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PLUG-AND-USE RENOVATION WITH ADAPTABLE LIGHTWEIGHT SYSTEMS

PLURAL

D1.1

Requirements: Context of application, building classification, used consideration – Definition of requirements and constraints

Version: 1.0

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Terms, definitions and abbreviated terms

AB	Apartment Block
ASTRW	Active Solar Thermo-Electric Radiant Wall
BAPV	Building Attached/Applied PhotoVoltaic
BIM	Building Information Model
BIPV	Building Integrated PhotoVoltaic
BISTS	Building Integrated Solar Thermal Systems
BMS	Building Management System
BPSM	Building Performance Simulation Model
DHW	Domestic Hot Water
GA	Grant Agreement
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
IEQ	Indoor Environmental Quality
LHTES	Latent Heat Thermal Energy Storage
MEP	Mechanical, Engineering and Plumping
MFH	Multifamily house
MVHR	Mechanical Ventilation with Heat Recovery
PnP	Plug and Play
PnU	Plug and Use
RES	Renewable Energy Systems
SCSI	Summer Climate Severity Index
SMHRU	Smart Modular Heat Recovery Unit
STACHWS	Solar Thermoelectric Air Conditioner with Hot Water Supply
TE	ThermoElectric
WCSI	Winter Climate Severity Index
WWR	Window to Wall Ratio

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Extended executive summary

PLURAL targets to design, validate and demonstrate a palette of versatile, adaptable, scalable, off-site prefabricated plug and play facades accounting for user needs ("Plug-and-Use" – PnU kits). For this purpose, PLURAL focuses on three main pillars:

- Assessing different core systems, which couple heating-cooling, ventilation, heat harvesting with smart windows, 3D printing, low carbon footprint-nano-enabled coating materials and smart control towards NZEB status for different European climates and different residential building typologies (<60 kWh/m^2 per year of buildings' total primary energy consumption and >50 kWh/m^2 per year of on-site renewable energy generation).
- Utilizing BIM based management platform coupled with Decision Support Tool (DST) in order to optimize the component selection and integration, as well as to optimize the PnU kit design, production, manufacturing time and cost, and installation (≥ 50% reduction in the time required for deep renovation of e.g. multi-family blocks, 58% reduction in renovation costs through off-site prefabrication lean manufacturing and construction, interactively supported by the BIM based platform and DST)
- Demonstrating the applicability of the PnU kits by implementing the solutions in three real and three virtual residential buildings in order to evaluate the renovation time and cost reduction, the PnU kits performance, carbon savings and users' comfort.

PLURAL will create best practice renovation examples for the residential sector based on innovation and competitiveness, with benefits for the citizens and the environment. It will develop business cases and models for key stakeholders and will improve life cycle based performance standards applied in the building sector.

In this deliverable, the preliminary requirements for the three PnU PLURAL solutions, namely the "Smart Wall", "eWHC" and "eAHC" are defined. D1.1 sets the basis for the project developments foreseen as part of the DoA, by reviewing existing requirements of State-of-the-Art prefabricated technologies and systems and off-site solutions, as well as by the consortium's experience gathered from previous projects, correlating their characteristics to building typologies, climatic requirements, and the possibility for market penetration.

The Deliverable presents an extensive review of the literature related to technologies and systems incorporated inside walls, of off-site prefabricated solutions and of marketed implementation cases. Besides, a literature review, including EU funded projects, regarding the integration of HVAC systems into multifunctional façades is performed. The main goal of all these projects was to assess what is feasible or technically suitable, minimizing occupants' disturbance. Demonstration in buildings has

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been used to prove the applicability and reproducibility of the proposed solutions by monitoring the energy performance, indoor air quality, mounting time on-site etc. Some of the main findings of these projects are:

- The total cost of retrofitting can be reduced by 40% due to efficient manufacturing and efficient use of labor;
- Most of the solutions incorporate Mechanical Ventilation with Heat Recovery;
- Utilization of smart windows is a significant aspect as they can significantly reduce the thermal radiation during summer season and thermal dispersion from the interior in winter period;
- When retrofitting a building to nZEB, the percentage share of Domestic Hot Water (DHW) rises significantly due the fact that the heating demand is reduced and the DHW demand stays on the same level, leading to the conclusion that DHW supply is getting more important when the building is well insulated;
- Technologies targeting RES integration on building envelop become more and more mature and cost attractive, such as Building Integrated/Attached Photovoltaics (BIPV / BAPV) to generate electricity, and Building Integrated Solar Thermal Systems (BISTS) to supply domestic hot water and thermal energy to contribute towards space heating demands. However, such solutions are not extensively tested yet.

Continuing the SoTA review, the Deliverable also reviews the off-site prefabrication processes and describes the main features and off-site prefabrication challenges of the PLURAL's solutions (core systems). According to the review of off-site prefabrication, the main findings are:

- Project timelines accelerate appr. 20–50 % ; prefabricated unit libraries (BIM) can result in time savings of 15–20 %.
- Off-site prefabrication success depends on:
  - Optimizing materials and integrated technologies to build quality units;
  - Achieving full scale, minimizing on-site works and labor;
  - Aiming for a certain degree of repeatability in the prefabricated solutions (standardization);
  - Adapting the manufacturing plants (by investment in engineering, equipment and skilled workforce) to achieve an efficient, competitive production;
  - Optimizing the unit size for transportation, manipulation and mounting at works.

Furthermore, the core systems of PLURAL PnUs are described regarding the technologies incorporated and the off-site prefabrication challenges. It is indicated that every PLURAL system developer takes into account the main off-site prefabrication challenges as guidelines for each system development.

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Concluding, the SoTA review deals with real market implementation cases, analysing reference projects, ongoing or already finalized that focus on:

- *Large or medium prefabricated add-on solutions for envelopes*: the scale of demonstration reveals the high potential of introducing the modular prefabricated technology in large-scale renovation market with significant revalorization of the property;
- *Circular passive and active solutions*: the solutions include reuse of construction and demolition waste materials for the production of high added value prefabricated elements, as well as integrated systemic service for the circular management and efficient use of water, waste, energy and material resources;
- *Volumetric addictions as main solutions*: the solutions include assistant building units (e.g. rooftop extensions) adopted to existing buildings towards to the reduction of the initial investment for deep renovation of existing buildings;
- *Differentiated solutions in different geo-clusters*: the solutions can take into account the particularities of Europe's geo-cluster for better and larger penetration of the renovation market;

A global analysis through a SWOT matrix is presented, taking into account the results of European projects related with energy renovation prefabricated solutions for buildings, creating a whole picture of conditions/limitations for building renovation with prefabricated solutions. The main findings of the SWOT analysis can be summarized as follows:

- Off-site prefabrication is superior to conventional retrofitting solutions from technical, social and environmental point of view;
- Demonstration of energy renovation using off-site prefabrication increases social awareness, improves stakeholder's knowledge and, thus promotes stimulus for renovation in European regions;
- The main weaknesses regarding high construction/maintenance costs and adaptability of the solutions to the singularity of each case (e.g. historic buildings, seismic zones etc.) can be minimized considering:
  - Public subsidies or tax systems promoting prefabricated solutions that have social/environmental benefits, improvement of manufacturing process to downscale the investment costs;
  - Development of new research projects which will increase the knowledge and experience of the technicians, as well as improve the prefabricated solutions, increasing its versatility and adaptability;

The Deliverable describes the details of the three off-site prefabricated plug and play façade systems that the PLURAL concept is based on, coupling heating-cooling, ventilation, heat harvesting systems with smart windows, 3D printing, low carbon footprint and nano-enabled coating materials, accounting for user needs ("Plug-and-Use" - PnU kits):

- "Smart Wall", a multifunctional wall, which can be installed either externally or internally (see *Figure 1-1. Smart Wall Layout*);
- "eWHC", an **e**xternal **W**all **H**eating and **C**ooling module, which is merely applicable externally (see *Figure 1-2. Redesigned eWHC Envelope Kit*);
- "eAHC", an air handling unit with **A**dvanced **H**eat/**C**ool recovery system, which is applicable only for the **e**xternal building surface (see *Figure 1-3. eAHC solution layout*);

D1.1 presents the main technology and systems, as well as off-site prefabrication requirements for the PLURAL solutions. The requirements are categorized based on location, geometry, energy and structural performance of the building. It is postulated that:

- The three PnU kits can be applied on every type of residential building;
- The "Smart Wall" can be installed either on the external or the internal side and can be applied in every European climate (covering heating and cooling requirements);
- The "eWHC" PnU can be installed only on the external side of the wall and is suitable for heating dominated climate conditions (Central and Northern European countries);
- The "eAHC" PnU kit can be installed only on the external side of the wall and is suitable for the most European countries except from Nordic conditions (extreme heating demands);
- The three PnU kits add thickness to the external walls or roofs and thus legislative requirements should be taken into account;
- The three PnU kits add weight to the whole construction and thus the structural adequacy of the existing building should be considered;
- The three PnU kits alter the fire safety conditions and thus the fire performance of the renovated building should be taken into account;

Regarding the off-site prefabrication of the PLURAL solutions:

- The "Smart Wall" production cannot be fully automatized, since the parts and components depend on the particular project design;
- The "eWHC" system have to fit exactly, thus the geometry of the existing wall has to be accurately measured.
- The "eAHC" system can be limited regarding its size, as depending on the climate conditions the unit's outer dimensions, particularly thickness, can be a restrictive parameter;

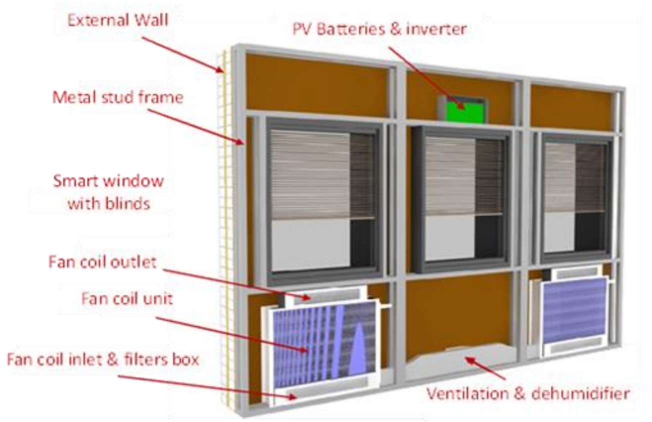

FIGURE 1-1. SMART WALL LAYOUT

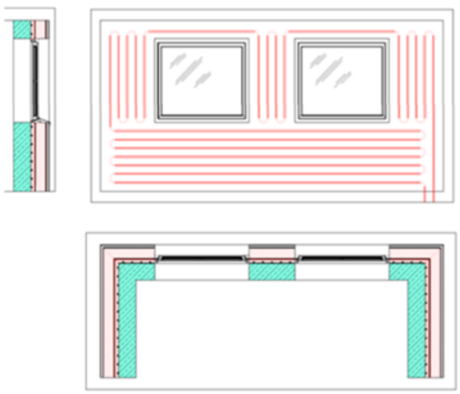

FIGURE 1-2. REDESIGNED EWHC ENVELOPE KIT

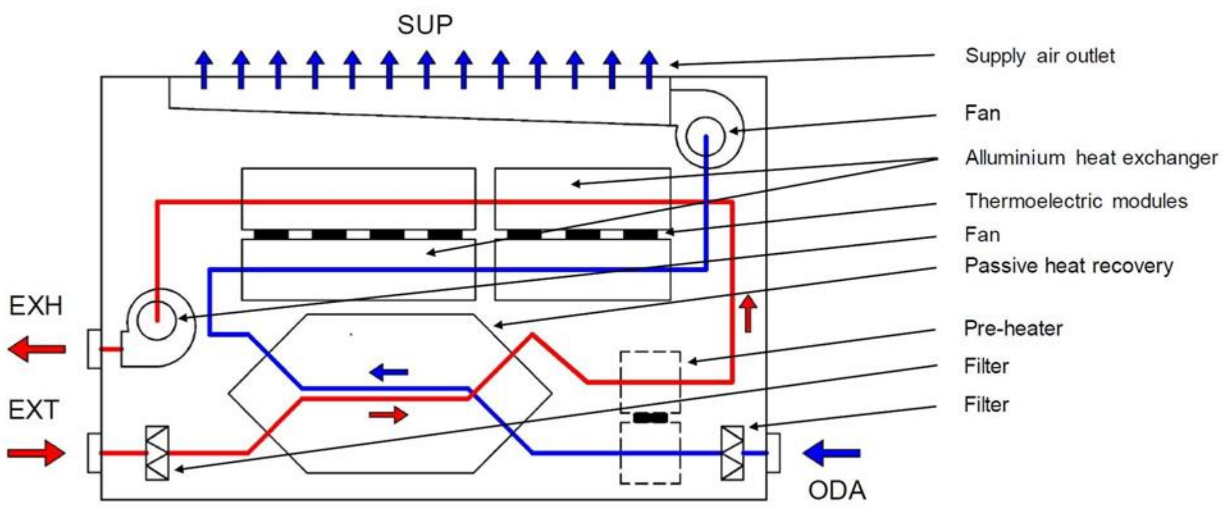

FIGURE 1-3. EAHC SOLUTION LAYOUT

As a result of the above analysis, detailed tables are presented, where specific requirements and preliminary specifications of PLURAL solutions are tabulated.

The Deliverable focuses on the analysis of the variables and requirements that are directly linked to the implementation of project solutions, the establishment of the different clusters among the

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represented countries, and refinement of the most representative residential building typologies in European regions. The analysis focuses on two main directions:

- *Geo-cluster classification* in order to define the differences and similarities between different regions taking into account climatic conditions, socioeconomic and/or financing constraints, long-term renovation strategies; The analysis led to six (6) main geo-clusters representing the 36% of the territory with a total of 324 regions. The non-characterized clusters can be either assimilated to one of the proposed clusters or neglected as they represent regions in countries with limited territory;
- *Building archetype* in order to identify the most frequent building typologies in each country to serve as a base of analyzing the replication potential of the PLURAL solutions; The analysis takes into consideration post war (WW II) buildings and thermal and energy regulations. Detailed tables regarding building typologies, envelope characteristics and active energy systems for different countries are presented. The study led to a conclusion that the most frequent building typologies from 1946 until 1980, are multifamily houses with a range of 2 up to 9 floor levels.

Based on the analysis performed regarding the geo-cluster classification and building archetype and the constraints identified in the analysis of the preliminary requirements of the PLURAL solutions, a general table is presented highlighting the characteristics and thresholds of the proposed solutions in order to determine the final archetype model to be used for simulation purposes within the project. General aspects relevant to geo-cluster classification, such as financial schemes, long-term strategies and climate indicators are also discussed, while the available information of the Demo Cases are presented.

Last but not least, the Deliverable presents a market analysis that studies the current situation of European building renovation trends in order to enable a successful market penetration of the PLURAL solutions. The analysis takes into account the different climate conditions, the actual energy efficiency state of buildings, barriers to renovation, governmental strategies and price structure for renovation. More detailed analysis has been introduced for two representative countries, Spain and Germany, where PLURAL demonstrator buildings are located. The overall analysis yields the following main findings:

- There is a positive potential of PLURAL solutions to penetrate European Market due to:
  - The very high renovation potential in the residential sector;
  - There is a large part of building stock that does not comply with the targeted energy efficiency standards;

- PLURAL solutions are in line with the new renovation strategy set by governments;
- PLURAL solutions are 20%-25% more economical than current market prices and offer the required nZEB standard (will become mandatory for all existing buildings by 2050);

- In order that the PLURAL solutions become competitive and dominate over conventional renovation solution, they have to provide multiple benefits:

- Short installation times;
- Little disruptions;
- Higher aesthetics;
- Innovative approaches to the business model (e.g. involvement of private investment possibly independent from the beneficiaries of the building renovation);

1. Introduction

Deliverable D1.1 "*Requirements: Context of application, building classification, used consideration – Definition of requirements and constraints*" has been prepared in the frame of Task 1.1 "*Residential building requirements for fast-low cost and NZEP deep renovation with PnUs*" (M01-M03). The core aim of D1.1 is to create a general vision of how the PLURAL technologies fit in the current building deep renovation market. More specifically, the main objectives of D1.1. are:

- **Objective 1**: Review the State-of-the art regarding the off-site prefabrication of PLURAL's all-in-one kits related technologies.
- **Objective 2**: Set the preliminary requirements of the PLURAL's technologies and systems for the off-site prefabrication.
- **Objective 3**: Define the most representative residential building typologies in European countries in terms of building geometry, climatic zones and energy performance characteristics, which are strong candidates for the implementation of the PLURAL concept (nZEB, low cost, fast off-site prefabrication)
- **Objective 4**: Identify the most relevant market segments and key target countries that PLURAL's all-in-one kits best fit.

The above objectives are fulfilled through a set of chapters that conduct an in-depth analysis on the PLURAL's technologies and systems, from a technological and market point of view. More specifically, in Chapter 2 an extended State-of-the Art review of PLURAL's related technologies and systems, off-site prefabrication solutions and real market implementation cases is performed, taking into account reference projects that already defined building archetypes for EU countries. Chapters 3 and 4, are summarizing the preliminary requirements of the PLURAL's technologies and systems, taking into account the know-how and experience gained by the participation in previous EU projects of the technology and system developers, the PnU integrators/manufactures, the building owners and designers participating in PLURAL project. Chapter 5 analyzes the residential building stock of the European countries/regions, and defines the most suitable candidate countries/regions that the PLURAL concept best fits, taking into consideration environmental conditions, socio-economic indicators and building typology. Finally, in Chapter 6 an in-depth market analysis is performed, where the most relevant market segments and key target countries are acknowledged.

D1.1, also contains three Annexes. Annex I tabulates the preliminary specification of the PLURAL's solutions, i.e. "Smart Wall", "eWHC" and "eAHC",Annex II describes relevant aspect to consider in geo-cluster classification, and Annex III tabulates all the up-to-day available information of PLURAL's Demo Cases.

The current deliverable sets the framework and create the prerequisites for the:

- Evaluation of the proposed concepts and their relative relationship as a function of the context of application, by defining KPIs taking into consideration economic, environmental, internal comfort, and renovation time criteria (Task 1.5).
- Development of the simulation framework, which will be based on the building classification of two representative multi-family houses that will be selected and modelled in terms of their energy performance is concerned. The reference houses will be built-up with all the hydraulics connections, SoTA components and developed modules and their efficiency in real time at a variety of dynamic conditions will be determined in real time (Task 3.3).
- Development of the IT renovation tools-BIM based LYSIS platform and Multi-objective Decisions Support Tool (MODEST) for fast and low cost deep renovation (WP5).

2. Review – State-of-the-Art of Off-site prefabrication

2.1 State of Art of PLURAL related technologies and systems

The three PLURAL core systems, which are proposed to form the PnU kits for deep renovation to nZEB, are based on several key technologies. However, innovative technologies cannot alone solve the problem of low renovation rates of existing buildings in Europe that is hindering reaching of EU-wide targets [S. D'Oca et al., 2018]. Technologies such as plug n' play prefabricated facades, information and communication technology (ICT), building management systems (BMS), integration of renewables (RES) need to be flexibly combined with each other, as well as, with specific construction materials in order to compose technological systems capable of fulfilling with the specific demands of different climates and building typologies.

High expectations of net zero-energy state through deep renovation schemes require efficient integrated HVAC systems and RES, as well as, full exploitation of heat recovery and passive systems. Smart windows, nano-enabled coatings and adaptive control systems also play a crucial role in the energy balance and optimization of the multifunctional wall panel. The integration of HVAC systems into multifunctional façade is a key technology that numerous EU-funded projects have dealt with. Many of them aim to assess what is feasible or technically suitable by integrating various combinations of heat pumps, convectors, ventilation (mostly mechanical) and heat recovery systems, embedded RES, thermoelectrical parts and smart control systems [P. O. t. Veld, 2016].

Relevant to PLURAL project systems that have already been explored and developed – mostly from EU funded projects – are summarized below.

- A prefabricated roof module combining heating units and integrated RES– **MORE-CONNECT**;
- Adaptive ventilated façade with smart heat recovery and thermal energy storage from phase change materials - **E2VENT** project;
- An innovative insulation solution combining low thickness and high effectiveness used to minimize losses - **NANO-HVAC** project;
- An externally added solution of prefabricated timber façade with integrated ventilation and solar thermal panel - **4rinEU** project;
- **iNSPire** integrated a micro heat pump with heat recovery into a prefabricated timber frame wall panel;
- A multifunctional façade wall with integrated modules that allows to monitor and smartly control the unit's behavior - **MeeFS concept**;

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- A Plug n Play and effective combination of multifunctional wall panel with smart windows and prefabricated HVAC system – **P2ENDURE**;
- A prefabricated wall panel with embedded duct system with heat recovery used for DHW minimizing distribution losses **- Swissframe in collaboration with SPF**;
- Thermoelectric system in building envelope that integrate radiant cooling with PV technologies;
- Attached or Integrated Photovoltaics and Solar thermal systems for electricity and hot water production;
- Thermal active insulation, which reduces heat losses from external surface and operates additionally to the heating system;

More specifically:

The project **MORE-CONNECT** developed roof modules with integrated RES and combined heating units. The first prototypes have been applied in Heerlen, the Netherlands. In this project, Dutch dwellings (prototypes) from the 60's were fully retrofitted with modular prefabricated integrated roof. The facades include integrated combined heating units (convectors) with decentral demand and CO_2 controlled mechanical ventilation units with heat recovery. The roof elements have 40.0 m^2 PV panels corresponding to 6.4 kWp.

A fully prefabricated installation box (engine) contains an air-to-air heat pump, boiler, mechanical exhaust fan and PV converters. This box was placed in the roof and can be accessed and replaced from the outside of the building. In case of system's maintenance or parts replacement no access or activities internal the dwellings are necessary, minimizing the disturbance for occupants [A. Tisov, 2017].

E2VENT[1] delivered energy efficient ventilated facades for optimal adaptability and heat exchange able to achieve remarkable energy savings, through the integration of an innovative adaptive ventilated façade system (see *Figure 2-1. E2vent system (left), Smart Modular Heat Recovery Unit (SMHRU, middle) and Latent Heat Thermal Energy Storage (LHTES, right))*, including:

[1] Project's website: http://www.e2vent.eu/ (2015-2018)

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- A Smart Modular Heat Recovery Unit (SMHRU) for the air renewal, which allows the heat recovery from the extracted air using a double flux exchanger. Indoor Air Quality is ensured while limiting the energy losses;
- A Latent Heat Thermal Energy Storage (LHTES) based on phase change materials that provides a heat storage system for heating and cooling peak saving;
- A smart management that controls the system on a real time basis targeting optimal performances. It includes new sensors, communicates with existing systems and recovers predicted weather;
- An efficient anchoring system that limits thermal bridges;

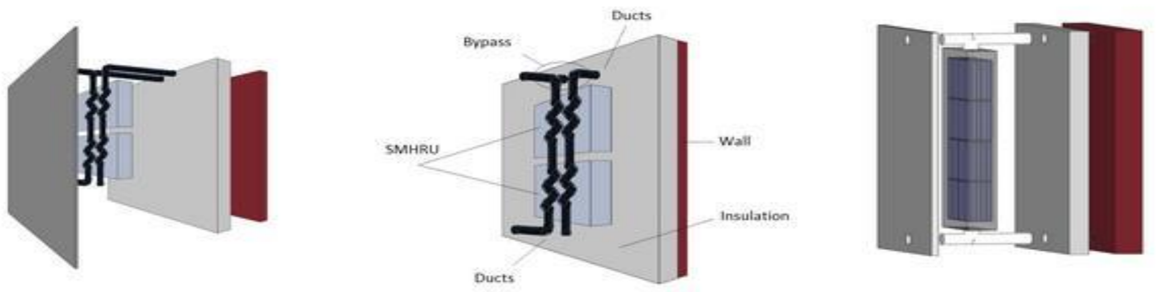

FIGURE 2-1. E2VENT SYSTEM (LEFT), SMART MODULAR HEAT RECOVERY UNIT (SMHRU, MIDDLE) AND LATENT HEAT THERMAL ENERGY STORAGE (LHTES, RIGHT)

Dealing with significant losses through conduction from poorly insulated HVAC ducts (can lose up to 50 % of the energy used to heat and cool the indoor environment), **NANO-HVAC**[2] project is an innovative development of ducts insulation. High insulating HVAC-ducts enable minimization of heat/cool losses; cost-effective, safe and extremely thin insulating duct layers can be applied both to circular ducts (wet-spray solutions) and to square ducts (pre-cast panel). Insulation is obtained using sprayable aeroclay-based insulating foams that can be automatically applied during manufacturing of ducts, avoiding manual operation needed for conventional materials. Such technologies coupled with advanced maintenance systems can guarantee a 50 % saving in energy losses compared with conventional ducts. The whole system aimed to be developed with a requirement of service life of the building of 25 years. A full-scale demonstration was developed and installed on an existing commercial demo building in

[2] Project's website: http://www.nanohvac.eu/ (finished in 2015)

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

Spain. The installation was used to measure and evaluate the performance of the system to be installed in the HVAC system, regarding the low energy consumption in combination with the high antimicrobial capability.

A timber-based prefabricated multifunctional façade developed from **4rinEU**[3] project (see *Figure 2-2. Prefabricated timber façade module)*. These prefabricated elements - in addition to other similar projects - do not replace the existing façade, but they are added externally to the existing façade to improve the performance and expand the number of functions of the existing envelope. This innovative technology consists of a prefabricated timber façade module in which components, such as new windows, decentralized ventilation machine or solar thermal panel are integrated. The use of timber makes the component potentially environmentally friendly as this enables its recycling at the end of life. Moreover, the integration of various components gives the advantage during envelope's renovation process to directly install devices (and therefore functions) that increase the energy performance of the building as well as users' comfort.

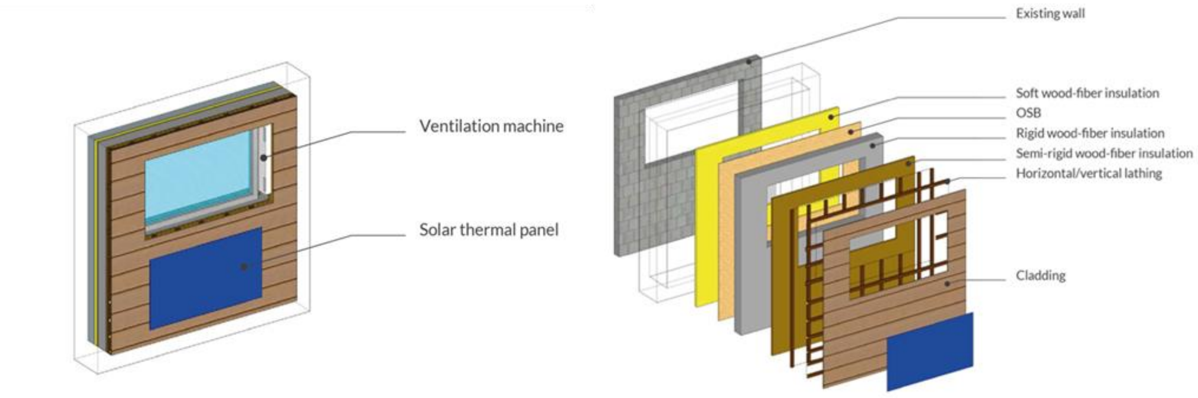

FIGURE 2-2. PREFABRICATED TIMBER FAÇADE MODULE

Another prefabricated system which is integrated into timber façade is developed by **iNSPire**[4] project. This Kit consists of a wooden frame envelope module incorporating ducts and air-to-heat pump. More specifically:

[3] Project website: https://4rineu.eu/

[4] Project website: www.inspirefp7.eu/

Pipes, ducts and wires for domestic water, heating, ventilation, electricity and solar energy generation were integrated to timber frame façade elements from the prefabrication stage. A micro heat pump was combined with the evaporator being added on the exhaust of the Mechanical Ventilation with Heat Recovery (MVHR) unit and the condenser to the supply air, exploiting the remaining heat to deliver active heating. Acoustic silencers have also been added in advance, while air outlets and inlets can be integrated through the prefabricated window reveals[5].

In previous projects, where a prefabricated timber envelope retrofit solution has been applied, it did not incorporate heat recovery ventilation systems due to the impact its installation has in occupied flats. A goal of this project was to overcome this by developing a system, which delivers a MVHR, minimizing the installation of ducts inside the occupied dwelling [F. Ochs et al., 2015] (see *Figure 2-3. MVHR with micro heat pump, prefabricated system)*.

The prefabrication of the ventilation parts has shown several advantages compared to the installation of ducts on site. Working in a horizontal position and in the protected environment of a factory improves the quality and reduces times, producing time/cost savings in the process.

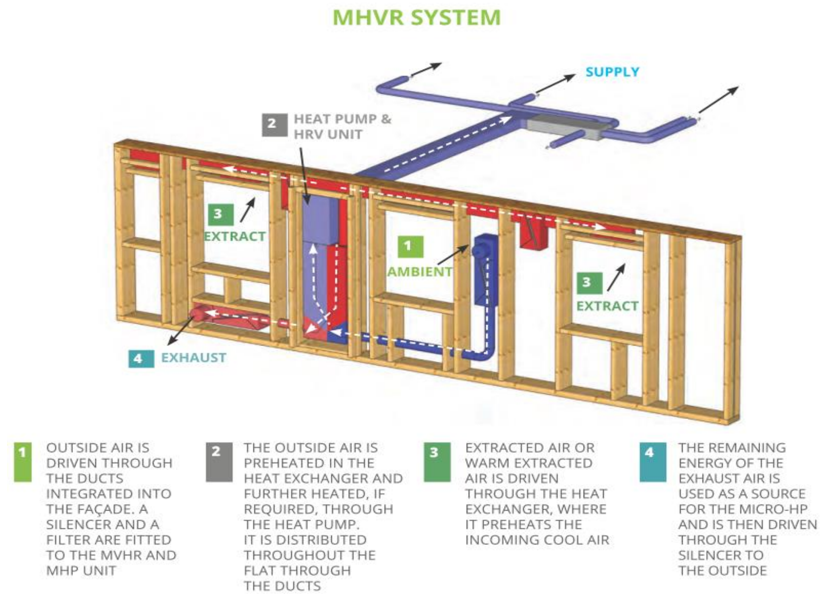

FIGURE 2-3. MVHR WITH MICRO HEAT PUMP, PREFABRICATED SYSTEM

[5] "D9 . 13 Guidebook for the Implementation of the Systemic Packages," pp. 1–90.

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MeeFS[6] project focused on the development of different components of a multifunctional energy efficient façade system that can be applied during building retrofitting (see

Figure 2-4. MeeFS concept: A Multifunctional Energy Efficient Façade System for Building Retrofitting*)*. It is composed of structural panels, which are fixed onto the building's façade and active modules which are installed into the panels. The whole façade system is managed and controlled by an Intelligent Control System.

For the energy management aspects, a BMS is installed. Finally, a guide of design and decision-support system has been developed to ensure the proper implementation, maintenance and use of the façade system. The developed solution was demonstrated on a building in Spain (city of Merida) in October 2016. Merida is in southern Spain and has continental climate (in summer above 35°C and in winter below 0°C). The panels were pre-assembled in a local workshop and transported on-site using a dedicated lifting beam and hoisted directly into their definitive position and securely attached to the supporting trays. Once the modules were properly installed, they were connected to the BMS, which manages and monitors the functioning of the active modules of the multifunctional façade, the energy consumption, as well as sun orientation for photovoltaic units and water feeding for organic green components. The performance of the refurbishment is monitored through an extensive array of sensors deployed in the dwellings.

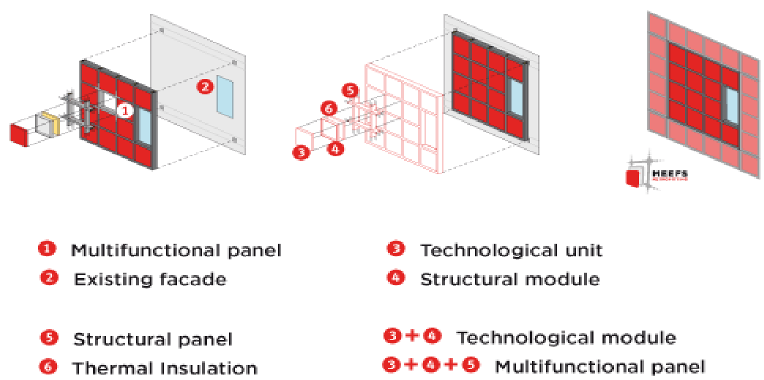

FIGURE 2-4. MEEFS CONCEPT: A MULTIFUNCTIONAL ENERGY EFFICIENT FAÇADE SYSTEM FOR BUILDING RETROFITTING

[6] Project website: http://www.meefs-retrofitting.eu/

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A complex Plug & Play (PnP) solution combining multifunctional wall panels with smart windows and prefabricated HVAC systems has been developed by **P2ENDURE**[7]. 180° rotating windows are attached in order to reduce thermal radiation during summer season and thermal dispersion from the interior in winter period from the double positioning low-E glass. This window pattern provides natural ventilation as well as integration with state-of-the-art home-automation solutions. It satisfies the needs for high energy-efficiency, better indoor climate, and top-class security features.

The combined PnP MEP/HVAC assembly includes air-heat pump, storage capacity for domestic hot water (DHW), mechanical ventilation system, expansion barrel, and control systems. It has an extra option of split- engine (two cores), i.e. one for energy conversion and storage, and the other for ventilation and heating/cooling. The mounting time on-site is significantly reduced by the application of smart connectors. This innovative solution has significant advantages:

- the total cost of retrofitting is reduced by 40% due to efficient manufacturing and efficient use of labor;
- quick assembly time of just 0.5 day to place engine, connect pipes/ducts, and then operate with predictable performance;
- the weight of the modules reduced by 35% compared to traditional components, due to redesign and combination of functions.

This solution has been used for pilot implementation of deep renovation in several single-family dwellings and apartment complexes in 2 European climate zones: moderate and Mediterranean. Supplementary thermal technologies utilizes a compact seasonal storage system based on novel high-density materials that can supply required heating, cooling and domestic heat water (DHW) with up to 100% RES. An integrated design for the different components and enhanced thermo-chemical materials has been tested. Prototypes of the system (for three different climate zones) have been demonstrated and evaluated in a field test.

When retrofitting a building to nZEB the share of the DHW rises from about 11% to 33%, due to the fact that the heating demand is reduced from ca. 120 kWh/m^{2}a to 30 kWh/m^{2}a and the DHW demand remains on the same level (15 kWh/m^{2}a) for example. This condition indicates that the domestic hot water supply is getting more important when the building is well insulated. Existing decentralized single-flat domestic hot water (DHW) boilers in multifamily housing are an important obstacle for the

[7] Project website: https://www.p2endure-project.eu/

introduction of renewable energy and energy efficiency into the DHW preparation. Introducing a new centralized DHW storage and distribution in an existing building can be prohibitively expensive. The same applies for the installation of MVHR for existing buildings. The breakthrough approach that was developed and patented by **Swissframe in collaboration with SPF** combined DHW storage and MVHR units with the prefabricated front-wall units that were used for bathroom renovations. The breakthrough innovation was the incorporation in this "hollow body" of an MVHR, a highly insulated DHW tank, and a heat pump for DHW preparation that uses the exhaust air from the mechanical ventilation system as a heat source (see *Figure 2-5. a) Prefabricated bathroom front wall with: 1) MVHR and 2) high-tech DHW storage and heat pump condenser unit, b) Combination of the components in the prefabricated front-wall units*). Thus, the energy conversion efficiency from electricity to useful thermal energy was increased from 0.7 of an electric boiler to 2.0 for the heat pump + tank system. Also, distribution losses were partially recovered, increasing further the efficiency of the system. The product is available in the market since 2018.

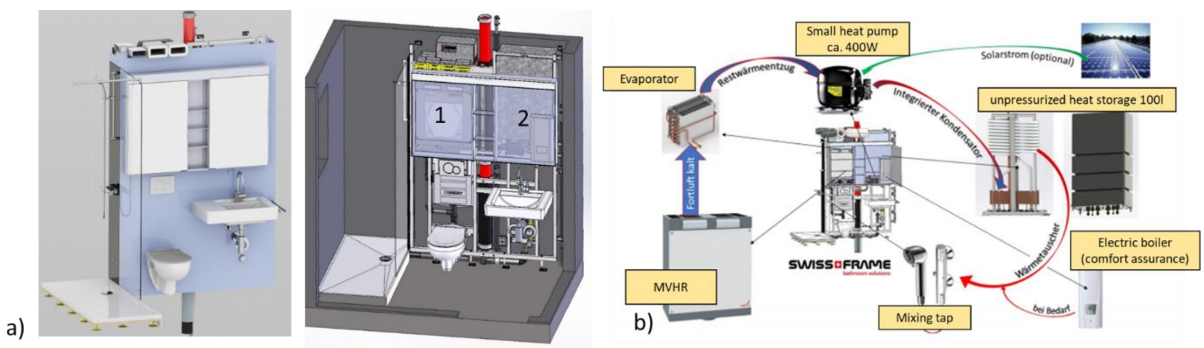

FIGURE 2-5. A) PREFABRICATED BATHROOM FRONT WALL WITH: 1) MVHR AND 2) HIGH-TECH DHW STORAGE AND HEAT PUMP CONDENSER UNIT, B) COMBINATION OF THE COMPONENTS IN THE PREFABRICATED FRONT-WALL UNITS

Apart from the EU funded projects that developed state-of-the-art systems towards more effective deep renovation schemes, technologies for RES integration tend to be a realistic future necessity in such hybrid and multiparametric systems.

Net-Zero Energy Buildings are increasingly being connected with Building Integrated/Attached Photovoltaics (BIPV and BAPV) to generate electricity, and Building Integrated Solar Thermal Systems (BISTS) to supply domestic hot water and thermal energy to contribute towards space heating demands [A. Pugsley et al., 2016]. BIPV is an integral part of a building which substitute or replace the traditional building materials or envelopes such as roof, window, atria and shading elements, components by PV and concomitantly generates benevolent electricity at the point of use [C. Peng et al., 2011]. The building attached/applied photovoltaic (BAPV) does not replace the construction component, can be rack-mounted or standoff arrays type, opaque in nature and are only employed for

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power generation and do not contribute to any heat gain into building interior, rather it alleviates heat gain by generating shading the roof or wall from direct solar heat [C. Peng et al.]. PV and ST panels are incorporated in accordingly designed cavities of the façade, wall or roof modules and are ready to plug and play. That way the maximum exploitation of insolation is achieved encompassing the benefits of a prefabricated solution. According to J. Curpek et al, the application of a phase change material (PCM) to the rear side of a PV module can provide both a decrease in PV panel temperature and thermal energy storage as well [J. Čurpek and M. Čekon, 2016].

Latest studies are striving to integrate thermoelectric (TE) systems in the building envelope. Some pioneer researches are referring to an active solar TE radiant wall (ASTRW), which integrates TE radiant cooling combined with PV technologies [Z. Liu et al., 2015] and a solar TE air conditioner with hot water supply (STACHWS), which uses TE modules powered by solar energy for heating hot water and cooling room simultaneously [Liu et al., 2016] (see *Figure 2-6. ASTRW system structure*).

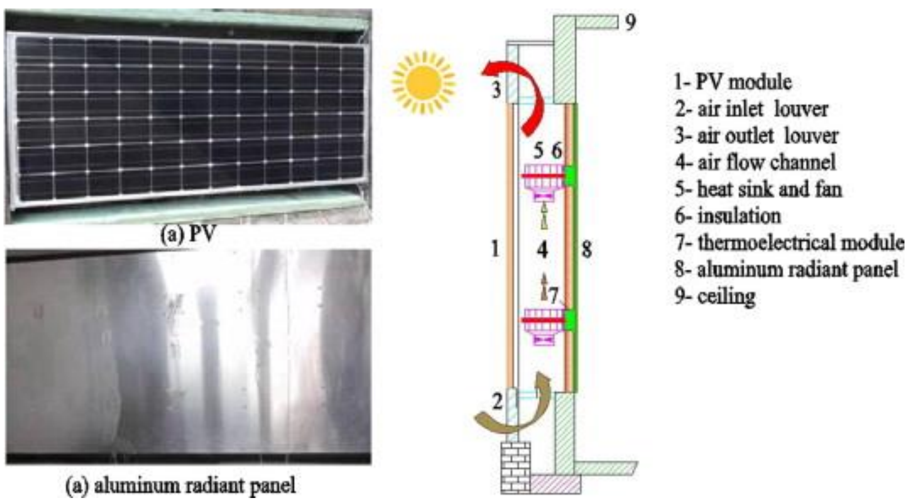

FIGURE 2-6. ASTRW SYSTEM STRUCTURE

While the aforementioned studies are in a preliminary level, where the constructive integration of the system is not solved, a first practical approach was made by Martín-Gomez et al. [M. Ibañez-Puy et al., 2016]. This prototype system has been designed as an independent, prefabricated, modular construction element that must fit perfectly between the structural floors and is easily adapted to the demands of different buildings.

In addition, mainly for heating intensive countries, the concept of active thermal insulation has been introduced. Active insulation reduces heat loss through external partitions without replacing the heating system. The operation of the active thermal barrier is not based on the direct transmission of low temperature energy to the room, but is related to the increase (or decrease during the summer) of the temperature inside the external envelope. The basic principle of active insulation is that it uses the energy of the medium at a temperature lower than the temperature of the internal room, but at a higher than that of the outside air [T. Kisilewicz et al., 2019].

Additionally, to its function of reducing thermal loss in cool climates, it is also considered in hot climate countries as protection against the inflow of heat to the building [A. Li et al., 2016]. *Figure 2-7. Thermal active insulation embedded in external wall* illustrates the thermal active insulation embedded in external wall (***t_i*** - internal temperature (°C), ***t_e*** – outdoor temperature (°C), ***t_{fo}*** - temperature in the active insulation layer when active insulation is not working (°C), ***t_f*** - temperature in the active insulation layer when active insulation (°C)) is running, ***U_o*** – thermal transmittance across the whole partition (W/(m^2 K)) and ***U_i*** – partial thermal transmittance from the internal space to the active insulation layer [W/(m^2 K)]).As a supplementary system, active thermal insulation improves the insulation parameters of an external wall, compared to corresponding passive systems [T. Kisilewicz et al., 2019].

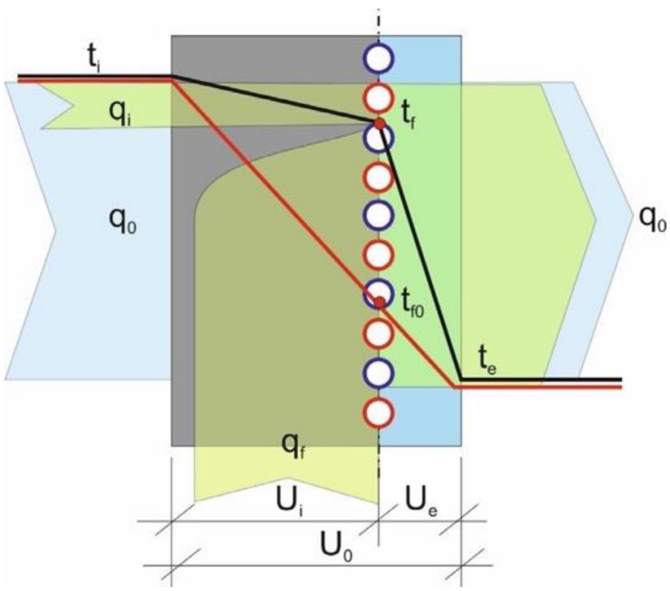

FIGURE 2-7. THERMAL ACTIVE INSULATION EMBEDDED IN EXTERNAL WALL

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Last but not least, as far as the integration of **IT solutions** is concerned, several projects (BERTIM[8], E2vent[9], iNSPiRe[10], RetroKit[11]) comprise also design and development of the building monitoring system that allows users interaction, control in operation and communication requirements for sensors and hardware. A real time intelligent management system and control strategies aim to control operation of the developed system and provide an optimized building performance, ensuring the availability of the captured information for detailed building supervision.

European Commission has acknowledged that such ICT based innovations as smart control systems can contribute significantly to deep renovation schemes. Several EU-funded projects, besides focusing not only on smart building controls but also on how to translate this building captured data into user attractive information and how to establish an effective communication with end-users [A. Tisov, 2017].

The main findings of the SoTA review regarding the technologies and systems can be summarized below:

- The total cost of retrofitting can be reduced by 40% due to efficient manufacturing and efficient use of labor;
- Most of the solutions incorporate Mechanical Ventilation with Heat Recovery;
- Utilization of smart windows is a significant aspect as they can significantly reduce the thermal radiation during summer season and thermal dispersion from the interior in winter period;
- When retrofitting a building to nZEB, the share of the Domestic Hot Water (DHW) significantly rises due the fact that the heating demand is reduced and the DHW demand remains at the same level, leading to the conclusion that DHW supply is getting more important when the building is well insulated;
- Technologies for RES integration tend to be a realistic future necessity, e.g. Building Integrated/Attached Photovoltaics (BIPV and BAPV) to generate electricity, and Building Integrated Solar Thermal Systems (BISTS) to supply domestic hot water and thermal energy to contribute towards space heating demands, but the solutions are not well tested yet.

[8] http://www.bertim.eu/
[9] http://www.e2vent.eu/ (2015-2018)
[10] www.inspirefp7.eu/
[11] http://www.retrokitproject.eu/

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2.2 SoTA of PLURAL related off-site prefabrication solutions

In past times, it was known that prefabrication did not have a spotless reputation and there was the impression that prefabricated construction is an ugly, cheap, poor-quality option. Though nowadays, this market perception starts shifting due to the adoption of new materials, the integration of new digital technologies and techniques enhancing design the capabilities and variability, improving precision and productivity in manufacturing and facilitate logistics. In addition, prefabrication companies tend to focus on sustainability, aesthetics, on higher end of the markets, aiming for an improved quality of the building, including better energy or seismic performance. Off-site prefabricated construction is lately attracting a fresh wave of interest and investment on the back of changes in the technological and economic environment [Bertram et al., 2019].

Recent modular projects have already established a solid track record of accelerating project timelines by 20–50 %. The approach also has the potential to yield significant cost savings, although that is still more the exception than the norm today.

Success in the implementation of the off-site prefabrication requires carefully optimizing the choice of materials and integrated technologies, identifying the right solution between 2D panels, 3D modules, and hybrid designs; and mastering challenges in design, manufacturing, technology, logistics, and assembly. It also depends on whether builders operate in a market where they can achieve scale and repeatability. On the other hand, off-site prefabrication design currently takes longer than traditional construction and thus creating libraries of prefabricated units (BIM) can result in time savings of 15–20 %.

Effort must still be put to achieve a more efficient manufacturing production systems for both technological modules and pre-fabricated components, by adopting a more industrialized model that takes advantage of the ability to coordinate and repeat activities, as well as increasing the levels of processes' automation. The adaptation of systems aiming to greater tolerance's precision during design and/or production is a necessity that needs further investigation. Inevitably, the implementation of an appropriate quality control system aiming to minimize the risk of defects where common inspection techniques are not able to identify onsite until many months or years later resulting to a harder and more expensive to rectify, is mandatory.

Off-site prefabrication technologies, systems and applications strongly differentiate from each other both in their nature and purpose, as well as regarding the obtained results. Nevertheless, the main challenges that off-site prefabrication has to quantify and deal with, could be summarized as follows:

- Optimizing materials and integrated technologies to build high-quality units.

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- Full scale construction that will minimize on-site works and labor.
- Repeatability in the prefabricated solutions (standardization).
- Adaptation by the manufacturers (by investment in engineering, equipment and skilled workforce) to achieve an efficient, competitive production.
- Optimization of the unit size for transportation, manipulation and mounting during installation.

Hereafter the main aspects of the State of Art of the PLURAL off-site prefabricated solutions are individually summarized, according to the initial information gathered from the system developers.

Core system 1: Smart wall – External/Internal air heating and cooling system (AMS)

The 98% of the materials used in this solution are recyclable and eco-friendly, only the air purification filters cannot be recycled. The technologies integrated comprise eco-friendly insulation and smart windows; slim-type fan coil; IEQ control system with automatic and manual capability; energy recovery system with batteries and PV panels; mounted sensors for activating an active fire protection and extinguishing system; BMS-toolbox connection interface; multi-functional coatings for anti-molding, IR reflectance and self-cleaning features. AMS installed a first prototype in its premises. It was identified during the investigation that the internal Smart Wall cannot be installed in bathrooms and kitchens.

As lines of research, the data monitoring and how this information will be sent to the controlling system developed by Intrasoft need to be resolved. Also, a challenging task would be the development of 3D printed structural frame and/or mechanical parts.

Core system 2: External wall heating and cooling system (SPF)

The external wall heating system has been tested on real buildings in different projects, but in a *"two-step approach"* (a two-step approach involves in-situ works and could not be considered as a fully off-site prefabrication). It is known that, by using aluminum fins, heat transmission increases around 30%. Efficient and fit-for-purpose, consolidated technologies that might be integrated in the system are: window's integrated ventilation; external wall heating, cooling and heating generation; PV and PVT; telecommunication hardware such as glass fibre; insulation.

However, some aspects need further investigation and development, such as:

- A minimum wall area with pipes is needed for a sufficient heating (distribution on the external existing wall increases the heating demand) and, if pipes are off-site integrated in the prefabricated element, the mounting at works becomes more complicated due to the system weight. Therefore, a method to attach pipes in direct contact with the existing wall should be found.

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- For wooden-based constructions, compliance with EU and National regulations is to be considered.
- Thermal bridges should be analyzed and minimized, sealing between modules needs to be studied.

Further investigation can be undertaken on the modules' configuration, with the restrictions imposed to the design by the height of the building. The thermal mass of the existing walls of the building results in a time-lag between production and demand of heat input into the rooms, so a smart building control with a weather forecast should be used.

Core system 2: Prefabricated timber façade and roof elements with solar integration (RDR)

RDR produces timber frame houses with integrated technologies as heating, air handling or electric power distribution network. The load bearing components are formed by massive pine wood and the houses are assembled from large panels, guaranteeing a long life, high-quality thermal insulation, while reliable fire prevention measures have been incorporated on them. Experience in the integration of heating air ducts, and electric power supply distribution system into panels was gained by the participation of RDR in previous projects.

A range of tests were carried out on prefabricated roofs with insulation as the energy harvesting system during the past time with very hopeful results. In a national project ("GibSol'), a first demo was studied in a church in Switzerland with a two-step approach. PV and PVT panels were mounted after installing the prefabricated roof. The results of this project indicated that full off-site prefabrication is feasible but needs therefore further development.

Core System 3: Air handling unit heating and cooling (CVUT)

The main characteristics of the system are the Extruded Polystyrene (XPS) body, the two Heat eXchangers (HX) (heat recovery HX and active HX with thermoelectric modules), two fully controlled fans, bypass (if needed around each HX), air temperature control and air flow control upon concentration of pollutants. Heat recovery system could be applied, but without the aid of a relevant temperature controller.

A key point to be further investigated are the external dimensions of the ventilation unit (especially its depth), which needs to be integrated in a panel. Further analysis could be executed on the acoustic performance, the drainage of condensation, and the total cooling output without the incorporation of a cooling device.

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Core System 3: Sensor platform for monitoring and control of IEQ (CVUT)

The system is based on a combined sensor of indoor temperature, humidity, CO_2 concentration, and volatile organic compounds. A technologically updated version of the system, taking in consideration the user's preferences and decisions might be used in PLURAL Project. A touch LCD version could be available as a end-user adjustable set point controller.

As more than 200 units have been manufactured and deployed in various buildings measuring on real conditions, no problems in terms of its design and production are expected.

Core System 3: Prefabricated ventilated façades, sunscreens and aesthetic skins with integrated systems (DENVELOPS)

A range of projects and tests exploiting the mentioned on the above technologies have been developed in the past with satisfactory outcomes. Denvelops uses technologies such as its own construction system to do off-site ventilated façades and roofs, sunscreens, pergolas, ceilings and walls.

As all high-quality prefabricated systems Denvelops system needs to be completely designed before the production begins. Installation of the necessary components must be carefully analyzed to properly adapt them to the renovated building. By the experience gained all these years it was proven that buildings with wide surfaces are more efficient than the small ones. Big frames of square sections are not easily to be produced while working with small steel plate sections is faster, easier to handle and therefore more preferred. Led lighting, photovoltaic cells, active shading and thermal insulation functions are being investigated for integration in the system.

Finally, these initial information on the PLURAL solutions are cross-analysed and linked with the main lines of development or general challenges for off-site prefabrication, identified and presented in the following *Table 2-1. How PLURAL Core system developments meet the pre-fabrication challenges*.

Nevertheless, the key point regarding the assessment of the PLURAL solutions, is that every technology provider and/or system developer when develops and customize its system, takes into consideration not only the main challenges for the off-site prefabrication as described below, but also the particular need for case-by-case building.

TABLE 2-1. HOW PLURAL CORE SYSTEM DEVELOPMENTS MEET THE PRE-FABRICATION CHALLENGES

LINES (*)	Core System 1 Smart Wall	Core System 2 External wall heating	Core System 2 Prefabricated timber façade	Core System 3 Air handling unit with heating and cooling	Core System 3 Sensor platform for monitoring	Core System 3 Prefabricated ventilated façades
a	Eco-friendly insulation, recyclable and non-combustible materials (98% of the materials). Recycled PETG as printed material. Reduction in heating consumption by 85% and in primary energy by 56%.	Components in a prefabricated timber-based module for a low ecological footprint and high comfort values. 20-30% lower electricity consumption with the combination of external wall heating and a heat pump.	The timber frame panel technology assures a heat transfer coefficient of 0.12 W/(m²K). Standard triple glazed windows are assembled in the panels. Heating, air ducts and electricity distribution are integrated in the panels.	Having no compressor circuit unit reduces the noise pollution. The system can operate without expensive battery energy storage and can adjust the power to the energy generated.	Design completed; technology optimized.	Led lighting, photovoltaic cells, active shading and thermal insulation functions are being investigated for integration in the system. To be further developed during the project.
b	Fast placement of fixings and hanging brackets (pre-drilled). Versatile structural design allows to reduce one hour on average the panel installation.	Including the hydronic system into the façade modules will reduce cost and time.	Façade and roof elements with solar energy converters reduce the installation time, and cost up to 20%, and disturbance of the inhabitants during the process.	Technology fully fabricated at the factory. Integration in other systems for full prefabrication to be considered.	Wireless IoT interfaces for fast deployment and installation without wire infrastructure. Technology fully fabricated at the factory.	Frames can be folded due to fixed hinges, so installation speed can be increased by hanging each façade sequence from the building top.

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LINES (*)	Core System 1 Smart Wall	Core System 2 External wall heating	Core System 2 Prefabricated timber façade	Core System 3 Air handling unit with heating and cooling	Core System 3 Sensor platform for monitoring	Core System 3 Prefabricated ventilated façades
			Mounting without scaffold eases the process.		Integration in other systems for full prefabrication to be considered.	
c	Feasible, although flexibility in the design is also desirable to adapt the system to different environmental conditions.	Feasible, although flexibility in the design is also desirable to adapt the system to different environmental conditions.	Feasible, although flexibility in the design is also desirable to adapt the system to different environmental conditions	Total: finished product to be integrated, defined technology.	Total: finished product to be integrated, defined technology.	Feasible, although flexibility in the design is also desirable to adapt the system to different environmental conditions.
d	Use of 3D printers. Novel practices in production during industrialization (advantage against market's competition).	--	Timber frame structure manufacturing line is flexible to integrate technologies as heating, air handling or electricity distribution. Panels produced on semi-automated manufacturing lines.	Manufacturing plant highly prepared.	Manufacturing plant already prepared.	Production of small components of the system with laser machines. New technology can be introduced by modifying the small components as much as needed. Manufacturing plant highly prepared.
e	Extremely versatile module, easily	To be considered during the project.	Inter roofs can be transported with one	To be considered for integration in	To be considered for integration in	The system can be decomposed in

LINES (*)	Core System 1 Smart Wall	Core System 2 External wall heating	Core System 2 Prefabricated timber façade	Core System 3 Air handling unit with heating and cooling	Core System 3 Sensor platform for monitoring	Core System 3 Prefabricated ventilated façades
	adjustable to any dimension.		or two trucks, making logistics simple.	other systems.	other systems.	small components. All façade functional components and layers can be integrated in one item, able to be transported and very fast installed in one time.

(*) Lines of development or general challenges for off-site prefabrication:
(a) Optimizing materials and integrated technologies to build quality units.
(b) Achieve full scale, minimizing on-site works and labor.
(c) Aim for a certain degree of repeatability in the prefabricated solutions (standardization).
(d) Adaptation of the manufacturing plants (by investment in engineering, equipment and skilled workforce) to achieve an efficient, competitive production.
(e) Optimization of the unit size for transportation, manipulation and mounting at works.

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2.3 State of Art of PLURAL related real market implementation cases

Several R&D projects in the past aimed to develop new technologies and methodologies in order to increase the attractiveness and benefits of the energy renovation procedures in the European building stock. Every proposed solution was not only pursuing to improve the existing energy efficiency of the buildings but also to reduce the building's environmental impact throughout its entire life cycle. The following chapter identifies some of the European projects -on going or completed- that had or expected to have a real market implementation. These examples are mainly focused on the optimization of building's performance e.g. comfort, use of resources (energy, water, etc.), while at the same time they are introducing improved installation procedures, or a better building's End-of-life. Most of them challenging the new technological perspectives are proposing with business models while owners and end – users have an active participation in the extent, quality, and cost of the renovation occurred.

2.3.1 Projects focus on Large or Medium prefabricated add-on solutions for envelopes

Figure 2-8. Pilots location for European projects on large/medium prefabricated add-on solutions for envelopes renovation (indicating the plural geocluster justified in chapter 5) presents the locations of the pilot buildings of the European projects on large/medium prefabricated add-on solutions, while in the following paragraphs a short description of these projects is presented.

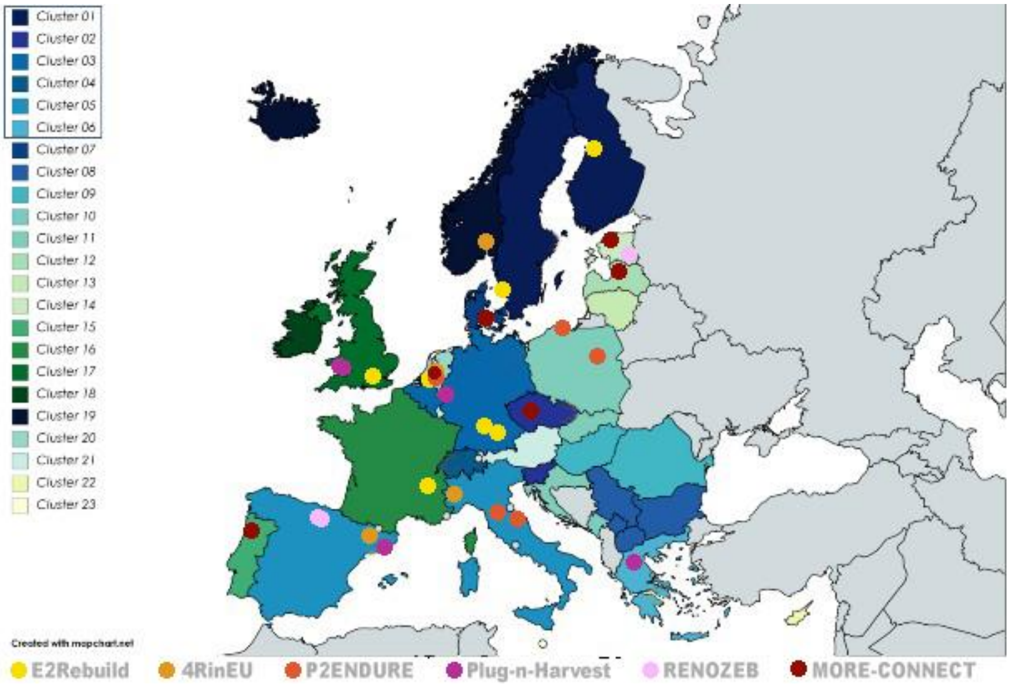

FIGURE 2-8. PILOTS LOCATION FOR EUROPEAN PROJECTS ON LARGE/MEDIUM PREFABRICATED ADD-ON SOLUTIONS FOR ENVELOPES RENOVATION (INDICATING THE PLURAL GEOCLUSTER JUSTIFIED IN CHAPTER 5)

E2ReBuild (Duration: 42 months (2011-2014))[12]

E2ReBuild aimed to facilitate the transition of the retrofitting construction sector from the current craft and resource-based construction towards an innovative, high-tech, energy efficient industrialized sector. 7 demonstration projects in 6 countries were implemented, achieving a total of 25,000m^2 of renovated buildings. Due to the introduction of industrial manufacturing methods, such as prefabricated elements and standardized retrofit measures, reductions of up to 75% in energy use were achieved. An innovative design and decision support tool for sustainable renovation strategies was developed. The project presented that the implementation of accurate design, efficient management and production of the prefabricated elements will be used for the retrofitting, can drastically reduce the construction time, thus the cost of retrofit projects, and minimize the social disturbance for the occupants of the buildings. In its long-term view, the project also initiates the

[12] http://www.ectp.org/project-database-list/project-details/industrial-energy-efficient-retrofitting-of-resident-buildings-in-cold-climates/

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energy-efficient operation and use of the building's resources, including encouraging energy-efficient behaviors by the occupants. E2ReBuild tried to introduce to the stakeholders involved in the retrofitting processes such as builders, housing organizations, architects etc. that modern industrialized processes can not only reduce retrofitting costs but also create functional, attractive and individual retrofitting solutions.

Real demo cases across European continent

- Demo 1: Munich Germany, Demo 2: Oulu Finland, Demo 3: Voiron France, Demo4: Augsburg Germany, Demo 5: Halmstadt Sweeden, Demo 6: Rosendaal Netherlands, Demo 7: London United Kingdom.

MORE-CONNECT (Duration: 54 months (2014-2019))[13]

More-Connect aims to develop and demonstrate technologies and components for prefabricated modular renovation elements in five different locations in Europe, offering different solutions depending on the specific climate conditions of each demo site. This includes the installation of durable, innovative, modular prefabricated building's envelope elements including the integration into them a range of multifunctional components e.g. for climate control, energy saving, building physics and aesthetics, with advanced easy to use plug & play connections (mechanical, hydraulic, air, electric, prefab airtight joints).

Real Demo cases across European continent

- Demo 1: Rijssen Netherlands, Demo 2: Cesis Latvia, Demo 3: Tallin Estonia, Demo 4: Odense Denmark, Demo: Prague Czech Republic, Demo 6: Vila Nova de Gaia, Portugal.

4RinEU (Duration: 57months (2016-2021))[14]

4RinEU targeted to renovate residential buildings to optimize energy efficiency, comfort and achieve Life Cycle Cost reduction through innovative technologies and methodologies. The proposed solutions aimed to address the following aspects:

- to reduce energy demand (Prefab Multifunctional Façade, Comfort Ceiling Fan),

[13] https://www.more-connect.eu/
[14] https://4rineu.eu/

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- to improve energy efficiency (Plug&Play Energy Hub, Objective-based RES Implementation),
- to improve building operations (Sensible Building Data Handler), and
- to reduce construction waste (Strategies for Components End-Of-Life).

Real Demo cases across European continent

- Demo 1: Oslo Norway, Demo 2: Mariënheuvel Soest Netherlands, Demo 3: Lleida Spain, 1 Pilot with Energy Hub solution: Pinerolo Italy.

P2ENDURE Duration: 48 months (2016-2020)[15]

P2ENDURE promotes evidence-based innovative solutions for deep renovation based on prefabricated Plug-and-Play systems in combination with on-site robotic 3D-printing and Building Information Modeling (BIM), demonstrated and monitored at 14 real projects in 4 EU countries with wide replication potential. The main Plug & Play systems proposed are:

- Prefab insulation panels composed by Textile Reinforced Concrete and expanded polystyrene core;
- Energy-efficient window (natural ventilation, integration of domotics and rotates 180º to change low-E glass position on winter/summer);
- folding balcony;
- PnP prefab MEP/HVAC (Mechanical, Electrical, and Plumbing/ Heating, Ventilation and Air Conditioning) engine;
- Compact energy storage;

Real Demo cases across European continent

- Demo 1: Florence Italy, Demo 2: Gdynia Poland, Demo 3: Ancona Italy, Demo 4: Warsaw Poland, Demo 5: Lekkerkerk Netherlands.

PLUG-N-HARVEST (Duration: 48months (2017-2021))[16]

PLUG-N-HARVEST is focused on the design of a new aluminum profile to support different components of an ADBE (Adaptable/Dynamic Building Envelopes) by taking into consideration the circular economy

[15] https://www.p2endure-project.eu/en
[16] https://www.plug-n-harvest.eu/

principles. The proposed solution, which includes a high insulation layer, photovoltaic panels, and an energy management system, can be applied in different types of buildings (residential, offices, institutional building etc.).

Real Demo cases across European continent

- Demo 1: Aachen Germany, Demo 2: Cardiff United Kingdom, Demo 3: South Wales United Kingdom, Demo 4: Barcelona Spain, Demo 5: Grevena Greece

RENOZEB (Duration: 48months (2017-2021))[17]

The main technology of the project is the modular Plug & Play Façade, which plays a pivotal and technology integrator role in the RenoZEB concept. It has a high potential to introduce new insulation and technologies for heating, ventilation, and air conditioning (HVAC) with solar RES (renewable energy sources into a large-scale renovation market with a significant revalorization of the property). Aim of the project is to analyze the best options to physically integrate controlling and monitoring systems that fulfil the requirements of monitoring models, considering robustness, reliability, response time etc.

Real Demo cases across European continent

- Demo 1: Rannaliiva Estonia, Demo 2: Durango Spain, 1 Real Pilot test: Bilbao Spain

2.3.2 Projects focus on circular passive & active solutions

Figure 2-9. Pilots location for European projects focus on circular passive & active renovation solutions (indicating the plural geocluster justified in chapter 5) presents the locations of the pilot buildings for the European projects that focus on circular passive and active deep renovation solutions. These projects are further described in the following paragraphs.

[17] www.renozeb.eu

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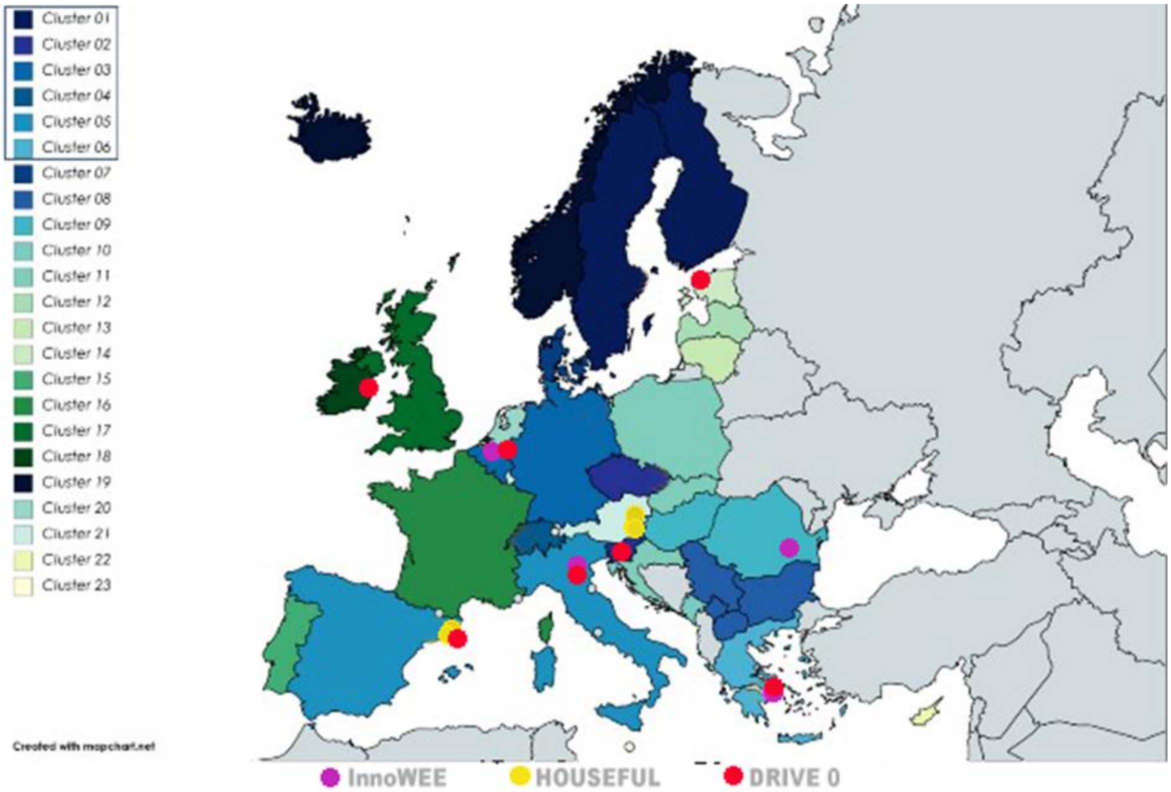

FIGURE 2-9. PILOTS LOCATION FOR EUROPEAN PROJECTS FOCUS ON CIRCULAR PASSIVE & ACTIVE RENOVATION SOLUTIONS (INDICATING THE PLURAL GEOCLUSTER JUSTIFIED IN CHAPTER 5)

INNOWEE (Duration: 48months (2016-2020))[18]

The basic idea is to recycle the waste from building demolition (fragmented bricks, fragmented plaster or concrete, fragmented glasses, machined wood from windows frame or from wood beams after demolition etc.) in a geopolymer matrix to produce prefabricated panels for different use. The main objective of InnoWEE is in fact the development of a process that can optimize the reuse of Construction and Demolition Waste (CDW) materials producing high add value prefabricated insulating and radiating panels used to improve the energy efficiency of a building.

Real Demo cases across European continent

[18] https://innowee.eu/

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- Demo 1: Padua Italy, Demo 2: Voula Greece, Demo 3: Bucharest Romania, Demo 4: Putte, Belgium.

HOUSEFUL (Duration: 54months (2018-2022))[19]

HOUSEFUL proposes an innovative transition towards a circular economy for the housing sector. The main goal is to develop and demonstrate an integrated systemic service (HOUSEFUL Service) composed of 11 circular solutions in the current housing value chain. At all stages of building's life-cycle, the HOUSEFUL Service focuses at the circular management and efficient use of;

- Material resources (S3), local materials and material passports based on advanced 3D building model (S4)
- Water (S5) Efficient treatment and reuse of rainwater, greywater and un-segregated water (S6),
- Waste (S7), Blackwater and Biowaste treatment for biogas production (S8), High quality fertilizer/compost of local origin (S9), Optimal management of waste at the end of building life cycle
- Energy (S10), Improvement of energy efficiency (increase envelope insulation or PV/ST systems) and Guarantee the energy savings/production (S11)
- To complement these strategies, HOUSEFUL develops a method for analysis building circularity (S1) and social engagement for co-creation (S2)

Real Demo cases across European continent

- Demo 1: Sabadell Spain, Demo 2: St Quirze del Vallès Spain, Demo 3: Fehring Austria, Demo 4: Vienna, Austria

DRIVE 0 (Duration: 48months (2019-2023))[20]

DRIVE 0 aims to enhance a consumer-centered circular renovation process, making the overall process more attractive, environmentally friendly and cost effective. This involves the development of proven deep renovation products based on local available materials and components, with emphasis given on

[19] https://houseful.eu/
[20] https://www.drive0.eu/

easy to install plug & play prefabricated solutions for building envelope elements and building services where their production is fully controlled by automated BIM processes.

Real Demo cases across European continent

- Demo 1: Barcelona Spain, Demo 2: Landgraaf Netherlands, Demo 3: Dublin Ireland, Demo 4: Saue Estonia, Demo 5: Attica Greece, Demo 6: Bologna Italy, Demo 7: Slovenia.

2.3.3 Projects focus on Volumetric addictions as the main solution to improve buildings performance and finance renovation costs.

Figure 2-10. Pilots location for European projects focus on building renovation combined with volumetric addiction (indicating the plural geocluster justified in chapter 5) presents the locations of the pilot buildings for the European projects that focus on building renovation solutions combined with volumetric addition. The illustrated projects are further described in the following paragraphs.

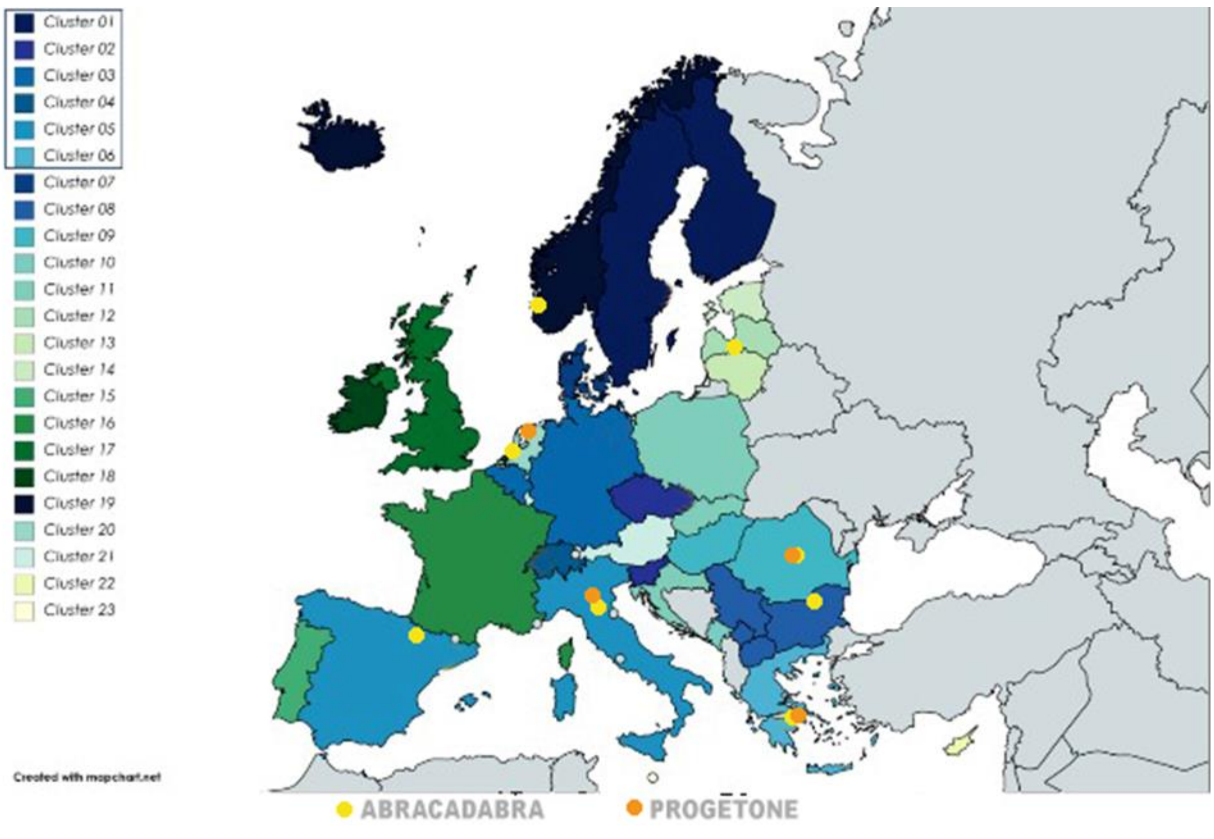

FIGURE 2-10. PILOTS LOCATION FOR EUROPEAN PROJECTS FOCUS ON BUILDING RENOVATION COMBINED WITH VOLUMETRIC ADDICTION (INDICATING THE PLURAL GEOCLUSTER JUSTIFIED IN CHAPTER 5)

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ABRACADABRA: Duration: 36months (2016-2019)[21]

ABRACADABRA focused on the creation of a substantial increase of the real estate value of the existing buildings through a significant energy and architectural transformation. The central goals of the proposal consisted of an important reduction of the payback time of the interventions, a strengthening of the key investors' confidence, increasing quality and attractiveness of the existing buildings' stock and, finally, reaching a concrete market acceleration towards the Nearly Zero Energy Buildings target. ABRA aimed at demonstrating to the key stakeholders and financial investors the attractiveness of a new renovation strategy based on façade addictions, rooftop extensions or even an entire new building construction - that adopt the existing buildings (the Assisted Buildings). The creation of these new Assistant Buildings' Additions integrated with RES aimed at reducing the initial investment allocated for the deep renovation of the existing building creating an up-grading synergy between old and new.

Real Demo cases across European continent

- Demo 1: Bologna, Italy, Demo 2: Netherlands, Demo 3: Stavanger Norway, Demo 4: Jaca, Spain, Demo 5: Riga, Latvia, Demo 6: Ruse Bulgaria, Demo 7: Brasov, Romania, Demo 8: Peristeri, Greece

PROGETONE (Duration: 60months (2017-2022))[22]

PRO-GET-ONE proposes the highest transformation of the existing building's shell with volumetric increase and implementation of energy buffer zones e.g. sunspace between the building and the outdoor environment, extra room, etc., aiming to promote a holistic optimized approach on Prefabricated Systems for Low Energy Renovation of Residential Buildings.

Real Demo cases across European continent

- Demo 1: Athens Greece, Demo 2: Brasov Romania, Demo 3: Groningen Netherlands, Demo 4: Reggio Emilia Italy.

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[21] http://www.abracadabra-project.eu/

[22] https://www.progetone.eu/project/

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2.3.4 Conclusions

All the aforementioned EU funded projects are focused one way or another to the concept of energy efficiency improvement of the existing buildings during or via renovation stage, though very few of them targeting on prefabricated multifunctional add-on envelope solutions. Even some of them are demonstrating improved prefabricated façade modules, their main target areas are the:

- circularity of the selected materials (recycled materials or materials that can be recycled),
- dismantling process (strategy for end-of-life)
- versatility (the ability to integrate different active systems and
- a home-automation system to optimize the intervention's performance.
- other proposals use the prefabricated panels installation to create new volumes in the building, increasing its market value, or even in some cases as a source to finance the renovation.

Nevertheless, from the technical point of view the relation between the existing envelope and the new panels, seems to be less defined in the aforementioned projects. There is very few information about the different structural, interlocking and/or anchoring and/or supports systems available for each case. Even fewer information is known to the stakeholders about the interconnection between the existing external surface and the panels related to the treatment of various technical issues such as rising dump, trapped humidity, thermal bridges, seismic requirements, etc. Another common conflictive point is the connection between the new panel's windows and the space occurs by the removal of the old windows.

Moreover, regarding the social point of view, just a few projects involve the building's occupants or end-users in the actual renovation procedure. The implementation of automation systems seems to be a more common approach to guarantee the efficient use of the building instead of investigating and introduce to the overall process the occupants or end-user's involvement.

Table 2-2. Tabulation of technologies and solutions for energy renovation in buildings summarizes the solutions proposed by all the aforementioned EU funded projects. In the table below, "***X***" stands for "***fully addressed***", while "***?***" stands for "***partially addressed***".

TABLE 2-2. TABULATION OF TECHNOLOGIES AND SOLUTIONS FOR ENERGY RENOVATION IN BUILDINGS

TECHNOLOGIES& SOLUTIONS	E2REBUILD	4RinEU	P2ENDURE	PLUG-N-HARVEST	RENOZEB	INNOWEE	HOUSEFUL	DRIVE 0	ABRACADABRA	PROGETONE	MORE-CONNECT

Large Multifunctional Prefab Panels	X	X	X	X	X	-	-	-	?	-	X
PV system	X	X	-	X	X	-	X	?	?	X	-
ST system	X	X	X	-	X	-	X	-	?	?	-
Ventilation units	X	X	X	-	?	-	-	-	?	-	X
Extended balconies / Volumetric addictions	X	-	X	-	-	-	-	-	X	X	?
thermal buffer zone	X	-	-	-	-	-		-	?	-	-
Exoskeleton: Energy Efficiency + Seismic structure	-	-	-	-	-	-	-	-	-	X	-
BIM	-	X	X	-	X	-	X	-		-	X
3D printing	-	-	X	-	-	-	-	-		-	-
Circular solutions to reduce waste and recycle materials	-	-	X	-	-	X	X	X	?	-	-
Building End-of-life Strategy	-	X	-	-	-	-	-	-	-	-	-
Strategies to involve building users	-	-	-	-	-	-	X	-	-	-	X
Controllers, automazed devices & Data visualization	-	X	?	X	?	?	-	-	?	?	-

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3. Experience and lessons learnt from previous projects

A global analysis has been done through a SWOT matrix, in order to identify and evaluate the results of the previous projects related to the proposed energy renovations solutions for buildings. By merging the common elements of every individual solution proposed, an overview of conditioners, limitations, stimulus and benefits can be obtained for the overall performance of the energy efficiency of the solutions already used.

NOTE: However, what should be taken into consideration is that the European continent consists of regions with different climate, social, technical and politic-administrative standards and habits, resulting to the generation of conditions where same outcomes might have diverse meaning and value across Europe.

The results of the SWOT analysis performed, clearly indicated that the offsite prefabrication procedures and techniques have a range of advantages both in technical, social and environmental point of view, compared to the conventional retrofitting solutions. Additionally, it is evident that all these EU funded projects focused in energy efficiency improvement during renovation stage acted as a stimulus by promoting the benefits of renovation in terms of the energy/cost ratio, increased the social awareness and enhanced the obtained knowledge to all stakeholders involved.

Nevertheless, there are still several challenges needed to be addressed in order to successfully transit from the conventional to renovation methodologies based in prefabrication elements, such as:

- Limitations and/or restrictions applied due to local climate, social, technical, financial conditions
- Cost and/or financing for both the construction and its maintenance,
- Adaptability of the technologies depending on end-user requirements,
- Singularity of each case e.g. historic buildings, seismic zones, urban regulations etc.

However, the weaknesses of the prefabricated retrofitting solutions can be easily minimized working on the strengths and opportunities identified. Synergies between the retrofitting processes and other actions can be applied in the building and contribute to solving financing difficulties. For example, the increase of surface or building's volume can upgrade the buildings value or offer direct important economic benefits that offset the renovation costs (Abracadabra or Progetone are European projects working in this direction). Other tools that can be applied in order to overcome construction cost could be:

- public subsidies;
- a tax system that promotes prefabricated solutions that have social/environmental benefits;
- in more singular cases, architectural prizes can also contribute to finance the high cost of these renovations;

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- formation of end-users or stakeholder associations to achieve better construction prices by bulk ordering.

On the other hand, improving the optimization of the manufacturing process by introducing for example standardization of the solutions or new technologies as 3D printing, can also contribute to the reduction of the initial production costs, which can be further reduced by mass production application.

A higher adaptability of the solutions can be achieved by the knowledge and experience obtained by the evolution of new R&D projects which are increasing the versatility of the prefabrication modules and techniques by developing solutions that can be applied in different parts of the building envelope (façade/roof – inside/outside), e.g. 4RinEU, INNOWEE projects etc.

TABLE 3-1. STRENGTHS/ WEAKNESSES/OPPORTUNITIES AND THREATS OF PREFABRICATION

STRENGTHS Characteristics of the previous projects that give them advantage over other practices	WEAKNESSES Characteristics that place the projects at a disadvantage relative to other practices
TECHNOLOGICAL STRENGHS OF PREFABRICATION	**TECHNOLOGICAL WEAKNESSES OF PREFABRICATION**
• Innovative products for optimized solutions (modular facade, roof elements, modular HVAC engines) • Integration of HVAC and RES in single elements • External envelope solutions minimize thermal bridges • Promotion of solutions with integrated renewable energy systems • High quality architectural elements • Modular, reusable and easy to disassemble systems may contribute to circular economy • Synergies between energy renovation sector and other sectors in the building industry • Fast implementation and reduction of onsite works due to high prefabrication • Improved Quality Control of the renovation works thanks to prefabrication	• Limited set of renovation solutions not always suitable to the specific needs of the building • Renovation elements may increase the thickness of outer wall elements • Additional weight due to the new technologies can cause problems in building structure • Need for different anchor systems depending on the structure of the building • The joints in prefabricated structures have difficulties to handle the stress reversals during earthquakes • In terms of modularity, the renovation projects have specific dimensions introducing limitations to replication • Higher risk of damage during handling or transportation • New products reach up to a limited TRL so nothing guarantees their real performance • It is necessary to ensure and enhance product and process quality during the whole life cycle • .
OTHER STRENGTHS FROM PREVIOUS PROJECTS	**OTHER WEAKNESSES FROM PREVIOUS PROJECTS**
• Real time system performance monitoring thanks to affordable embedded monitoring systems • Indoor Environmental Quality (IEQ) monitoring system is often connected with BMS (Building Management System) to improve	• Only relatively simple BIM models can be created for complex renovation solutions • Uncertainty about the final cost of the new technologies; generally higher cost than standard retrofit

building performance and maintenance • Digitalization of building and energy information through BIM and BEM to improve building maintenance • Holistic view of the different steps in building renovation and the different actors involved • Faster development of Intellectual Property Rights • Prefabrication minimizes the exposure of workers to harsh weather conditions or hazardous environment • Raised public awareness regarding recycling, energy consumption and cyclical economy • Less annoyance to neighbours/to tenants • Creation of up-to-date data base regarding energy data, procedures, laws etc. • Networking with EU countries and Institutions interchanging knowledge and experience. • Facilitate investments in local construction and energy sector	• Risk for unpredicted operation and maintenance cost • Late acceptance of the market and lack of supporting industrial chain • Low public dissemination of the projects results
OPPORTUNITIES **Elements in the building sector that the previous projects can benefit from**	**THREATS** **Elements in the building sector that could lead to problems for the projects**
TECHNOLOGICAL OPPORTUNITIES	**TECHNOLOGICAL THREATS**
• Increasing technicians' knowledge and experience about renewable energy systems, sustainable construction practices and energy efficient buildings • Increasing knowledge in BIM systems • Specific site conditions can be a driver to make better adaptable in different climate regions • Increasing availability of recyclable materials may increase the circularity of the solutions	• Low investor, architects, building engineers and constructors awareness and experience in sustainable practices for building renovation • Low knowledge and popularity of building prefabrication in some European countries • Low BIM experience of architects / constructors • Lack of experienced constructors / installers • Some materials or technologies cannot become unavailable in

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• Use of 3D scanning technology to reduce errors on offsite solutions for renovation • Integration of advanced robotics and smart materials in 3D printing might enable market entry much quicker than other solutions • Several architectural prizes	certain regions • Difficulties to repair some solutions in the future • Conflict between the requirements of the technologies and the urban/technical regulations (e.g. fire codes) • Requirements for plugin updates make its maintenance cost/time consuming • Compatibility between technologies (e.g., open codes, easy replacement of partial elements...). If codes are kept open they could be easily updated
OTHER ASPECTS	**OTHER ASPECTS**
• Ancient building stock in Europe needing retrofit. 40% of the European building stock was built before 1960 and 85% before 1990[23] • Achievement of targets of the Local Actions Plan for Sustainable Energy and Climate under EU Covenant of Mayors regarding reduction of energy consumption and CO2 emissions towards a climate-neutral economy • National Energy and Climate Plans (NECPs) for the period 2021-2030 (including provision of funds) • European Commission new strategy to boost renovation called "Renovation wave for Europe", aiming to double annual energy renovation rates in the next ten years. (current rate 1%/year)[24]-	• Low renovation rates (1-2%) • Lack of financial instruments to replicate the new technologies in economy of scale • Economic crisis reduces funds and grants for investing in energy efficiency • Establish protocols to avoid that COVID-19 restrictions, interrupt the project's implementation or the management • COVID-19, Brexit and similar unpredictable events occur and threaten the timeline of the project • Difficult to match the timing of the European Project (deadlines – WP completion) with time requirements for public procurements • High Legal restrictions for renovating historical and traditional

[23] http://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU(2016)587326_EN.pdf
[24] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

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Local markets looking forward to new products and new business lines related to energy renovation • Volumetric additions on existing buildings could be an opportunity to finance renovation of the entire building • New EU projects and initiatives can contribute to improve the previous European projects' solutions • Increasing of awareness of public about circular economy and energy renovations • Key stakeholders and financial investors can be attracted to new renovation strategies due to its advantages (make revenues from the investment in new technologies and the production of energy, while reducing expenditures from reduced energy consumption)	buildings • Need to increase the inhabitants' involvement and experience • Difficulties to reach agreements when several owners are involved in the building renovation

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4. Preliminary requirements for the off-site prefabrication of all-in-one kits

The PLURAL concept is based on the application of three off-site prefabricated Plug and Play facades systems, accounting for user needs ("Plug-and-Use" - PnU kits):

- "Smart Wall",
- "eWHC" (**e**xternal **W**all **H**eating and **C**ooling) and
- "eAHC" (**e**xternal **A**ir handling unit with **H**eating & **C**ooling)

The PnU kits integrate heating-cooling, ventilation, heat harvesting systems with smart windows, 3D printed elements, overall low carbon footprint and nano-enabled coating materials, which are briefly presented in following paragraphs.

4.1 Description of the PLURAL core systems

4.1.1 Smart wall

The multifunctional panel of the "Smart wall" core system was developed in 2019 and combines several technologies including fully prefabricated walls with eco-friendly insulation, slim-type fan coil for heating and cooling, mechanical ventilation, IEQ control system consisting of filters, high performance commercial PV panels and heat recovery windows (see *Figure 4-1. Internal and External side* and *Figure 4-2. Smart Wall Layout*). It can be applied either to the building's exterior as a façade panel, or to the interior as an additional internal component.

As a plug and use panel, "Smart Wall" contains a flexible piping system that can accommodate either the existing or a new heating/cooling system, as well as electrical wiring connections to various electrical power services (switches, plugs etc.). Construction materials are selected in respect to the environmental-friendly and high - performance behavior of the wall. The majority of the "Smart Wall" elements (98% of the materials, apart from the air filters) are eco-friendly, recyclable and non-combustible. The structural frame can be manufactured by several materials such as timber, aluminum, high-performance polymers or even by high performance industrial plastics developed with the aid of 3D printing technology. The utilization of 120 mm recyclable mineral wool will decrease the wall's U-value to 0.28W/(m2K). The ventilation system of the "Smart Wall" is based on a standard integrated function of modern fan coils, to recycle the air from the interior of the room. However, ventilation is planned to utilize an integrated compact system with heat recovery in order to supply fresh air to the

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interior through electronically controlled dampers. The air flow and indoor quality can be controlled either manually or automatically via CO2, temperature and humidity sensors. Furthermore, various combinations of commercial filtration types can be installed in the ventilated unit or the fan coil, depending on the occupants' requirements and the local climatic conditions. In order to further enhance the sustainability of the "Smart Wall", the integration of a power energy system with (BI)PV panels and batteries embedded into the wall panel can be applied. The specific core system presents significant advantages for climates with high demand for cooling.

FIGURE 4-1. INTERNAL AND EXTERNAL SIDE

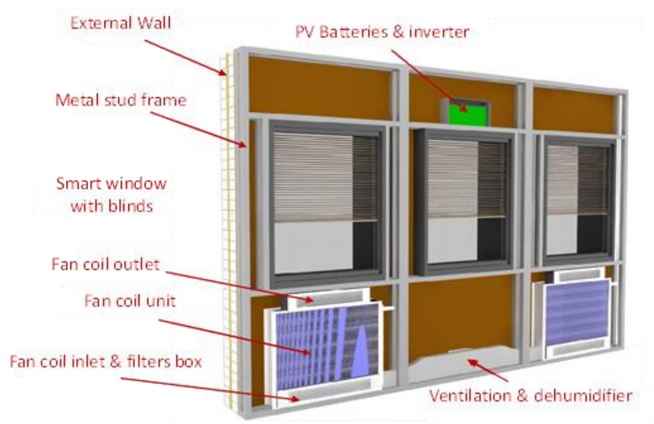

FIGURE 4-2. SMART WALL LAYOUT

4.1.2 eWHC

The external Wall Heating and Cooling (eWHC) module is a solution referring to the wall that is merely applicable externally (either on the external wall or on the roof), as it integrates a low temperature exterior hydronic wall heating system between the existing wall layer and the new added external envelope. All the main components of this solution are enclosed in a prefabricated timber-based module (envelope-kit) (see *Figure 4-3. Layout of eWHC solution* and *Figure 4-4. Redesigned eWHC Envelope Kit*), operating towards nZEB state with minimum ecological footprint and high degree of comfort conditions for the inhabitants. This multifunctional unit consists of:

- Timber frame construction with insulation of about 20-30 cm (depending on climate).
- Integrated triple-glazed windows.
- Window integrated ventilation system with heat recovery.
- Low temperature external wall water-based heating distribution system.
- External blinds for window shading.

- Building integrated photovoltaic (BIPV) modules for renewable electricity production (roof and facade).

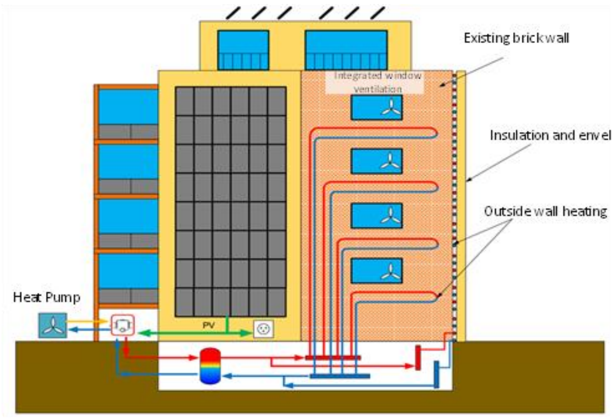

FIGURE 4-3. LAYOUT OF EWHC SOLUTION

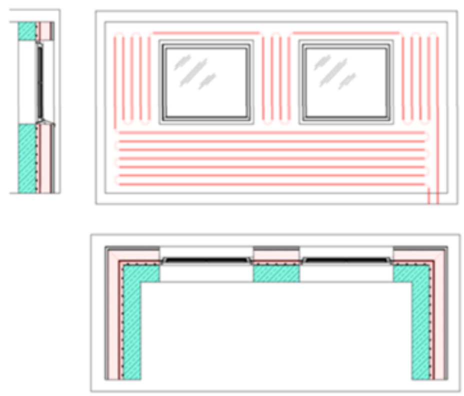

FIGURE 4-4. REDESIGNED EWHC ENVELOPE KIT

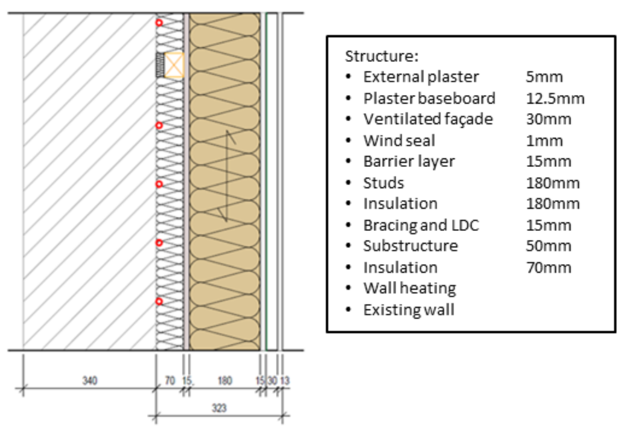

FIGURE 4-5. THE PRELIMINARY LAYOUT OF THE EWHC WALL

This technology introduces the low temperature hydronic heating or cooling distribution from the outside, with minor or low disturbance on the inside of the building. This is accomplished by combining the heat distribution system with the additional high-performance insulation at the external side. Such solution addresses mostly buildings with high heating demand in colder climates, since it activates the thermal mass of the existing wall and shifts the heating period to day time, increasing "self-consumption" and mitigating as a result the energy demand for heating. However, eWHC applications may also cover low cooling demands in heating dominated countries such as Switzerland, Germany and Czech Republic. This issue will be investigated in the upcoming tasks of the PLURAL concept. The eWHC PnU kit can be enriched with the integration of solar energy converters for the production of heat and electricity (PV or BIPVT collectors). Such a combination can be used for thermal energy harvesting or even passive cooling during night hours.

4.1.3 eAHC

The eAHC (**e**xternal **A**ir handling unit with **H**eating & **C**ooling) PnU system is an air handling unit with an advanced heat/cold recovery system (see *Figure 4-6. eAHC Solution Layout*). It combines a patented combination of standard passive heat exchanger in series with active thermoelectric heat exchanger providing the capability of temperature control of supplied air. The active air heat exchanger uses thermoelectric elements to heat up the air in the winter season or cool down the air during the summer. The switching between cooling and heating is simply provided by reversing the current in the thermoelectric modules. Depending on the climate conditions, drainage of condensed water vapour is required. The solid-state cooling-heating technology simplifies the AHU and provides a novel solution to be easily integrated in the facade panels. Since there is no compressor circuit, the produced sound from the operation is significantly reduced. The eAHC unit is combined with a sensor platform for monitoring and control of Indoor Air Quality. The system is intended for indoor use and it measures indoor environmental parameters: temperature, humidity, CO_2, VOC. The parameters data is processed via WiFi (http, mqtt, modbus TCP), LoRaWAN or RS485. Special preparation is required during the system installation when RS485 is used.

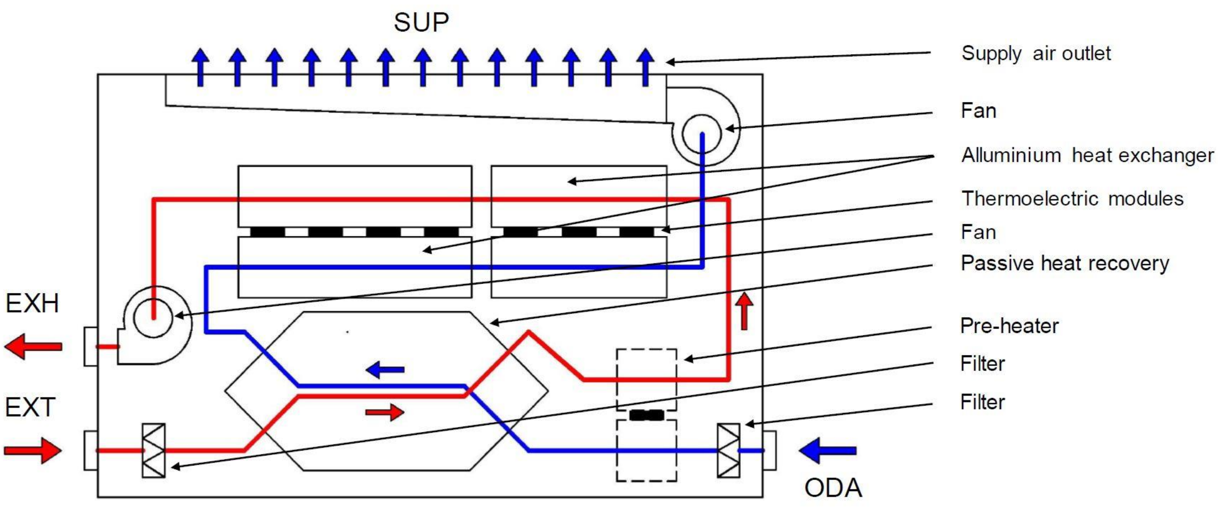

FIGURE 4-6. EAHC SOLUTION LAYOUT

The integration of PV systems to eAHC unit provides adequate energy that can be used for cooling - mainly in summer season and especially during daytime. Photovoltaic energy sources can be used for direct heat generation in winter or cold generation in the summer. An important advantage is that the system can operate without using expensive battery energy storage and can adjust the power to the energy generated. The eAHC wall element is applicable only for the external building surface.

4.2 Technology and systems requirements

The parameters / requirements, which determine the application of PLURAL core technologies in each building, could be summarized in the following categories:

- The location of building (climate conditions, heating and cooling demands);
- The building geometry and restrictions (type, height, Window to Wall Ratio - WWR, balconies, historical façades, architectural & structural projections & recessions, maximum permissible insulation thickness);
- The energy performance of the building envelope (U-value, thermal mass, heating / cooling systems);
- The structural capacity and behavior of the existing building (load bearing capacity, movement behavior, seismic design limitations, adjacent to building joints treatment, etc.);

Table 4-1. Requirements of PLURAL core technologies (Green: The PnU can be applied, red: the PnU cannot be applied and orange: specific design is needed in order to be applied), provides an overview of the minimum parameters / requirements and limitations of the PnU kits.

TABLE 4-1. REQUIREMENTS OF PLURAL CORE TECHNOLOGIES (GREEN: THE PNU CAN BE APPLIED, RED: THE PNU CANNOT BE APPLIED AND ORANGE: SPECIFIC DESIGN IS NEEDED IN ORDER TO BE APPLIED)

Parameter		Smart Wall	eWHC	eAHC
EU Climate Zone[25]	Warm Mediterranean (W1S3)			
	Mild Mediterranean (W2 S2)			
	Warm Continental (W3S2)			
	Continental (W3S1)			

[25] According to the analysis of the following Chapter (Section 5.1.1)

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Parameter		Smart Wall	eWHC	eAHC
	Oceanic (W3S0)			
	Subarctic (W4S0)			
Type of building	Single Family			
	Terrace			
	Multifamily			
	Apartment block			
Height / Number of storeys	<2			
	3-4			
	4-7			
	> 7			
Presence of balcony			Dismantle and rebuild	
Historical buildings, other than listed buildings				
Thermal mass	Low			
	Medium			
	High			
	Very high			
U-value of the wall [W/(m²K)]	> 3			
	2 - 3			
	1 - 2			
	0.6 - 1			
	< 0.6			
Window to Wall Ratio [%]	< 10 %			
	10 % - 20 %			
	20 % - 35 %			
	> 35%			
Existing heating system		No limitation.	Everything except from floor heating	No limitation.
Existing cooling system		No existing cooling system	Everything except from floor cooling	No existing cooling system

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Although, from Table 4-1 outcomes, it is clear that all of the PLURAL PnU kits can be applied on almost every type of residential building (single family, terrace, multifamily and apartment), the following parameters / requirements and limitation for each PnU kit can be extracted:

The "Smart Wall" PnU kit:

- Could be installed either on the external or the internal side and applied in almost every European climate covering the heating and cooling requirements, except from the extreme cold conditions, such as the Northern European countries.
- The thermal mass of the building's envelope does not affect its application, while the U-value of the existing walls should be higher than 0.6W/(m2K), due to the thickness of required insulation.
- Easily applied on buildings lower than 4 storeys (ca. 12m height), while specific design is required for buildings with 5 to 7 storeys, due to structural stability and specific seismic design.
- Structural requirements and envelope performance limitations set that the windows to the wall ratio of the building façade should be lower than 35%. However, the presence of balconies does not affect the implementation of the "Smart Wall".
- The integrated control system, equipped with temperature, humidity and CO2 sensors, controls the main ventilation system of the building, as well as the luminance sensors adjusts the lighting equipment.
- The "Smart Wall" is the only PLURAL PnU kit that can be applied on a historical façade, since it can either replicate the external façade or can be installed on the internal side of the existing envelope.

The "eWHC" PnU kit:

- It is installed only on the external side of the wall and is suitable for heating dominated climate conditions (Central and Northern European countries) with small cooling demands.
- The U-value of the existing walls should be higher than 0.6W/(m2K), due to the thickness of required insulation.
- Applied on buildings lower than 7 storeys (ca. 21m height), while specific design is required for higher buildings, due to fire and structural regulations.
- Buildings with a high window-to-wall ratio (more than 35%) should be appropriately designed if "eWHC" kit would be installed to cover the energy demand.
- The presence of balconies affects the application of the "eWHC" kit. For the installation of "eWHC" kit the balconies must be dismantled and new balconies should be re-built after the installation.

- The "eWHC" PnU must be operated in conjunction with a heat pump. It should not be used with high temperature heating systems such as pellet/wood heating systems or district heating networks, due to the low-temperature hydronic distribution. In case that the building has a floor heating system the "eWHC" has to be applied without the hydronic external wall piping.
- An integrated control system by means of an advanced monitoring system will measure weather data, supply temperature of heating system, room temperature and CO2 concentration and will control the thermal comfort as well as the IAQ.

The "eAHC" PnU kit:

- It is installed only on the external side of the wall and is suitable for the most European countries except from Nordic conditions with extreme heating demands, while the system can be modified in order to cover the heating and cooling demands of the Southern countries (Mediterranean condition with high cooling needs).
- For buildings with more than 7 storeys and high window-to-wall ratio (more than 35%) the "eAHC" kit should be appropriately designed to cover the energy demands and meet the safety requirements.
- It can be coupled with any hydronic heating system with radiators under windows as well as other systems such as floor heating.
- The control system of the "eAHC" kit along with a sensor platform are able to configure the supply air temperature for heating and cooling, to control the IAQ of the room and the thermal comfort as well as, to protect the indoor environment against outside noise.

In any case PLURAL's PnU kits must meet the national Building and Health and Safety Regulations (e.g. mechanical stability, safety in use, fire and seismic behavior, acoustic, waterproofing and durability).

More specific requirements and preliminary specifications of the PLURAL solutions are provided in *Annex* I – Preliminary specification of PLURAL solutions.

4.3 Off-site prefabrication requirements

The general requirements on the off-site prefabrication are focusing on those aspects which are aiming to accelerate project's timelines and yield significant cost savings, in the different stages of the construction process:

- Design;
- Manufacturing;
- Transportation;

- Installation;
- Maintenance;

For the fulfilment of these requirements, a careful optimisation in the selection of materials and components is necessary, as well as the implementation of digital technologies that enhance design capabilities and variability, improve precision and productivity in manufacturing, and facilitate logistics. A consideration on how the production repeatability of the prefabricated systems should be obtained, in conjunction with the optimal unit sizes which will be suitable for both installation and transportation.

On the other hand, quality control is more effective and easier to be applied in an industrial environment than in a construction site. The adaptation of an appropriate quality control system aiming to minimize the risk of defects where common inspection techniques are not able to identify onsite until many months or years later resulting to a harder and more expensive to rectify, is mandatory.

A brief summary of the requirements, conditions and/or constraints of the PLURAL PnU kits off-site prefabrication in relation with the climate conditions, building's geometry and their interaction with it, their manufacturing process, transportation, handling, installation, monitoring and control, etc., are provided in the following paragraphs, while more details are presented in ANNEX I part of the current deliverable.

4.3.1 Smart wall

The "Smart Wall" system height is adjustable to any dimension up to 4 m (on height) per module, its width is 1200 mm and its thickness could be at minimum 130 mm. It can only be installed on flat surfaces and on buildings up to 4 storeys on height.

Its production cannot be fully automatized, since the parts and components sizes, dimensions and properties depend on the particular design of each "Smart Wall" module. Existing electrical plugs and switches must be mapped in advance in order to correctly embed them in the Smart Wall panel, while there are no limitations for integration of any additional power plugs or switches or control points. The windows and the existing radiators (if any) must be removed before the internal "Smart Wall" installation, while for the external "Smart Wall" installation only windows removal is mandatory.

The communication protocols between the local control panel, and the sensors, as well as the data gathered by the central system (BIM) must be further determined and technically adjusted by Intrasoft and other core technology partners.

4.3.2 eWHC

The prefabricated elements of "eWHC" system has to fit exactly to the geometry of the existing wall. For this reason, the geometry of the existing building is essential to be accurately measured. Especially, the heating pipes must be in direct contact with the wall (contact pressure) to assure the maximum

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thermal transportation into the building. The heating pipes must be connected to the (new) central heating system. In most cases the old insulation and windows have to be removed.

The overall size of the module might be restricted to the transportation possibilities of each country. The prefabricated systems with incorporated PV modules have to be carefully transported and installed to avoid mechanical stresses and damages. The PnU kits should be transferred and installed following the crane restrictions to the maximum weight of each module applying. The mounting work is executed without the use of scaffolding, speeding up the process.

In order to control the window's ventilation and the external shading (blind) a control panel should be adopted which end-user could be easily interacted with. The heating system control might be local or centralised and independent of the PnU module control systems.

4.3.3 eAHC

The "eAHC" PnU kit is an all-in-one module with outer dimensions (120 x 70 x 16) cm or (60 x 24 x 80) cm (particularly thickness, could result in system limitations in relation to other involved technologies), while the weight of the entire "eAHC" unit is around 20 kg. The housing for the ventilation unit could be made from XPS or any other thermal insulation material to avoid thermal bridging of the PnU module and the building facade. Also, volumetric changes due to temperature changes during operation (heat / cold) should be considered.

The module requires a back-insulation layer, two grills in the outer layer of PnU panels connected to the unit and two openings through a building wall (air supply and extraction). Grills should be orientated and installed in the outer layer of the module in such a manner to eliminate the possibility for cross contamination.

The "eAHC" PnU kit can be designed with special characteristics and components, custom on demand functionalities depending on the climatic conditions and end-user's specific needs. Monitoring equipment and sensors can be easily integrated into the system during the production stage. Key point for the proper production and installation of the system, is the provision of as much accurate and detailed drawings of the façade will be installed as any modifications especially on the dimensions of the system, might occur during installation stage would be difficult to be applied.

Depending on the finishing materials, special protection needs to be considered. The system can be installed frame by frame or by means of folded frames of facades fixed by hinges. In both cases, a crane (or some sort of elevation system) will be necessary.

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5. Target Building Typologies

This chapter aims to analyse the different variables and requirements that are directly linked to the implementation of PLURAL solutions, establish the different geo-cluster across the Europe, identify the most representative residential building typologies in European regions and finally define the building archetypes for modelling purposes.

The geo-clustered classification aims to highlight the differences and the similarities of the PLURAL solutions among different EU regions, facilitating the extraction of more accurate data from the implementation of PLURAL concept under different local climatic, socioeconomic and financing characteristics. Additionally, others aspects considered to have a broader impact to the implementation of PLURAL solutions in each EU region, and will be further analyzed in Chapter 6, are:

- the long-term renovation strategies of each country, as presented by the local administrations during 2019 and
- the financial mechanisms adopted by each EU member state country to promote the renovation of the existing building stock.

Thus, to summarize the establishment of the geo-clusters, the intersection of the climatic conditions and the socioeconomic aspect have been selected as relevant factors.

Furthermore, the analysis of the most representative buildings in each region will serve as a baseline to identify which are the most ordinary typologies in each country. Therefore the aim of this chapter is to analyse the replication potential of the PLURAL solutions in each geo-cluster by simultaneously identifying and cross-reference the existing construction characteristics of each building typology. In this sense, the existing building's elements and systems, as well as their relevant construction procedures and aspects, have been compared with the PLURAL demo cases, and crossed referenced with them in order to verify their potential feasibility of implementing the selected PLURAL solutions on similar geo-clustered buildings.

5.1 Geo-clusters

As mentioned above, several factors have been taken under consideration in order to define regional clusters of the EU regions. Among others, two of them, the climatic conditions and the socioeconomic indicators, have a direct relation and potential impact with the energy consumption and the regional economic limitations correspondingly, therefore they were selected as main factors to define the geo-clusters.

5.1.1 Climate zones

The climate characteristics of the area where a building is located, directly affect the external conditions to which are exposed to. Therefore, the climate determines the building thermal behavior and consequently the energy consumption for the end-user's needs and requirements.

Following the methodology adopted by 6 different projects [ENTRANZE[26], 4RinEU[27], TRIHP[28], iNSPIRE[29], PVsites[30] and HAPPEN project[31]) the climatic zones classifications typically identify regions and sub-regions in the different countries. Since there are a number of weather variables that affect building's behaviour, it is not a straightforward to establish a definition of the climatic clusters. For this reason, different approaches have been considered, such as:

- The Köppen-Geiger classification, developed by the climatologist Wladimir Köppen in 1884 [W. Köppen and E. Translated, 2011], which classifies regions according to temperature and precipitations,
- The degree day's methodology, developed during the 19th century in the USA [T. Day, 2006], which provides an indication of severity of the climate in different locations by documenting when during a given year the external air temperature falls below (Heating Degree Days - HDD) or rises above (Cooling Degree Days - CDD) a specified temperature,
- The European Heating Index (EHI) [S. Werner, 2006] and the European Cooling Index (ECI)[32], developed by the Ecoheatcool project during 2005 using 80 reference cities, that considers the HDD and CDD but also the interrelation with insulation, solar gains and internal gains, and finally

[26] ENTRANZE Project Intelligent Energy – Europe (IEE) programme, "ENTRANZE," SEVEn, The Energy Efficiency Center, 1 April 2012. [Online]. Available: https://www.entranze.eu/contacts/contacts. [Accessed October 2020].

[27] 4RINEU European Union's Horizon 2020 Project, "4RINEU," WIP Wirtschaft und Infrastruktur GmbH & Co Planungs-KG, 1 January 2016. [Online]. Available: https://www.pvsites.eu/. [Accessed Otcober 2020].

[28] TRI-HP European Union's Horizon 2020 Project, "TRI-HP," SPF Insitute for Solar Technolgy at the University of Applied Science in Rapperswil Scwitzeralnd (HSR-SPF), 1 march 2019. [Online]. Available: https://www.tri-hp.eu/. [Accessed October 2020].

[29] INSPIRE-FP7 European Union's Project, "INSPIRE-FP7," EURAC, 1 november 2008. [Online]. Available: https://inspire-fp7.eu/. [Accessed October 2020].

[30] PVSITES European Union's Horizon 2020 project, "PVSITES," FUNDACION TECNALIA RESEARCH & INNOVATION, 1 1 2016. [Online]. Available: https://cordis.europa.eu/project/id/691768/results/es. [Accessed 2020].

[31] MEDZEB HAPPEN European Union's Horizon 2020 Project, "MEDZEB-HAPPEN," National Research Council of Italy - Institute for Construction Technologies (ITC-CNR), 1 April 2018. [Online]. Available: http://medzeb-happen.eu/?page_id=1407. [Accessed October 2020].

[32] ECOHEATCOOL Intelligent Energy Europe Project, "The Europen Cold Market," ECOHEATCOOL project WP2, Belgium, 2005-2006.

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- The climate severity index [T.A. Markus, 1982] [J. Salmerón et al., 2013] (Summer Severity Index SCSI and Winter Severity Index WCSI), introduced in Section HE-1 of the Spanish Technical Building Code which combines the cooling/heating degree-days and the insolation hours in a specific latitude in a way that it can be demonstrated that when two localities exhibit the same climatic “severity”, the energy demands of same buildings situated in both localities are equal.

Further analysis of the projects involved the climate zone classification, the majority of references defined the geo-clusters based on only heating indicators, while only three of them, PVSITES project[33], ENTRANZE project[34] and HAPPEN project[35] defined the geo-clusters considering both heating and cooling aspects.

For PLURAL purposes, and since cooling need is an extremely important factor for warmer climates, it was considered as benchmark the references that uses both heating and cooling variables. Based on the availability of the requested data, the HAPPEN project has been considered as a reference baseline, introducing both the WCSI and SCSI indexes to establish the climactic zones for PLURAL project.

The severity index was developed by Markus, Thomas A. Strathclyde in 1982 [T.A. Markus, 1982] and at 1984 intended to establish a correlation between the energy demand, three climatic variables and three physical parameters describing the building itself. It is hence not only a description of the climate but a description of the behavior of a certain building within a range of climates. It has been subsequently used to propose correlations between the average consumption of a mix of building prototypes and two or three climatic variables.

Climate Severity Index - CSI is calculated following the methodology described in Section HE-1 of the Spanish Technical Building Code [J. Salmerón et al., 2013]. The Index is a single number on a dimensionless scale which is unique for each building and location. The equation for winter is formulated as follows:

[33] PVSITES European Union's Horizon 2020 project, "PVSITES," FUNDACION TECNALIA RESEARCH & INNOVATION, 1 1 2016. [Online]. Available: https://cordis.europa.eu/project/id/691768/results/es. [Accessed 2020].

[34] ENTRANZE Project Intelligent Energy – Europe (IEE) programme, "ENTRANZE," SEVEn, The Energy Efficiency Center, 1 April 2012. [Online]. Available: https://www.entranze.eu/contacts/contacts. [Accessed October 2020].

[35] MEDZEB HAPPEN European Union’s Horizon 2020 Project, "MEDZEB-HAPPEN," National Research Council of Italy - Institute for Construction Technologies (ITC-CNR), 1 April 2018. [Online]. Available: http://medzeb-happen.eu/?page_id=1407. [Accessed October 2020].

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$$\boldsymbol{WCSI} = \mathbf{a} \times \mathbf{HDD} + \mathbf{b} \times \frac{\boldsymbol{n}}{\boldsymbol{N}} + \mathbf{c} \times \boldsymbol{HDD}^2 + \mathbf{d} \times \left(\frac{\boldsymbol{n}}{\boldsymbol{N}}\right)^2 + \mathbf{e} \ (1)$$

And the respective for summer:

$$\boldsymbol{SCWI} = \mathbf{a} \times \mathbf{CDD} + \mathbf{b} \times \frac{\boldsymbol{n}}{\boldsymbol{N}} + \mathbf{c} \times \boldsymbol{CDD}^2 + \mathbf{d} \times \left(\frac{\boldsymbol{n}}{\boldsymbol{N}}\right)^2 + \mathbf{e} \ (2)$$

Where HDD and CDD are the degree days for heating/cooling using the same base temperature of 20°C for both the winter months (October to May) and summer months (June to September), while nN is the ratio of the actual insolation hours (n) and the maximum insolation hours (N) for that latitude and for the respective months. This set of inputs were obtained from a typical meteorological year for each location. The coefficients for the above equations are tabulated in *Table 5-1. Coefficients for the winter and summer climate severity index equations*.

TABLE 5-1. COEFFICIENTS FOR THE WINTER AND SUMMER CLIMATE SEVERITY INDEX EQUATIONS

Winter		Summer	
a	$3.546\ 10^{-3}$	a	$3.052\ 10^{-3}$
b	$-4.043\ 10^{-1}$	b	$1.784\ 10^{-1}$
c	$8.394\ 10^{-8}$	c	$-1.343\ 10^{-7}$
d	$-7.325\ 10^{-2}$	d	$-2.339\ 10^{-1}$
e	$-1.137\ 10^{-1}$	e	$-2.041\ 10^{-1}$

As indicated in HAPPEN project[36], the data from 71 locations were obtained and then classified according to the thresholds described in *Table 5-2. Intervals for winter and summer zoning*.

These thresholds were obtained starting from the limits used by Briggs in 2003 [R. Briggs et al., 2003] for the climatic classification of the United States of America. First, the bin boundaries that occur at 500 degree-days Celsius were converted to climate severity units using the equations 1 and 2, respectively. Finally, the limits have been corrected considering smooth granularity, in order to include, within the same climatic zone, locations that in their respective building's regulations are considered of equal intensity.

TABLE 5-2. INTERVALS FOR WINTER AND SUMMER ZONING

Winter				
Winter 0	Winter 1	Winter 2	Winter 3	Winter 4
CSI < 0	0 ≤ CSI < 0.522	0.522 ≤ CSI < 1.52	1.52 ≤ CSI < 2.77	2.77 ≤ CSI

[36] *D 3.1 – Representative Climates and Zoning* of HAPPEN project

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Summer				
Summer 0	Summer 1	Summer 2	Summer 3	Summer 4
CSI < 0	0 ≤ CSI < 0.508	0.508 ≤ CSI < 1.34	1.34 ≤ CSI < 2.00	2.00 ≤ CSI

Finally, in order to create the climatic zones for the selected region, the numbers are combined, thus resulting in 5 subcategories in each case, and 25 possible combinations of winter and summer conditions, as shown in *Table 5-3. Climate zones according to CSI values*.

TABLE 5-3. CLIMATE ZONES ACCORDING TO CSI VALUES

	S0	S1	S2	S3	S4
W0	W0S0	W0S1	W0S2	W0S3	W0S4
W1	W1S0	W1S1	W1S2	W1S3	W1S4
W2	W2S0	W2S1	W2S2	W2S3	W2S4
W3	W3S0	W3S1	W3S2	W3S3	W3S4
W4	W4S0	W4S1	W4S2	W4S3	W4S4

From these 25 open options, an analysis for all the European regions have been implemented, resulting in 13 real climatic zones as indicated in *Table 5-4. Summary of regions in Europe*, whilst the remaining 12 being options not representative in Europe.

TABLE 5-4. SUMMARY OF REGIONS IN EUROPE

ZONE	WCSI	THRESHOLD WINTER	SCSI	THRESHOLD SUMMER	Nº OF REGIONS	REPRESENTED COUNTRIES
01	W4	2.77 ≤ CSI	S0	CSI < 0	84	Mainly in 5 countries Sweden, Estonia, Iceland, Finland and Norway
02	W4	2.77 ≤ CSI	S1	0 ≤ CSI < 0.508	30	Mainly in one country **Latvia** (also present in some regions of Lithuania)
03	W3	1.52 ≤ CSI < 2.77	S0	CSI < 0	217	Mainly in **Denmark, Lithuania, Netherlands** and **England** (also present in some regions of Latvia, Sweden, Belgium, Ireland, Poland and Norway)
04	W3	1.52 ≤ CSI < 2.77	S1	0 ≤ CSI < 0.508	376	Mainly in Germany, Czech Republic, Switzerland, Belgium, France, Croatia, Luxemburg, Hungary, Austria, Romania, Slovenia, Poland
05	W3	1.52 ≤ CSI < 2.77	S2	0.508 ≤ CSI < 1.34	138	Mainly in **Bulgaria, North Macedonia** and **Serbia** (also present in Portugal, Italy and Austria)
06	W2	0.522 ≤ CSI < 1.52	S0	CSI < 0	24	Mainly in one country **Ireland** (also present in some regions of England)

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ZONE	WCSI	THRESHOLD WINTER	SCSI	THRESHOLD SUMMER	Nº OF REGIONS	REPRESENTED COUNTRIES
07	W2	0.522 ≤ CSI < 1.52	S1	0 ≤ CSI < 0.508	16	Not the most frequent in any country, only in some regions of Spain, Portugal and France.
08	W2	0.522 ≤ CSI < 1.52	S2	0.508 ≤ CSI < 1.34	113	Mainly in **Spain**, **Italy, Albany** and **Montenegro** (also present in some regions of Slovenia, North Macedonia, Portugal, France and Greece)
09	W2	0.522 ≤ CSI < 1.52	S3	1.34 ≤ CSI < 2.00	10	Mainly in **Greece** (also present in some regions of Spain and Italy)
10	W2	0.522 ≤ CSI < 1.52	S4	2.00 ≤ CSI	1	Not the most frequent in any country, only in Sicily (Italy)
11	W1	0 ≤ CSI < 0.522	S2	0.508 ≤ CSI < 1.34	8	Not the most frequent in any country, only in some regions of Portugal, Italy, France and Spain.
12	W1	0 ≤ CSI < 0.522	S3	1.34 ≤ CSI < 2.00	8	Mainly in **Malta** (also present in some regions of Greece, Spain and Portugal)
13	W1	0 ≤ CSI < 0.522	S4	2.00 ≤ CSI	8	All of them in **Cyprus**

Finally, to conclude the climatic analysis, as shown in *Figure 5-1. Climatic zones in EU members and PLURAL demo cases*, a map was developed using the available information. Out of the 13 zones, 4 are covered by the selected real and virtual demo cases; ZONE1_W4S0 in the Sweden demo case, ZONE3_W3S1 represented by Germany, Czech Republic and Switzerland, ZONE8_W2S2 in Spain and ZONE12_W1S3 covered by Greece demo case. Two zones out of the rest nine, W3S0 and W3S2 represent two other significant climates zones that can be consider in the region ZONE3_W3S0 a more oceanic climate (with a total of 217 regions) and ZONE5_W3S2 a continental climate but with warmer summers (with a total of 138 regions). However, for the purpose of the PLURAL project only the six selected demo cases will be studied in detail.

Table 5-5. Represented climate zones and countries shows a summary of the zones, the correspondent winter and summer severity, the countries where the zone is more frequent and in bold letters the presence of demo cases or representative countries. These 6 zones represent 56% of the regions in Europe, a total of 581 regions. As conclusion, worth to be mentioned that if a simpler classification is chosen, e.g. numbering only the most frequent zone in each country, almost all territories could be considered as covered.

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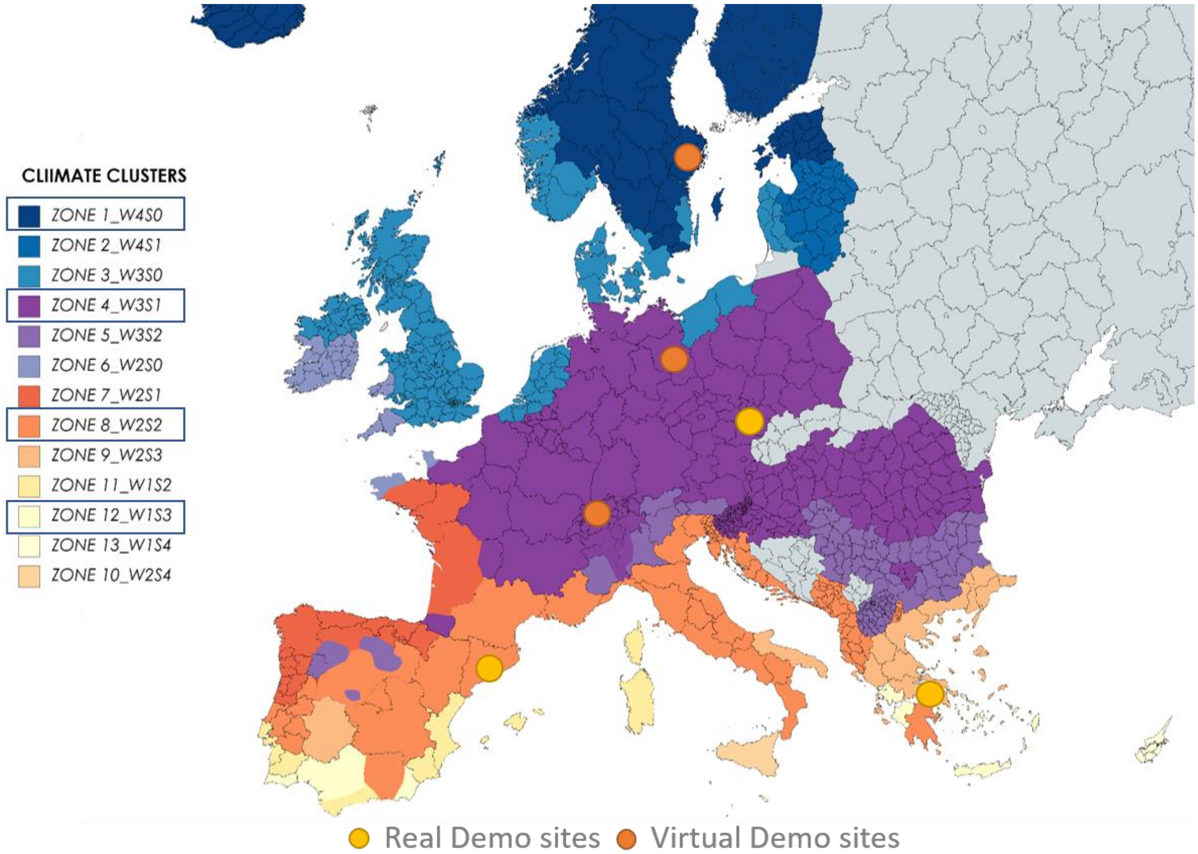

FIGURE 5-1. CLIMATIC ZONES IN EU MEMBERS AND PLURAL DEMO CASES

TABLE 5-5. REPRESENTED CLIMATE ZONES AND COUNTRIES

WCSI SCSI COMBINATION	NUMBER	COUNTRIES and REGIONS
W4S0	ZONE 01	**Sweden,** Estonia, Iceland, Norway and Finland
W3S1	ZONE 04	**Germany, Czech Republic, Switzerland,** Belgium, France, Croatia, Luxemburg, Hungary, Austria, Romania, Slovenia, Poland
W2S2	ZONE 08	**Spain,** Italy, Albany and Montenegro.
W1S3	ZONE 12	Malta, **Greece**

5.1.2 Socio-economic indicators

Current analysis for the use of PLURAL solutions also incorporates the socio-economic conditions applying to the represented regions. The socio-economic aspect (the Income and Living Conditions in

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the different households) considers as an important factor that can determine the boundaries among which the implementation of PLURAL solutions would be feasible for the users.

The aim is to carry out comparative analyses of the:

- income distribution
- the quality of life in the different countries
- verify if there are similar or different conditions in each situation.

The Median equivalised net income by household (ILC_DI04)[37] was extracted from the Statistical Office of the European Union (Eurostat)[38]. The original six levels established were desegregated in seven levels as shown in *Table 5-6. Income levels and represented countries* to clearly separate Switzerland, Iceland and Norway that have noticeably distinctive incomes.

TABLE 5-6. INCOME LEVELS AND REPRESENTED COUNTRIES

Levels	Threshold established	Represented Countries
Level 1	[3.021,00 € to 7.142,00 €]	Bulgaria, Hungary, Romania, Montenegro, North Macedonia, Serbia, Turkey and Kosovo
Level 2	[≥ 7.142,00 € to 8.200,00 €]	Croatia, Latvia, Lithuania, Poland and Slovakia
Level 3	[≥ 8.200,00 € to 15.015,00 €]	Czech Republic, Estonia, Greece, Portugal and Slovenia
Level 4	[≥ 15.015,00 € to 23.504,00 €]	Spain, France, Italy, Cyprus, Malta and United Kingdom
Level 5	[≥ 23.504,00 € to 25.528,00 €]	Belgium, Germany, Netherlands, Finland and Sweden
Level 6	[≥ 25.528,00 € to 36.500,00 €]	Denmark, Luxembourg and Austria
Level 7	[≥ 36.500,00 €]	Iceland, Norway and Switzerland

By using this classification, a graphical map was developed aiming to clearly identify and present the socioeconomic clusters and their financial tendency in the EU regions.

Table 5-7. Median equalized net income by household type for the reference countries defines the median equalized net income by household type for the countries of the demo sites, identified as representatives of the EU climatic zones. As it is presented, among the reference countries, Greece has the lowest income among the represented sites, followed by Czech Republic. Moreover, the income in

[37] EUROSTAT, "Eurostat ILC_DI04," EUROSTAT, 1 12 2020. [Online]. Available: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_di04&lang=en. [Accessed November 2020].

[38] European Commission, "Eurostat," Statistical office of the European Union, [Online]. Available: https://ec.europa.eu/eurostat/about/who-we-are.

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Germany and Sweden is double than of that of Czech Republic, and Switzerland has the highest income among all regions. As it is shown from the *Table 5-7. Median equalized net income by household type for the reference countries*, the regional data of the selected demo sites are representing 4 out of the 7 levels income levels (as presented in Table 5.6), corresponding to the 56% of the countries within the EU regions in a total of 31 countries.

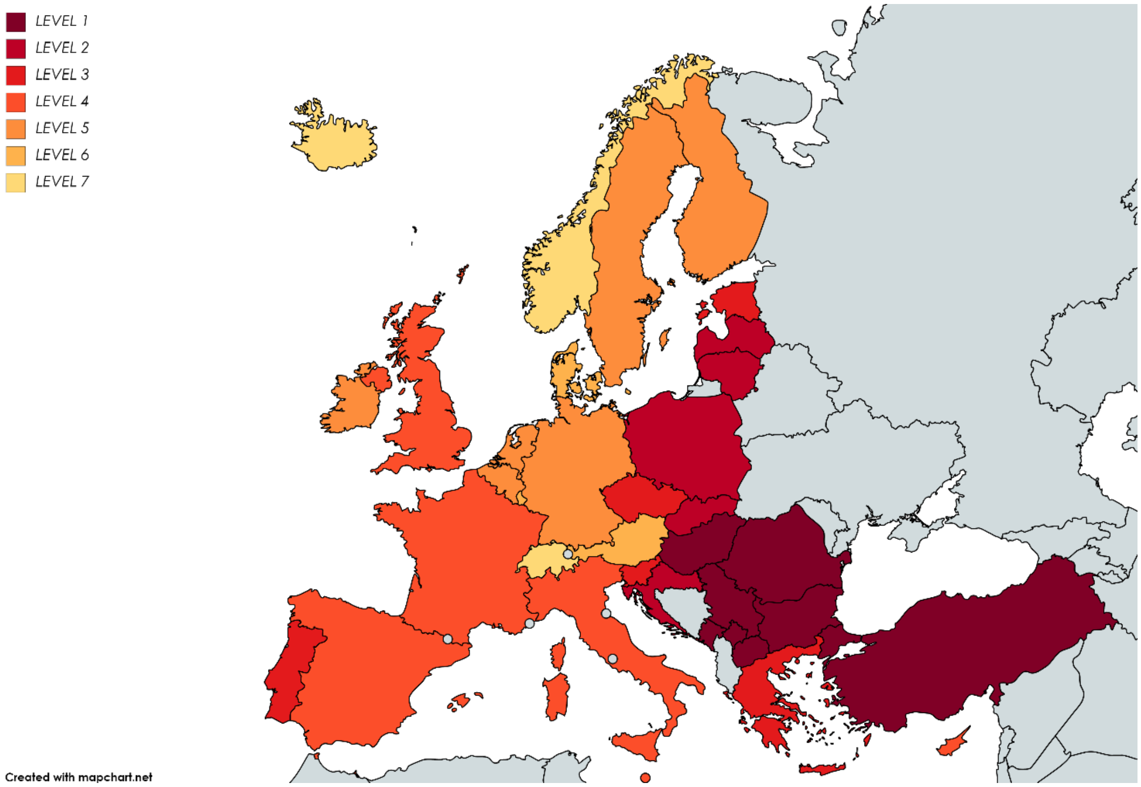

FIGURE 5-2. INCOME LEVELS BY COUNTRIES

TABLE 5-7. MEDIAN EQUALIZED NET INCOME BY HOUSEHOLD TYPE FOR THE REFERENCE COUNTRIES

Country	Median equivalised net income by household type EU-SILC and ECHP surveys	Levels	Threshold
Switzerland	42.802,00 €	Level 7	[≥ 36.500,00 €]
Germany	23.504,00 €	Level 5	[≥ 23.504,00 € to 25.528,00 €]
Sweden	24.490,00 €	Level 5	[≥ 23.504,00 € to 25.528,00 €]
Spain	15.015,00 €	Level 4	[≥ 15.015,00 € to 23.504,00 €]
Czech Republic	9.995,00 €	Level 3	[≥ 8.200,00 € to 15.015,00 €]
Greece	8.200,00 €	Level 3	[≥ 8.200,00 € to 15.015,00 €]

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Furthermore, the socio-economic classification was cross-linked with the most frequent climatic zone of each country and a final map was developed with the potential clusters as presented in *Figure 5-3. Climatic and income combined clusters*, while *From the above data is extracted that the 6 selected geo-clusters represent the* 36% of the territory of a total of 324 regions. In addition, the higher and intermediate incomes, which represent the most frequent climate index of severities, covers the 56% of overall income recorded in the total of all the climate zones. Regarding the not selected geo-clusters, in most cases, either they could be assimilated to one of the 6 selected clusters, considering that the majority of the regions have intermediate climates with median incomes, or they represent regions with limited territory, such as Malta and Cyprus. From all the above, is more than evident the necessity to take into consideration the socio-economic conditions and capabilities applying in the EU regions in the implementation of PLURAL solutions.

Table 5-8. Income level and climatic zoning in selected countries: PLURAL cluster definition presents the demo sites with the correspondent climate and income classification.

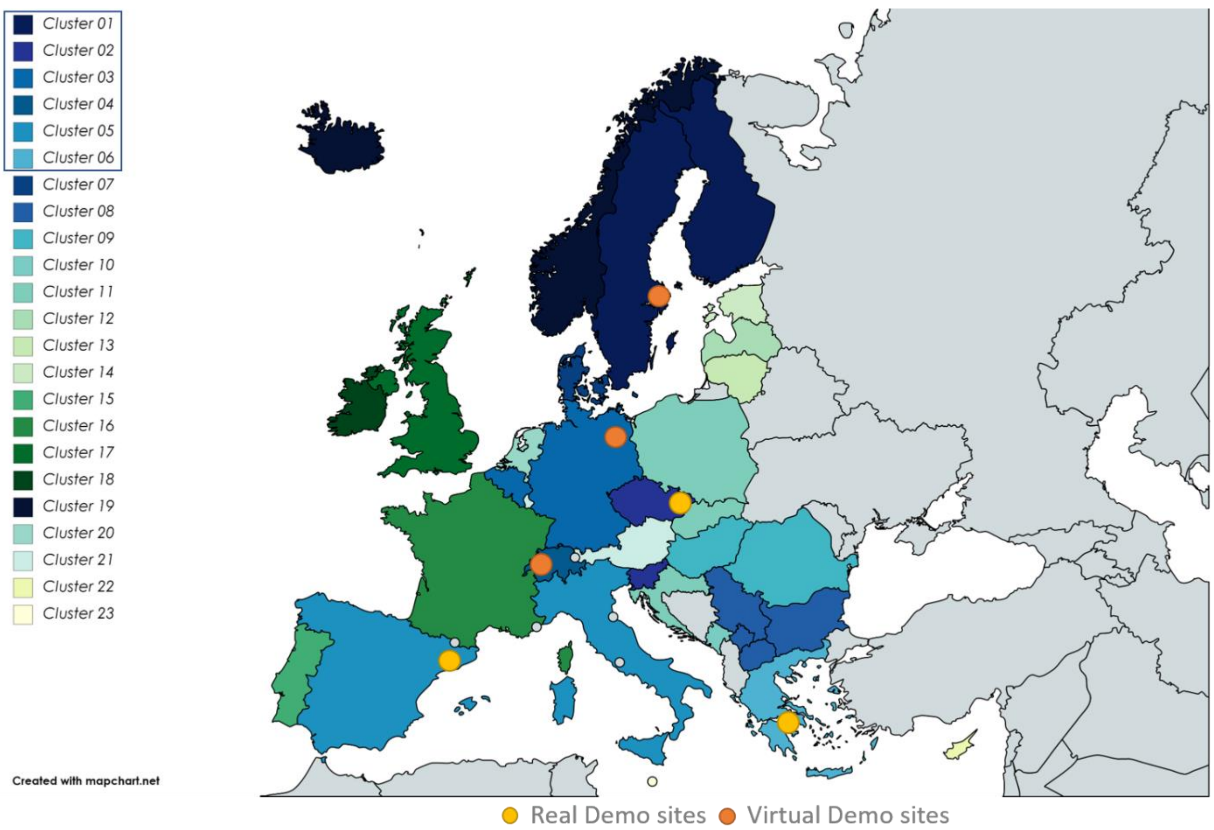

FIGURE 5-3. CLIMATIC AND INCOME COMBINED CLUSTERS

From the above data is extracted that the 6 selected geo-clusters represent the 36% of the territory of a total of 324 regions. In addition, the higher and intermediate incomes, which represent the most frequent climate index of severities, covers the 56% of overall income recorded in the total of all the climate zones. Regarding the not selected geo-clusters, in most cases, either they could be assimilated to one of the 6 selected clusters, considering that the majority of the regions have intermediate climates with median incomes, or they represent regions with limited territory, such as Malta and Cyprus. From all the above, is more than evident the necessity to take into consideration the socio-economic conditions and capabilities applying in the EU regions in the implementation of PLURAL solutions.

TABLE 5-8. INCOME LEVEL AND CLIMATIC ZONING IN SELECTED COUNTRIES: PLURAL CLUSTER DEFINITION

Country	Climate Zone	Income Level	Cluster
Sweden	ZONE 01_ W4S0	Level 5	Cluster 1
Czech Republic	ZONE 04_ W3S1	Level 3	Cluster 2
Germany	ZONE 04_ W3S1	Level 5	Cluster 3
Switzerland	ZONE 04_ W3S1	Level 7	Cluster 4
Spain	ZONE 08_ W2S2	Level 4	Cluster 5
Greece	ZONE 12_ W1S3	Level 3	Cluster 6

5.2 Building Archetypes

The objective of the archetype analysis is to identify the most representative building typology within the existing building stock in each of the regions where buildings of the demo sites are located, aiming to estimate the potential replicability of PLURAL solutions and, simultaneously, to establish a reference building that would act as the baseline to evaluate the energetic and economic savings derived from applying the solutions.

Although there are several sources defining residential building archetypes, most of those are focused at the classifications on territorial level, and mainly linked to the existing regulations. Thus, the conducted analysis is based on data available at TABULA web tool[39] and the individual reports available

[39] TABULA and EPISCOPE Intelligent Energy Europe projects, "TABULA WEB TOOL," IWU – Institut Wohnen und Umwelt GmbH / Institute for Housing and Environment, 6 November 2017. [Online]. Available: http://webtool.building-typology.eu/#bm. [Accessed October 2020].

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in the main website of the project, as it offers a wide and normalized approach for several European countries and has been used as reference for some European directives. The analysis performed focused on the period between the years 1945, after the second world war (WWII), up to 1980 when the first thermal and energy regulations was established. Furthermore, this period chosen is the period with the highest proportion of constructed buildings, for many reasons e.g. reconstruction of the damaged buildings by the WWII, socio-economic, demographic factors etc. Regarding the typology, both multifamily houses (MFH) and apartment buildings (AB) were reviewed and included in the analysis. This methodology allowed to:

- exclude heritage buildings constructed before WWII with considerable regulations limitations to be renovated from the outside
- target buildings with the worst energy performance.

Table 5-9. Most frequent building typologies highlights the main characteristics and typologies of residential buildings being the most common and representative in the building stock for the selected period.

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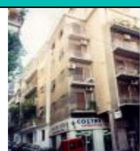
TABLE 5-9. MOST FREQUENT BUILDING TYPOLOGIES[40]

Location	Picture		Number of buildings				Construction year		No. loors	
Country	**MFH**	**AB**	**MFH**	**% over MFH of total Stock**	**AB**	**% over AB of total Stock**	**MFH**	**AB**	**MFH**	**AB**
Greece			134423	29%	NA	NA	Pre-1980	NA	5	NA
Spain			581.307	46%	NA	45	1980-2006	1960-1979	4	9
Czech Republic			103.300 No disaggregated data approximately 54% (between 1946 and 1980)				1961-1980	1946-1960	4	4
Switzerland			163.793	34%	NA	NA	1958-1968	1969-1978	4	4

[40] http://webtool.building-typology.eu/#bm

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Germany			550.000	20%	80.000	31%	1958-1968	1969-1978	5	8
Sweden			77.000	47%	NA	NA	- 1960	NA	4	NA

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In the cases of Greece and Sweden, the TABULA project characterises multifamily houses as the most common typology in the existing building stock. Additionally, in the case of Switzerland, and due to the absence of information in TABULA web tool, the data were extracted from reports developed by the Federal Statistical Office[41] and, due to similarities, data from German building stock were used to complete the building's profile.

Moreover, the TABULA web tool was also used in order to extract the thermal characteristics of the different envelope constructive components and the description of the existing systems in order to include a comprehensive overview of the building typologies. All available data regarding the characteristics of multifamily houses and apartment buildings are presented in *Table 5-10. Multifamily houses characteristics* and *Table 5-11. Apartment building characteristics*, respectively.

The available information about both the virtual and the real demo sites were gathered and compared to TABULA typologies to verify the representability of the demo sites. As shown in *Table 5-12. Characteristics of the demo cases* all demo sites were constructed between the representative periods obtained from TABULA project, except for the case of Spain. However, even though the building was constructed two years later and in consequence the thermal calculations applied in order to obtain the Building Permit were aligned with the representative period's thermal regulations.

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[41] DHA, "Switzerland Federal Statistical Office," FDHA, [Online]. Available: https://www.bfs.admin.ch/bfs/en/home.html. [Accessed 2020].

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TABLE 5-10. MULTIFAMILY HOUSES CHARACTERISTICS

<table>
<tr><th colspan="15">Multifamily Houses</th></tr>
<tr><th rowspan="3">Demo location</th><th colspan="11">Envelope</th><th colspan="2">Systems</th></tr>
<tr><th rowspan="2">Heating demand [kWh/m²y]</th><th rowspan="2">Description</th><th colspan="5">U-value [W/(m²K)]</th><th colspan="2">Total Surface [m²]</th><th rowspan="2">Window to wall ratio</th><th rowspan="2">Heating system</th><th rowspan="2">Hot water system</th></tr>
<tr><th>U average</th><th>Roof</th><th>Wall</th><th>Floor</th><th>Window</th><th>Wall</th><th>Windows</th></tr>
<tr><td>Greece</td><td>40,8</td><td>• Roof: Conventional flat roof
• wall: Brickwork 20cm - Plastered on both sides
• Load bearing structure - Reinforced concrete (thickness less than 80 cm) – both Plastered and unplastered on both sides
• Floor: Slab on grade Windows: Single glazed, wooden or synthetic frame</td><td>3,34</td><td>3,05</td><td>2,60</td><td>3,1</td><td>4,7</td><td>630</td><td>161</td><td>26%</td><td>• Generator: Constant temperature non-condensing boiler - fuel oil.
• Distribution: central distribution, pipeline inside of thermal envelope – two pipes, not insulated.
• Auxiliary electricity type: central system, central distribution water pipes
• Elements: -</td><td>• Generator: Direct electric, with Thermal solar plant (20%)
• Storage: decentral electric hot water storage, close to tap – inside heated space
• Distribution: decentral DHW system, without or small distribution pipe network
• Auxiliary electricity type: decentral DHW system, no distribution pipes available</td></tr>
</table>

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Multifamily Houses													
Demo locati on	Envelope											Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wa		Heating system	Hot water system
Spain	3,9	• Roof: Ventilated flat roof with concrete horizontal framework • Wall: Cavity wall with insulation inside the cavity • Floor: one-way framework, wooden joints • Windows: metal frame, single glazed, with thermal break	0,68	0,56	0,6	2,38	3,37	829,5	-	-		• Generator: natural gas old boiler (non-condensing) • Distribution: central distribution / poorly insulated strings in unheated rooms (e.g. cellar) • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: radiators	• Generator: non-condensing boiler ...-1992 • Storage: central hot water storage, inside of thermal envelope • Distribution: central system with circulation loop / insulated • Auxiliary electricity type

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Multifamily Houses													
Demo locati on	Envelope											Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wa		Heating system	Hot water system
Czech Republic	167,4	• Roof: warm flat roof, gas silicate boards 150mm, cement screed 30 mm, waterproofing • Wall: Sandwich wall element 220mm panel - ŽB 150 mm, EPS 60 mm, ŽB 50 mm • Floor: concrete ceiling insulation 10 mm • Windows: casement window	1,34	0,85	1,08	1,03	2,8	505,6	120,2	24%		• Generator: district heating central substation • Distribution: central distribution, completely in the thermal envelope • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: -	• Generator: district heating central substation • Storage: central hot water storage, outside thermal envelope / until 1994 • Distribution: central system with circulation loop / from 1979 to 1994 • Auxiliary electricity type: central domestic hot water system, with circulation pump

Multifamily Houses												
	Envelope										Systems	
Demo locati on	ng dema nd [kWh	Description	U-value [W/(m^2K)]					Total Surface [m^2]		ow to wa	Heating system	Hot water system
Switzerland	115,5	• Roof: concrete ceiling with 5 cm insulation • Wall: masonry of hollow blocks or honeycomb bricks • Floor: concrete ceiling with 1 cm insulation • Windows: plastic frame window with dual-pane glazing	1,23	0,51	1,2	1,08	3	2039	507,5	25%	• Generator: gas central heating, poor efficiency (multi-unit housing) • Distribution: central distribution, horizontal strings in unheated rooms (e.g. cellar) or in the soil / from 1979 to 1994 • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: -	• Generator: low temperature non-condensing boiler / from 1995 • Storage: central hot water storage, outside thermal envelope / until 1994 • Distribution: central system with circulation loop / until 1978 • Auxiliary electricity type: central domestic hot water system with thermal solar system, no circulation pump

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Multifamily Houses														
Demo locati on	Envelope											Systems		
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wa	Heating system	Hot water system
Germany	115,5	• Roof: concrete ceiling with 5 cm insulation • Wall: masonry of hollow blocks or honeycomb bricks • Floor: concrete ceiling with 1 cm insulation • Windows: plastic frame window with dual-pane glazing	1,23	0,51	1,2	1,08	3	2039	507,5	25%	• Generator: gas central heating, poor efficiency (multi-unit housing) • Distribution: central distribution, horizontal strings in unheated rooms (e.g. cellar) or in the soil / from 1979 to 1994 • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: -	• Generator: low temperature non-condensing boiler / from 1995 • Storage: central hot water storage, outside thermal envelope / until 1994 • Distribution: central system with circulation loop / until 1978 • Auxiliary electricity type: central domestic hot water system with thermal solar system, no circulation pump

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Multifamily Houses												
Demo locati on	Envelope										Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wa	Heating system	Hot water system
Sweden	184,6	• Roof: Sloping roof, horizontal attic floor • Wall: Standard wall • Floor: concrete slab Basement floor • Windows: Double glazed windows	0,64	0,36	0,616	0,32	2,22	800	180	23%	• Generator: heating system with fuel, oil • Distribution: central distribution, uninsulated pipes, inside the thermal envelope • Auxiliary electricity type: Central heating system, circulating pump - constant flow rate • Elements: -	• Generator: oil non-condensing boiler • Storage: - • Distribution: central system with circulation/50%/20% loss • Auxiliary electricity type: central DHW system, circulation pump

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TABLE 5-11. APARTMENT BUILDING CHARACTERISTICS

Apartment Blocks													
Demo location	Envelope											Systems	
	Heating demand [kWh/m²y]	Description	U-value [W/(m²K)]					Total Surface [m²]		Window to wall ratio	Heating system	Hot water system
			U average	Roof	Wall	Floor	Window	Wall	Windows			
Greece	-	-	-	-	-	-	-	-	-	-	-	-

Apartment Blocks												
Demo location	Envelope										Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wall	Heating system	Hot water system
Spain	4,3	• Roof: flat roof: one-way framework with pre stressed joint • Wall: cavity wall: brick, air cavity and masonry of coating bricks • Floor: one-way framework with pre stressed joint • Windows: metal frame, single glazed, no thermal break	1,92	1,92	1,59	1,13	5,7	803,7	103	13%	• Generator: natural gas old boiler (non-condensing) • Storage: - • Distribution: central distribution / poorly insulated strings in unheated rooms (e.g. cellar) • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: radiators	• Generator: non-condensing boiler …-1992 • Storage: central hot water storage, inside of thermal envelope • Distribution: central system with circulation loop / insulated • Auxiliary electricity type: -

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Apartment Blocks												
Demo location	Envelope										Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		wind ow to wall	Heating system	Hot water system
Czech Republic	155,7	• Roof: timber joist ceiling with thin insulation layer between joists • wall: masonry 375 mm • Floor: concrete ceiling insulation 10 mm • Windows: casement window	1,36	0,94	1,43	1,03	2,8	637,3	115,5	18%	• Generator: district heating central substation • Storage: - • Distribution: central distribution, completely in the thermal envelope • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: -	• Generator: district heating central substation • Storage: central hot water storage, outside thermal envelope / until 1994 • Distribution: central system with circulation loop / from 1979 to 1994 • Auxiliary electricity type: central domestic hot water system, with circulation pump

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Apartment Blocks												
Demo location	Envelope										Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wall	Heating system	Hot water system
Switzerland	104,2	• Roof: concrete ceiling with 5 cm insulation • wall: concrete panels with insulation • Floor: concrete ceiling with 2 cm insulation • Windows: plastic frame window with dual-pane glazing	1,24	0,51	1,1	0,77	3	2130	545	26%	• Generator: low temperature non-condensing boiler / from 1995 • Storage: - • Distribution: central distribution, horizontal strings in unheated rooms (e.g. cellar) or in the soil / from 1979 to 1994 • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: -	• Generator: low temperature non-condensing boiler / from 1995 • Storage: central hot water storage, outside thermal envelope / until 1994 • Distribution: central system with circulation loop / until 1978 • Auxiliary electricity type: central domestic hot water system with thermal solar system, no circulation pump

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Apartment Blocks													
Demo location	Envelope										Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		ow to wall	Heating system	Hot water system
Germany	104,2	• Roof: concrete ceiling with 5 cm insulation • wall: concrete panels with insulation • Floor: concrete ceiling with 2 cm insulation • Windows: plastic frame window with dual-pane glazing	1,24	0,51	1,1	0,77	3	2130	545	26%	• Generator: low temperature non-condensing boiler / from 1995 • Storage: - • Distribution: central distribution, horizontal strings in unheated rooms (e.g. cellar) or in the soil / from 1979 to 1994 • Auxiliary electricity type: central heating system, standard pump, multi-family house • Elements: -	• Generator: low temperature non-condensing boiler / from 1995 • Storage: central hot water storage, outside thermal envelope / until 1994 • Distribution: central system with circulation loop / until 1978 • Auxiliary electricity type: central domestic hot water system with thermal solar system, no circulation pump

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Apartment Blocks												
Demo location	Envelope										Systems	
	ng dema nd [kWh	Description	U-value [W/(m²K)]					Total Surface [m²]		wind ow to wall	Heating system	Hot water system
Sweden	-	-	-	-	-	-	-	-	-	-	-	-

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TABLE 5-12. CHARACTERISTICS OF THE DEMO CASES

General Characteristics					U-value [W/(m²K)]												Energy use [kWh/m²y]	
DEMO CASE			TABULA		DEMO CASE						TABULA						DEMO	TABULA
Demo Location	Year of construction	Nº floors	Representative period	Nº floors	U average	Roof	Wall	Floor	Window	Window to wall ratio	U average	Roof	Wall	Floor	Window	Window to wall ratio	Heating	Heating
Greece (RD)	1971	4	Until 1980	5	NA	NA	1,6	NA	4,5	16%	3,34	3,05	2,60	3,1	4,7	26%	173	40,8[42]
Spain (RD)	2008	3	1960-2006	4-9	NA	NA	1,6	NA	3,78	18%	0,68-1,92	0,56-1,92	0,6-1,59	2,38-1,13	3,37-5,7	13%	-	3,9[4]

[42] The values were extracted from TABULA even though the numbers declared seem lower than the expected based on the introduced U values, specifically in the case of Spain the introduced energy is even lower than the new NZEB regulation.

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Sweden (VD)	Germany (VD)	Switzerland (VD)	Czech Republic (RD)
1960	1965	1964	1962
8	2	4	3
Until 1960	1958-1978	1958-1978	1946-1980
4	5-8	4	4
NA	NA	1,11	NA
NA	0,24	0,4	NA
0,45	0,64	0,98	0,8
NA	1,07	1,5	NA
2,8	3,0	1,8	1,4
17%	18%	12%	22%
0,64	1,23-1,24	1,23-1,24	1,34-1,36
0,36	0,51	0,51	0,85-0,94
0,62	1,2-1,1	1,2-1,1	1,08-1,43
0,32	1,08-0,77	1,08-0,77	1,03
2,22	3	3	2,8
23%	25%-26%	25%-26%	24%-18%
126	NA	128	210
184,6	115,5	115,5	167,4

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Concluding, it is obvious that the more frequent building typologies in the majority of the EU countries in TABULA project are dated from 1946 until 1980, before the introduction of the first EPBD in 2002[43]. The above highlights the urgent need for deep renovations in order to reduce the current energy consumption. Specifically, in the case of Spain, the representative period has a wider range including not only buildings before 1979, when the first thermal regulation was established, but also residential buildings constructed between 1979 and 2006, when the EPBD was not introduced by the establishment of the Technical Edification Code CTE.

With respect to the typologies, multifamily houses are the most frequent building construction for most of the cases, with an average representability of 29% in the total country's building stock. Apartment blocks, on the other hand, have an average representability of 16%. The number of floors ranges between 2 and 9 levels considering the data from both demo site cases and TABULA project. Additionally, the wall U-values of Greece, Czech Republic, Switzerland and Sweden Demo Cases are lower than the values presented in TABULA. Though, worth to be mentioned that the U-values of the Greek demo site and the respective values presented in TABULA are considerably different, while for the German and Spain demo cases the U-values are among the TABULA range of values. Furthermore, the windows to wall ratio (WWR) of the demo cases are in a range between 12% and 22% being in most cases lower than the ratios stated in TABULA, except for the case of Spain where the WWR of demo site is 18% and the TABULA value is 13%.

Lastly, the HVAC systems already installed in the demo site buildings could not be compared since the information about them are not available at the time this report was written and more information than the existing are required to accurately compare and define the existing conditions, and due to timing, this will be presented at the *Deliverable 7.1 Preliminary Design*.

5.2.1 Archetype model

Based on the characteristics of the buildings, and by taking into consideration the limitations and constraints of PLURAL solutions introduced in Chapter 4, the following *Table 5-13. Comparative between tabula representative data and plural requirements* highlights the characteristics and thresholds of the different PLURAL PnU kits.

[43] ZEBRA2020 Project Intelligent Energy – Europe (IEE) programme, "ZEBRA2020," Vienna University of Technology, Energy Economics Group, 1 April 2014. [Online]. Available: https://zebra2020.eu/. [Accessed October 2020].

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TABLE 5-13. COMPARATIVE BETWEEN TABULA REPRESENTATIVE DATA AND PLURAL REQUIREMENTS

Characte-ristic	Value from TABULA typologies	Limit values to implement PLURAL solutions	Acceptable Threshold for all PLURAL solutions	Additional comments
Climate	• Two Mediterranean locations. (W2S2, W1S3) • Three continental (W3S1) • One subarctic continental (W4S0)	• Mediterranean: the "Smart Wall" can be applied, the "eWHC" and "eAHC" PnU kits have limitations. • Continental: all PnU kits • Subarctic: only the "eWHC"	• All solutions can be applied in four of the clusters considered in the analysis (Germany, Switzerland, Czech Republic) • For more extreme climates: the "Smart Wall" can be applied in Mediterranean and the "eWHC" in Subarctic	• The implementation of "eWH" and "eAHC" systems need to be studied more in detail for the Mediterranean climate.
Number of floors	• Between 4 and 9	• All solutions are applicable between 2 and 4. • From 5 to 7 there are some restrictions in the case of the Smart wall. • More than 7 might be acceptable only for "eWHC" and "eAHC" systems with special design	• 2-7	• The specific limitations of systems have to be analysed if the solution is going to be implemented in buildings that have more than 4 levels.
U-value Wall [W/(m²K)]	• 2.6 – 0.6	• > 0.6	• > 0.6	• The U values of the representative buildings introduced in TABULA are in between the ranges that are acceptable to implement PLURAL

Characte-ristic	Value from TABULA typologies	Limit values to implement PLURAL solutions	Acceptable Threshold for all PLURAL solutions	Additional comments
				solutions
Window to wall ratio	• 27%-13%	• Up to 35% all solutions are applicable • Only the “eWH” and the “eAHC” (with limitations) systems are applicable in buildings with a WWR higher than 35%	• <35%	• The limitations of the “eWHC” and “eAHC” have to be analysed more in detail for these specific ranges.
Heating system	• Central systems and distribution. Mostly old boilers or condensing boilers. In Czech Republic the buildings are connected to district heating.	• The “eWHC” cannot be applied in buildings with heating floors. Preferable boiler and radiators with hydronic heating systems.		• At this point there is no information available regarding the possible interactions between the existing distribution and the PLURAL solutions. This aspect needs to be reviewed in detail in the future.
DHW system	• Electric in Greece, district heating with storage for Czech Republic and boilers in the other countries.	• No limitations		
Cooling system	• No existing cooling system	• No limitations		
RES	• Solar plant (20% of DWH) in Greece	• No restrictions		

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Regarding the geometry of the buildings, the characteristics of the demo cases are similar to the most frequent typologies and therefore, they could accurately represent the building stock. However, in the case of the Greece and German demo cases some characteristics differ from the representative buildings; the Greek demo site has less windows to wall ratio than the data provided in TABULA and the German demo site has less floors than the common typology introduced in TABULA project. For this reason, the simulation methodology and the extrapolation of the results in order to obtain data for the Preliminary Design should be very carefully considered.

6. Current market status and representative countries

6.1 Introduction

To enable the successful market entry of the PLURAL solutions is important to understand the current situation in Europe regarding renovation. A brief market study has been carried out focusing on two partner countries, i.e., Germany and Spain, representing not only two different European climatic zones, but also accommodating demo sites. In Spain, a real demo case is located, while in Germany, one of the three virtual demonstrator buildings is based. The two countries were also investigated because they are characterized by a large building stock in comparison to other European countries, as depicted in *Figure 6-1. Floor space distribution in European countries*. Germany has the largest floor space distribution (residential and non-residential) across European countries, while Spain has the fifth largest floor space distribution (fourth largest for residential buildings only). Within the PLURAL project, the partners' countries represent countries with a very large building stock.

Considering the floor space distribution in Europe (as depicted in *Figure 6-1. Floor space distribution in European countries*) it can be assumed that Germany and Spain offer a large-scale market potential, purely due to the size of the existing building stock. In addition, both countries have very strong construction industries, which will be able to adopt and promote the developed PLURAL solutions. Furthermore, it is expected that both countries offer a good potential of transferring the know-how into other markets However, the analysis is only a starting point and will be extended for other target countries as part of other tasks more oriented to PLURAL's solutions marketability. Thus, the market study will be further elaborated in *WP8. Market and Business Oriented Exploitation*, under *Task 8.3*, which is dedicated to the development of a business model for the PLURAL's solutions and PnU kit appraisal.

The current study has been carried out in such a way, to identify similarities and differences of the European markets, focusing on Germany and Spain markets. More specifically, the analysis followed the next steps:

- ***Step 1***: The actual energy efficiency state of the existing building stock has been analyzed to identify the market potential for possible applications of the PLURAL solutions;
- ***Step 2***: Barriers to renovation have been identified, as these represent one of the most important issues when using a renovation solution. Moreover, these barriers have been analyzed in order to identify how they reflect to the development of PLURAL solutions. **Overcoming these barriers is paramount for the success of the project**;

- ***Step 3***: Governmental strategies that boost the renovation rate have been studied, as they deliver important knowledge on how to overcome renovation barriers identified in the previous step;
- ***Step 4***: Renovation projects (focusing on Germany and Spain) have been analyzed regarding construction cost and price tables have been compiled on the basis of this data. Such tables have been used as a basis for the development of an initial cost analysis of the PLURAL solutions.
- ***Step 5***: Opportunities for the PLURAL solutions have been formulated that shall be further defined and exploited during the course of the project, in particular in WP8 as mentioned above.

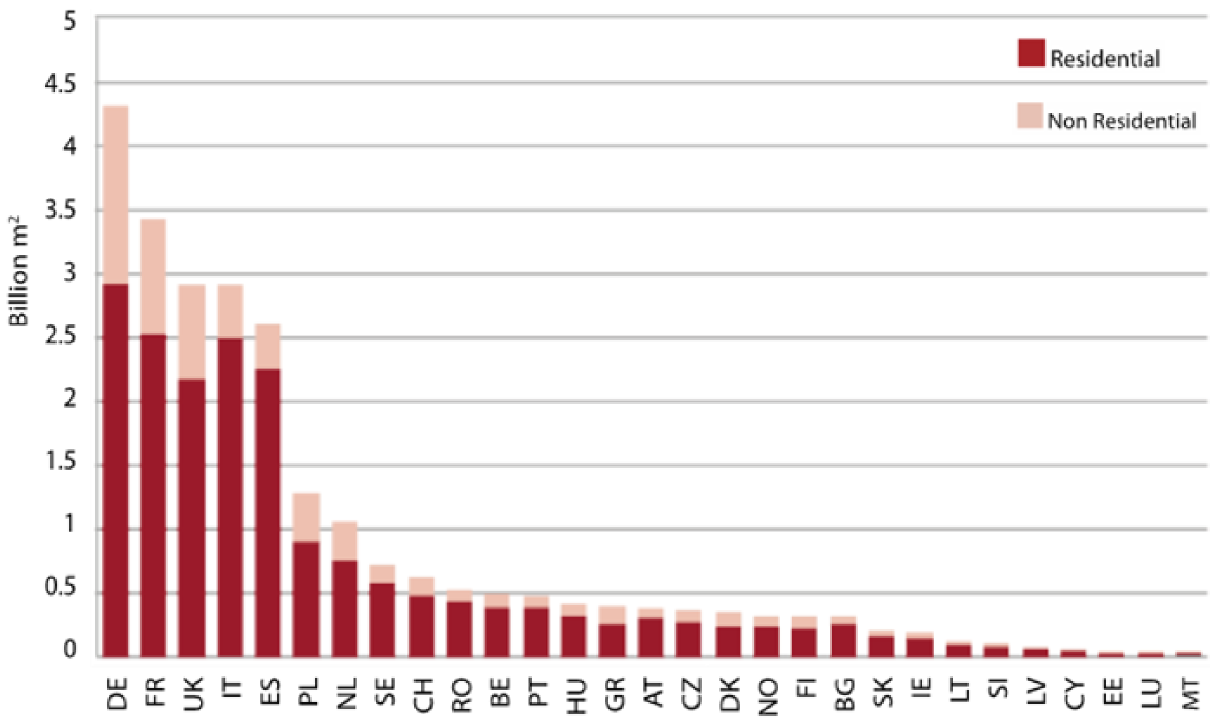

FIGURE 6-1. FLOOR SPACE DISTRIBUTION IN EUROPEAN COUNTRIES[44]

[44] Buildings Performance Institute Europe (BPIE): Europe's buildings under the microscope; p. 29

6.2 Building sector background in Europe

With 41% of the total, final energy demand in 2010, the European building sector is the largest consumer of final energy consumed, followed by transport (32%) and industry (25%)[45]. At the same time, the building sector is also responsible for the 55% of the electricity consumption. The sum up of the figures related to the building sector represents the 36% of CO_2 emissions, while the average annual energy consumption per m^2 floor area for all building typologies sums up to around 200 kWh/m^2. The difference between residential buildings (170 kWh/m^2) and non-residential buildings (300 kWh/m^2) is quite significant.

The fact that the European building stock is relatively old, with 40% of the buildings being constructed before 1960 and 90% before 1990[46], has a significant impact to the increased energy consumption. Amongst the different EU member states, the energy demand differs considerable in relation to climatic conditions, the proportion for space heating or air cooling, as well as the characteristics of the buildings[47]. Nordic countries with a colder climate demonstrate in general a higher energy demand.

Despite European and national legislation aiming to improve the energy efficiency of buildings (by setting a specific target of 3% annual retrofitting of the existing building stock), the average weighted renovation rate in all European countries ranging around 1.0% is low and even smaller around 0.2% when looking at deep renovation[48].

Taking into consideration all the above, it is obvious that addressing the energy efficiency of the European building stock is crucial not only to mitigate climate change, but also to improve the comfort for building occupants. The next paragraphs illustrate the existing situation in Spain and Germany in order to understand the difference between a warm and a cold country in more detail.

[45] Didier Bosseboeuf, Energy efficiency trends in the EU – Lessons learned from the Odyssee-Mure project. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/overall-indicator-brochure.pdf

[46] Directorate -General for Internal Policies: Boosting building renovation: What potential and Value for Europe?

[47] https://www.odyssee-mure.eu/publications/policy-brief/buildings-energy-efficiency-trends.html, last accessed 10.12.2020

[48] European Commission: Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU.

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

6.2.1 Building sector background in Spain

While in the EU, the energy proportion used by the building sector is ca. 40%, in Spain, the relative energy proportion is approximately 30%[49], which is still a very large portion. At National level, the Law 8/2013, about urban rehabilitation, regeneration and renovation, sets the objectives to regulate the conditions to guarantee a sustainable development, supporting the activities that lead to renovation of buildings and urban areas, with the final aim to reach the Europe 2020 objectives. In parallel, the Real Decree 238/2013 has modified certain articles and technical instructions from the RITE- regulation dedicated to the thermal HVAC equipment of the buildings, which became more demanding on the energy efficiency. The Order FOM/1635/2013 has also actualized the DB-HE- a document focused on the energy saving in buildings, and established more strict objectives and rules. The Real Decree 235/2013 has established the procedure for energy certification of buildings. Another important document is the Decree 67/2015, which focuses on the conservation, maintenance and renovation of buildings, which is important in order to determine the actual state of the building stock. Finally, the Real Decree 732/2019 further increases the requirements of Spanish Technical Code and particularly the DB-HE, which focuses on energy efficiency. This document also defined the nZEB conditions for the first time in the Spanish legislation.

The most common way to map the existing building stock is to classify the buildings according to their age. According to the 2018 data survey (see *Table 6-1. Distribution of the residential units according to their surface and year of construction (thousands of units), source: mitma based on questionnaire of homes 2018*), stated in thousands of residential units, the majority of the building stock is dated within the period 1981-2010, 12721.7 thousands of buildings, and in the period 1961-1980, 9667.2 thousands of buildings. Only 1721.0 thousands of buildings were constructed before 1940, and 313.0 after 2010. Within period 1941-1960, approximately 2550.3 thousands of buildings were constructed.

The flats, depending on the period constructed, have quite different characteristics that should be taken into account. The dwellings constructed before 1940 are larger, with ca. 50.2% of the buildings are larger than 90 m^2. The most recent units are also relatively large, both those built between 1981 and 2010 and those after 2010, with percentages of 47.5% and 48.2% above 90 m^2, respectively. The dwellings of the period 1941-1960 are those with the highest percentage of dwellings smaller than 60

[49] Rehabilitacio energetica d'edificis, Generalitat de Catalunya, Institut Catala d'Energia, 10/2016

m^2 (21.2%). The dwellings of the period 1961-1980 are those with the highest percentage of dwellings between 61 and 90 m^2 (51,8%)[50].

TABLE 6-1. DISTRIBUTION OF THE RESIDENTIAL UNITS ACCORDING TO THEIR SURFACE AND YEAR OF CONSTRUCTION (THOUSANDS OF UNITS), SOURCE: MITMA BASED ON QUESTIONNAIRE OF HOMES 2018

	< 60 m^2	61 – 75 m^2	76 – 90 m^2	91 – 120 m^2	121 – 150 m^2	> 150 m^2	TOTAL
< 1940	243.6	183.2	225.9	303.4	134.6	221.2	1311.9
1941-1960	377.5	382.9	390.3	365.2	127.2	134.0	1777.1
1961-1980	930.2	1,469.2	1,827.8	1,424.9	369.1	349.0	6370.2
1981-2010	781.2	1,203.1	2,666.6	2,210.8	845.8	1,144.5	8852.0
After 2010	28.6	31.5	56.4	44.8	23.2	40.6	225.1
TOTAL	**2,361.1**	**3,269.8**	**5,167.1**	**4,349.1**	**1,499.8**	**1,889.1**	**18536.3**

Considering the building typology (see *Table 6-2: Distribution of the residential units according to their typology and year of construction (thousand of units), source: mitma based on questionnaire of homes 2018*), the Spanish residential building stock is mainly composed of multifamily houses (three and more flats), representing 64.72% of the total building stock, while the independent single-family houses count for 13.89% and the coupled single-family houses or buildings with two residential units represent the 21.16% of the building stock.

TABLE 6-2: DISTRIBUTION OF THE RESIDENTIAL UNITS ACCORDING TO THEIR TYPOLOGY AND YEAR OF CONSTRUCTION (THOUSAND OF UNITS), SOURCE: MITMA BASED ON QUESTIONNAIRE OF HOMES 2018

	Before 1940	1941 – 1960	1961 - 1980	1981 - 2010	After 2010	Total
Single family house-independent	359,4	269,9	635,5	1265,7	44,7	2576,2
Single family house in row or double	405	362,2	657,9	1850,2	50,6	3325,8
Building with 2 units	94,8	67,8	192,8	236,9	4,2	596,5
Building with 3 to 9 units	197,7	365	1168,6	1493	18,4	3242,6
Building with 10 more units	250,3	706,7	3700,5	3989,5	107	8754,1
TOTAL	**1312**	**1777**	**6370,2**	**8851,8**	**224,9**	**18535,9**

[50] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.

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An interesting fact for the Spanish territory is that 11.6% of the total building stock do not have a heating system, therefore the 88.4% of the buildings (i.e. 16,598,128 residential units), are responsible for the total energy demand and consumption (see *Figure 6-2. Evolution of the energy consumption in the residential sector according to use (gwh), orange: cs, red: heating, blue: cooling, light blue: lighting and appliances, dark red: kitchen; source: mitma based on data idea (2019)*). Regarding the energy demand in the residential building stock, the current distribution of energy demand is 45.4% for heating, 26.3% for home appliances, 15.5% for domestic hot water, 7.9% for kitchen appliances, 3.8% for illumination and 1.1% for cooling[51]. As it is shown in the figure below, within the period between 2010-2014 there was a decreasing trend regarding the energy consumption, while in the next years, period after 2014, the tendency changed and the energy demand has an increasing trend. The increase in the energy consumption is approximately 1.3% annually. Within the period of the decreasing energy demand (2010-2014), the total energy demand reduction was ca. 43.5% for the heating, 30.3% for the domestic hot water and only 0,5% only for cooling. On the other hand, within the period 2014-2017, the total energy demand increase was ca. 48.3% for the heating and 50.6% for the domestic hot water, while the rest of the uses continued to decrease.

[51] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.

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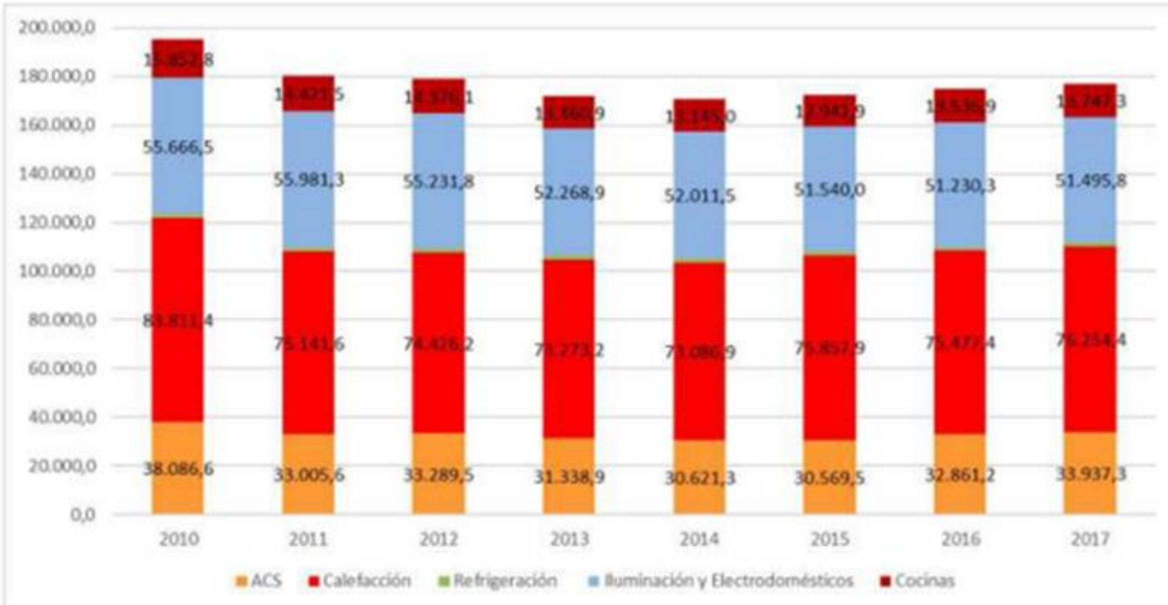

FIGURE 6-2. EVOLUTION OF THE ENERGY CONSUMPTION IN THE RESIDENTIAL SECTOR ACCORDING TO USE (GWH), ORANGE: CS, RED: HEATING, BLUE: COOLING, LIGHT BLUE: LIGHTING AND APPLIANCES, DARK RED: KITCHEN; SOURCE: MITMA BASED ON DATA IDEA (2019)

Renovation rate

In the recent years, there has been a significant increase of the building renovation rate in Spain (see *Figure 6-3. Evolution of the business volume in the residential construction: proportion between new construction and renovation, orange: new construction, blue: renovation in %; source: spanish ministry of transport, mobility and urban agenda*). Specifically, between 2017 and 2019, the building permits for renovation works increased by ca. 9.1%, for residential buildings, increasing from 25.996 in 2017 to 28.364 in 2019, respectively.

Moreover, the investment in renovation market has significantly increased between 2017 and 2019 (35.6%) (see *Figure 6-3. Evolution of the business volume in the residential construction: proportion between new construction and renovation, orange: new construction, blue: renovation in %; source: spanish ministry of transport, mobility and urban agenda*), reaching a total volume of 4.2 billions Euro in the last year. Particularly for residential buildings, the annual budget reached 1.4 billions Euro in 2019, increasing by 25.2% compared to 2017[52].

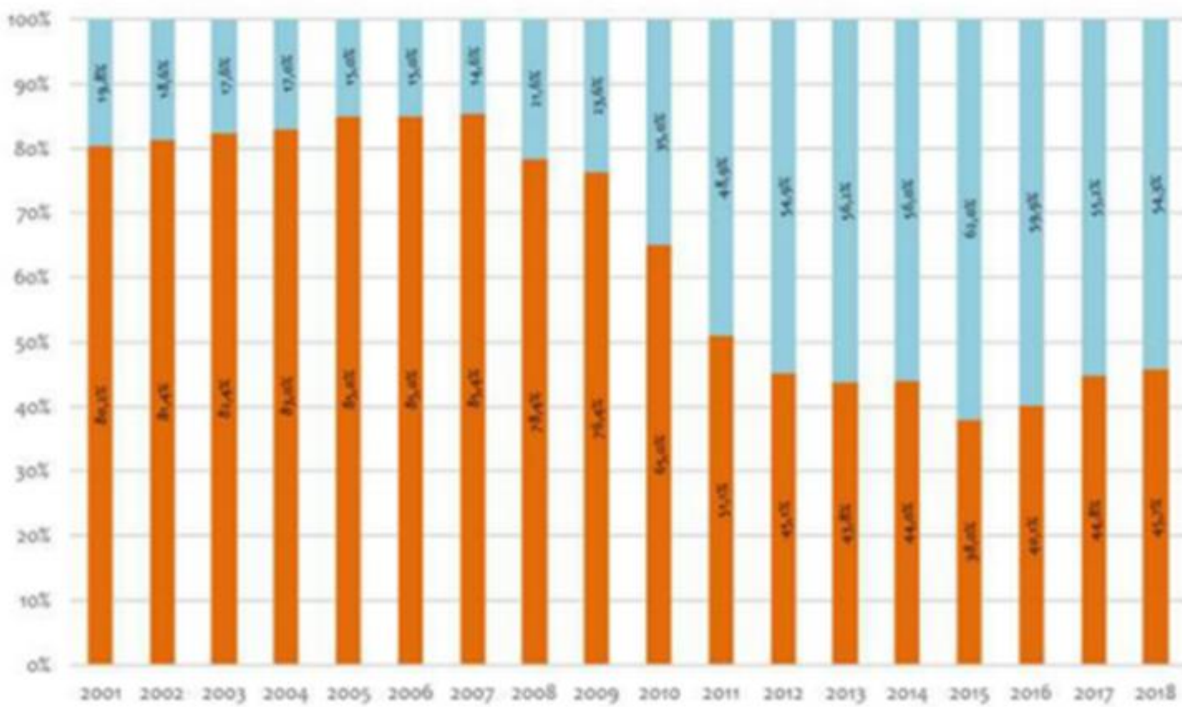

FIGURE 6-3. EVOLUTION OF THE BUSINESS VOLUME IN THE RESIDENTIAL CONSTRUCTION: PROPORTION BETWEEN NEW CONSTRUCTION AND RENOVATION, ORANGE: NEW CONSTRUCTION, BLUE: RENOVATION IN %; SOURCE: SPANISH MINISTRY OF TRANSPORT, MOBILITY AND URBAN AGENDA

In the residential sector, since 2012, the renovation activity overpasses the new construction investments, taking the 54.3% of the construction market in 2018. The total investment volume for renovation has reached its historical maximum in 2018, 30.545 billion Euro.

The tendency of the renovation rate in Spain can be considered positively, however the rate being 0.8% in 2014, was still low compared to other European countries, like 1.82% in Austria, 1.75% in France or 1.49% in Germany[53].

[52] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.

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6.2.2 Building sector background in Germany

The building sector in Germany is the largest energy consumer and is responsible for the 40% of the final energy consumption and the 30% of all the produced greenhouse gas (GHG) emissions in the EU[54]. For that reason, the building sector in Germany plays a key role in the implementation of energy measures in order to mitigate climate change and to achieve the long-term climate protection goals set by the European Union (EU), regarding the reduction of greenhouse gas (GHG) emissions by 80-95% below 1990 levels until 2050[55]. The German government has adopted these goals and intends to transfer the existing building stock into an almost climate-neutral one by the year 2050. For this purpose, the non-renewable primary energy requirements of the building stock have to be reduced by ca. 80 % by the year 2050 compared with the reference year 2008[56]. For residential buildings, this comprises the final energy consumption for heating, cooling and hot water, including auxiliary energy consumption for the operation of heating and hot water systems, as well as the consumption for the operation of ventilation systems.

These ambitious goals require not only sustainable energy production, but also more efficient use of energy. Approx. 65% of building facades in Germany are not insulated, while another 20 % are not state of the art. More than 80% of residential buildings were built before the introduction of the third heat insulation ordinance in 1995. Two thirds of these buildings require energy-related renovation. In addition, approx. 70 % of the building services are not state of the art and thus to a large extent in urgent need of renovation or exchange[57].

Figure 6-4. Annual final energy demand for heating for different building categories [BPIE, 2015] illustrates the annual final energy demand for heating, according to different building categories in Germany. Non-residential buildings (e.g. offices, commercial buildings, hospitals etc.) have been grouped regarding the year of construction. On the other hand, residential buildings have been grouped regarding the year of construction and the type of housing (single-family houses and apartment buildings). As it is shown in the figure, for both typologies of residential buildings being

[53] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.
[54] BPIE (2015) Die Sanierung des Deutschen Gebäudebestandes. Brussels: BPIE, ISBN: 9789491143137
[55] Europäischer Rat, Oktober 2009
[56] Energy efficiency strategy for buildings (background paper), Bundesstelle für Energieeffizienz (2015)
[57] https://www.initiative-energieeffiziente-gebaeude.de/de/zum-thema, last accessed on 23.11.2020.

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constructed until 1995, consume 79 kWh/m² – 158 kWh/m² gross floor area, which is high. Due to the unfavorable A/V ratio (area to volume), single-family houses perform worse than apartment blocks. For all non-residential buildings, the energy performance is consistently poor and ranges between 159 kWh/m² - 122 kWh/m² gross floor area. The results clearly show the urgent need for a large fraction of the German building stock to be renovated in due course, in order to reduce the energy demand for all building types and to achieve the net zero standard by 2050.

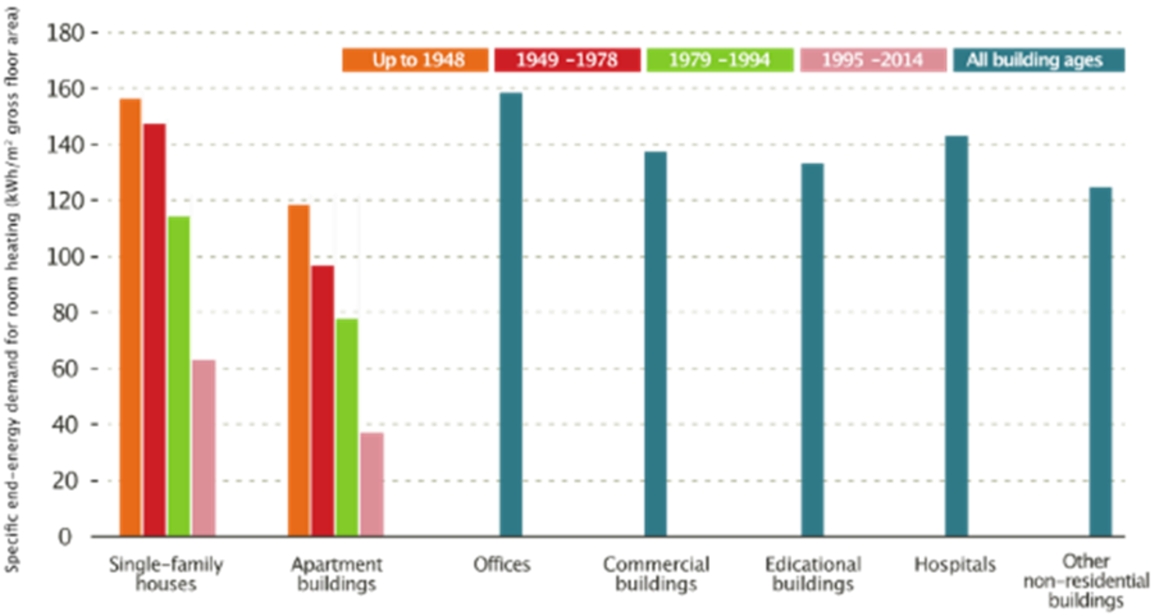

FIGURE 6-4. ANNUAL FINAL ENERGY DEMAND FOR HEATING FOR DIFFERENT BUILDING CATEGORIES [BPIE, 2015]

Improved energy efficiency can significantly reduce energy consumption and at the same time bring numerous of benefits, such as cost savings, job creation, improved energy security, increased comfort, higher productivity and environmental benefits in the form of improved air quality and lower GHG emissions. However, the renovation of the building stock in Germany is currently still characterized by a standstill. With the current annual renovation rate of ca. 1%, it would take more than 100 years, in order to refurbish the entire building stock in Germany. In addition, most renovations today do not

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achieve the total energy saving potential[58]. In order to achieve the set targets, the renovation rate must rise to over 3% and the depth must increase significantly[59].

Studies showed that more than 75% of the private building owners are not even informed about the energy performance of their building. In the renovations that already carried out, only 18% of the building owners have taken advantage of energy advice. A large number of these renovations have therefore not been optimally carried out. On average, only the 30% of the savings potential has been realized[60].

In order to reduce the use of non-renewable primary energy until 2050 by 80 % compared to 2008 in the building stock, two major measures should be considered[61]:

- **Energy efficiency**: The energetic modernization of the building envelope and the plant engineering, as well as the use of new, efficient technologies can reduce the final energy consumption of the buildings;
- **Use of renewable energies**: The decarbonisation of the final energy consumption of the buildings through the use of renewable energies can reduce the consumption of non-renewable primary energy of the buildings;

Through this holistic approach to renovation, which addresses both the building envelope and building technology, the energy consumption of the building stock can be reduced by approx. 80%. The replacement of the outdated equipment with modern technical systems, results up to 50% energy reduction, as well as to the reduction of large amounts of CO_2 emissions. In addition, the implementation of automation, adapting the user behavior, can save another 30% of heating energy and CO_2 emissions. The requirements for building renovation are set out in the new building energy law (GEG), which came into force on the 01. November 2020 and replaces the energy saving ordinance (EnEV).

[58] Didier Bosseboeuf, Energy efficiency trends in the EU – Lessons learned from the Odyssee-Mure project. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/overall-indicator-brochure.pdf

[59] https://www.initiative-energieeffiziente-gebaeude.de/de/zum-thema, last accessed on 23.11.2020

[60] https://www.initiative-energieeffiziente-gebaeude.de/de/die-initiative#vorsitzende-und-geschaeftsfuehrung, last accessed on 23.11.2020

[61] Energy efficiency strategy for buildings (background paper), Bundesstelle für Energieeffizienz (2015).

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6.3 Barriers to renovation

Despite national regulations and manifold initiatives, the desired and urgently needed renovation rate in all European member states stays far behind the defined goals and aspirations stipulated by the EU. It is therefore important to identify and understand the reasons for these shortcomings. At European level, various barriers to renovation have been identified through different studies and surveys and can be summarized as following[62]:

- ***Financial Barrier***: The most important barriers are related to finances. Building renovation requires large investments, especially if a deep renovation is targeted and the building envelope and services will be fully upgraded. Clients often fear of such expenses, in conjunction with the sometimes-unpredictable renovation costs in comparison to the costs for new construction. This is often paired with limited access to finance and low energy prices, which prevents clients from taking the risk that is linked to a decision for a deep refurbishment.
- ***Technical/process Barrier***: Technical and process barriers have been identified, either related to the lack of technical solutions or purely to the lack of knowledge about professionals working in the construction industry and being able to implement the renovation. In addition, the supply chain is often fragmented and demonstrate burdens for home owners, who are not familiar with construction processes.
- ***Regulatory Barrier***: Regulatory aspects and processes demonstrate considerable hurdles as ambitions regarding performance requirements often vary and the goals for renovation lack of clear definition.
- ***Awareness Barrier***: There is still a lack of awareness of certain stakeholders, so that the need for renovation is not understood and therefore not being tackled.

To overcome these barriers within the PLURAL project, it is important to understand the barriers at national level, as specific market situations might affect differently. The next paragraphs illustrate the existing situation in Spain and Germany in order to understand the barriers and identify common potential, as well as differences in detail.

[62] https://www.odyssee-mure.eu/publications/policy-brief/buildings-energy-efficiency-trends.html,last accessed 10.12.2020

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6.3.1 Barriers to renovation in Spain

The barriers for renovation in the Spanish market can be divided into several categories.

Economic/Financial barrier

The economic considerations are important in the effectiveness of the renovation process. The most common one is the elevated cost of the initial investment, in conjunction with the reflected negative effects of the economic-financial crises started in 2008 and recently by the Covid19 pandemic. The result of the economic-financial crises was the significant decrease of the annual income of the Spanish families between 2010 and 2015. The situation was being recovered slowly until 2018, with data not known for the last period. In addition, the energy poverty has been above 18% since 2011, and although there has been a recent decrease, it is still above 19% according to 2018 data[63].

In conjunction to the economic barriers, another finance barrier to renovation in Spain is the elevated financial risk. The financing tools, like credits are also not considered easily accessible. The Spanish banks already have an important exposure in the real estate sector and in the credit market, making higher the interests for the loans related to the renovation. In addition, there is a lack of knowledge about the energy renovation at the financial markets, which does not help to remove limitations[64].

Energy saving potential barrier

Another discouraging fact for renovation actions, considering the climate conditions, is the low total energy demand in Spain compared to other European countries. The total energy demand in Spain is ca. 103.04 kWh/m^2, which is ca. 44% lower than the European average (184.14 kWh/m^2) and ca. 67% lower than the situation in Romania (308.09 kWh/m^2)[65]. The feasibility of the business models for energy retrofit are normally based on the energy savings. In Spain, the energy savings potential is not very high, mainly due to the fact that the actual heating of the buildings has a lower impact on the overall energy consumption. In addition, the cooling energy demand is very low, reaching just 1% of the overall energy use in residential buildings, which again decreases the energy savings potential. Additionally, similar effects can be considered within the boundaries of the Spanish territory, with 6 climate zones with very different energy demands, causing difficulties in territorial planning, where in some of the zones it makes more economical sense to intervene than in the others.

[63] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.
[64] Rehabilitacio energetica d'edificis, Generalitat de Catalunya, Institut Catala d'Energia, 10/2016.
[65] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.

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Regulatory barrier

Several considerations regarding the regulations have been already made, being in close relation with the economic barriers. An important issue within this topic is the production of renewable energy by building owners, which has passed through several changes and is to be discussed in further details.

Management barrier

Other renovation barriers in Spain are the social and psychological barriers. One of the main social aspects is the structure of property in Spain. More than 45% of the residential units in Spain are located in multi-family houses with individual property. This means that the management of the buildings is collective, and the decisions in regard to the energy or other retrofit have to be taken between the community of flat owners, which makes the process complex, although some adjustments to the related legislation have been made in order to facilitate the renovation of the buildings.

Architectural/urban barrier

Other barriers are architectural and urban planning related, where the accessibility to buildings and conservation of the cultural heritage has to be taken into account when intervening in the buildings. These barriers may be particularly important when considering the integration of renewable energy sources at the building envelope.

Success story barrier

Finally, the lack of references and success cases in the Spanish market makes it more difficult to explain to the citizens the renovation advantages and gain their acceptance. In conjunction with the few success stories, another barrier related to the lack of interest by age is identified. According to a study, which examined 916 residential units, it was determined that the older generations spend less energy and are less open to invest in energy efficiency measures. This can be a logical consequence of the fact that the older generations cannot enjoy the advantages of this investment for long enough[66].

[66] Rehabilitacio energetica d'edificis, Generalitat de Catalunya, Institut Catala d'Energia, 10/2016.

6.3.2 Barriers to renovation in Germany

There are several barriers responsible for the very low renovation rate in Germany. The main reason is related to economic considerations that are justified differently for the various building owners. Many apartments in Germany are not privately owned. Due to regulations[67], it is often not economically viable to invest in buildings, as renovation costs cannot be refinanced or compensated by higher rents and tenants benefit from the investment transacted by the building owner. In addition, a large part of the building stock is owned by housing associations, dependent on public monies. Budget consolidation in many municipalities means that only limited investments are possible. Furthermore, in the municipal budget, renovation costs are allocated to the asset budget. However, the savings achieved relieve the administrative budget. Since no equalization between the budgets can take place, this makes it more difficult to refinance renovation measures. In addition, the extremely low energy prices extend the payback period of energy saving measures and stop property owners undertaking bigger investments, in conjunction with the substantial financial risks.

If this complex building ownership in Germany is coupled with a certain skepticism regarding the planned energy savings and if they can be achieved through energy-related renovations, a decision for an investment becomes more difficult. Moreover, the general lack of knowledge, expertise and skills of experts in the construction industry, e.g. about effective measures among architects and many untrained workers on the construction site, impede the renovation to take place. In addition, occupant disturbance has been identified as a major barrier to renovation, as tenants are allowed to lower the rent during renovation.

Furthermore, internal administrative processes in Germany are complex and time-consuming. These processes often inhibit and delay investments. On top of that, short time frames for applying for and using subsidies for the implementation of extensive renovation measures discourage building owners.

Finally, there is also another barrier to renovation in Germany, which is related to a general attitude about the property value and the view that energy efficiency is not an indicator of the economic value of a building resulting to a lack of interest among customers, investors and the media about comprehensive refurbishments.

[67] e.g. Mietpreisbremse (new legislation to freeze the rent))\

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6.4 Renovation Strategies

Building renovation is essential for decarbonizing the building sector and achieving the declared climate goals set out by the EU to make Europe climate neutral by the year 2050. Large parts of the building stock (approx. 75%) are too energy consuming. Up to now, only the 1% of the buildings in Europe undergo an energy efficient renovation, by improving the building envelope and producing-providing energy from renewable sources. The majority of the existing building stock (85% - 95%) will still be in use by the year 2050. A renovation boost has to be triggered in order to achieve the goal of climate neutral buildings by this year. The EU has therefore announced the European Green Deal, a key initiative for delivering results regarding the energy efficiency goals in the building sector[68].

Moreover, the EU has recently set up a new recovery instrument, called NextGenerationEU, which will make available an unprecedented number of resources that can be used for building renovation. This instrument runs alongside the Multiannual Financial Framework and aims to help overcoming the current COVID 19 crises. The EU focuses on sustainability, resource efficiency, resilience and greater social inclusion and aims to address barriers to renovation in order to make the initiative successful. The objective is to double the annual renovation rate not only for residential, but also for non-residential buildings by 2030[69].

In order to achieve this goal, the European member states were requested to develop national long-term renovation strategies (LTRS) until March 2020. Such strategies are expected to address cost-efficient deep renovations that deliver, if needed in stages, significant final energy consumption reductions from now on up to 2050. In addition, these measures are expected to offer other benefits like decreasing energy bills, improving occupants' comfort and health and also addressing fuel poverty. Another side effect is the generation of new green jobs, increasing the economic strength of the country.

Up to now, only 12 member states have submitted their guidelines and although most of them are not in line with the requirements of the EPBD, it is still important to understand their approach. Strategies developed by the Spanish and German government have been reviewed in more detail and shall be taken into consideration for the development of the PLURAL solutions, even though they might

[68] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en, Last accessed 23.12.20
[69] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662, Last accessed 23.12.20.

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demonstrate potential shortcomings. These shortcomings will be addressed and overcome by the PLURAL approach.

6.4.1 Renovation Strategy by the Spanish Government

At national level, there are 2 documents related to the renovation of buildings in Spain:

- the Long-term Strategy for Energy Renovation (Estrategia a largo plazo para la Rehabilitación Energética ERESEE) and
- the National Plan for Residential Buildings (Plan Estatal de Vivienda)[70].

The critics say that these documents are not related to each other and therefore they do not provide the necessary tools to increase the energy efficiency of the building stock.

However, the Long-term Strategy for Energy Renovation (ERESEE) has been actualized in 2020, in collaboration with various actors from the building sector. Apart from providing a detailed diagnostic of the existing building stock, the ERESEE defines a series of objectives and scenarios of the renovation strategies. For the residential sector, the particular strategies are more rational controlled and reduce the energy demand by improving the building envelope, by improving the HVAC systems and controlling the ventilation, and by implanting RES. The document also includes the axes of action and interventions, along with indicators to allow follow-up[71].

At regional level, in February 2014, the Catalan Government has published the Catalan Strategy for Energy Retrofit of Buildings (ECREE), with the objective to impulse the renovation of residential and tertiary buildings, in order to improve energy savings and to increase their habitability and comfort.

6.4.2 Renovation Strategy set out by the German Government[72]

The existing instruments of Germany's Energy Saving Ordinance (EnEV), the Building Energy Law (GEG), which was introduced in November 2020, as well as the framework conditions, are not sufficient to carry out comprehensive renovation activities at a larger scale and provide adequate financial

[70] Por un cambio en las políticas públicas de fomento de la rehabilitación residencial, GBCe, 2018.
[71] ERESEE 2020, ACTUALIZACIÓN 2020, de la Estrategia a Largo Plazo Para la Rehabilitación Energética en el Sector de la Edificación en España.
[72] NABU-Bundesverband Naturschutzbund Deutschland (NABU) e.V. (2012) Strategie für eine wirkungsvolle Sanierung des deutschen Gebäudebestandes. Berlin, NABU, Art.-Nr. 5315

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resources. The main shortcomings regarding the Germany's renovation strategy have are the followings:

- missing knowledge of the owner regarding the actual state of his/her building and the target level;
- missing knowledge regarding the renovation strategies, as well as how and utilizing what measures the target energy efficiency level can be achieved;
- sufficient and permanent economic incentive to start measures;
- correspondingly flanking funding regime, which differentiates between energetic and social standards and is coordinated according to the different modules.

In addition to the redefined EnEV, a new set of instruments has been developed that will provide an incentive for deep and on time renovation. The main core of the proposal is a long-term building-specific renovation plan, which enables a stepped approach over the next 30 years in order to achieve a nearly climate-neutral building stock by 2050. The plan consists of the following instruments:

Climate protection classes

In the future, each building will be categorized in a climate protection class, in line with the energy label introduced by the EU for electrical appliances. The class will reflect the position of the building in a system of energetic quality levels. By this way, the energetic condition of the building will be presented in a generally understandable and transparent way and both, the building envelope and building services will be addressed.

Specification of an orienting staircase curve for each building

Differentiated according to building types, gradually more demanding climate protection classes will be defined that existing buildings have to achieve over time. In such a way, near-zero emissions of greenhouse gases by 2050 for the existing building stock will be reached. This staircase curve provides a long-term perspective for each building, on which the owner can prepare the necessary renovation steps.

Renovation roadmap as part of a consulting campaign

Renovation timetables for individual buildings show different strategies and document necessary sub-steps to achieve the applicable climate protection class. As part of a nationwide renovation campaign such plans are developed, marketed and carried out by certified energy consultants.

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Climate protection obolus as continuous incentive to renovation

Homeowners pay a penalty, if their building, has not achieved the required step on the stair curve in the respective year. The amount relates to the missing steps on the ladder. The building owner has to provide the required documentation. Otherwise the building will be classified into the lowest energy efficiency class. This penalty takes into account that in a large number of buildings heating or cooling is not regulated by emission trading and especially oil and gas heating systems are not taxed in relation to their CO_2 emissions.

Funding regime

Building owners, who want to improve the energy efficiency above the required threshold level, receive a subsidy. The climate protection obolus of the "non-refurbisher" is diverted into the corresponding funding programs for the "better- refurbisher".

The strategy has been criticised for lacking some of the financing strategy elements, milestones beyond 2030 and a quantifiable goal until 2050. Furthermore, cost-effectiveness and facilitating financing progress shall be improved[73]. However, the measures presented above offers great potential for the PLURAL project. Solutions anticipated so far tackle both, the renovation of the building envelope and building services. In addition, the planned decision support tool can be developed in such a way that important instruments from this strategy are incorporated, e.g. the staircase curve or renovation roadmaps in order to enable building owners to benefit from the funding scheme.

6.5 Importance of renovation cost

According to the above analysis, the financial issues have been identified as one of the main barriers to building renovation, not only at European level, but also in Spain and in Germany. Hence, it is of great important to understand the current cost structure for renovation at national level, in order to have a successful development of the PLURAL's solutions, as well as to achieve as much as possible high penetration of the PLURAL's solutions to the renovation market.

[73] A review of EU member states' long-term renovation strategies BPIE 2020.

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The costs of different renovation strategies have been approached for all PLURAL countries. The target is to establish a cost structure for Business as Usual (BAU) approaches in order to define a project specific reference. As PLURAL aims to deliver cost efficient solutions, these BAU cost structures have been taken as maximum value. In addition, they serve as a starting point for the technical development and enable a draft evaluation of the market potential.

In order to identify the current cost structure for renovation, the renovation costs for the defined target buildings (see Chapter 5) have been determined, taking into consideration the year of construction and the typology. The costs are calculated in Euro per square meter of the useful area ($€/m^2_{\text{useful area}}$) of a residential unit or as Euro per defined reference area (e.g. €/ m^2 wall area). Four different renovation strategies were examined, as described below:

- Passive strategies (renovation of façade, roof, etc.);
- Active strategies (heating, cooling, etc.);
- RES- renewable energy strategies (PV production, etc.);
- Management (BEMS).

It must be pointed out that this cost provision should be used with utmost care, especially if used as a reference for PLURAL, in order to draw the right conclusions. Construction costs generally depend on many specific conditions in each renovation project, as well as on local factors and market incidents. The forecast of renovation cost is even more volatile, as the documentation of existing buildings is often incomplete and projects have to deal with many unknown factors. In addition, the data, especially in the sum for each category is not directly comparable between countries, as each of the sources is based on a different cost structure, slightly different building typologies, different unit surfaces, different renovation levels and include different specific measures. This cost assessment is therefore considered as first approach that shall be further elaborated in WP8 under Task 8.3.

6.5.1 Renovation cost in Spain

Considering the renovation costs in Spain, it has already been defined (see paragraph 6.3) that the initial investment costs are quite high. The reason to this can be associated to the overall poor management and organization of the construction sites and projects, as well as to the low transparency between the involved stakeholders. Both of these aspects can be related with the uncertainties in terms of cost, delivery time, quality, and availability of quality workers.

Table 6-3. Average cost for the refurbishment of buildings or building elements illustrates that there are quite important variation between the minimum and maximum costs of interventions, mainly due to

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the variety of the renovation solutions that result to similar energy efficiency of the building. Considering the cost per m^2 of useful area, the highest costs can be perceived when installing PVs.

TABLE 6-3. AVERAGE COST FOR THE REFURBISHMENT OF BUILDINGS OR BUILDING ELEMENTS

			COST [€ / m2 gross floor area]	
COUNTRY		CATALAN DATA REFERENCES Source: Rehabilitacio energetica d'edificis, cuadern n.10, Generalitat de Cataluña	SPAIN- CATALONIA	
BUILDING TYPE			Residential buildings, Multi-family-housing, constructed after 1951 (86,8%) F,G,H,I according to ref.	
Approx. Floor area: net [m2]			82,58	
Cost type material /labour			MATERIAL	LABOUR
PASSIVE MEASURES	**average**	thermal insulation facade	50,5 €	
	min		10,5 €	
	max		90,6 €	
	average			
	min			
	max			
	average	thermal insulation roof	29,3 €	
	min		16,6 €	
	max		42,0 €	
	average	windows and solar protection	73,5 €	
	min		67,5 €	
	max		79,6 €	
	average			
	min			
	max			
	average	airtightness	1,4 €	
	min			
	max			
	average		**154,8 €**	
	min			
	max			

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ACTIVE MEASURES	**average**	heating, cooling, ventilation, hot water	38,1 €
	min		1,7 €
	max		74,5 €
	average		
	min		
	max		
	average		
	min		
	max		
	average		
	min		
	max		
	average	illumination	3,1 €
	min		
	max		
	average	electrical appliances	15,1 €
	min		
	max		
	average		**56,3 €**
	min		
	max		
RES	**average**	**PV installation**	**82,5 €**
	min		**60,0 €**
	max		**105,0 €**
MANAGEMENT	**average**	**BEMS**	**no data**
	min		**no data**
	max		**no data**

However, this concept counts with its own business models, which makes it more sustainable as a concept, compared to the other strategies that have only economic advantage in the energy savings.

The cost data are based on a Catalan market analysis, which considers the impacts of different renovation strategies (the least and most expensive strategies) to the energy efficiency of the residential building stock. The differences between the renovation strategies are focused on the material selection and the type of technology applied. The buildings constructed after the year 1951 of the following typologies have been considered according to the PLURAL target typology: F- Multifamily houses 1951-1980 with central heating, G- Multi-family houses 1951-1980 without central heating, H- Multi-family houses 1981-1990, I- Multi-family houses 1991-2011[74].

6.5.2 Renovation cost in Germany

The main driving force for or against an energetic refurbishment are often the predicted cost for the intervention itself. Although cost structures are always difficult to transfer from projects to other projects, as they are influenced by many factors such as the market, building geometry, performance standard, project size, wall to window ratio etc. a cost estimation based on data published by the Building Cost Information Center of the German Chambers of Architects (BKI) has been undertaken. BKI is the central service facility for over 100,000 architects and their construction cost databases include several thousand invoiced projects for new and historic buildings as well as outdoor facilities. The aim of this brief cost analysis is to provide rough guidance for the further development of the project, in order to enable a successful penetration of the PLURAL's solutions to the renovation. It has to be pointed out that all data listed below have only orientating character and have to be adapted, if they are taken as a reference for a PLURAL project.

Table 6-4. Average cost for the refurbishment of buildings or building elements according to bki lists specific cost values according to the cost categories of DIN 276 for the second level of the refurbishment of multy storey, residential buildings, constructed after 1945 in Germany. The cost status of all figures is 02/2020, including 19% VAT and have been averaged for the whole of Germany. The basis of all figures are real case projects, where invoiced costs have been provided. The number of reference projects, 18 in total, and the specific project diversity impact on the listed figures. Apart from one building, all buildings were occupied during construction. The project size varies between 381 m^2 (3 units) – 15.978 m^2 (179 units) gross floor area, which shows the large variety of the benchmark projects. The depth of renovation differs also for all projects. There is no indication, whether prefabrication as a means of construction has been applied or not. Due to the fact that no costs for plug and use solutions could be established, cost for the refurbishment of the building envelope and building services have been provided separately. Cost have been provided in €/m^2 gross floor area or €/m2 reference area as average / minimum and maximum figures.

[74] Por un cambio en las políticas públicas de fomento de la rehabilitación residencial, GBCe, 2018.

In addition, specific cost values according to the cost categories of DIN 276 for the third level for the refurbishment of historic buildings refurbished in Germany have been provided, as they reveal a greater level of detail in light of the specific construction and materials applied. The values are provided by BKI on the basis of statistical evaluations of more than 600 billed historic buildings, reflecting various different building typologies, including residential, office and school projects etc. Cost for passive measures, RES and management could not been provided according to the third level, due to lack of information. Cost values up to the second level have been used instead. All values are net without the application of VAT. Cost have been provided in €/m^2 gross floor area or €/m^2 reference area as average / minimum and maximum figures.

Overall the table shows that renovation costs are quite expensive. Especially the refurbishment of the building envelope is costly and ranges between 220 €/m^2 and 682 €/m^2, with an average value of 452 €/m^2 per reference area when looking at the second level of the cost categories. If a greater level of detail is included (third level of the respective cost category) is taken into consideration, the amounts are even higher and range between 703 €/m^2 and 1,152 €/m^2 per with an average value of 875 €/m^2 per reference area. This relates most likely to the fact, that for the latter cost assessment sustainable building materials e.g. timber, wood fibre insulation, wood-aluminum windows have been priced that are generally still more expensive in Germany due to the limited market share.

The cost for active measures in comparison are relatively low, ranging between 26 €/m^2 and 169 €/m^2, with an average value of 76 €/m^2 per gross floor area. These costs relate only to minor interventions and not to a full replacement of the respective building services.

The prices for PV panels have been established on the basis of a tender for a real project due to the lack of data provided by BKI and offer a good market representation.

Although the cost provision has to be treated with great care and it is difficult to make clear indications at this point of the project regarding cost forks for the solutions to be developed, the structure will be taken as a reference point for the development for PLURAL solutions for the German market and the following recommendations can be made:

- PLURAL solutions have to be accurately compared to the cost provided
- PLURAL solutions should target the minimum cost of 700 € / m^2 for the building envelope
- Active measures have to be studied, once the components have been clarified

Annex IV provides an extended cost table, where other partner countries are included.

TABLE 6-4. AVERAGE COST FOR THE REFURBISHMENT OF BUILDINGS OR BUILDING ELEMENTS ACCORDING TO BKI

				COST [€ / m² gross floor area] groos incl. 19 % VAT			COST [€ / m² gross floor area] net without VAT	
COUNTRY		GERMAN DATA SYSTEM Source: Building Cost Historic Buildings Statistical Cost Parameters taken from BKI, II Quarter 2020		GERMANY A		BKI Kostenplanung 2020 Statistical cost parameter all cost are excl. VAT and labour cost	GERMANY B	
BUILDING TYPE				For residential buildings, constructed after 1945, Status 2. Quarter 2020, average value in Germany				
Approx. Floor area: net [m2]								
Cost type material /labour				MATERIAL	LABOUR		MATERIAL	LABOUR
PASSIVE MEASURES	**average**	Cost Group 300: Building and building construction	330 External walls, vertical, exterior:	**217 €/m² wall area**	57 €/h	2 layer substructure in timber, thermal insulation mineral wool for rear ventilated facade, incl. fire barrier+ windproof protection, substructure and timber weatherboards	202,0 €	57 €/h
	min			103 €/m² wall area	49 €/h		145,0 €	49 €/h
	max			311 €/m² wall area	71 €/h		276,0 €	71 €/h
	average							
	min							
	max							
	average		360 Roof construction:	**235 €/m² roof area**		thermal insulation roof (wood fibre)	**62 €/m² wall area**	

	min			117 €/m^2 roof area			47 €/m^2 wall area	
	max			371 €/m^2 roof area			82 €/m^2 wall area	
	average					wood-alu windows, 1 leaf u-value 0.7 W/m^2 K	**678 €/m^2 wall area**	
	min						563 €/m^2 wall area	
	max						881 €/m^2 wall area	
	average							
	min							
	max							
	average							
	min							
	max							
	average			**452 €/m^2 ref. area**			**875 €/m^2 wall area**	
	min			220 €/m^2 ref. area			703 €/m^2 wall area	
	max			682 €/m^2 ref. area			1.152 €/m^2 wall area	
ACTIVE MEASURES	**average**	Cost Group 400: Building and building	420 Heat supply facilities:	**38,0 €**		420 Heat supply facilities:	**38,0 €**	
	min			14,0 €			14,0 €	
	max			75,0 €			75,0 €	

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	average	services				
	min					
	max					
	average					
	min					
	max					
	average		430 Ventilation systems:	**22,0 €**	430 Ventilation systems:	**22,0 €**
	min			7,0 €		7,0 €
	max			58,0 €		58,0 €
	average		440 Electrical systems:	**16,0 €**	440 Electrical systems:	**16,0 €**
	min			5,0 €		5,0 €
	max			36,0 €		36,0 €
	average					
	min					
	max					
	average			**76,0 €**		**76,0 €**
	min			26,0 €		26,0 €
	max			169,0 €		169,0 €
RES	**average**	**PV installation cost for pitched roof, taken from real project**		**430,0 €**	**PV installation cost for pitched roof, taken from tender for a real project**	**430,0 €**
	min			370,0 €		370,0 €
	max			495,0 €		495,0 €
MANAGEMENT	**average**	**BEMS**		**13,0 €**	**BEMS**	**13,0 €**
	min			no data		no data
	max			no data		no data

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6.5.3 Anticipated cost for PLURAL solutions

To enable a smooth and successful market penetration of PLURAL's solutions to the renovation market and to boost the renovation wave in Europe, the project aims to provide solutions that are 20-25% more cost efficient in comparison to the standard renovation constructions. *Table 6-5. Cost savings of PLURAL's solutions* presents the main aspects for these ambitious cost reductions.

TABLE 6-5. COST SAVINGS OF PLURAL'S SOLUTIONS

Type of cost saving	Cost Saving
Material and labour cost savings as a result of prefabrication	Approx.. > 6%
Cost savings from "all-in-one" PnUs greater productivity	Approx. > 20-25%
Cost savings due to large scale projects	Approx. > 5-10%

At this moment, it will be difficult to predict whether the above cost reductions estimates can be achieved or if certain aspects will turn out to be difficult, e.g. cost savings due to the size of the project. However, overall it can be stated that the industrialisation of the construction process, towards renovation will lead to lower costs for energy renovations, as prefabrication is not commonly applied. In combination with measures for deep renovation, it is anticipated that the PLURAL's solutions will turn out to be more cost efficient than conventional renovation solutions and therefore will lead to a higher renovation rate.

6.6 Opportunities for PLURAL solutions in Europe

Due to the considerable building renovation needs identified in all European countries, there is an urgent need to boost the renovation rate and the introduction of extensive measures (e.g. LTRS) and funding schemes. Hence, the general market potential of PLURAL's solutions can be considered as extremely advantageous.

Looking in more detail at the PLURAL's approach, the concept fits very well with the goals set out by the European Union. The PLURAL concept pursues:

- The application of sustainable and renewable materials (e.g. timber, wood fibre insulation) in order to minimize CO_2 emissions regarding the material extraction and provision.
- The development of prefabricated solutions in order to minimize the construction costs, time and occupants disturbance.

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- The principal of circular construction that reduces the negative impact on the environment further as, the developed solutions offer either the potential for a full reuse or recycling.
- The integration of renewable energy systems into the prefabricated solutions in order to reduce the negative impact on the environment (another focal point defined by the EU).

Apart from the above technical innovations/solutions, PLURAL addresses barriers to renovation identified in the paragraph 6.3. The development of a decision support tool that will inform potential clients, as well as final users about the best possible renovation solutions beforehand, is a tempting factor for increasing the market penetration of the PLURAL's solutions. In addition, the decision support tool will inform the stakeholder about the operation challenges of the best possible renovation solutions and what the impact of the applied solutions will be. However, there are also challenges regarding system complexity and cost that have to be reviewed carefully during the course of the project.

Based on the previous analysis, the market potential of PLURAL in Spain and Germany have been identified in more detail.

6.6.1 Opportunities for PLURAL solutions in Spain

According to the above-mentioned data, the renovation in the residential sector in Spain is being at its historical maximums, considering also the investment amounts, providing a positive environment for the penetration of the PLURAL's solutions to the Spanish renovation market. The legislative conditions, especially considering the production of renewable energy at the residential buildings, have significantly improved. The latter, is an important driver, because the energy production is considered an important asset in the business models, providing to the overall renovation action the potential to become economically feasible. That means there is a potential of introducing private capital where before there was no interest.

On the other hand, the main challenge of the PLURAL's solutions may become its complexity and resulting costs. The developed solutions will be compared to the simplest intervention practices generally used in the region, such as ETICS, and the installation of PVs to the roofs of the residential buildings. The roofs of the residential buildings are generally dedicated to the installation of HVAC systems and are not allowed to be used by the residents for leisure, providing in overall suitable conditions for the PV installation. In order to be successful, the PLURAL's solutions will have to provide multiple benefits when compared to the traditional solutions, such as short installation time, little disruption, higher aesthetics, in conjunction with innovative approaches to the business models, allowing the mentioned involvement of private investment, possibly independent from the beneficiaries of the building renovation.

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6.6.2 Opportunities for PLURAL solutions in Germany

As illustrated before, there is a huge market in Germany for applying innovative solutions in building renovation, as a large part of the existing building stock does not comply with the targeted energy efficiency standards set out by the German government. In addition, the German government has set up a new renovation strategy in order to unlock investments and to actively promote the potential of deep renovations. The project's approach responds perfectly to this strategy, as it addresses very well the renovation barriers identified by experts in Germany. The followings illustrate how the PLURAL's solutions address the identified renovation barriers in Germany.

- The PLURAL's solutions will be 20%-25% more economical than current market prices, which is a strong argument for building owners and public to take a decision for an investment. The benefits of a deep renovation, such as reduced energy demand and cost, reduced dependency on energy prices, improved thermal comfort, and reduced negative impact on the environment will become available at a much lower cost. In addition, the German government offers, on the one side, funding for building owners, and, on the other side, sets out penalties for building owners that do not comply with the new renovation strategy and meet the targeted climate protection class.
- The PLURAL's solutions offer the required nZEB standard, which will become mandatory for all existing buildings in Germany by 2050.
- The PLURAL project develops an IT platform in combination with a decision support tool, which enables building owners to take an informed decision about the different measures. This will also reduce doubts regarding the effectiveness of the respective strategy. Again, these measures are also part of the renovation strategy, set out by the German government. The PLURAL project will consider these measures in detail, when developing such elements as part of the project.
- The PLURAL's solutions are all prefabricated, which means that on-site disturbance is reduced to a minimum in relation to duration of construction time and interference to the day-to-day operation of the site and its occupants. Noise, dust pollution, congestion and waste will be also limited. In addition, elements that upgrade building services (e.g. IEQ etc.) will be carried from externally, as such elements are part of the wall elements as plug and use solutions. Therefore, the occupant's disturbance will be limited to the bare minimum.
- The PLURAL's solutions are based on RES, such as heat pumps and PV, again measures that are supported by the German government.

7. Conclusions

Deliverable D1.1 overviewed the State of Art regarding off-site prefabrication of the PLURAL all-in-one kits and related technologies and identified:

- the preliminary requirements of the PLURAL technologies and systems for off-site prefabrication,
- the most representative residential building typologies in European countries, which are strong candidates for the implementation of the PLURAL concept,
- the most relevant market segments and key target countries that the PLURAL all-in-one kits

Detailed "specification sheets" regarding the preliminary specifications of PLURAL's solutions, i.e. "Smart Wall", "eWHC" and "eAHC" are presented in Annex I. Detailed "information sheets" regarding the PLURAL Demo Cases are presented in Annex III.

More specifically, the main conclusions of the overall analysis of D1.1 can be summarized in the following:

State-of-the-Art regarding PLURAL related solutions

<u>Relevant technologies and systems</u>

According to the SoTA analysis, the total cost of retrofitting with PLURAL technologies and systems is reduced by 40% due to efficient manufacturing and efficient use of labor. Most of the solutions incorporate Mechanical Ventilation with Heat Recovery to ensure the IEQ specification in conjunction with the increased energy efficiency. The utilization of smart windows can significantly reduce the thermal radiation during summer season decreasing the cooling demands, as well as reducing the thermal dispersion from the interior in winter period decreasing the heating loads. Another significant aspect that should be taken into consideration is that when retrofitting a building to nZEB, the percentage share of the Domestic Hot Water (DHW) rises due the fact that the heating demand is reduced and the DHW demand stays on the same level. This indicates that DHW supply is getting more important when the building is well insulated and thus special treatment should be considered. Last, but not least, RES integration into prefab systems offers several opportunities either to generate electricity (e.g. Building Integrated/Attached Photovoltaics (BIPV and BAPV)), and/or to supply DHW and thermal energy to contribute towards space heating demands (e.g. Building Integrated Solar Thermal Systems (BISTS)).

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Off-site production process

Based on the SoTA analysis regarding the offsite prefabrication process, it can be seen that project timelines accelerate approximately 20–50 % (e.g. the creation of prefabricated units libraries (BIM) can result in time savings of ca. 15–20 %). In order to achieve such time acceleration the prefabrication production should consider materials and integrated technologies optimization to build quality units, minimization of the on-site works and labor to achieve full scale production, focus on standardization aspects to achieve a certain degree of repeatability in the prefabricated solutions, adaptation of the manufacturing plants (e.g. investment in engineering, equipment and skilled workforce) to achieve an efficient, competitive production, and optimization of the unit size to achieve the best transportation, manipulation and mounting at works conditions of the prefabricated solutions.

Market implementation

The SoTA analysis of the PLURAL PnU kits market implementation highlighted four main aspects. The scale/size of demonstration project can reveal the high potential of introducing large or medium prefabricated add-on solutions for envelopes in large-scale renovation market leading to significant revalorization of the property. Prefabricated solutions that incorporate reusable materials (e.g. construction and demolition waste materials) and/or utilize integrated systemic service (e.g. circular management and efficient use of water, waste, energy and material resources) increase their market potential. Prefabricated solutions that include assistant building units (e.g. rooftop extensions) adopted to existing buildings can gain increased share in the renovation market, as they can reduce the initial investment for deep renovation of existing buildings. Last, but not least, prefabricated solutions that take into account the particularities of Europe's geo-cluster have by default better and larger penetration of the renovation market.

European projects with prefabricated solutions for buildings

Several European projects deal with prefabricated solutions for buildings' energy renovation, creating a clear picture of the conditions and the limitations for building renovation with prefabricated solutions. Prefabricated solutions surpass conventional retrofitting solutions from technical, social and environmental point of view. In addition, demonstration of energy renovation using off-site prefabrication increases social awareness, improves stakeholders' knowledge and promotes stimulus for renovation in European regions. On the other hand, the main weaknesses of prefabricated solutions are the high construction/maintenance costs and adaptability of the solutions to the singularity of each case (e.g. historic buildings, seismic zones etc.). Those disadvantages can be compensated by considering public subsidies or tax systems promoting prefabricated solutions that

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have social/environmental benefits, improving the manufacturing process in order to downscale the initial investment costs, and developing new research projects which will increase the knowledge and experience of the technicians, as well as improve the prefabricated solutions, increasing its versatility and adaptability.

PLURAL solutions' requirements

All the SoTA analysis performed and presented in D1.1 was used in order to take into account all the technical and market aspects regarding building renovation with prefabricated solutions and set the preliminary requirements of the PLURAL solutions, i.e. "Smart Wall", "eWHC" and "eAHC".

PLURAL solutions' preliminary requirements

As a result of the overall analysis, it can be seen that PLURAL's solutions are versatile and adaptable solutions, when considering the location, the geometry, the energy and structural performance of a building to be renovated. Firstly, the three PnU kits can be applied on every type of residential building.

In more detail, the "Smart Wall" can be installed on either the external or the internal side and is applied in every European climate (covering heating and cooling requirements). On the other hand, the "Smart Wall" production cannot be fully automatized, since the parts and components depend on the particular project design.

Moreover, the "eWHC" PnU can be installed only on the external side of the wall and is suitable for heating dominated climate conditions (Central and Northern European countries). On the contrary, the "eWHC" system have to fit exactly, thus the geometry of the existing wall has to be accurately measured.

Lastly, the "eAHC" PnU kit can be installed only on the external side of the wall and is suitable for the most European countries except from Nordic conditions (extreme heating demands). On the other hand, the "eAHC" system can be limited regarding its size, as depending on the climate conditions the unit's outer dimensions, particularly thickness, can be a restricted parameter.

In conjunction to all the above, PLURAL's solutions have to focus on several other issues, such as the legislation regarding thickness addition to the external walls and/or roofs, the legislation regarding weight addition to the whole construction, and the legislation regarding fire safety conditions.

PLURAL solutions penetration to renovation market

Considering the advantages, as well as the constraints/limitations of the PLURAL's solutions, their penetration to the European renovation market is considered. From one side, their technical

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penetration is considered regarding the adaptability and versatility. From the other side, their market penetration is considered regarding the European's building stock renovation strategy, financial potential etc.

Candidate buildings for PLURAL solutions

In order to define the technical penetration of the PLURAL solutions in the European building stock (candidate buildings), a geo-cluster classification and building archetype selection were performed. Regarding the geo-cluster classification, the analysis led to six (6) main geo-clusters representing 36% of the territory with a total of 324 regions. Regarding the building archetype, the analysis led to the conclusion that the most frequent building typologies are situated from 1946 until 1980, are multifamily houses with a range of 2 up to 9 floor levels. The above conclusions were combined with the advantages and limitations of the PLURAL's solutions in order to create a "map" of the applicability of the PLURAL solutions.

Market potential for PLURAL solutions

Finally, scrutinizing the European building renovation market led to the identification of the PLURAL solutions penetration potential, as well as their current drawbacks. The current conditions in the European renovation market are very favorable for the PLURAL PnU kits as the renovation in the residential sector is very high and the PLURAL solutions are in line with the new renovation strategy set by EU country governments. The PLURAL solutions are overall 20%-25% more economical than current market prices and offer the required nZEB standard, which will become mandatory for all existing buildings by 2050.

On the other hand, the market penetration potential of the PLURAL solutions could be further increased (dominate against conventional renovation solutions) when considering shorter installation times, less disruptions, higher aesthetics, and innovative approaches to the business model (e.g., involvement of private investment possibly independent from the beneficiaries of the building renovation).

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9. Annex I – Preliminary specification of PLURAL solutions

9.1 Preliminary specifications of "Smart Wall"

Envelope materials

<table>
<tr><th>Component</th><th>Product</th><th>Installation / manufacturing specificities</th><th>Installation / manufacturing standards</th><th colspan="2">Product characteristics</th></tr>
<tr><td rowspan="9">Cement board</td><td rowspan="9">Outdoor board</td><td rowspan="9">• For external installation must be installed with corrosion-protected screws and the temperature of the board before its installation must be over 5°C</td><td rowspan="9">• ETA 07-0173
• A1 rating in accordance with EN 13501-1: 2007, non-combustible
• EN 12467</td><td>Height (mm)</td><td>900</td></tr>
<tr><td>Width (mm)</td><td>1200</td></tr>
<tr><td>Thickness (mm)</td><td>12.5</td></tr>
<tr><td colspan="2">Non toxic</td></tr>
<tr><td>Approximate mass per unit area (kg/m²)</td><td>16</td></tr>
<tr><td colspan="2">For design purposes, the board may be assumed to have the following mechanical properties:</td></tr>
<tr><td>Allowable flexural stress (N/mm²)</td><td>2.4</td></tr>
<tr><td>Flexural modulus (N/mm²)</td><td>4000</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="4">Plaster board</td><td rowspan="4">Indoor board</td><td rowspan="4">• For internal installation only</td><td rowspan="4">• A2 rating in accordance with DIN 4102, non-combustible
• GKB type according</td><td>Height (mm)</td><td>1200</td></tr>
<tr><td>Width (mm)</td><td>2000</td></tr>
<tr><td>Thickness (mm)</td><td>12.5</td></tr>
<tr><td>Approximate mass per unit area (kg/m²)</td><td>8.15</td></tr>
</table>

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			to DIN 18180	Non toxic	
				Odorless	
Smart wall insulation	Rockwool insulation with aluminium foil	• To be specified in the design	• A1 rating, non-combustible • EN 13162:2012 + A1:2015	Length (mm)	<1400
				Width (mm)	<900
				Thickness (mm)	Varying
				Thermal resistance (m^2K/W)	>0.70
High performance windows	Window	• To be specified in the design	• CE	Window integrated ventilation system with heat recovery	
				Low U-values and high g-values	
Smart wall internal fire extinguishing system	Automatic fire suppression system	• The system consists of a heat sensitive tube made of special plastic, which is closed by a stainless-steel fitting on each end. The tube has both storage and detection function, which means that the extinguishing agent is stored directly in the tube and no additional storage device like cylinder is needed. • The system should operate automatically independent of any power supply by detecting higher temperatures. When the	• Fire class rating: A, B, C, E	Activation temperature (°C)	120
				The system does not require power supply for activation	
				The concentration of the agent is harmless to people and poses no threat to health once activated.	
				Fire extinguishing agent	HFC-227ea or

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		temperature in the protected enclosure rises to a critical threshold, the detection tube melts down at the point where the affecting temperature is the highest. Melting the tube creates a hole releasing the entire extinguishing agent stored in the tube onto the source of the fire.			or HFC-236fa
Multifunctional coatings for exterior/interior surfaces	Waterproof paint for exterior walls; acrylic paint for interior walls	• Applied by spray gun, roller or brush	N/A	• Self-healing • Self-cleaning • Anti-molding (Class I) • IR- reflective	
Multifunctional coating with PCMs for exterior/interior surfaces	Organic PCMs incorporated in acrylic paint	• Applied by roller or brush	N/A	Working temperature range (°C)	20 ~ 40
				(other temperature range can be also available)	
				Latent heat capacity (J/g)	140
Intumescent	Intumescent paint-coating for passive fire protection	• Applied by spray or brush	N/A	60-120min fire-resistance @ 0.2-0.8mm	

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HVAC systems

Component	Product	Installation / manufacturing specificities	Installation / manufacturing standards	Product characteristics	
Fan coil unit/ heat pump convector	Heating and cooling device	• Vertical installation • Must be installed at least 80mm above the ground • Must be connected with hot/cold water pipe network	• (EU) 2016/2281 • EN60335-1 • 2014/35/UE • 2014/30/UE	Cooling capacity (kW)	>1
				Heating capacity (kW)	>1
				Height (mm)	<650
				Width (mm)	<1000
HEPA filter	Air filter	• Must be placed on the air outlet/inlet	• EN 1822	Maximum air temperature (°C)	80
				Average efficiency (%)	>80
				Height (mm)	<310
				Width (mm)	<620
				Depth (mm)	<70
Pipes for heating & cooling	PP-R pipe	• Must be flexible • Has to be installed with PP-R fittings • Compared to metal pipes PP-R pipes require a considerably thinner insulation. • The joining method requires no additives such as fluxes or solder. The connection is made by socket fusion. • All parts of the system must be verified as	• With Oxygen barrier • Certified according to DIN 4726 • B2 DIN 4102 (normal inflammable).	100 % corrosion resistant materials	
				Heat and sound insulating characteristics	
				Inflammation temperature (°C)	490
				Coefficient of thermal conduction	0.15

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		compatible with the medium being carried before installing them. In addition, while PP-R pipes do not require treatment to protect them from corrosion, metals (ferrous and non-ferrous) in the system may be susceptible to corrosion. • First welding – soonest 5 minutes after reaching the welding temperature. • The General Guidelines for Heated Tool Socket Welding acc. to DVS 2207 Part 11 must be applied. • On locating fixed points, the pipelines are divided into individual sections. This avoids uncontrolled movements of the pipe. In principle, fixed points have to be measured and installed in a way that the forces of expansion of aquatherm PP-R-pipes as well as probable additional loads are accommodated. On using threaded rods or threaded screws, the drop from the ceiling should be as short as possible. • Swinging clamps should not be used as fixed points. Vertical distributions can be installed. Risers do not require expansion loops, if fixed points are located immediately before or after a branch. To compensate the forces arising from the linear expansion of the pipe there must be sufficient and stable clamps and mountings. • Sliding clamps have to allow axial pipe movements without damaging the pipe. On locating a sliding clamp, it has to be ensured that	• In case of fire, there is no risk of dioxin emissions.	(W/mK)	

		movements of the pipelines are not hindered by fittings or armatures installed next to the clamps.			
ATEX-certified cable glands	ATEX-certified cable glands	• Must be combined with ATEX certified equipment	• EN 60423 • EN 60529 • AISI 303 steel • IP68 • IP69	Equipment class II	
ATEX Flexible Conduit	ATEX Flexible Conduit	• Must be combined with ATEX certified equipment	• EN 61386 • IP66 • IP67 • IP68 • IP69K	Equipment class II	
Smart wall energy storage	Battery	• Not to be charged in a sealed container	• CE • Recyclable	Lead acid	
				Nominal Voltage (V)	12-24
				Length (mm)	<250
				Width (mm)	<150

Load bearing structure and anchoring

Component	Product	Installation / manufacturing specificities	Installation / manufacturing standards	Product characteristics
Exterior fittings for cement board	Screws, brackets & fittings	• Fixing to light gauge steel profiles • Sizes to be determined by the	• EN 14566:2008 • A1 rating in accordance with EN 13501-1: 2007, non-combustible	Twice galvanised and ceramic coated or Made by stainless steel
				Number of screws: • For a wall application with stud or battens at 600mm centres, it is 15 screws per

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		design		square metre • For a soffit with C Channels at 300mm, 30 screws per square metre	
				Diameter (mm)	4.2
				Length (mm)	>25
Steel stud frame	Steel hollow section	• To be specified in the design	• S355 according to EN10025/ST52 according to DIN17100	Steel stud frame	Steel stud frame
Smart wall anchoring	Metal expandable anchors	• To be specified in the design	• AISI 316 steel • Fire resistant according to EOTA TR020 • Seismic resistant class C2 according to EOTA TR045		

Solar collectors

Component	Product	Installation / manufacturing specificities	Installation / manufacturing standards	Product characteristics	
Solar panel for external Smart Wall	Solar panel	Final dimensions and sizes will be determined by the panel design though PV panels should comply with the following: • Residential type • DIN VDE 0100 Installation of power installations with nominal voltages up to 1,000 V • DIN 1055 Load assumptions for structures • BGV A2, A3 Electrical systems and equipment • If the modules are connected in parallel, the	• ISO 9001:2015 • ISO 14001:2015	Monocrystallic or Polycrystalline	
				Rated power Pmpp [Wp]	100
				Width (mm)	<600

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		total current strength corresponds with the total of the current strengths of the individual modules. Even contact with a direct current voltage of 30 volts or higher is potentially dangerous. • Never disconnect the module under load. Before working on the PV system, disconnect the AC and DC inverter circuits. • Cover the module fully with a non-transparent material during installation to avoid the generation of current. • Adhere to the safety regulations for all other components used in the system including cables, plugs, charge controllers, inverters, accumulator batteries, rechargeable batteries etc. • The assembly rack for the module must be made of durable, corrosion- and UV-resistant material.		Length (mm)	<1200
				Junction Box	IP 65
Transparent coatings for PV	Transparent coatings for PV	• Applied by spray gun	N/A	• 3% increase Transmittance in Visible light • hydrophilic (contact angle – 15°) • Self-healing • Self-cleaning	

9.2 Preliminary specifications of "eWHC"

Envelope materials

Component	Product	Installation / manufacturing standards	Product characteristics	
baseboard			Thickness	12.5 mm
back ventilation board			Thickness	30 mm
			Size	30/60 mm
wind sealing	Gyso		Thickness	1 mm
insulation	Fermacell	DPL 1	Thickness	15 mm
construction with insulation between		C24 with Fermacell	Thickness	1800 mm
			Size	60/180 mm
reinforcement	LDS OSB		Thickness	15 mm
substructure with insulation	(insulation Flumroc)	DPL 1	Thickness	50 mm
glazing			Triple glazing	

HVAC systems

Component	Product	Installation / manufacturing specificities	Installation/manufacturing standards	Product characteristics	
"floor" heating pipes	Haka Gerodur - PE-RT	Oxygen-tight with co-extruded EVOH layer in accordance with DIN 4726, five-layers structure	KOMO, DIN 16833 / 16834	Dimension	15-25
Heat recovery (heat exchanger)				heat recovery efficiency	minimum 0.7
Solar collector	any		Solar-Keymark certification		

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Solar panel (PV)	Any	Residential type (Similar with Smart Wall)			

9.3 Preliminary specifications of "eAHC"

HVAC systems

Component	Product	Installation / manufacturing specificities	Installation / manufacturing standards	Product characteristics
Heating and cooling system	Air handling unit with heating & cooling	• electric connection (fans, entire unit, control systems) • drainage of condensate water vapor • two grills in outer envelope • two grills in inner wall	• EN 308 • EN 13141-8	Acoustic power up to 30 dB(A) at 30 m^3/h (night régime), Decrease of supply temp in summer for 10 K from outside air temp (at 32 °C), Cooling power 200 W at 90 m^3/h.
Heat recovery	Air handling unit with heating & cooling			Max. air flow 90 m3/h, Min. air flow approx. 20 m^3/h, Efficiency HR min. 85 % at 60 m^3/h, Demand control of air flow rate (CO2, VOC),

IEQ control

Product	Installation / manufacturing specificities	Product characteristics
Sensor platform for monitoring and control of IEQ	power supply 12-24VDC from RS485 or wall socket AC/DC adapter	120 x 77 x 20 mm

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10. Annex II – Geo-cluster classification

10.1 Relevant aspects to consider in geo-cluster classification

10.1.1 Financial schemes and Long-term strategies

In conjunction with the socio economic and climate factor indicators, other indicators were incorporated in the initial analysis to have a more comprehensive view of the existing conditions in each of the regions. Data from the ZEBRA project[75] were extracted to obtain information over the number of subsidies and investments in building renovation. Additionally, the *Science for Policy report Accelerating energy renovation investments in buildings,* developed by the Joint Research Centre (JRC) [M. Economidou et al., 2019], was also consulted to extract data for grand, loans and tax reductions policies. Lastly, indicators integrated in the BPIE report *A Review of EU Member States' 2020 Long-term Renovation Strategies* [D. Staniaszek et al., 2019], were incorporated in the chart to have a general view of the long-term strategies declared by each member. A summary of these other indicators is introduced in *Table 10-1. Financial schemes and long-term renovation strategies*.

[75] ZEBRA2020 Project Intelligent Energy – Europe (IEE) programme, "ZEBRA2020," Vienna University of Technology, Energy Economics Group, 1 April 2014. [Online]. Available: https://zebra2020.eu/. [Accessed October 2020].

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TABLE 10-1. FINANCIAL SCHEMES AND LONG-TERM RENOVATION STRATEGIES

Demo location	Financial mechanisms							EU Member States' Long-term Renovation Strategies						
Country	Yearly subsidies dedicated to thermal building renovation. Year 2020 (M€)	Total yearly investments in thermal building renovation including expenses for public support. Year 2020 (M€)	% Public over total	Average cost for renovation the building envelope (residential) €/m2	Grants Subsidies	Loans/Soft loans	Tax exemption/ reduction	Cost-effective approaches to renovation, including trigger points	Policies and actions to stimulate cost-effective deep renovation	Policies to target worst performing segments, split-incentives, market failures, alleviation of energy poverty	Roadmap with measures, progress indicators, and indicative milestones	Mechanisms for mobilising investments	Implementation details of latest LTRS	Aggregate score
Greece	-	-	-	-	✔	✘	✘	NS	NS	NS	NS	NS	NS	**NS**
Spain	217,00 €	4949	4%	362,19	✔	✔	✘	4	5	4	4	4	5	**4,3**
Czech Republic	111,85 €	1412,37	8%	167	✔	✔	✘	2	4	1	1	2	0	**1,7**
Switzerland	181,82 €	20.210,00	1%	428	✔	✔	✔	1	3	2	3	3	0	**2,0**
Germany	991,00 €	24309	4%	155,05	✔	✔	✘	3	4	3	2	2	1	**2,5**
Sweden	-	-	-	177	✔	✘	✔	2	3	3	3	3	3	**2,8**
Bulgaria	-	-	-	-	✔	✔	✘	NS	NS	NS	NS	NS	NS	**NS**
England	-	-	-	-	✔	✔	✔	NA	NA	NA	NA	NA	NA	**NA**
Denmark	-	-	-	-	✔	✘	✔	4	3	3	0	3	4	**2,8**

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10.1.2 Climate indicators

As indicated in Chapter 5 there are several climate indicators that can be used to classify the different regions. As shown in *Figure 10-1. European's project geo-cluster classification comparative* six different projects were analyzed to verify the indicators used and the available information.

ENTRANZE	4RinEU	TRI-HP PROJECT	iNSPIRe	PVsites	HAPPEN
10 geo-clusters **25 cities analysed**	**6 geo-clusters**	**6 geo-clusters**	**7 geo-clusters**	**5 geo-clusters**	**25 possible combinations**
	Climate zones (köppen G)	Climate zones	Climate zones	Climate zones (köppen G)	Based on severity index and data from 70 cities.
Winter Severity Index	HDD U value	HDD (more pilot cities to cover the different behaviour)		EHI European Heating index	Winter Severity index
Summer Severity Index Climatic Cooling Potential				ECI European Cooling index	Summer severity index

FIGURE 10-1. EUROPEAN'S PROJECT GEO-CLUSTER CLASSIFICATION COMPARATIVE

From the initial analysis, it can be concluded that four different indicators were used to construct climate clusters:

- The Köppen-Geiger classification, originally developed by Wladimir Köppen around 1900 [W. Köppen and E. Translated, 2011], that divides the different territories according to their temperature and precipitations. Projects such as TRIHP[76] and iNSPIRe[77] used this type of climatic classification to establish the boundaries of the regions. However, due to the limited factors considered in this classification in most cases other indicators are combined to establish regions.
- The degree-day's methodology, developed during the 19th century in the USA [T. Day, 2006], provides an indication of severity of the climate in different locations by documenting when during a given year the external air temperature falls below or rises above a specified

[76] TRI-HP European Union's Horizon 2020 Project, "TRI-HP," SPF Insitute for Solar Technolgy at the University of Applied Science in Rapperswil Scwitzeralnd (HSR-SPF), 1 march 2019. [Online]. Available: https://www.tri-hp.eu/. [Accessed October 2020].

[77] INSPIRE-FP7 European Union's Project, "INSPIRE-FP7," EURAC, 1 november 2008. [Online]. Available: https://inspire-fp7.eu/. [Accessed October 2020].

temperature, requiring thus heating or cooling. Specifically, the HDD expresses the severity of the cold season over a specific period taking into consideration outdoor temperature and a specific base temperature. The 4RINEU project [78] combined the initial Köppen-Geiger classification of climates with the Heating Degree Days (HDD). Specifically, in this case, apart from consulting the data included in the 4RINEU project, more sources were consulted to verify the HDD and CDD of each of the demo sites.

- The European Heating Index (EHI) and the European Cooling Index (ECI) developed by the Ecoheatcool[79] project during 2005 [S. Werner, 2006] using 80 reference cities. The EHI and ECI considers not only the HDD and CDD but also the interrelation with insulation, solar gains and internal gains. The PVSITES project[80] combines Köppen-Geiger classification with the EHI and ECI.
- Lastly, the climatic severity index [T.A. Markus, 1982, J. Salmerón et al., 2013] (Winter Severity Index (WCSI) and the Summer Severity Index (SCSI)). The climate severity index, introduced in Section HE-1 of the Spanish Technical Building Code (Appendix 2 "determination of climatic zones based on climatic records"), combines the cooling/heating degree-days and the insolation hours in a specific latitude in a way that it can be demonstrated that when two localities exhibit the same climatic "severity", the energy demands of same buildings situated in both localities are equal. Both the ENTRANZE project[81] and the HAPPEN project[82] considered this classification to establish the clusters.

Table 10-2. Climatic indicators summarizes the different indicators analyzed and the sources of the data. As it can be seen, there are significant differences in the data of the HDD and CDD. In other cases, the information was not available for all the countries involved.

[78] 4RINEU European Union's Horizon 2020 Project, "4RINEU," WIP Wirtschaft und Infrastruktur GmbH & Co Planungs-KG, 1 January 2016. [Online]. Available: https://www.pvsites.eu/. [Accessed Otcober 2020].

[79] ECOHEATCOOL Intelligent Energy Europe Project, "The Europen Cold Market," ECOHEATCOOL project WP2, Belgium, 2005-2006.

[80] PVSITES European Union's Horizon 2020 project, "PVSITES," FUNDACION TECNALIA RESEARCH & INNOVATION, 1 1 2016. [Online]. Available: https://cordis.europa.eu/project/id/691768/results/es. [Accessed 2020].

[81] ENTRANZE Project Intelligent Energy – Europe (IEE) programme, "ENTRANZE," SEVEn, The Energy Efficiency Center, 1 April 2012. [Online]. Available: https://www.entranze.eu/contacts/contacts. [Accessed October 2020].

[82] MEDZEB HAPPEN European Union's Horizon 2020 Project, "MEDZEB-HAPPEN," National Research Council of Italy - Institute for Construction Technologies (ITC-CNR), 1 April 2018. [Online]. Available: http://medzeb-happen.eu/?page_id=1407. [Accessed October 2020].

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TABLE 10-2. CLIMATIC INDICATORS

Demo location		Climatic conditions																
		Climate	Heating								Cooling							
Country	City	Koppen Geiger Climate zone	HDD Eurostat by COUNTRY	HDD Invert by COUNTRY	HDD Eurostat by REGIONS	HDD https://www.degreedays.net/ by CITIES	HDD specific calculation	European Heating Index EHI	Winter severity index ENTRANZE	Winter severity index (by zone) HAPPEN	CDD Eurostat by COUNTRY	CDD Invert by COUNTRY	CDD Eurostat by REGIONS	CDD https://www.degreedays.net/ by CITIES	European Cooling Index ECI	Summer severity index ENTRANZE	Summer severity index (by zone) HAPPEN
Greece	Athens	CSA Hot-summer Mediterranean climate	1.448,99	2521,73	1073,77	845		62,3		1	373,09	524,77	492,05	450,5	161		3
Spain	Barcelona	CSA Hot-summer Mediterranean climate	1.670,72	2211,15	1756,95	927		70,5	0,5	2	247,65	256,94	200,34	256	147	1,5	2
Czech Republic	Kasava	DFB Humid continental climate without dry season and warm summers	2.998,07	4507,41	2925,12	2275		111,5	1,2	3	40,21	61,93	43,81	89	89	0,1	1
Switzerland	Bern	CFB Oceanic climate without dry season and warm summers		4861,85		2319	2503	105,3		3		10,83		84	85		1
Germany	Berlin	DFB Humid continental climate without dry season and warm summers	2.800,81	4118,34	2643,31	2007		103,5	1	3	46,05	50,07	79,25	108	94	0,4	1
Sweden	Upplands Väsby	DFB Humid continental climate without dry season and warm summers	5.119,61	5411,39	3737,56	3168		117,2	-	4	0,98	17,4	1,33	29	73	-	0
Bulgaria	Sofía	DFB Humid continental climate without dry season and warm summers	2.152,56	3607,27	2.545,45	2111		103,4	1,1	3	163,85	271,74	44,47	140	116	0,6	2
England	London	CFB Oceanic climate without dry season and warm summers	-	4180,14	-	-		92,9	-	3	-	0,83	-	-	74	-	0
Denmark	Copenhagen	CFB Oceanic climate without dry season and warm summers	3.026,80	4405,5	2.907,98	2203		110	-	3	2,19	24,06	0,95	7	559	-	0

As a conclusion, it can be seen that even though the majority of the projects construct the clusters based on heating conditions only three of them incorporate cooling aspects.

After evaluating the different indicators and based on the availability, the Climate Severity Index used in HAPPEN and ENTRANZE projects was selected. As indicated in the HAPPEN project, the severity index, developed by Markus, Thomas A. Strathclyde in 1982 [T.A. Markus, 1982] and 1984, intended to establish a correlation between the energy demand, three climatic variables and three physical parameters describing the building itself. It is hence not only a description of the climate, but also a description of the behaviour of a certain building within a range of climates. It has been subsequently used to propose correlations between the average consumption of a mix of building prototypes and two or three climatic variables.

11. Annex III – Demo Case available information

Table 11-1. Demo Case available information tabulates all the available information for the PLURAL's demo cases, real and virtual.

TABLE 11-1. DEMO CASE AVAILABLE INFORMATION

General Characteristics				Areas [m²]					Energy use [kWh/m²y]				U-value [W/(m²K)]						System				Notes
Demo Location	Construction Year	TABULA representative period	Nº floors	Total Surface	Façade	Roof	Window	Door	Heating	Cooling	Lighting	Hot water	$U_{average}$	Roof	Wall	Floor	Window	Window to wall ratio	Heating	Hot water	Coo-ling	Ventilation	
Greece (real)	1971	Until 1980	4	994	755,8	236	124,1	NA	173	0	NA	NA	NA	NA	1,6	NA	4,5	16%	NA	NA	NA	NA	A previous renovation is planned: • high efficiency doors & windows (0.96 W/m²K) with shutters • Installation of 50mm thick DUROSOL thermal insulation at the exterior walls: 567,05m². • Installation of 70mm thick DUROSOL roof insulation: 280.25 m² • Painting with KRAFT eco exterior paint all external surfaces: 894.21 m²

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Spain (real)	2008	1980-2006	3	1280	725	263	130	NA	0	0	NA	NA	NA	NA	1,6	NA	3,78	18%	NA	NA	NA	NA	The renovation will be executed in 2 phases. During 2020 the whole complex will be retrofitted (32 dwellings). In the 2nd phase, the building will be inhabited. AHC proposes to improve its energy behaviour by using 1 block (18 dwellings) as a demo case.
Czech Republic	1962	1961-1980	3	150	134	150	30	11	210	NA	11	NA	NA	NA	0,8[83]	NA	1,4	22%	NA	NA	NA	NA	-
Switzerland (virtual)	1964	1958-1968	4	1861	1075	393	128	NA	128	0	NA	16	1,11	0,4	0,98	1,5	1,8	12%	NA	NA	NA	NA	Renovated in 2019 towards NZEB and monitoring by SPF until 2022.
Germany (virtual)	1965	1958-1968	2	400	255	145	45	NA	NA	NA	NA	NA	NA	NA	1,2	NA	3	18%	NA	NA	NA	NA	Residential building deep-renovated towards NZEB in 2009.
Sweden (virtual)	1960	Until 1960	8	6700	5167	NA	859	NA	126	0	8,5	NA	NA	NA	0,45	NA	2,8	17%	NA	NA	NA	NA	Residential building deep-renovated towards NZEB in 2013.

[83] The declared U value must be reviewed, the description introduced indicates that it is masonry – 450mm - with no insulation

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12. Annex IV - Extended cost table for all partner countries

Table 12-1. Extended cost table for all partners' countries tabulates the extended cost per gross floor area for all the PLURAL's partner countries.

TABLE 12-1. EXTENDED COST TABLE FOR ALL PARTNERS' COUNTRIES

		COST [€ / m² gross floor area] groos incl. 19 % VAT		COST [€ / m² gross floor area] net without VAT		COST [€ / m2 gross floor area]		COST [€ / m2 gross floor area]		COST [€ / m2 gross floor area]		COST [€ / m2 gross floor area]
COUNTRY	GERMAN DATA SYSTEM Source: Building Cost Historic Buildings Statistical Cost Parameters taken from BKI, II Quarter 2020	GERMANY A	BKI Kostenplanung 2020 Statistical cost parameter all cost are excl. VAT and labour cost	GERMANY B	CATALAN DATA REFERENCES Source: Rehabilitacio energetica d'edificis, cuadern n.10, Generalitat de Cataluña	SPAIN-CATALONIA	CZECH DATA REFERENCES Source: projects of Energy agency of the Zlin region - 2019/2020	Czech Republic	GREEK DATA, Source : "Regulation of descriptive job prices" , Greek Government Gazzete, Issue B' 1746/ 19.05.2017	Greece	NATIONAL DATA REFERENCES Source:	Switzerland
BUILDING TYPE		For residential buildings, constructed after 1945, Status 2. Quarter 2020, average value in Germany				Residential buildings, Multi-family-housing, constructed after 1951 (86,8%) F,G,H,I according to ref.		-		Block of residential dwellings built in 1971		Multi-family-housing with 10 Appartmens, renovation to nZEB (Minergie, Swiss standard) (see REF tabel)
Approx. Floor area: net [m2]						82,58		-		215,09		1000
Cost type material		MATE LAB		MATE LAB		MATE LAB		MATE LAB		MATE LAB		MATE LAB

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/labour				RIAL	OUR		RIAL	OUR		RIAL	OUR		RIAL	OUR		RIAL	OUR		RIAL	OUR
PASSIVE MEASURES	**average**	Cost Group 300: Building and building construction	330 External walls, vertical, exterior:	**217 €/m² wall area**	57 €/h	2 layer substructure in timber, thermal insulation mineral wool for rear ventilated facade, incl. fire barrier+ windproof protection, substructure and timber weather boards	202,0 €	57 €/h	thermal insulation facade	50,5 €		thermal insulation facade	73,0 €		thermal insulation facade	34,2 €	40,5 €	thermal insulation facade	189,2 €	
	min			103 €/m² wall area	49 €/h		145,0 €	49 €/h		10,5 €			64,0 €			28,5 €	32,0 €			
	max			311 €/m² wall area	71 €/h		276,0 €	71 €/h		90,6 €			79,0 €			57,5 €	65,0 €			
	average											floor insulation						thermal insulation cellar	30,9 €	
	min																			
	max																			
	average		360 Roof construction:	**235 €/m² roof area**		thermal insulation roof (wood fibre)	**62 €/m² wall area**		thermal insulation roof	29,3 €		thermal insulation roof	35,0 €		thermal insulation roof	60,3 €	64,7 €	thermal insulation roof	34,5 €	
	min			117 €/m² roof area			47 €/m² wall area			16,6 €			19,0 €			54,5 €	58,5 €			

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	max			371 €/m^2 roof area			82 €/m^2 wall area			42,0 €		83,0 €		105,0 €	116,0 €		
	average					wood-alu windows, 1 leaf u-value 0.7 W/m^2 K	**678 €/m^2 wall area**		windows and solar protection	73,5 €	windows	95,0 €	windows and solar protection	575,0 €	220,0 €	windows and solar protection	79,2 €
	min						563 €/m^2 wall area			67,5 €		92,0 €		450,0 €	180,0 €		
	max						881 €/m^2 wall area			79,6 €		98,0 €		1.150,0 €	425,0 €		
	average										solar protection	13,0 €					
	min											13,0 €					
	max											15,0 €					
	average								airtightness	1,4 €						airtightness	44,0 €
	min																
	max																
	average			**452 €/m^2 ref. area**			**875 €/m^2 wall area**			**154,8 €**		**216,0 €**		**669,5 €**	**325,2 €**		**377,7 €**
	min			220 €/m^2 ref.			703 €/m^2 wall					**188,0 €**		**533,0 €**	**270,5 €**		

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				area			area										
	max			682 €/m² ref. area			1.152 €/m² wall area					**275,0 €**		**1.312,5 €**	**606,0 €**		
ACTIVE MEASURES	**average**	Cost Group 400: Building and building services	420 Heat supply facilities:	**38,0 €**		420 Heat supply facilities:	**38,0 €**		heating, cooling, ventilation, hot water	38,1 €	boilers	36,0 €	heating upgrade (individual gas boilers)	43,5 €	15,5 €	heating , Heat Pump	55,0 €
	min			14,0 €			14,0 €			1,7 €		21,0 €		37,0 €	12,0 €		
	max			75,0 €			75,0 €			74,5 €		69,0 €		65,0 €	22,0 €		
	average										ventilation	25,0 €	solar hot-water panel	12,5 €	12,2 €	hot water is included in heating (heat pump)	
	min											14,0 €		10,5 €	9,0 €		
	max											52,0 €		18,0 €	17,5 €		
	average															cooling, additional costs to heating	16,5 €
	min																
	max																
	average		430 Ventilation systems:	**22,0 €**		430 Ventilation systems:	**22,0 €**						air-conditioning	18,0 €	4,8 €	ventillation	110,0 €
	min			7,0 €			7,0 €							12,5 €	3,0 €		
	max			58,0 €			58,0 €							22,5 €	6,0 €		
	average		440 Electrical systems:	**16,0 €**		440 Electrical systems:	**16,0 €**		illumination	3,1 €			high-efficient lighting system	2,8 €	5,5 €	illumination	
	min			5,0 €			5,0 €							2,2 €	4,3 €		
	max			36,0 €			36,0 €							8,0 €	15,0		

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										s		€		
	average					electrical appliances	15,1 €						electrical appliances	
	min													
	max													
	average		76,0 €		76,0 €		56,3 €		61,0 €		76,8 €	38,0 €		181,5 €
	min		26,0 €		26,0 €				35,0 €		62,2 €	28,3 €		
	max		169,0 €		169,0 €				121,0 €		113,5 €	60,5 €		
RES	average	PV installation cost for pitched roof, taken from real project	430,0 €	PV installation cost for pitched roof, taken from tender for a real project	430,0 €	PV installation	82,5 €	PV installation	8,0 €		no data		PV installation, 333 m2 PV, costs of 2000 CHF/m2 installed	110,0 €
	min		370,0 €		370,0 €		60,0 €		8,0 €		no data			
	max		495,0 €		495,0 €		105,0 €		8,0 €		no data			
MANAGEMENT	average	BEMS	13,0 €	BEMS	13,0 €	BEMS	no data	BEMS	no data		no data		Planing of the renovation	66,0 €
	min		no data		no data		no data		no data		no data			
	max		no data		no data		no data		no data		no data			