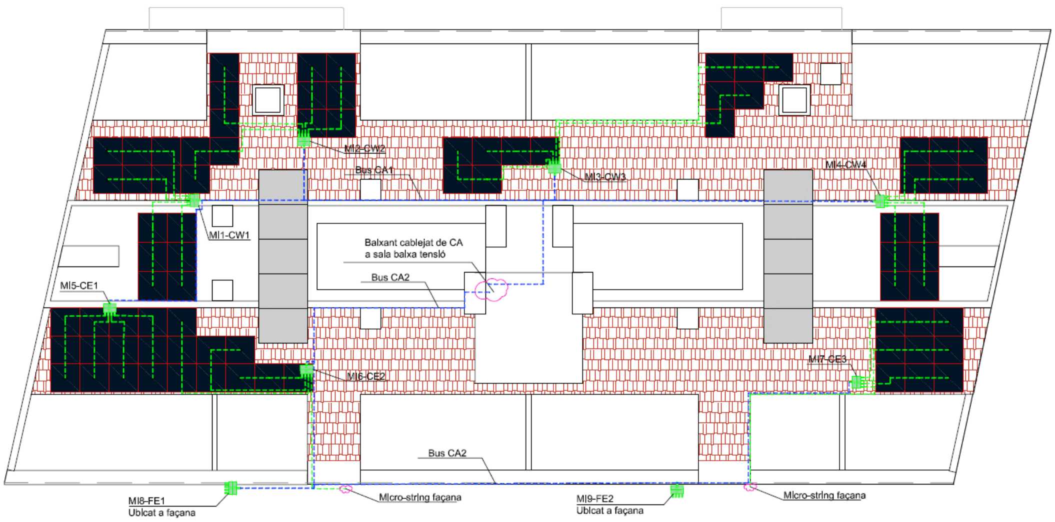

FIGURE 55: PLAN

The panels will be distributed over the roof so that the effects of the shadows of the existing elements (chimneys, thermal solar panels, walls, rafters, antennas) are minimized. However, some of the panels will be affected by shadows at some point during the day. An installation with micro-inverters in order to minimize the effect of shadows. The panels will go supported by metal structures developed by the company Denvelops, partner of the PLURAL project. There are 3 different inclinations and orientations:

- East slope → orientation of the panels will be east (-81º) and the inclination of the roof (20º).
- Horizontal part → orientation of the panels will be south (0º) and the inclination practically horizontal (5º).
- West slope → orientation of the panels will be west (99º) and the inclination of the roof (20º).

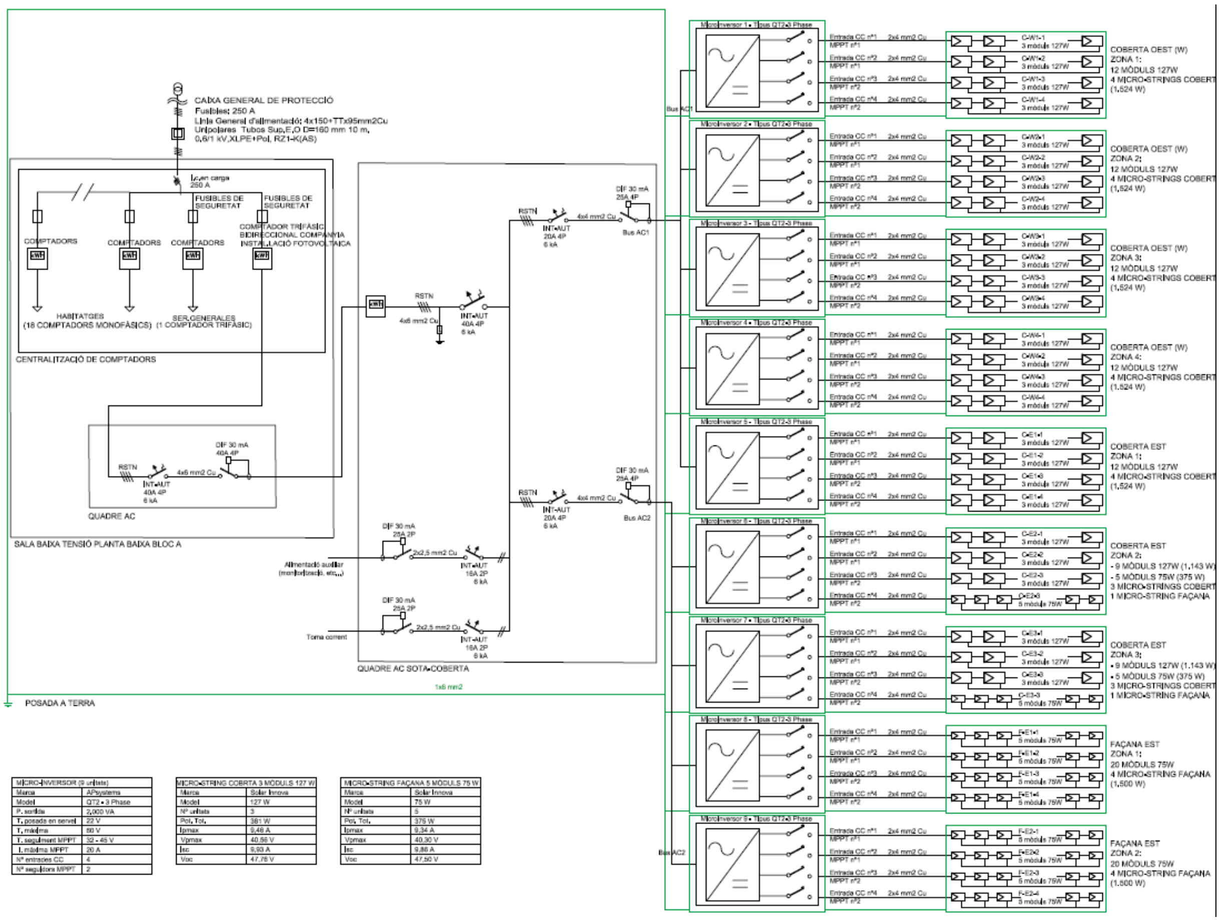

FIGURE 56 ELECTRICAL CONNECTIONS OF THE PV INSTALLATION

5.2.6 Smart system (as per T3.4)

The Terrassa building counts with individual HVAC units in each room. The cooling is provided with electric radiators, the cooling with electric air conditioning system, both of them are previous to PLURAL installation, and each of them has its own control system to follow the setpoint introduced by the user. Ventilation is provided by the eAHC, and this counts with its autonomous control based on PID to follow the IEQ/IAQ setpoints provided by the IAQ Multisensor. An intelligent Fault Detection system is developed in the PLURAL project (T3.3.3) to track the eAHC operation and detect the faults that appear gradually, before the global performance of the unit decreases significantly.

As in the other demo-sites, the operation data of the HVAC systems are monitored and recorded in the LYSIS system in order to track and assess their performance.

5.3Post-design life-cycle phases

5.3.1 Manufacturing

The eAHC Hybrid Wall will be produced aligned with the standard production system that Denvelops does for them project. Of course, in spite the basis of the production line is the same, the Hybrid wall includes new functions that requires to add manufacturing stations to the process.

An initial manufacturing process has been already large descried in task 4.4, point 3.3, and 3.4. And in fact, to produce the Demo Project same process will be used, maybe with some modifications, as them will be described in tasks 6.1 and tasks 6.2.

As a brief resume to improve the comprehension of this task, the manufacturing of the eAHC Hybrid walls of Terrassa Demos will be divided in the next steps:

- Detailed design
- Components and provision process
- Components storage
- Components production process
- Frame assembly process
- Frame storage

In the next table are explained how, where, and by whom, will be done each one.

More description can be found in the deliverable *D4.4. PnU kit prototypes addressing the 3 demo building requirements.*

Phase 1: DETAILED DESIGN

MATTER	DESCRIPTION
WHAT	• Double check that the overall project dimensions fit with the real dimensions of the building site. • Take the technical project from this task and work in them to create a codification list with all the components that will need to be produced to the assembly. • Double check that all the assembly drawn in the computer fits ok and there are no mistakes.
WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project
WHERE	• Denvelops offices
HOW	• Some real dimensions taken in the building demo site. • Autodesk cad drawing programs. • Microsoft office (excel and word)

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TABLE 16: DETAILED DESIGN

Phase 2: COMPONENTS PROVISION PROCESS

MATTER	DESCRIPTION
WHAT	• Denvelops is not a material or components producer, it is a chain assembly company, which means that all the components they install are produced by specialized providers. So, this task is related to work with Denvelops providers in other to buy the components with the lower price and the maximum quality. • Quality control of all components must be done at them arrival. • Determinate a Delivery date for all components.
WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project. • Providers technical office.
WHERE	• Denvelops offices, providers offices.
HOW	• For each customised component that need to be cut with cnc machines, and special for the new one, works meeting between technical offices are required to define the best way to produce a component piece at the time the required technical characteristics are respected. • For standard components, such isolation, screws, standard buying criteria are followed to buy them.

TABLE 17: COMPONENTS PROVISION PROCESS

Phase 3: COMPONENTS STORAGE

MATTER	DESCRIPTION
WHAT	• Optimize the space. • Reduction of the time to move components from entrance/storage place/ assembly place • Respect storage ambient and safety conditions. • Keep updated the data of the storage. • Type of industry and fabrication process • Type of components (ready for assembly or to do some process before installing)
WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project.
WHERE	• STAGE 1- STORAGE. Denvelops factory. The factory is divided in 4 big areas, 1) storage, 2) manufacturing 3) assembly station and 4) Storage and delivery.

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	• Storage area is large sited in front the assembly area, so that each type of component, according to his function, is storage close to the workstation where every component is required during the assembly.
HOW	• By using forks and lifts, components will be storage over the floor or in bookshelves.

TABLE 18: COMPONENTS STORAGE

Phase 4: COMPONENTS PRODUCTION PROCESS

MATTER	DESCRIPTION
WHAT	• Manufacture the Denvelops components that has arrived with no final dimensions. • Give to the waste a property and green treatment.
WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project.
WHERE	• STAGE2- MANUFACTURING. Denvelops factory. The factory is divided in 4 big areas, 1) storage, 2) manufacturing 3) assembly station and 4) Storage and delivery. • Special manufacturing stations will be prepared: ○ Isolation cutting table ○ Fibro cement board cutting table
HOW	• By using cutting tools, components will be produced following the detailed components plans.

TABLE 19: COMPONENTS PRODUCTION PROCESS

Phase 5: FRAME ASSEMBLY PROCESS

MATTER	DESCRIPTION
WHAT	• Do the assembly of the each of the PnU according to the detailed design project.
WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project.
WHERE	• STAGE 3- ASSEMBLY STATIONS Denvelops factory. The factory is divided in 4 big areas, 1) storage, 2) manufacturing 3) assembly station and 4) Storage and delivery. • The assembly will be divided in 4 stations: ○ **A) For horizontal PnU assembly works** ○ **B) For vertical PnU assembly works** ○ **C) Preassembly window:** ○ **D) Preassembly louvers:**

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HOW	• By using standard assembly tools (see lower description) • The system has been designed I order to use the maximum same type of tools.

TABLE 20: FRAME ASSEMBLY PROCESS

Phase 6: FRAMES STORAGE

MATTER	DESCRIPTION

WHAT	• PnU must be storage before send them to the building demo site.
	• PnU must storage following the next criteria:
	    ○ Installation order.
	    ○ Optimizing the number of palette and transport to be done

WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project
WHERE	• STAGE 4- STORAGE AND DELIVERY Denvelops factory. The factory is divided in 4 big areas, 1) storage, 2) manufacturing 3) assembly station and 4) Storage and delivery.
HOW	• By using standard tools (see lower description) • By using forks and lifts

TABLE 21: FRAME STORAGE

5.3.2 Transportation

The Hybrid Wall PnU will be loaded on a truck in a standard way. Otherwise, it would have supposed to modify the transport system, which would have made the system not useful for exportation uses.

In fact, the responsible for the transportation are the transport company, so that they already have protocols to fix the good over the trucks.

However, the PnU pallets has been developed to have enough resistance to endure it is travel over a truck

MATTER	DESCRIPTION
WHAT	• Load the PnU pallets over a truck In order to send them to the building site. • Ensure that no damages will be produced.
WHO	• Denvelops technical office. Made by the personal assigned to the Plural Project • Transport drivers.
WHERE	• STAGE 4- STORAGE AND DELIVERY

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	Denvelops factory. The factory is divided in 4 big areas, 1) storage, 2) manufacturing 3) assembly station and 4) Storage and delivery.
HOW	• By using standard tools () • By using forks and lifts or cranes.

TABLE 22: TRANSPORTATION

5.3.3 Installation (+Minimum occupant disturbance)

An initial installing process has been already large descried in task 4.4, point 3.3.8. And in fact, to produce the Demo Project same process will be used, maybe with some modifications, as them will be described in tasks 6.4.

However, it is important to highlight the benefits in how the system has been thought to reduce the disturbance of the occupant of the building site. There are certainly tasks that produce disturbances; there is way to avoid them. This task is related to remove or prepare the façade before to install the PnU, and most of them should not be understood as noises of the PnU system. So, in the next table it is described the type of job and how they can disturbance:

Terrassa jobs not directly required for the PnU installation:	
Types of installation work	**Range of disturbance**
• Take out old windows and blinds.	• Not heavy noise work • Need to add some protection since window hole leave empty under PnU window is reinstalled again. Note: Hybrid wall could be installed without taking off the old windows, and leave it as a second protection layer.
• Increase the window hole to increase the incoming light to the interior spaces	• Need some noise in order to knock down the wall façade area that need to be removed to make bigger the hole. But it is a small area made of a weak wall so it will be not a heavy work. • Need some time to do the perimetral finish of the hole in order to prepare the future installation of the PnU windows.
• Remove old railings.	• Easy and fast with no noises.

TABLE 23: INSTALLATION

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Terrassa jobs required for the PnU installation:	
Types of installation work	**Range of disturbance**
• Install anchoring system	• Not heavy noise work • Need to do some small holes to attach the anchors with screw of M10 dimensions. • This operation is made with a scissor lift.
• Drilling small ventilation pipes and electrical cable holes	• Need some noise to do the hole, but these holes are small and fast to do. • Beside since they are made from outside the disturbance is even lower.

TABLE 24: INSTALLATION

The implementation plan for the Terrassa Demo project will be divided in two phases, a) previous works to prepare the façade for the PnU kits installation and b) installation of the PnU Hybrid Wall kits.

For both phases and accurate time plan will be asked for the installation works.

a) Previous works to prepare the façade for the PnU kits installation

In the tender process to chose the installation provider, a detailed time plan will be asked in relation to the following action:

- Time to remove the windows and blinds
- Time to shot down and increase the dimension of the windows façade holes.

In relation of the global installation process these activities should not be considered as risk because are standard works with no innovation tasks which should not have contingencies, beyond some delays due to bad weather.

b) Installation of the PnU Hybrid Wall kits

Denvelops will provide together to final installation an exhaustive implementation time excel file for each component and function of the Hybrid Wall Terrassa Demo PnU. So that together with the installer a sort of time will be able to be detailed to have a global time length of the installation for all the PnU kits to be installed in the Terrassa Demo job.

This timetable will be done two times, one optimistic propose and another more pessimistic. This sort of prevision will help for the prevision when the other related task to the facades measurements can start.

This task will be developed in task 6.4 installation process.

As an example see attached table in were appears all the tasks that will need to be done for the Hybrid wall installation:

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		MEDICIONES		INSTALACIÓN EN OBRA										
				€/H	35,00	€/H	35,00		€/H	7,00	€/H	100,00		
		CANTIDADES		peón		oficial					MEDIOS AUXILIAR			
	MEDICIONES	TOTAL AMOUNT	INSTALACIÓN	MIUNTES FOR EACH TAKS WORKER 1	AMOUNT TOTAL TIME WORKER 1	MIUNTES FOR EACH TAKS WORKER 2	AMOUNT TOTAL TIME WORKER 2	AMOUNT HAND WORKER COST	TIME FOR SCISSOR LIFT	AMOUNT TIME FOR SCISSOR LIFT	TIME FOR CRANE	AMOUNT COST FOR CRANE	AMOUNTOF AUXILARY MACHINES	TOTAL AMOUNT OF INSTALLATION COST
FACADE ANCHORS														
LOAD GUIDES														
Average (40x40x3xLenght)		41,00		45,00	1845,00	45,00	1845,00	5,20	45,0	1845,0	45,0	1845,0	8,0	13,2
Ancho 2		0,00		0,00	0,00	0,00	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Ancho 3		0,00		0,00	0,00	0,00	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Load Guides attachment														
Attatchment cargol		82,00		5,00	410,00	5,00	410,00	1,16	5,0	410,0	5,0	410,0	1,8	2,9
Attatchement femella		82,00		0,00	0,00	0,00	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Attatchment arandela		164,00		0,00	0,00	0,00	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
LOAD ANCHORS														
Load Anchor COMP1		82,00		30,00	2484,60	30,00	2484,60	7,00	30,0	2484,6	0,0	0,0	0,7	7,7
Load Anchor COMP2		82,00		10,00	828,20	10,00	828,20	2,33	10,0	828,2	0,0	0,0	0,2	2,6
Tac quimic		246,00		10,00	2484,60	10,00	2484,60	7,00	10,0	2484,6	0,0	0,0	0,7	7,7
Cargol unir COMP 1 AMB COMP 2		164,00		0,00	0,00	0,00	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
WIND LINES														
		0,00		0,00	0,00	0,00	0,00	0,00	2,0	0,0	0,0	0,0	0,0	0,0
WIND ANCHORS														
WA 230.30.3		205,00		15,00	3382,50	15,00	3382,50	9,54	15,0	3382,5	0,0	0,0	1,0	10,5

FIGURE 57 TIME TABLE EXAMPLE IN WERE AN INSTALLATION TIME (AND COST AS WELL) CAN BE INSERTED IN ORDER TO HAVE A GLOBAL TIME AND COST INSTALLATION FOR ALL THE PROJECT.

As a brief resume to improve the comprehension of this task, the installation of the eAHC Hybrid walls of Terrassa Demos will be divided in the next steps:

MATTER	DESCRIPTION
WHAT	• Install de PnU eAHC Hhybrid Wall in the Demos site. Phases: ○ Building surface preparation. ○ Install of anchors. ○ Install PnU ○ Finish Installation of functional kits: ▪ Window and it is perimetral finishing. ▪ Ventilation unit ▪ Photovoltaics tiles. ▪ Insulation joins ▪ Perimetral finishing of the façade.
WHO	• Task will be done by standard installation workers. This installation worked will be chosen in a tender process made by AHC partners. • Denvelops technical office. Made by the personal assigned to the Plural Project will supervise the installation process.
WHERE	• In Terrassa demos site building.
HOW	• By using scissor lift, Forklift, Strap, and Crane to hang the PnU sequences. (see low descriptions)

	• By using command tools to install the rest of functions.

TABLE 25: MANUFACTURING PROCESS

The installation process in detail as defined by the producer DEN is as follows.

1) **Pallet Transportation.** Inserting the pallets over or in a truck box. Fix the pallets to the anchoring pints of the truck box with straps.
2) **Positioning of the pallets in the installation area**. Pallets must be placed close to the façade with enough distance to the façade to let a Scaffold Lift have access between the crane and the façade.
3) **Frame / sequence generation**. Remove the pallet packaging. Cut the flanges that are blocking the movement of the insulation trough the knives. Pull up the first frame (top) with a strap attached to the Load line and positioned it over the next frame sequence. Connect top frame with the next down by installing the M5 rivets on the hinges. Connect PV tiles between frames. Repeat this operation until the amount frames of the sequences are linked with the hinges.
4) **Attach sequence to load anchors**. Take the sequence over their load anchors positions. Attach the load guide of the sequence to the load anchor with M10 screw, nuts, and washer. Remove the strap from the crane.
5) **Wind anchors installing**.While the crane is going for sequence generation, use the Scaffold lift to install the wind anchors. According to installation plane place the anchors in their facade position and present it to mark the point where the attachment hole needs to be done. Make the hole with a wall drill and install the basement of the wind anchor with M10 chemical or mechanical anchors according to each case. Install the cap of the wind anchor catching the line with the M3 rivets leaving the required distance between the line and the façade wall.
6) **Window installation**. Place the scaffold lift in front of the window. Take out the tiles that hides the top and the bottom of the window, were the temporal window anchors are placed. Take out the pre attached windows finishing by cutting the flanges. Move the regulation screw of the temporal window anchor to move the window into the final opening in the façade position. With the window provisionally placed, drill the holes on the wall using the holes of the windows frame as guide. Make the hole with a wall drill and install the M10 chemical or mechanical anchors according to each case. Remove the temporal anchors. Seal the external and the internal join between the windows frame and the faced hole. Install the windows finishing to the window frames holes with the M5 screws and washers. Place the insulation without leaving space to the window load guide or the window finishing. Install the tiles again in the top and the bottom of the window.
7) **Ventilation unit installation**. Place the scaffold lift in front of the UV. Take out the tiles that hides the top and the bottom of the UV, were the pipes and the temporal window anchors are placed. Move the regulation screw of the temporal UV anchor to move the UV to the wall final position.
With the UV provisionally placed, drill the holes on the wall using the holes of the UV anchors as guide. Make the hole with a wall drill and install the M10 chemical or mechanical anchors according to each case. Remove the temporal anchors. Install the 90º pipe to connect the ventilation unit to the interior. Install the electrical cable to the interior through the wall hole. Seal the join between the pipe and the wall. Adjust the position of the insulation to cover the maximum

surface and other small part to no leave thermal bridges. Install the tiles again in the top and the bottom of the window.

8) **Installation PV tiles.** Connect all PV tiles cables between sequences or to the wall.
9) **Insulation installation**. Looking at the position of the knives in the installation plane take out the tiles and press the insulation against the wall façade. Install flanges in the holes of the knife to block the insulation positioning over the wall façade. Reinstall the tiles taken out before.
10) **Install the ending / finishing façade perimeter**. Following installation plan take the pieces and install them on its position.
11) **Reinstall signs, lights, cables, etc.**

5.3.4 Operation phase

The interaction between the user and the PLURAL system during the use phase is mostly related to the ventilation unit and to the solar shading.

Ventilation unit operation. The ventilation unit operates based on a programmed control system triggered by temperature set points and CO2 concentration. The information is provided by a IAQ Multisensor, installed in each room that has a ventilation unit. The set points are provided by the producer of the unit, but can be adjusted based on the user requirements. The user does not need to interact with the ventilation unit for its correct operation. The user is though able to turn off the ventilation unit if its functioning is temporarily not desired.

Solar shading. The solar shading depends only on the user. Its operation is manual and allows for multiple situations, each suitable for different condition. Based on the requirement based on the local cultural preferences to close the window in a completely opaque way, the system allows to close the shutters covering close to 100% of the window surface. This is useful for the sleeping hours, which is where the requirement comes from, but also for hot summer days when any radiation is not desired and the room is not occupied. The opposite situation of 0% covered area is suitable during the winter months, when the solar radiation gains are positive, according to the simulations. All the rest of the positions of the solar shading resolve intermediate situations, where both views to the exterior and solar shading are seeked by the user.

5.3.5 Accessibility for maintenance and repair

The maintenance and repair phase is mostly dedicated to the integrated technological units, the ventilation unit eAHC and the photovoltaic system.

The regular maintenance of the ventilation unit. Compared to the previous design, the accessibility of the ventilation unit for exchange of filters improved, because the solar shading system has been located in the external layer of the façade only, so it does not interfere with the layer where the ventilation unit is placed. Therefore, the regular maintenance and filter replacement becomes more straightforward. The maintenance needs were described in *D2.6 First stage design of PnU kits.*

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Need to develop a system to replace the ventilation unit. With the analysis of the first prototype, the Plural team for Terrassa Demo, realized that in case of having to take out the ventilation unit of the façade, it would be too complicated and expensive, because to do that operation, one whole sequence should be removed from the top to the bottom of the façade. To improve this maintenance operation, a new component called UV load extraction, was designed. It is a small load line that can be fixed temporarily to the façade, and create a little reinforcement to create a hole in the Denvelops system, just in front of the ventilation unit, with enough space to let the UV be taken off.

Maintenance of the photovoltaic installation. Periodic maintenance of the installation is necessary, with a review of the status of hoses, earth presses and cables. The recommended minimum maintenance periodicity is 1 year. The selected micro-invertor QT2 from AP Systems provides diagnostic and maintenance of the system at a distance, via an application or web portal. It is interactive with electrical networks through a function called RPC (reactive power control) to better manage the photovoltaic power peaks in the network. In addition, it offers 97% maximum efficiency with 20% fewer components compared to the last generation product. It represents a change in the three-phase installations for residential and commercial photovoltaic roofs. For repair, access to the façade or roof will be needed with specialized equipment. However, the revision or replacement of each individual PV panel is then possible, thanks to its mechanical connection to the system.

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6. Greek demo: VOULA

6.1 Architectural and structural design

6.1.1 Resume of the renovation objectives and changes

As extensively presented and described in *Deliverable D7.1 – "Preliminary Design"* and *Deliverable D2.1 "Architectural and structural design of PnU kits",* for Voula demonstration building, the PLURAL renovation procedure will be part of the 2nd Renovation Stage works scheduled by the VVV Municipality in terms of the three years Hostel's and Elderly's People Accommodation Buildings Renovation Program of the Municipality. Their design is dividing the overall renovation in two (2) Renovation Stages, mainly for budget reasons, as well as, to minimize tenant's reallocation in other buildings, as the building provides accommodation to elderly people with limited financial capabilities. The 1st Stage Renovation works were completed in September 2020. The 2nd Renovation Stage which is focused on the energy upgrade of the whole building is foreseen to include:

- ETICS installation on all external envelope of the building;
- Roof renovation and insulation;
- Refurbishment of the apartments on the two upper floors (A1, A2 & B apartments);
- Refurbishment of the common areas, corridors, staircases, lift etc., (inside the building);
- Refurbishment of the storage, power plant and boiler room in the ground floor.

This Renovation Stage was expected to start in the mid-2022, but due to the worldwide instability caused unexpectedly first, by the COVID 19 situation, and then (at the beginning of 2022), by the high increases on the energy prices, the renovation works were postponed until the mid of 2023; (the aforementioned "crisis" has led to shortages of raw materials and price increase of goods, services and transportation, which consequently affected VVV Municipality's pre-estimated budget).

The basic objectives of the PLURAL Renovation works have remained the same and are briefly described below:

- Refurbish and upgrade each apartment with recyclable and eco-friendly materials
- Upgrade all energy systems in order to reduce energy consumption and
- Ameliorate the thermal, acoustic and visual comfort of the residents.

Besides, the basic target – objective of the PLURAL renovation is to reduce the primary and final energy consumptions of the retrofitted areas of the building in terms of reaching the NZEB status, according to each country's directives for NZEB standards. In addition, through the installation of prefabricated panels, the cost of renovation should be reduced by 58% and the time of renovation should be reduced by 50%.

More information regarding the NZEB standards related to the Greek Demo building and the overall design of PnU kits, are extensively described in *Deliverables D2.1 "Architectural and structural design of PnU kits"* and *D2.6 "Initial Design of PnU kits"*.

The following table summarizes the most important characteristics of VVV's Renovation:

Topic	Unit	Area*	% of the total
Renovated façade	sqm	111.13	15.73%
Total area of replaced windows	sqm	36.21	30.20%
Renovated roof		Roof will be insulated by VVV Municipality in the context of the 2nd stage renovation works (not part of the Plural Renovation)	
New facade	–	–	–
New roof	–	–	–
Total area of new windows	–	–	–
TOTAL renovated/ new envelope	**sqm**	**147.34**	**17.83%**
* Only the areas where SmartWall panels will be installed are included in the renovated area			

TABLE 26: FINAL DEFINITION OF THE IMPLEMENTATION SCOPE

6.1.2 Aesthetics and functional design criteria

Through the deliverables of WP2 (*D2.6 "First stage design of PnU kits" and D2.2 "Technologies and materials selected for the demo sites")* the versatility and adaptability of the SmartWall PnU kit was proved in terms of aesthetics, functionalities, and each project's needs.

It was demonstrated that SmartWall is a solution that in terms of aesthetics has almost no limitations or restrictions as:

- different setups and designs can be developed / applied according to the specific demands of the owner /architect / engineer,
- a very wide range of materials / technologies can be integrated into and onto it and
- it can replicate existing building's aesthetics by using the same materials / finishes as the existing or the original building.

On the other hand, in terms of the Voula demonstration building, no new or different data for the aesthetics and/or the functional design criteria have arisen after the completion of the related Tasks of WP2 and WP4. Several parameters were considered at the initial design stage of the PnU kits in relation to the demo buildings, which affect the aesthetic result of the building and are derived by either the owners' requirements, the laws restrictions or the building's geometry and use (social shelter). The parameters affecting the aesthetics and functional design of the Voula demo building are summarized below:

- Facades' shape, geometry, and aesthetics should not be differentiated from the already renovated floors or from the rest of the building;
- Facades' openings' dimensions and positioning cannot be altered;
- PnU systems should be installed individually for each apartment and every apartment has to be energetic autonomous;
- Use of eco-friendly and recyclable materials;
- It is a necessity to keep the PnU's control units, as simple as possible.
- Additionally, for safety reasons, the PnU's control systems should provide the option to override their integrated control unit (AMscope) to a simple manual (mechanical) function without the use

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of electric power. E.g. the roller shutters apart from operating via AMscope, should also be able to be controlled manually (mechanically) by the tenants.

- In the kitchen area of A1 apartment, sink is attached to the envelope wall restricting the installation of SmartWall on that wall, and VVV Municipality is not in favor to relocate its position due to the limited space in the kitchen area. This condition impacts the design of SmartWall systems in two different ways:
  a) As in Voula demo building was decided to install both internal and external SmartWall systems this condition affected the decision making process to which areas each type of SmartWall systems will be installed (externally or internally) and
  b) The heating – cooling device of the kitchen area could not be incorporated inside the SmartWall, therefore it was decided to install a wall mounted fan coil solution on the upper part of the internal wall (above the sink). The fan coil model selected for this reason was the DAIKIN FWXT20ATV3.
- Similar condition applies for the kitchen in A2 apartment where a structural wall close to the balcony door is restricting the use of a heating – cooling device incorporated inside the SmartWall. The same solution of DAIKIN FWXT20ATV3 fan coil model was adopted to be installed on the upper part of the internal wall of the kitchen.

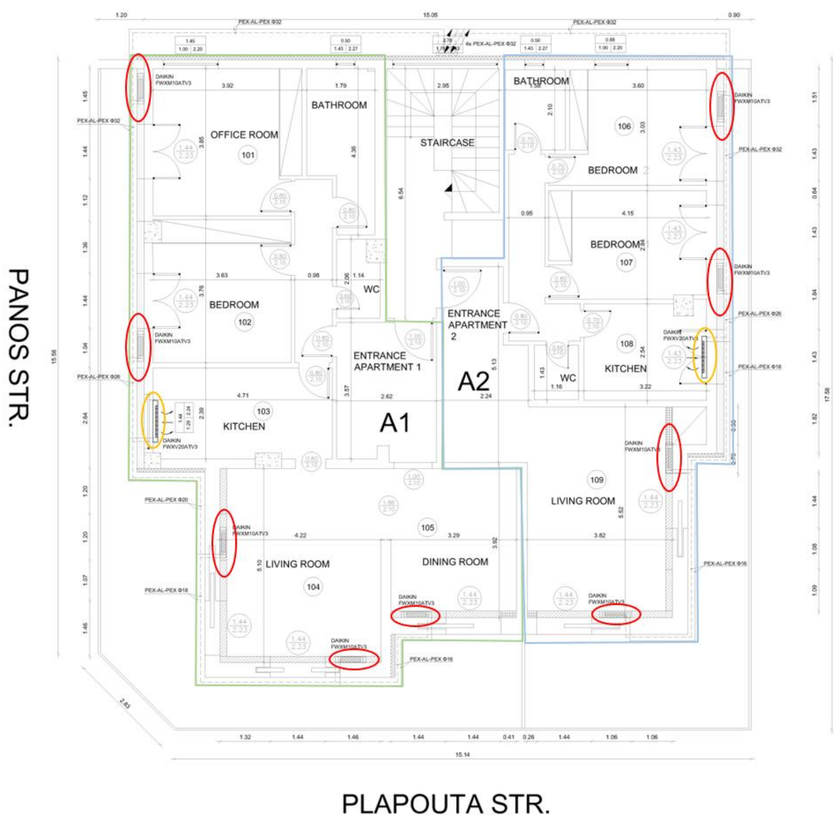

FIGURE 58: PROPOSED POSITIONING OF FAN COILS INSIDE THE APARTMENTS (YELLOW COLOR @ KITCHENS- FWXT20ATV3 MODEL, RED COLOR - FWXM10ATV3 MODEL)

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As a conclusion, the initial concept of keeping the same aesthetics on the external surfaces of the whole building was not altered, whereas the necessary decisions were made where needed, in order to follow the VVV Municipality's requirement for energy independence of the renovated apartments (Figure above).

6.1.3 Final architectural design of the PnU kits

The main objectives, limitations and/or constraints, as well as an extensive analysis of the architectural design for Voula demo site were presented in deliverables D2.1 "Architectural and structural design of PnU kits", D.7.1 "Preliminary Design", D.2.2 "Technologies and materials selected for the demo sites" and D2.6 "First stage design of PnU kits".

FIGURE 59: INTEGRATION AND POSITIONING OF SMARTWALL PANELS IN GREEK DEMO SITE

Briefly, In the Greek demo site will be installed in total (*Figure above*):

- 17 SmartWall panels in apartment A1 (7 exterior and 10 interior panels)
- 16 SmartWall panels in different dimensions in apartment A2 (9 exterior and 7 interior panels)

All the details regarding the dimensions, the number and the types of SmartWall panels, as well as the electromechanical components that will be integrated in each SmartWall panel of the Greek demo building, are presented in the *Deliverable D2.1 "Architectural and structural design of PnU kits".*

The final architectural design of the SmartWall system has also incorporated the results of the optimization process conducted during WP4 and has adopted the solutions proposed under *Task4.1 "PnU components Optimization – Main systems"* and validated by the revised structural survey, which was executed for the optimized version of the SmartWall system (see next chapter 6.1.4). In addition, the simulations conducted for estimating the U value of the different SmartWall types, and for calculating the created thermal bridges,

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were also considered in terms of introducing other/extra insulation measures. In brief, the parameters that were changed in order to enhance the overall design of the SmartWall system for Voula demo site were:

- Changes in the proposed anchoring system; the anchoring system presented in the preliminary structural design (Deliverable D2.1), seemed to be time-consuming and thus the target of reducing the renovation time would not be achieved.
- The thickness of insulating material was altered to improve the overall U value of the system.
- The need to incorporate lighter frame sections was also identified. The updated structural survey indicated that lighter and bigger panels could be produced.
- Some of the components incorporated inside the SmartWall panel made necessary the introduction of fire protection measures (see *deliverable D4.1 "Optimized components for PnU kits"*)
- Some auxiliary materials were utilized to address the thermal bridges issues, like the sheets of cork in between the frame and window's sill and the high dense rubber spacers in between the panel's metal frames (*Figures below*).

FIGURE 60: CORK SHEET INSTALLED BETWEEN THE WINDOW FRAME AND THE SILL

FIGURE 61: RUBBER SPACERS BETWEEN PANEL'S METAL FRAMES

The following table (*Table below)* summarizes the differences in the renovated area before and after the retrofitting based on the final solution's properties:

Topic	Unit	Original building/apartments	Renovated building/apartments
Thermal properties			
U-value wall	W/m^{2}K	2.44	0.22 – 0.43 depending on

			the Type of SmartWall panel installed on each facade
U-value window	W/m^2K	4.2	1.4
U-value roof *	W/m^2K	3.05	3.05
Solar shading type		Wooden sliding shutters	Alluminum roller shutters with electric switch
Shading factor			
Acoustic properties			
Sound resistance wall		n/a	n/a
Sound resistance window		n/a	n/a
Lighting properties			
Internal Lighting		No lighting controls – energy consuming light bulbs	No lighting controls – energy meters will measure the lighting consumptions – all old lighting systems-bulbs will be replaced with new energy saving ones
Fire protection			
Passive measures	n/a	No fire protection measures	Intumescent paints, fire resisting materials
Active measures	n/a		Intumescent grilles, automatic fire suppression system, smoke detectors & tempreature sensors
Interior air quality			
Ventilation system/Control of Indoor air quality	n/a	No control of the interior air quality	Some enviornmental parameters will be constantly monitored and measured through AMScope, however, no mechanical ventilation system will be finally applied
* The roof will not be renovated under PLURAL project but from VVV Municipality during the 2nd stage of Renovation Works			

TABLE 27: MAIN CHARACTERISTICS OF THE RENOVATION SOLUTION

6.1.4 Final structural design of the PnU kits

The structural design requirements, the parameters considered for the installation in Voula demo case, as well as the regulations and norms in which the specific design is based were thoroughly described in deliverable *D2.1 "Architectural and structural design of PnU kits"*. In addition, the results of the preliminary structural survey were also presented, along with the suggested anchoring system to the existing walls.

This first Structural Analysis proposed an anchorage method based on chemical resins fixings, commercialized by HILTI and FISCHER. Their behavior has been evaluated with success during the conducted tests. However, the fastening's resin capability is directly connected with the parameters of time and temperature (winter & summer period) and thus, a significant amount of time is required for the adhesive to hook, while in case of inadequate "for-the-fastening" weather, the whole process will be notably delayed. For this reason, alternative solutions were investigated under WP4 and the proposed ones were assessed again by the aid of a second structural analysis (final one).

Along with the need to investigate and evaluate a new anchoring solution, the necessity to examine a lighter steel structure for the frame of the SmartWall was also revealed, as lighter structures would allow more and different options of anchoring to be examined.

The new structure evaluated by the second final structural survey, is consisted of two (2) lightweight steel frames type S245 @ RHSC 50mm (l) x 30mm (w) x 1.8mm (t), which will be interconnected to each other by horizontal and vertical supports of the same material as the main frame ((S245 @ RHSC 50mm (l) x 30mm (w) x 1.8mm (t)) *(Annex 1.2 – "SmartWall's Final Structural Analysis").* This lighter frame will reduce the overall weight of SmartWall panels by 35 – 45%, resulting to less imposed load on the façade's walls.

As a result, by frame's weight reduction, an alternative anchoring to the façade wall system has been developed, which will reduce significantly the required installation time and will provide a simpler installation process.

Three (3) Z shaped metal guide rails (of 85mm width) will be installed by the use of chemical anchors on the top, middle and bottom of the existing walls. The same Z (reversed Z) shaped hangers will be welded to the same spots of the SmartWall frame, so that these can be hanged and secured upon the guide rails (*Figures below*).

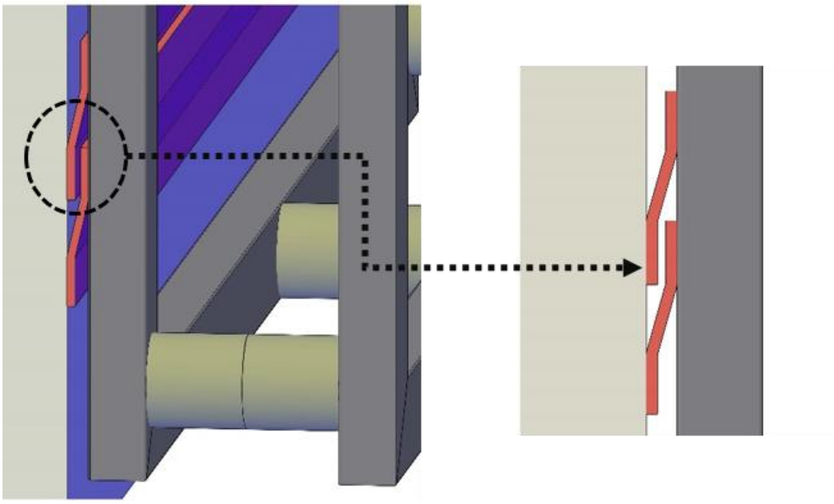

FIGURE 62: DETAIL OF THE NEW PROPOSED ANCHORING SYSTEM

Material of Z shaped mounts:
Steel S245 custom made
Dimensions:
Length depending on the length of the wall/panel (l) x 85mm (h) x 4mm (w)
Screws – Chemical anchors on the existing wall:
Stainless steel TEK screws 4 x M8 @25mm (l)
Z mounts on the SmartWall panel:
3 items welded to the SmartWall frame in three heights:

1. @ the center of the SmartWall frame depending on the panel's dimensions,
2. @ 9.5 cm from the top of the SmartWall's frame (regardless SmartWall's overall dimensions),
3. @ 23.5 cm from the bottom of the SmartWall's frame (regardless SmartWall's overall dimensions).

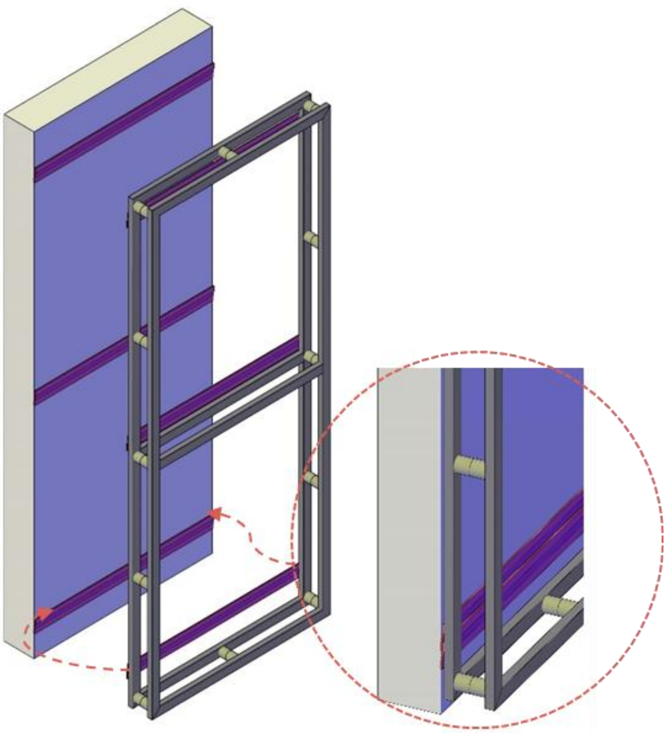

FIGURE 63: POSITIONING OF THE Z GUIDE RAILS AND OF THE CORRESPONDING HANGERS UPON THE SMARTWALL FRAME

The final (second) structural survey has also evaluated and verified the use of the proposed rubber spacers (anti vibration mounts), placed between the panel's frames (for addressing the thermal bridges), and proposed a final solution for the interlocking of the SmartWall panels between them.

The solution proposed for the interconnection of the panels was a slim interlocking channel attached to the sub frame's left and right side of two SmartWall panels (*Figure below*).

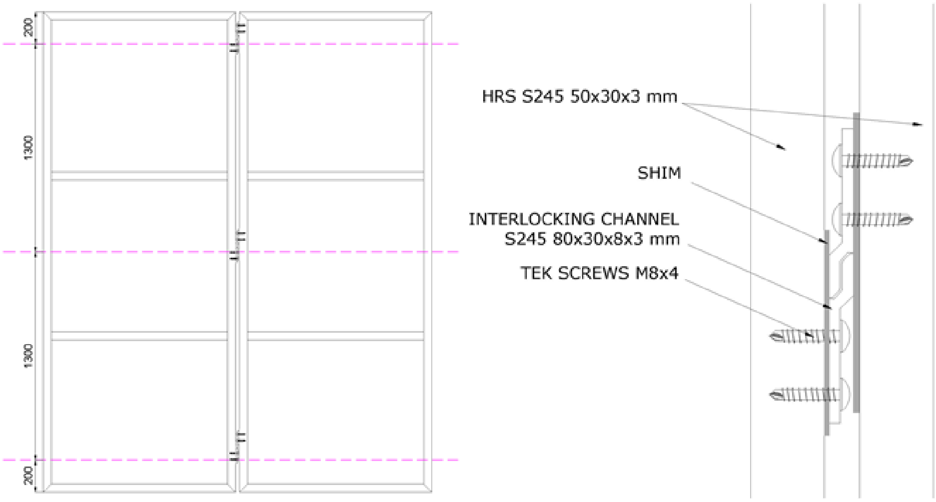

FIGURE 64: SLIM INTERLOCKING CHANNEL DETAIL

a) Material: Steel S245 custom made channel
b) Dimensions: 30mm (l) x 80mm (h) x 8mm (w) x 3mm (t)
c) Screws: Stainless steel TEK screws 4 x M8 @25mm (l)
d) Fixing: 3 items on pre-drilled to SmartWall frame holes:
@ 200 c/c from the top and bottom SmartWall's sub frame's edge
@ c/c of SmartWall's subframe(regardless SmartWall's overall dimensions)

The final structural survey is presented in the *Annex 1.2 – "SmartWall's Final Structural Analysis"*of the current report.

6.2Final definition of the HVAC and energy systems

6.2.1 Energy efficiency of the building vs. Nzeb

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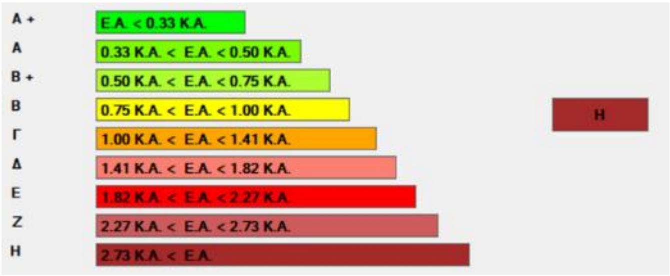

FIGURE 65: BUILDING'S CURRENT ENERGY CLASSIFICATION

As was presented in Deliverable *D.7.1 "Preliminary Design"*, taking into consideration the existing state of the Voula demonstration building along with all its characteristics (existing envelope, insulating materials, energy systems, existing windows etc.), the current energy performance and classification of the building was derived. Therefore, the building as it is at the moment, has been classified in the **H** Energy Class of the Greek Energy Classification Scale (*Figure aside),* as its primary energy consumption exceeds the 300kWh/m^2.

The energy performance calculations for the classification of the building before and after the retrofit have been conducted by the aid of the official Greek Energy Certification software - TEE-KENAK[1] .

A complete analysis of building's Energy Efficiency on its current state has been presented in *Deliverable D7.1 – "Preliminary Design"*.

As far as the energy classification is concerned, this is calculated based on the Greek Regulation of Building Energy Performance[2] (KENAK) as presented in the *Deliverable D1.2 "Technical and Market Codes*".

In general, in order to characterize a building as NZEB building in Greece, it is needed to be classified at least as:

- A class in the Energy Performance Certification scale, if it's a newly constructed building or,
- B+, if it is an existing building.

For each Climatic Zone (of the four Climatic Zones in which Greece is divided), the required primary energy consumption in order to classify the buildings in the A or B+ class differentiates according to the following Table 13[3]:

Energy Class	Primary Energy Consumptions of residential buildings for each Climatic Zone (kWh/m^{2}a)			
	A	B	C	D
A+	11 - 25	14 - 35	10 - 44	17 - 36
A	18 - 56	21 - 55	26 - 74	54 – 88
B+	32 - 81	31 - 99	45 - 125	37 - 128
B	45 - 112	56 - 126	72 - 172	63 - 184

[1] http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/tee_kenak
[2] http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak
[3] https://ypen.gov.gr/wp-content/uploads/2020/12/.pdf

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Energy Class	Primary Energy Consumptions of non-residential buildings for each Climatic Zone (kWh/m^{2}a)			
	A	B	C	D
A+	12 - 77	14 - 91	52 - 69	30
A	65 - 185	41 - 114	68 - 119	82
B+	98 - 218	60 - 196	99 - 218	105 - 156
B	133 - 266	115 - 245	120 - 280	149 - 218

TABLE 28: PRIMARY ENERGY CONSUMPTION RANGE IN GREECE FOR THE ENERGY CLASSES B TO A+

According to the above table, for the Greek demo case which is the case of an existing residential building situated in the Climatic Zone B (Athens), the target is to be classified after the renovation as B+ class, and thus, its primary energy consumption should be between 31 and 99 kWh/m^{2}a or lower, in order to meet the NZEB standards.

The energy performance calculations were revised after introducing into the software the renovation measures that will be adopted in Voula demo building. These measures involve as thoroughly presented in deliverables of WP2 (D2.1, D2.2, D2.3, D2.4 and D2.5), thermal insulation, high performance windows, heating and cooling by the use of fan coils and heat pumps, production of DHW from solar collectors and energy production through PV installation.

The outcome of the revised energy performance simulations proved that post PLURAL renovation, both A1 and A2 apartments of the building's first floor, are classified as A+ according to the Energy Efficiency Classification Scale (*Table above).*

In the following *Tables above and below*, it is indicated that the NZEB target is achieved even before the PV installation, as before introducing the photovoltaic parameters into the software, the apartments are classified in the B+ category, whereas when the PV variables are introduced in the software, the energy class is improved to A+.

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Primary Energy per End Use (kWh/m²) for A1 Apartment			
End Use	Original Building	Renovation Measures – No PV Installation	Renovation Measures – With PV Installation
Heating	212.6	17.5	17.6
Cooling	42.6	14.8	14.6
DHW	44.7	15.3	15.3
Lighting	0.0	0.0	0.0
RES – CHP	0.0	0.0	35.1
Total Primary Energy	300.0	47.5	12.4
Energy Class	**H**	**B+**	**A+**

TABLE 29: PRIMARY ENERGY CONSUMPTIONS PER END USE FOR A1 APARTMENT

Primary Energy per End Use (kWh/m²) for A2 Apartment			
End Use	Original Building	Renovation Measures – No PV Installation	Renovation Measures – With PV Installation
Heating	211.5	15.9	15.8
Cooling	50.3	17.5	17.5
DHW	59.2	20.3	20.3
Lighting	0.0	0.0	0.0
RES – CHP	0.0	0.0	44.8
Total Primary Energy	321.0	53.6	8.8
Energy Class	**H**	**B+**	**A+**

TABLE 30: PRIMARY ENERGY CONSUMPTIONS PER END USE FOR A2 APARTMENT

Topic	Unit	Original building		Renovated building	
		A1 Apartment	A2 Apartment	A1 Apartment	A2 Apartment
Cooling energy demand	kWh/m^2	42.6	50.3	29.6	34.7
Heating energy	kWh/m^2	75.2	70.2	14.4	9.5

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demand					
DHW production demand	kWh/m^2	15.1	20.0	15.1	20.0
Overall primary energy	kWh/m^2	300.0	321.0	12.4	8.8
Renewable energy production (yearly)	kWh/kWp	–	–	1566.84	1566.84
nZEB standard reached?	Y/N	NO	NO	YES	YES
Which document defines the nZEB standard?	N/A	N/A		Given in footnote 3 above – https://ypen.gov.gr/wp-content/uploads/2020/12/.pdf	

TABLE 31: ENERGY EFFICIENCY – RESULTS BASED ON TEE-KENAK SOFTWARE

6.2.2 Passive strategies implemented

As passive strategies are usually considered passive design measures which may include building orientation, continuous insulation, appropriate design of windows for maximizing day lighting and natural ventilation, shading etc. The existing state of the Voula demonstration building, along with the fact that not all building would be renovated (but only the two apartments of the first floor), did not allowed the implementation of many different passive strategies.

The orientation of the building, the materials composing its structure and the openings size and position have been already determined from the year of the building's construction (in 1971).

Besides, since homogeneity should be kept for the whole building, the size and positioning of the windows (in a way that could allow more light to enter the apartments) could not be altered due to the restriction imposed by VVV Municipality that "facades' shape, geometry, and aesthetics should not be differentiated from the rest of the building". Therefore, the only possible passive strategies that could be included were the addition of insulating measures and the upgrade of the shading devices.

160mm of rockwool insulation will be finally integrated inside the SmartWall panels in terms of providing the appropriate thickness of insulation for the building. The insulation will fill all the possible gaps inside the SmartWall panel, whereas other insulating materials such as cork or VIP will be also introduced to protect the structure from thermal bridges.

Regarding the shading devices, these should again follow the general aesthetic of the building, and for this reason, the existing wooden sliding shutters will be replaced with aluminum roller shutters, which will be controlled manually and electrically. The new shading devices will provide better protection from the direct sunlight (from entering into the house) and from overheating during summer.

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Another important element regarding the passive strategies implemented, is the replacement of the old sliding wooden windows/balcony doors with new high performance PVC ones, which will also have the ability to open and tilt, and thus, they will allow a better and safer natural ventilation of the interior spaces, by the use of the tilting position.

6.2.3 Ventilation system (as per T2.3)

In deliverable *D2.3 "Ventilation systems selected for each demo site",* all the requirements set by the Greek Laws/Regulations and by the owners of the Voula demonstration building (VVV Municipality) were presented, along with all the systems/technologies that were investigated as more appropriate (suitable) for the specific building.

The different solutions were investigated for their simplicity on installation, operation and maintenance. However, since:

a) the tenants of the building are elderly people with limited familiarization with mechanical ventilation systems and
b) in Greece, the users of residential buildings are naturally ventilating their houses all year round due to the mild temperature conditions,

it was decided by VVV Municipality not to include a ventilation system in the final PnU solution, in order not to complicate the system. Besides, the installation of such a system would end up useless, as the tenants of the building would probably only use the windows for ventilating their houses.

6.2.4 Heating and cooling system (as per T2.4)

As it has been described in previous deliverables of the project (*D7.1 "Preliminary design"*, *D2.2 "Façade panel technologies selection*" and *D2.4 "Selected heating and cooling technologies for each demo site"*), the renovation scheme of the Greek demonstration case, involves two air to water heat pumps (one for each apartment) which will be combined with the appropriate number of fan coil units and will provide both heating and cooling.

More specifically each apartment's heating /cooling system will be consisting of:

- a mono-block type heat pump by DAIKIN EBLA09D3V3,
- slim type FWXM10ATV3[4] fan-coils by DAIKIN capable to be fitted internally in the SmartWall, @ 576 mm (h), 725 mm (l) 126 mm (w) and

[4] https://www.daikin.eu/content/dam/document-library/catalogues/heat/heat-emitters/fwxv-atv3/Daikin%20Altherma%20HPC_Product%20catalogue_ECPEN21-793_English.pdf

- two wall mounted fan coil units by DAIKIN (FWXT20ATV3(C/CL)), which will be installed in the kitchen areas of the apartments, due to the limitation of space.

In addition, it was decided that the heat pump solution will support the production of Domestic Hot Water (DHW) for the two apartments, when solar energy is not sufficient to produce the required amounts of DHW (DHW will be provided by the use of selective flat plate solar collectors described in *D2.5 "Report with design and operational features of toolbox"*).

The number and type of heat pumps and fan coil units are illustrated in following *Table.*

DAIKIN SYSTEM	Type/Model	Quantity
FANCOILS	FWXM10ATV3	9
	FWXT20ATV3(C/CL)	2
HEAT PUMPS (mono-block Single-Phase)	EBLA09D3V3	2

TABLE 32: DAIKIN FAN COILS & HEAT PUMP SELECTED FOR VOULA DEMO SITE

The heat pumps will be installed in a designated area on the terrace of the building, whereas all the auxiliary equipment, such as buffer tanks, electro valves etc. will be placed in the existing terrace room adjacent to the heat pumps. The FWXM10ATV3 fan coils will be incorporated inside the corresponding SmartWall panels, that will be attached on the existing walls of the building, whereas the FWXT20ATV3(C/CL) fan coils will be hanged/attached on the upper part of the kitchen wall (wall-mounted) of the two apartments. In the following drawings the installation areas of the heat pumps and of the fan coils are indicated (following *Figures*).

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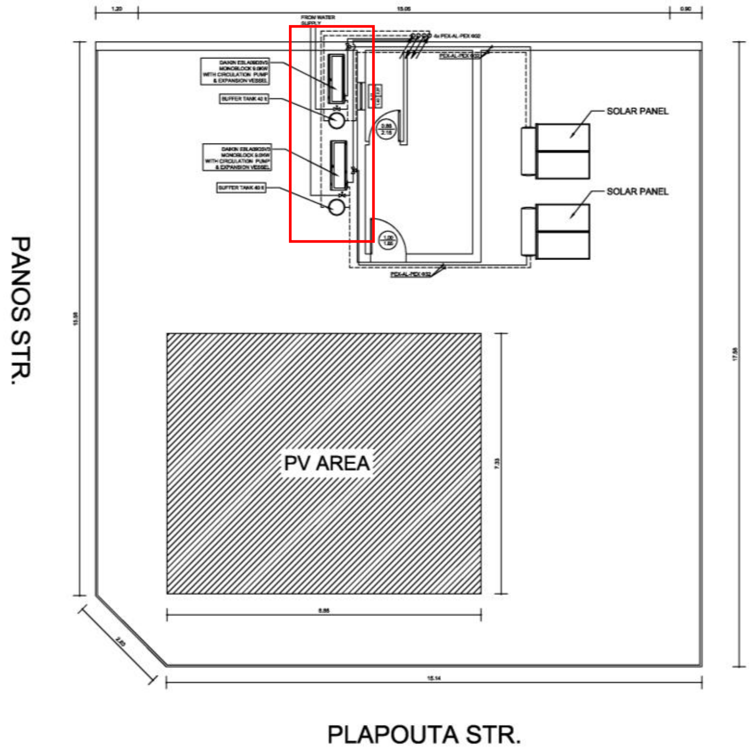

FIGURE 66: HEAT PUMPS POSITIONING ON THE BUILDING'S TERRACE

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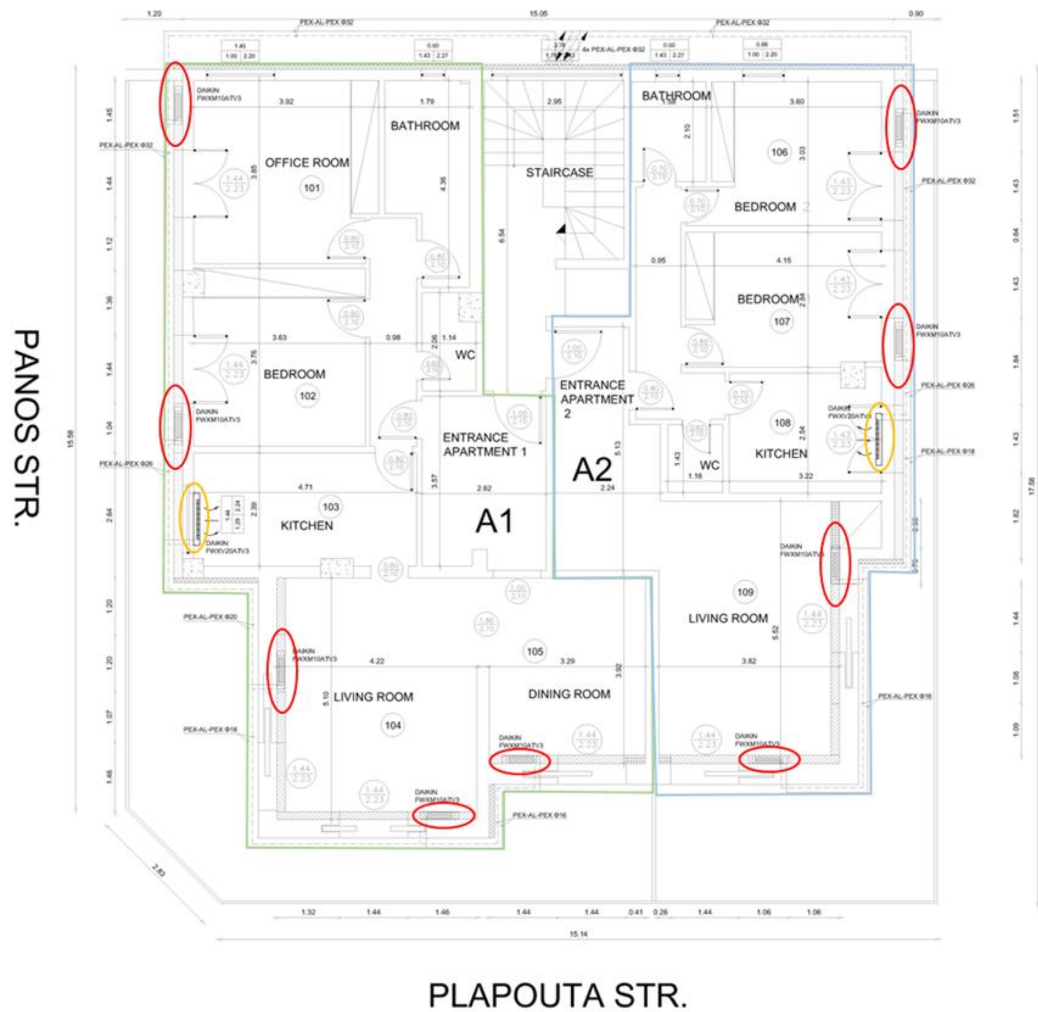

FIGURE 67: PROPOSED POSITIONING OF FAN COILS INSIDE THE APARTMENTS (YELLOW COLOR - FWXT20ATV3 MODEL, RED COLOR - FWXM10ATV3 MODEL)

6.2.5 Energy system, PV installation (as per T2.5)

A surface of approximately $65m^2$ has been allocated on the roof of Voula demonstration building (Figure below) for the installation of the photovoltaic modules that will generate the required electricity for the Smart Walls' operation. The electricity needs (consumption) for the operation of the SmartWall panels that will be installed on the facades of the two apartments are presented and analysed in deliverable *D2.5 "Report with design and operational features of toolbox"*.

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	Daily consumptions/needs	Annual consumptions/needs
A1 Apartment	2.17 kWh/day	792 kWh/year
A2 Apartment	1.83 kWh/day	668 kWh/year
Total (A1 + A2)	**4.00 kWh/day**	**1460 kWh/year**

TABLE 33: DAILY/ANNUAL CONSUMPTIONS/NEEDS OF THE SMARTWALL PANELS FOR EACH APARTMENT

The photovoltaic system that is foreseen will be standalone, thus not connected to the grid, whereas a PV Energy Sharing (PVES) scheme is going to be followed in order to limit any electrical waste and to efficiently respond to the fluctuated energy requirements of each apartment.

The detailed calculations conducted for the definition of the number and type of photovoltaic panels that will be installed, are included in the aforementioned deliverable *D2.5. "Report with design and operational features of toolbox"*.

The closest to the above requirements solution, seemed to be a PV module of type NU-JD450[5] of the SHARP Corporation with the following characteristics:

Basic Data and Characteristics of PV Module	
Company	SHARP Corporation
Name	NU-JD450
Cell type	Si-monocrystalline
Capacity (Nominal Output in W)	450 Wp
Efficiency in %	20.37
Dimensions	1048mm(W) x 2108mm(H) x 35mm(D)
Surface in m^2	2.21
Weight in kg	25

TABLE 34: DATA OF PROPOSED PHOTOVOLTAIC PANEL

The proposed PV scheme will be consisted of two (2) independent PV arrays, one(1) for each apartment, and will be accompanied by one (1) inverter for each apartment, and one (1) battery system with its battery inverter for each apartment. So, each PV array will be consisted of 4 PV modules of 450W (8 PV modules in total) and each apartment will be equipped with one batteries system which it is proposed to be consisted of 4 batteries of LG Resu 13[6] type (of 252Ah capacity – thus, 8 batteries in total). **The proposed**

[5] https://www.sharp.eu/monocrystalline-solar-panels/450-wp-mono-nujd450

[6] https://www.europe-solarstore.com/lg-chem-resu-13-48v-lithium-ion-storage-battery.html

configuration of PV arrays, inverters and batteries will be re-evaluated before the final installation of Task 7.4 ("Installation of PLURAL system in Voula – Athens(Greece) real demo case"), in order to reconsider any space limitations and to take into account the at that time availability of products/ materials, due to the upcoming issues of cost raising and materials shortages.

Regarding the orientation of the PV array towards the South, the optimal orientation for the demo's location is considered to be $\gamma = 180^o$ ($\pm 5^o$) (following *Figure*). For the inclination of the PV panels their optimal positioning was estimated to be the 28^o ($\beta=28^o$) and was based on the area latitude of the building's location (Latitude: 37° 50' 31.96" N) and the time period (yearly) for which the calculations take place.

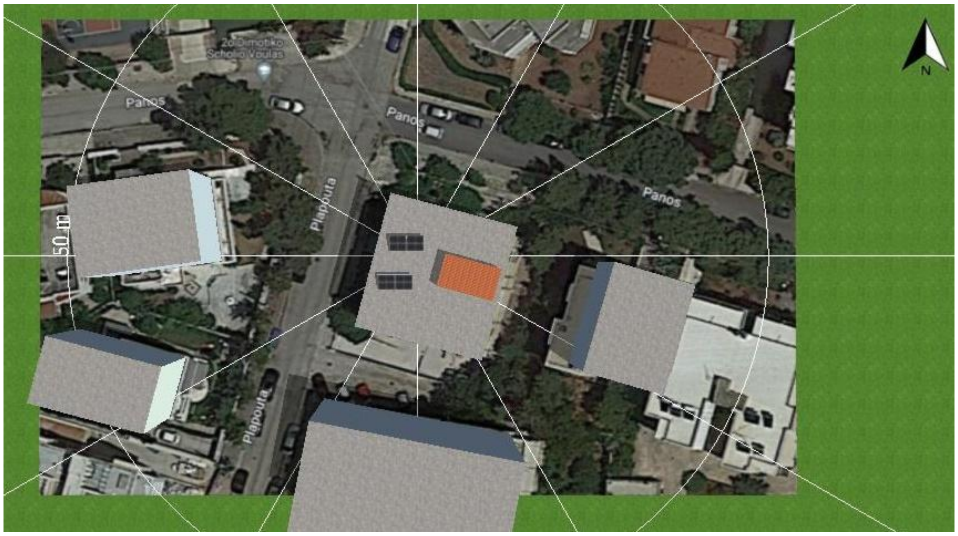

FIGURE 68: OVERHEAD VIEW OF PV ARRAYS – PROPOSED POSITIONING

Topic	Unit	Original building	Renovated building
PV panel type	N/A	–	NU-JD450[7] (SHARP)
PV panel size	m^2	–	2.21
PV panel peak power	Wp	–	450
Nr. of panels: per orientation South / inclination 28^o	units	–	8 PV modules
TOTAL installed PV peak power	kWp	–	3.6 kWp

[7] https://www.sharp.eu/monocrystalline-solar-panels/450-wp-mono-nujd450

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TOTAL PV energy production	kWh/year	–	5640.63 or 1566.84 kWh/kWp
% of Total heating and cooling demand covered	%	–	100% SmartWalls' operation needs are covered
**The type of materials and equipment, as well as the final PV configuration will be re-evaluated before the installation of Task 7.4 ("Installation of PLURAL system in Voula – Athens(Greece) real demo case") in order to take into account the at that time availability of products.*			

TABLE 35: PV PRODUCTION

Each apartment of the first floor (A1 and A2) will be equipped with its own solar collector system in terms of preserving the required by the VVV Municipality, autonomy of the apartments.

The surface that was allocated for the installation of the solar collectors is depicted in the next drawing, along with the area where the PVs will be placed.

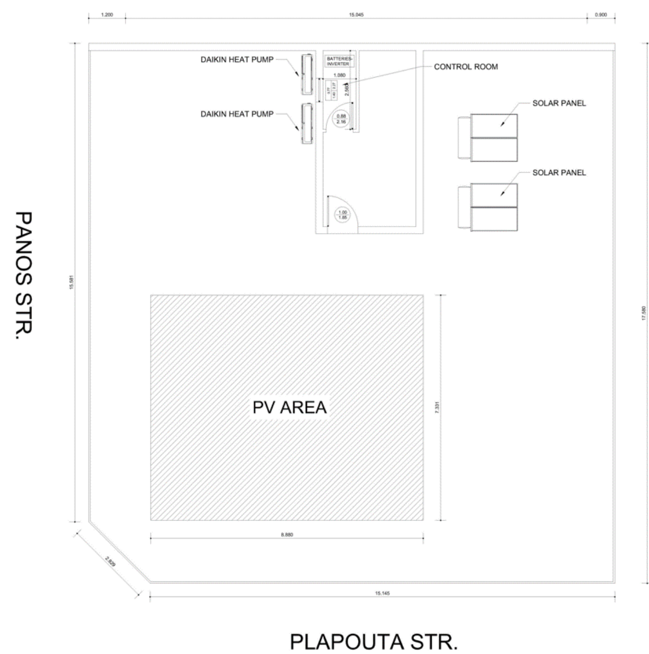

FIGURE 69: ROOF PLAN OF VOULA DEMO BUILDING

The proposed system will be consisted of flat plate selective solar collectors of approximately 2.10m^2 area for each apartment, and it will be supported by the DAIKIN heat pump (described under *Deliverable 2.4 "Selected heating and cooling technologies for each demo site")* and an extra electric heat element to provide the required heat loads, when sunshine is not available or heat pump is out of order due to failure or maintenance. A triple energy system will be therefore utilized which will ensure uninterrupted supply of DHW to the renovated apartments.

The solar collector system for each apartment will be consisted of:

- the solar collector of a single panel of around 2.10 m^2 of area,

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- the appropriate thermal storage tank (of at least 160lt capacity) that is provided with the solar collector that should also be equipped with an appropriate heat exchanger for external source (heat pump) and an electric heat element,
- the piping along with its accessories and fittings.

The characteristics of the solar collectors systems are presented in thefollowing Table.

Topic	Unit	Original building	Renovated building
Solar collector type	N/A	–	Flat plate selective
Solar collector size	m^2	–	2.10
Solar collector peak power	Wp	–	n/a
Nr. of panels: per orientation South / inclination 45°	units	–	2 panels of 2.10m^2 (one for each apartment)
TOTAL installed peak power	Wp	–	n/a
TOTAL energy production	kWh/year	–	2581
% of Energy demand for DHW production covered	%	–	73.32

TABLE 36: SOLAR COLLECTORS

6.2.6 Smart system (as per T3.4)

In Deliverable *D4.3"Pre-assembled toolbox with control system"*of PLURAL project, the Toolboxes of the three Plural demonstration buildings were optimized based on the specific needs of each PnU kit and the respective demonstration building. The Toolbox is in general responsible for the cooperation of the systems, either integrated to the PnU kit or not, and facilitates their control. As "Toolbox" was defined a set of systems and sensors that is responsible for controlling the various subsystems of a PnU kit and optionally its auxiliary to it and/or other systems of the indoor space where the toolbox is installed. As was thoroughly described in Deliverable *D4.3 "Pre-assembled toolbox with control system"* and *D2.5 "Report with design and operational features of toolbox",* the SmartWall's toolbox follows a decentralized approach as each SmartWall panel is equipped with a toolbox.

More specifically, every SmartWall, which integrates a fan coil and/or a window with external blinds, will include a toolbox. In principle, each toolbox will be consisted of three basic parts:

1. The controller (AMScope) with integrated HMI via display and buttons;
2. The NTUA Multisensor and
3. An active fire protection system.

AMScope is a controller that is made especially to control SmartWall's functionalities and integrates:

- microcontroller with Wi-Fi and Bluetooth adapter (ESP-32 based);
- display (OLED);

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- a series of output relays;
- smoke detector, and
- two temperature sensors for overheating and fire safety warnings.

The Multi-Sensor is a system of multifunctional sensors developed by NTUA that is able to constantly monitor:

1) Temperature, 2) humidity, 3) air velocity, 4) luminance levels, 5) and CO_2 and VOC concentration in every room.

The data from the Multi-Sensor are transmitted wirelessly to the AMScope unit for processing. In addition, via a dedicated Wi-Fi network, will be uploaded to a web hosted database developed by NTUA for monitoring purposes and for further processing by other cloud tools (Streamhandler, Lysis) etc.

The active fire protection system is an independent to the Multisensor system controlled by the AMScope, equipped with a smoke detector and temperature sensors. Depending on the temperature readings and / or the existence of smoke is preconfigured to take certain actions (alarm, power cut-off), in order to protect the toolbox and its enclosed hardware from overheating that could cause a fire.

The battery system was originally designed to be installed within the toolbox and be directly charged by the PV panel attached on the outer surface of SmartWall panels. However, due to the restrictions mentioned in Deliverables *D2.1 "Architectural and structural design of PnU kits"*, *D2.2 "Technologies and materials selected for each demo site"* and *D2.5 "Report with design and operational features of toolbox"*, which have resulted in moving the PV panels from the SmartWall's façade to the roof of the building, the battery system will not be finally incorporated inside the SmartWall's toolbox, but on the existing terrace room of the building.

To summarize, the specific systems that are going to be automatically controlled by the toolbox are the:

- Fan coil units in each room for heating and cooling;
- Window blinds in each room;
- Emergency system of the toolbox within the SmartWall and
- Humidification/dehumidification control (optionally).

6.3Post-design life-cycle phases

6.3.1 Manufacturing

The generic process of manufacturing will be based on the prototypes manufacturing procedure described in *Deliverable D2.6 "First stage design of PnU kits"*, whereas the assembly of the SmartWall's components will take place in BGTeC's premises by their technical stuff. The methodology that will be followed for the assembly of the SmartWalls, along with some crucial parameters that should be considered during the manufacturing, are subject of *WP6 "Manufacturing & Assembly of PnU kits"*.

6.3.2 Transportation

The packaging, handling and transportation of the SmartWall panels have been described in the corresponding chapter of Deliverable *D2.6 "First stage design of PnU kits"*. The means of transportation are also described in D2.6 and involve common tracks for SmartWalls of regular size, whereas for bigger size panels, long – vehicle / open-trailer tracks might be required (roads and access restrictions need to be taken into consideration).

When at installation site, SmartWall panels and/or elements should be stored properly without the risk of bending and always protected by a rainproof and well ventilated cover.

Any additional requirements regarding the handling, transportation and storage of the SmartWalls may result during the related tasks of *WP6 "Manufacturing & Assembly of PnU kits"*.

6.3.3 Installation (+Minimum occupant disturbance)

A basic guide of the activities that will take place during the installation phase of the SmartWall panels on the Greek demo site is provided in *Deliverable D2.6 "First design stage of PnU kits"*. However, a more detailed installation guide along with any changes or extra procedures/activities that might arise during the PLURAL project will be described in *Deliverable D7.4 "Installation of PLURAL system in Athens (Greece) real demo case".*

One of the initial targets of this project is to renovate the proposed demo by reducing the renovation time and by causing the minimum possible disturbance to its occupants. According to the aforementioned guide of installation activities included in D2.6 *"First design stage of PnU kits"*, the only possible disturbance to the occupants could result from:

- The "auxiliary to SmartWall's installations" that might be needed and where traditional construction methods would be applied;
- The removal of the existing windows/doors of the openings and their possible remedial works;
- Holes and openings on the existing walls for the installation of the ventilation / heating / cooling system air grilles;
- The internal SmartWall panels installation.

However, in order to further eliminate the overall provoked fuss, additional precautions should be taken such as:

- SmartWall panels will be prefabricated to the biggest possible dimensions to minimize installation time, thus less disruption for the occupants will occur;

- Installation might be planned in "room by room" approach and not simultaneously to all the rooms;
- Extra measures should be adopted to eliminate transfer of air-born dust, e.g. air-tight the installation room, use of hoovers, etc.

6.3.4 Operation phase

For a limited period after the installation completion, e.g. one month, the systems will be commissioned, corrected, modified or readjusted if necessary, and the occupants will be trained to the operational functions of SmartWall systems.

During this operational phase, all SmartWall systems will be activated and a series of tests will be performed to all its electromechanical and electronic components to ensure that everything performs according to user's and technical requirements as were defined in the previous stages of design, manufacturing and testing by the outcome of WP2, WP3, WP4, WP6 and WP7.

In this stage, it is important to adjust and modify any parameters that may cause malfunctions or do not satisfy user's requirements and keep a timetable of downtime, or operations out of the required and set values. In this way, data and feedback will be provided to settle an operation and maintenance schedule and develop operational contingency plans. In addition, this operational phase will facilitate the prognosis of possible failures and the definition of the critical timing for repairs.

It is also foreseen to inform the occupants about the changes that have been undergone to the building during the renovation works, which by extend have altered the behaviour and performance of the building. As a result, different operational patterns should be adopted by the occupants (if possible) to aid in the optimal operation of the building and of its systems. This involvement of occupants in the use and operation of the building's systems is required in order to minimize the "performance gap", that is, the difference between the expected/predicted and the actual energy consumption of the renovated area.

6.3.5 Accessibility for maintenance and repair

SmartWall panels are designed and fabricated in such a way to minimise the future need of maintenance and repairs. Even when maintenance and / or repairs might be needed, SmartWall panels design allows easy and uninterrupted access to PnU kits installed into it, minimising the need of extensive and messy works inside or outside the habitant areas of the building, resulting to very limited disturbance of the occupants.

The maintenance of the externally installed SmartWall panels, will be conducted in the external areas of the renovated apartments – balconies –, whereas for the internally installed SmartWalls it will be realized on the interior of the renovated apartments. In addition, the inspection, maintenance and repairs of the auxiliary systems and technologies that have been installed remotely from the SmartWalls e.g. on the terrace of the building, will be conducted without causing any disturbance to the occupants.

More specifically regarding the equipment or systems that are installed / incorporated inside or upon the SmartWall panel:

- All systems integrated into SmartWall's frame are easily accessible via access points of such dimensions allowing easy interrupted substitution/repair of the component, if required (following *Figure*).

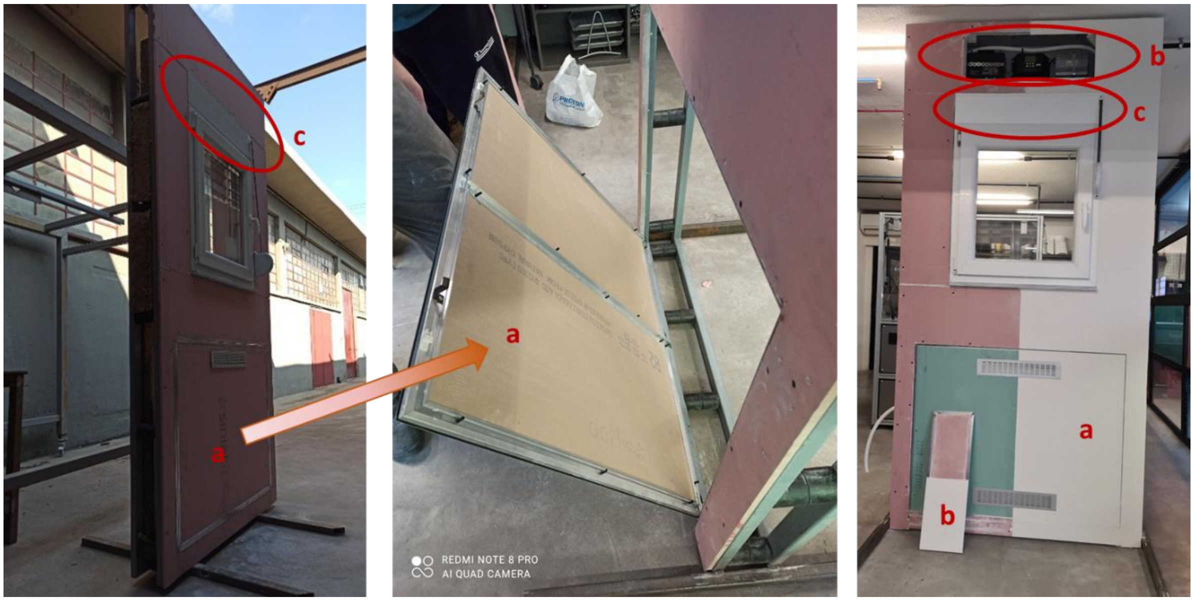

FIGURE 70: SMARTWALL ACCESS POINTS

In the illustrated prototypes above, three (3) different access points are indicated:

a. Push – lock on fan coil area access point, dimensioned @ 950mm (l) x 750mm (h) allowing access to the fan coil, its valves, wiring, drainage, plumbing and its individual fire-protection system;
b. Bolted on the toolbox casing, access point, dimensioned @ 600mm (l) x 250 mm (h) allowing access to AMScope, batteries (if included), sensors, PV inverter (if included), and its individual fire-protection system and PSU.
c. Interlocking to the roller blinds frame access point, dimensioned @ 750mm (l) x @00mm (h) allowing access to the windows blinds and their motor.

- The wiring of SmartWall systems is encapsulated within suitable ATEX conduit system, allowing easy replacement, if by reason cables need to be replaced.
- Windows are attached on the out sub-frame of SmartWall panel (as any traditional window), bolted with the appropriate type and size screws. Once it will be removed, there is direct access to its sill and its heat-breaker (if any repairs or substitution might be required).

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- SmartWall electronics (AMScope) can be remotely (via cloud) or locally (via the LCD panel attached on the panel) controlled, rebooted and programmed if necessary.

It is recommended to inspect all systems of the PnU kit once a year, either they are incorporated inside the SmartWall or placed in different areas of the building. The inspection should be conducted by a technical member of the manufacturer's team and a report of "good operation" should be given to the technical manager of the building. Besides, regular inspections should be also conducted throughout the year by the technical department of VVV Municipality to ensure that no damages or failures have been caused. No special equipment is needed for the maintenance works.

As for the Blazecut active fire protection system, it is a system that requires no maintenance according to its manufacturer, during its entire working life. However, it needs to be checked after the passing of some years, as the fully sealed system has a life expectancy of up to 10 years depending on the type application and the system's surrounding environment.

An "operation and maintenance schedule" with dates of maintenances/repairs should be kept for the building by the Technical Department of VVV, in terms of keeping track of the components damaged, replaced and/or repaired.

7. Conclusions

The final design of the PnU kits, developed in the PLURAL project, has been presented in this deliverable. Given that the pilot site conditions and requirements were used as a case study for their development, these conditions are also described in this deliverable. However, the replicability of the concept and its applicability in the previously defined range of the European residential building stock has been considered at all times and will be demonstrated at the virtual pilot sides, where the same PnU kits are applied in different conditions.

The three PnU kits, ConExWall, HybridWall and SmartWall, as they have recently been renamed in order to increase their market attractivity, went through an intense development process. International and multidisciplinary teams were formed around each of the PnU kit, in order to come up with the architectural, structural and HVAC design, but also to assure the compliance with regulations, user requirements, nZEB standard, outstanding thermal and acoustic comfort and interior air quality, low maintenance, accessibility of the integrated technologies and considerations of a circular design. Given that in all the 3 cases the building owner is coming from the public administration institution, the maintenance consideration and user requirements were very stringent. This fact helps to the replicability of the solution, together with the flexibility of the design.

The results of the development process will now be tested by the actual implementation on the pilot sites. The production and installation process is being developed within the work package 6 *Manufacturing & Assembly of PnU kits*. The final design as developed within the D2.7 is final design from the architectural perspective, but the stakeholders responsible for manufacturing and installation might still add different considerations, while analysing the production and installation process in more depth. So, another level of design for the PnU kits will be developed, following the concepts established in this deliverable, but incorporating any new considerations, but also even more precision into the design. In the architectural design, certain simplification is needed, especially when considering the dimensions, in order to keep the BIM files and drawings workable. At the next stage, each of the PnU kit panels and its components, windows or cladding, will be defined with a milimetric precision, using the 3D scanning files as a base.

In order to make a first evaluation of the PnU design, it could be concluded that a high level of industrialization and a successful integration of technologies has been achieved in all the three cases. On the other hand, the prefabricated solutions with multiple layers and components have to be considered as a complex solution with multiple crucial points to be controlled at the implementation, such as the protection of the fragile elements during transportation, waterproofing and air-tightness of the joints between the panels or the tolerances for the windows and other elements that depend on the actual state of the building.
The final evaluation of the PnU kits design and implementation will be performed within *D7.6 Technical Viability Assessment*.

8. Annexes (Submitted as separate documents due to their size)

8.1 Final drawings of the PnU kits at the CZ demo

8.2 Structural survey of the CZ demo

8.3 Results of the 3D scanning of the CZ demo

8.4 Final drawings of the PnU kits at the ES demo

8.5 Final drawings of the PnU kits at the GR demo

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