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**Deep Renovation of the European building stock adopting Plug-and-Play solutions**

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## ABSTRACT

The European (EU) Energy Roadmap 2050 impose to reduce greenhouse gas emission to 80-95% below 1990 levels by 2050. Moreover the – EU Climate & Energy package introduced 3 main targets to achieve for year 2020: 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables, 20% improvement in energy efficiency. In this scenario, the building sector has been identified as one of the key sectors in consideration to the fact that buildings count for 40% of the EU's energy consumption, 36% of its CO2 emissions and 55% of its electricity consumption. In particular, 90% of the existing building stock in Europe was built before 1990 and exist an urgent need for a significant improvement of energy efficiency through "deep renovation". So, the main today priorities of the European Commission are to swiftly improve energy efficiency and decarbonization of the building sector. Deep renovation is the term coined by the Energy Efficiency Directive of the European Community (2012/27/EU) for defining economically advantageous building renovation interventions that make it possible to reduce the energy consumption of a building by at least 60% compared to the condition prior to the refurbishment.

The paper introduces the innovative methodology and techniques for the "deep renovation" of the European building stock promoted by the P2ENDURE research project funded by the European Union's Horizon 2020 research and innovation program grant number 723391. The project goal is to apply and monitor, on specific demo-cases, cost-effectiveness and energy efficiency renovating strategies proposing Plug-and-Play solutions. The prefab PnP technologies proposed regards building and Heating Ventilation Air Condition components and are supported by Building Information Modelling (BIM) to overcome the main barriers of deep renovation inside the building process. The paper presents: the P2ENDURE concepts; the PnP solutions used for the deep renovation; the main tools adopted inside the 4M process in order to assess the building condition before, during and after the renovation; the demonstration cases and finally the methodology to assess the energy saving target.

**INTRODUCTION**

The 28th of November 2018 the European Commission (EC) presented its strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050 (The Energy Roadmap 2050). The commitment is to reduce greenhouse gas emission to 80-95% below 1990 levels by 2050. One of the priorities to meet long-term climate and energy targets is to swiftly improve energy efficiency and decarbonization of the existing buildings stock.

This challenge follows the previous 2020 – European (EU) Climate & Energy package which is a set of binding legislation to ensure the EU meets its climate and energy targets for year 2020. The package has been sets three key targets: i) 20% cut in greenhouse gas emissions (from 1990 levels); ii) 20% of EU energy from renewables; iii) 20% improvement in energy efficiency. In this scenario, the building sector has been identified as one of the key sectors to achieve the “20/20/20 targets” of the EU and to meet “The Energy Roadmap 2050” in consideration to the fact that buildings count for 40% of the EU’s energy consumption, 36% of its $CO_2$ emissions and 55% of its electricity consumption. Moreover, 90% of the existing building stock in Europe was built before 1990 and exist an urgent need for a significant improvement of energy efficiency through “deep renovation”.

In order to meet these goals, the EU has adopted in the last years specific energy saving policies and directives. In the 2002 the EU issued the Directive 2002/91/EC on the energy performance of buildings. In comparison to the previous policies, this Directive introduced additional important topics such as: the need to adopt a calculation methodology on the building energy performance; the definition of minimum energy requirements; the adoption of specific energy performance measures for new and existing buildings. Recently, two other important Directives have completed the reference framework at European level. The Directive 2010/31/EU on the energy performance of buildings (EPBD) and the Directive 2012/27/EU on energy efficiency, which currently constitute the main European regulations on the subject (EU 2010, 2012). Among the most novel elements presented by the new Directives there are two important notions. The first concerns the concept of “nearly Zero Energy Buildings” (nZEBs), which emphasizes the need to reduce energy demand to minimum standards and use renewable energy to meet the remaining demand. The second is the introduction of the "Deep renovation" concept which means the important restructuring of the existing building stock as an energy saving strategy. However, the directive does not suggest any specific definition and transfers the task of defining a specification to the Member States. In this contribution an important restructuring is intended as a redevelopment capable of leading to an effective and high reduction of energy consumption, in relation to the pre-intervention status, for a minimum level of 60%. The deep renovation also implies a contextual improvement of the building comfort, healthiness, safety and usability.

Despite in the last years several building technologies has characterized and improved the sector of the building retrofit, the building deep renovation process is characterized by complementary barriers: economic (high costs, minimum public contributions and return on investment only in the long term), procedural (fragmentation of the production chain); regulations (differences between national and European requirements and guidelines) and technical (high complexity and extreme typological variety) (*Artola, 2016*).

H2020 P2ENDURE project (Plug-and-Play product and process innovation for Energy-efficient building deep renovation), presented in this paper, demonstrate that is possible to overcome these barriers adopting Plug-and-Play (PnP) solutions for deep renovation. PnP solutions are industrialized prefab architectural and MEP-HVAC components which simplifies on-site assembly, reducing construction time and costs.

The P2ENDURE research project started in September 2016 and will finish in August 2020. The project, financed by the European Commission with 4 millions of Euro (EU Programme H2020-EE-2016-PP_Grant Agreement n°723391) involve a multidisciplinary consortium composed by16 partners coordinated by the Dutch company Demo Consultants B.V.

## P2ENDURE CONCEPT

A large number of innovative technologies and tools for deep renovation have become available in the last decade. In this field, P2Endure is working to resolve the main barrier for wide-scale implementation of innovative solutions concerning the absence of solid empirical evidence that such innovative solutions deliver the expected performance, both energetically and financially. The project provides evidence-based innovative solutions for deep renovation that are applicable and replicable for the widest range of building typologies.

P2Endure takes on a progressive principle:

- to build further on credible state-of-the-art solutions of 3D scanning and printing technologies in combination with prefab renovation systems;
- to develop modular processes for deep renovation through BIM-based design, engineering, production and installation for speeding up the implementation of the state-of-the-art solutions;
- to optimize and integrate the state-of-the-art solutions grounded in practical evidence of their performance through real deep renovation cases;
- to perform real deep renovation projects at a higher complexity level and with a larger performance impact than typical residential buildings through transformation of obsolete public and historic buildings.

This challenge is pursued by achieving five main aims:

1. to optimize, integrate and validate state-of-the-art prototypes and commercially available packages of PnP prefab solutions for deep renovation;
2. to demonstrate and promote innovative on-site processes for fast deep renovation projects with low disturbance for the residents, and significantly improved Indoor Environment Quality (IEQ) after completion;
3. to measure, monitor and validate P2Endure product and process innovations based on live demonstration projects of deep renovation, virtual simulation and prototyping;
4. to provide solid empirical evidence of the performance and quality of P2Endure solutions while ensuring their scalability and replicability at district, city, region, country and EU level,
5. to ensure the market uptake and upscaling of P2Endure innovations during and immediately after the project by directly involving ‘launch customers’, value-chain and distribution network partners, and other stakeholders at local, regional,

and EU level.

The innovative solutions for deep renovation are based on PnP prefabricated systems, combined with innovative technologies for the control and implementation of the intervention, such as 3D printing, advanced diagnostic techniques and Building Information Modeling (BIM). The integration of these solutions takes place by adopting a methodology, called 4M process, consisting of 4 main steps:

1. *"Mapping*". This step is dedicated to perform a condition assessment of the existing building, to measure the energy consumption as well as the IEQ before the renovation. This step includes the use of 3D laser and thermal scanning and other tools (e.g. comfort eye) to facilitate and improve the analysis. The purpose of the mapping is to develop a detailed technical plan and economic feasibility report for deep renovation, as a starting point for the renovation design.
2. "Modelling". This step is dedicated to create (if not exist) the As-Built BIM input for BIM-based renovation designing and Building Energy Modelling (BEM) for simulating the performance of viable renovation measures.
3. "Making". This step takes place both off-site and on-site. BIM is used for product engineering and in support of off-site prefabrication. In certain cases, BIM is used for on-site 3D printing with collaborative robotics. This step will result in improved, tested and implemented innovative PnP to be installed ensuring the P2ENDURE goal of 60% in energy improvement, 15% improvement in first cost, and an overall time reduction needed for completing a deep renovation.
4. "Monitoring". It is the final step dedicate to measure the building performance. This step is continuing throughout the entire life cycle of the building measuring the status of the energy and IEQ performance with sensors and control instruments whose data, connected to the BIM model, are compared and verified with those simulated in the design phase.

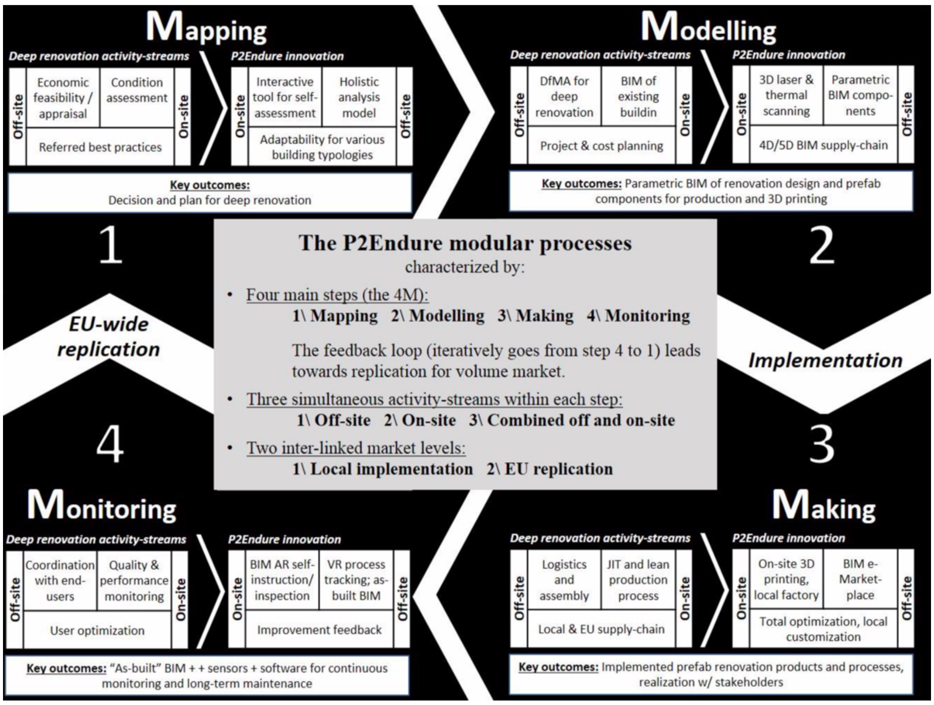


**Figure 1. Scheme and flow of the 4M process adopted by the P2ENDURE**

The 4M process is designed to allow for staged renovations. Through the iterative nature of the 4M process – the last stage monitoring directly provides the input for the first stage mapping – renovation activities can be spread out over a longer period (10-15 years) and a continuous energetic performance can be guaranteed.

## P2ENDURE PLUG & PLAY SOLUTIONS AND TOOLS

Main scope of the introduced "Deep renovation" is to drastically reduce the building energy consumption. As presented, P2ENDURE follows this scope demonstrating that is possible to improve the building performance adopting PnP solutions and using specific tools inside the introduced 4M Process. The research consortium has analyzed advanced technologies allowing energy efficient deep retrofits (PnP prefab components), tools for the building assessment and/or real-time monitoring.

5 PnP prefab components have been selected in order to set-up specific intervention on the "building envelope":

1) *"FC multifunctional panel"*. FC multifunctional panel was developed by Fermacell. It is a versatile prefabricated facade panel composed from a wooden or steel substructure that will allow integrating of water ducts and pipes, air supply or/and even ventilation channels, heating and cooling functions. Within the P2Endure project Fermacell developed a construction kit "versatile PnP facade for renovation" that will be a solution for deep renovation of existing buildings.
2) *"EASEE multifunctional panel"*. The EASEE prefab panels are composed of two layers of textile reinforced concrete (1,2cm each) and insulation core between them made of expanded polystyrene (10,0cm). The total thickness of the panels is 12,4cm. The thickness of the insulation may be increased if needed. The width of the panel is in the range of 0,5m - 1,5m and the height 1,5m – 3,0m. The weight of the panel is around 54 kg/m$^2$. The anchorage system allows achieving flexibility and capability to adapt to different architectonic configurations and building typologies. When applied, these panels increase the thermal properties of the envelope after retrofitting (U<0.23 W/m$^2$K for retrofitted wall), reduced installation time by 50% in comparison with traditional retrofitting, high aesthetic properties that allows application of the solution to buildings under cultural heritage protection.

**Figure 2. Example of PnP building component: multifunctional façade panel constructed by Fermacell**

3) *“Smart windows”*. Windows designed by Bergamo Tecnologie, that can be rotated by 180° to reduce the thermal radiation from the outside during summer season and reduce the thermal dispersion from the interior in the winter, thanks to the double positioning of the low-E glass. The smart window provides natural ventilation, rotating and locking mechanisms which enhance anti-burglary features, as well as integration with domotics solutions. It satisfies the needs for high energy-efficiency, better indoor climate, and top-class security features. The reversible window technology is enabled by innovative hydraulic gaskets and burglar-proof electro-magnetic locking mechanisms fully integrated in the frame.
4) *“Rooftop retrofitting”*. Adding new dwellings on existing roofs increases the sustainability and lifetime of the buildings, at the same time reduces the energy consumption. This has successfully been demonstrated in several pilot projects within the EU-IEE (Intelligent Energy Europe Programme) project SuRE-FIT (Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe). The pilot additional new roof-top dwellings partially cover the expenses for the refurbishment of the existing apartments. It has been proven as a well-performing deep renovation solution that results in energy neutral dwellings. Flexible roof-top extension retrofit has been proven as a viable solution, both technologically and financially and combining social, ecologic and economic advantages.
5) *“Folding balcony”*. Bloomframe, designed by Hofman Dujardin Architects, is an innovative window that transfers into a balcony at the touch of a button. The advantages of the concept are especially clear in transformation projects were housing is realized and a regular balcony is not possible or not allowed while residents in congested urban areas demand private outside space to enjoy the weather. The cost of the bloomframe folding balcony as demonstrated will trend to the cost of a large window frame of the same quality and performance and a traditional balcony of the same size. The energy performance of a bloomframe folding balcony (high insulation rate and high solar factor) for deep renovation will help to realize zero energy target for the building, which puts the Return on Investment (RoI) realized at zero.

4 PnP prefab components have been selected in order to set-up specific intervention on the “MEP-HVAC”:

1) *“Compact energy store”*. Thermal technologies do not have such general interconnectivity and therefore rely on sizing typically meeting 90% of summer demands in moderate climates. This existing approach provides little benefit in winter. Therefore, an obvious approach is that of thermal energy storage that overcomes issues of heat loss, substantially increasing the overall use of Renewable Energy Sources (RES) in buildings throughout the seasons. The innovative P2ENDURE product derived from the MERITS project is 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.
2) *“Prefab HVAC systems”*. P2ENDURE will implement a complete PnP MEP/HVAC (Mechanical, Electrical, and Plumbing/ Heating, Ventilation and Air Conditioning) engine for deep renovation. This solution includes air-heat pump, storage capacity for 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 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: 1) the total cost of retrofitting is reduced by 40% due to efficient manufacturing and efficient use of labour; 2) quick assembly time of just 0,5 day to place engine, connect pipes/ducts, and then operate with predictable performance; 3) weight of the modules reduced by 35% compared to traditional components, due to redesign and combination of functions.

3) *"Smart connectors"*. P2ENDURE will apply smart connectors for mechanical, hydraulic, electrical, air and ICT joints in order to reduce the danger of cracking.
4) *"The RenoZEB Units"*. It consists of prefabricated units aimed at simplifying the renovation process in terms of performance, time, and costs. The unit is a prefabricated component composed by a steel frame which contains several types of layers. Eight typologies of units have been developed to fulfill different building requirements. The units are created and installed following a modular approach to improve the production line, the design, and the installation process. The deep know-how and experience in the fields of building facades and aluminum allow the company to manage each step of the design process (design, production, and installation). The product modularity simplifies both the design of the whole façade and the installation of the units. In fact, the different types of units can be arranged according to the existing façade layout. The units have been developed to improve the thermal performance of the building.

5 Tools have been selected in order to characterize the innovative P2ENDURE 4M process:

1) *"Comfort Eye"*. It is a low-cost sensing device which allows real-time monitoring of indoor thermal comfort. It is based on a microcontroller and a set of sensors and embedded algorithms to derive Predicted Mean Vote index (PMV) for multiple subjects in different positions of the room. The advantages of Comfort Eye are non-invasive multipoint measurement, interoperability and ease of integration and installation. The technician installs the scanning system on the ceiling of the room and connects it to the control unit. The system scans continuously all the surfaces to measure their average temperatures and sends the results back to the control unit.
2) *"Energy grid and RES production"*. P2ENDURE targets maximum flexibility in power generation (heat and electricity), distribution and usage. P2ENDURE will propose innovative solutions for RES and energy grid through the following three-step approach: to pursue the best utilization of suitable portions of the building-envelope to lodge the RES production; to promote the best utilisation of PnP compact energy storage systems at building level; to promote the development and deployment of combined heat and power (CHP) plants, associated to centralized storage systems.
3) *"Thermal and acoustic scanning technologies"*. In P2ENDURE, the quality controls for prefab panels will be adopted to provide data for the ICT Platform. The main purpose is to eliminate or reduce the quality gap between the design and construction phase through self-inspection and self-instruction techniques connected with an enhanced Augmented Reality (AR) and a detailed BIM. The

following functionalities using advanced low-cost sensors geo-referencing of the 3D data will be deployed at live demonstration projects in P2ENDURE for: thermal bridges detection; thermal transmittance degree; structural integrity diagnosis; acoustic leakages detection; 3D geometric scanning and reconstruction; continuous update of the BIM can be performed in order to have a complete and detailed time history of the performance evolution of the building and of each building components.

4) *"3D scanning (geomatics) – laser and photogrammetry"*. Applications of 3D laser scanning technologies range from the building scale to environment assessment, up to infrastructures, for refurbishment/renovation projects, to manage the construction site or to condition assessment. Different devices can be used depending on needs and application (exterior/envelope, interior morphologies, accurate inspection aimed at energy refurbishment, etc.).
5) "*3D printing and robotics"*. P2ENDURE further develops and implements robotic technologies for on-site 3D printing for façade retrofitting. This solution works with various sorts of materials, yet a mix of thermosilit and limestone is currently preferred to create effective layers of insulation. 3D printing is primarily used to create plastering with special limestone material on concrete walls, ventilation ducts, or water pipes. It gives a 3D design exterior finishing in combination with painting. 3D printing is also used to create a façade layer with any kind of materials suited for the new or retrofitted building structure. In combination with robotic technologies, mounting of windows or other PnP prefab components can also be done very effectively and efficiently on-site. The robots are controlled by an on-site scanning and coordination system. 3D BIM model is used to pre-programme the robots and on-site processes. By using robots, the number of construction workers on-site can be kept up to 2 or 3 persons.

## DEMONSTRATION CASES

P2Endure mainly aims to provide scalable, adaptable and ready-to-implement innovative PnP prefab solutions for deep renovation of building envelopes and technical systems. The innovative solutions are complemented with a proof-of-performance, which is based on pilot implementation and monitoring in several live demonstration projects representing deep renovation characteristics in all main EU geo-clusters.

The following paragraphs introduce an overview of the main P2ENDURE demonstration cases, and the PnP solutions adopted for the Deep Renovation:

1) *"Menden (Germany) demonstration case"*. It is an office building erected between 1910 and 1930. It is part of an industrial area containing mostly storehouses and manufacturing companies. The building is attached to the neighbour buildings that are aligned on the street side. The office is a 1 floor building with basement and has a footprint of 187 m² and a gross volume of 744 m³. The deep renovation solutions proposed: adding prefabricated facade elements, additional thermal roof insulation, thermal insulation of the basement ceiling, installation of new windows with triple glazing and installation of a new gas boiler.
2) *"Korsløkken (Denmark) demonstration case"*. The building no.34.3 at Korsløkken is a typical Danish 2 floor residential building from the 1970's. The building is

part of one of the biggest residential housings in Odense city. The overall objective in this building is a total renovation interior and exterior. Furthermore, they would like to have some 3D design and promotion of the whole residential park Korsløkken. The target is to make a 3D design facade faster and with less manpower onsite.

3) *"Ancona (Italy) demonstration case"*. This case study is a multi-apartment block, located in Ancona and built in 1980. The building is composed of 100 dwellings, 6 floors and total gross area of 1720 $m^2$. The objective is to demonstrate the energy savings from advanced retrofit solutions (e.g. insulation materials, renewables and MEP, comfort monitoring and improvement).
4) *"Florence (Italy) demonstration case"*. This historical residential building in Florence is part of the expansion and rehabilitation area implemented in the period from 1864 to 1871. Considering the location and architecture typology the building was born with a multifunctional used: commercial / craft on the ground floor, and residential use on the upper floors. The objective is to demonstrate the energy savings from advanced retrofit solutions as: adding insulation materials on the roof, new MEP-HVAC systems, replacement of high-performance windows.
5) *"Genova (Italy) demonstration case"*. The nursery school called NEMO is located on the second floor of a two-level building, built in 1930s with concrete structure and non-structural brick walls. The building is listed under the Italian Legislative Decree 42/2004, which poses cultural heritage constraints on its conservation. The goal of this project is the reduction of heating consumption through replacement of high-performance windows.
6) *"Reggio Emilia (Italy) demonstration case"*. The historical hotel was built in the Middle Age and refurbished in the early 1900 by one of the most important architects of the period, Guido Tirelli, under the influence of art deco and liberty. Unfortunately, the building has been abandoned for many years. It had been extended, and it was definitively closed in 1999 in consideration of structural and functional requirements problems. Today 300 $m^2$ net floor area of the pavilion is subject to a deep renovation to get an energy efficient building, preserving its historical elements. Building morphology: the historical part of the building is made from brick walls, not insulated floors and wooden pitched roof. The south facade is mostly covered by large windows with scarce thermal performances. The restoration project will improve the energy performances and will explore prefab products. Application of P2Endure prefab solutions on: building envelope (smart efficient windows) and technical systems.
7) *"Breda (Netherlands) demonstration case"*. Renovation of row homes for a social housing company to the level of NOM. Area Kruiskamp is in the city of Den Bosch, Netherlands. The homes to be renovated were built in 1967. Demonstration of applicability of NOM concept, stemming from the Dutch Government program' Energiesprong' carried within the regional program SB NOM.
8) *"Enschede (Netherlands) demonstration case"*. This demonstrator is the deep retrofit, redesign and transformation of an abandoned university building, originally built in 1965, into a student hostel and hotel building. The goals are to improve the energy efficiency of the building from energy label G to B (target A) and extend the lifespan of the building. The field demonstration activities will

focus on the testing and inspection of new facade panels and parts of the new MEP system.

9) *“Tilburg (Netherlands) demonstration cases”.* Lidwina monastery is a historical building (1935) used as a temporary guest accommodation. The 5400 $m^2$ building accommodates approximately 60 (potential) rooms. Most parts of the building are well maintained but never been replaced. The objective is to fully renovate the monastery to a new level of comfort, improving energy performance substantially, increasing flexibility of rental situation and modernizing the monastery. The plan is to add to every room a new bathroom, new ventilation and installation concept, insulate windows and façade and reduce sound comfort of the rooms.

**Figure 3. Enschede (NL) demonstration cases. Transformation of university building to student hostel in Enschede, the Netherlands**

10) *“Gdynia (Poland) demonstration case”.* Demonstration building is a two-story kindergarten building, attended by about 130 children. It was constructed in year 1965 and it has the function of kindergarten from the beginning. Building volume is 2712 $m^3$ and built up area is 464 $m^2$. The main goal of the demonstration is to minimize the energy consumption especially for heating needs through the retrofitting of the envelope (add insulation layer), implementing new windows and improve aesthetic appearance of envelope. The building is connected to district city network.

11) *“Warsaw (Poland) demonstration case”.* The building was built in 1983. It is in the southern part of the city, in Ursynów District, and is one of 55 municipal

nurseries in Warsaw. It is a place for temporary care to 108 children aged 1-3. The main goal of the demonstration is support Warsaw's climate targets – energy efficiency, $CO_2$ reduction thanks to the opportunity to test innovative solutions.

At the end third year of the project several demonstration cases are finalizing the construction site activities moving from the "Making" step to the "Monitoring" step.

In consideration of the completed tasks, in the following paragraph is introduced the adopted methodology to assess the energy saving target with the PnP solutions proposed. Per each demonstration case is presented the actual measured energy performance.

## METHODOLOGY TO ASSESS THE ENERGY SAVING TARGET

The targeted reduction of net primary energy use is calculated in accordance with European Directive 2010/31/EU on the energy performance of buildings, which encourage the adoption of a methodology for calculating the energy performance of buildings.

In this field, the total primary energy demand is then the sum of the primary energy associated with many possible end-uses: heating, electricity, hot water, cooling and ventilation. The numerical indicator of primary energy use is kWh/m$^2$ per year, *id est* the overall primary energy demand, in kWh/year, associated to the fulfilment of the various end uses of interest, divided by the net floor area of the relative demo case (m$^2$).

The value, assumed as the reference in the calculation of the saving, is, indeed, the one associated to the specific primary energy demand in the pre-renovation scenario. For each of the presented demonstration cases, the reference primary energy demand is hence determined is based on the characteristic of the existing building before the retrofit:

When direct recordings were not available (vacant buildings), an indirect procedure has been adopted to compute the pre- renovation primary energy:

- Electricity needs, the related primary energy is calculated using standard national coefficients (i.e. the average efficiency associated to the transformation of primary energy into electricity, considering the available plants that operate in the country: thermo-electric plants fed by oil, carbon, etc., PV plants, wind farms, etc.);
- Thermal needs for heating, calculated from energy bills and/or through site specific calculation (normally considering a quasi-steady state heat exchange between the building envelope during the cold season), also considering the energy vectors involved in the transformation processes (e.g., hot water, air, etc.);
- Hot water demand is computed considering the average usage of hot water for the specific facility and the efficiency of the technology adapted to its production;
- Thermal needs for cooling, it is usually extrapolated from the electricity consumption, isolating the needs that can be referred to the cooling consumptions.

It is clear that the reliability and precision of the calculation are strictly related to the available information and the knowledge of the building, of its activity and, in general, of its energy behaviour:

- 1$^{st}$ level: a general knowledge of the energy needs is available from the energy bills (it has been recommended to consider at least two years of data, in order to avoid seasonal variation and or demand anomalies); once the electricity consumptions are known, it is possible to calculate the primary energy, associated to the electricity demand, applying the National Primary Energy Factors. Historic energy use from bills is, therefore, the first reference used in the analysis of the energy use breakdown. When these documents were not available, the requirements have been reconstructed using similar data taken from scientific literature and/or reports of comparable buildings in the same country/geo-cluster. Thermal energy demand and hot water needs can be calculated similarly using energy bills through a similar procedure, however considering the efficiency of the thermal plant installed in the building, instead of national factors. Again, some exception could be considered as it happens in case the dwelling is fed by a district heating network.

- 2nd level: a deeper knowledge of the building is provided by an energy audit: a systematic procedure with the purpose of obtaining adequate knowledge of existing energy consumption profile of a building or group of buildings (Directive 2012/27/EU. The energy audit is the outcome of a deep analysis of the building, its activity and historical energy consumptions; it is provided by a specialist considering the local norms and it can include a site inspection (if needed).
- 3rd level: the creation of a detailed energy model of the building permits a complete awareness of the building and its energy behaviour though the running of energy simulation and analyses.

In general, primary energy consumption is strictly related to the activities and the occupancy of the building. Therefore, the acknowledgement of some usage information, such as the usage time pattern, or the temperature set-point of the plant is pivotal and might help in finding reliable result, both in the pre and post renovation scenarios.

Since the complexity of the last variables in the energy balance equations, the availability of an energy model of the building highly facilitates the validation of the various selected opportunities to get the energy savings, also helping in the standardization of the results for future comparison.

In P2ENDURE the calculation of Primary Energy Consumption has been performed through two different methodologies.

1) “Manual calculation”: many different tools are available on the market for the energy use assessment; each of them required at least a detailed knowledge of historic energy bills and specifications of the installed systems: electricity, natural gas, hot-water plants, and/or others; finally, it is necessary to have a deep knowledge of current lighting and HVAC plants;
2) “Digital model of the building”: this methodology is based on BIM to BEM concept where is necessary the availability of a model of the building, created in a digital environment, where one can simulate the energy behaviour of the subject applying meteorological data, and simulating the operation of the installed on the MEP, in accordance to their given efficiencies. Tools and software yield energy demand through their calculation engines, using heat transfer algorithms, giving very precise results. Different freeware and not freeware software are available on the market and the required input may be substantially different.

These procedures have been adopted to define per each demonstration cases the "energy consumption" before the renovation. At the same time, this result defines the minimum level of energy performance to achieved after the deep renovation (60% less than the pre-intervention status).

| PRE RENOVATION | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country, Partner, Demo case | | | Energy Assessment - Primary energy consumption | | | Geometric data and modelling | | Energy and Indoor environmental data | | | | | | | | energy consumption |
| | | | reference of baseline | | | BIM-to-BEM | | transmittance | | indoor usage | | systems | | | | |
| | | | bills | energy audit | energy model | Completed | Validated | envelope | interior | indoor operating temperature | time pattern | HVAC | lighting | power | other | kWh/m2y |
| DE | 3L | Menden | Y | Y | N | N | N | Y | - | Y | Y | Y | Y | Y | - | 255 |
| DK | INV | Korsløkken | N | Y | N | Y | Y | N | N | Y | N | N | Y | Y | - | 64 |
| IT | UNIVPM | Ancona | Y | Y | Y | Y | N | Y | Y | N | N | Y | Y | N | - | 85.8 |
| IT | SGR | Firenze | N | Y | N | Y | Y | Y | N | Y | N | N | N | N | - | 366.3 |
| IT | RINA | Genoa | Y | N | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | - | 161 |
| NL | HIA | Breda | N | Y | N | | | | | | | | | | | 501 |
| NL | CAM | Enschede | Y | Y | N | | | | | | | | | | | 300 |
| NL | PAN | Tilburg | Y | Y | N | N | N | Y | Y | Y | Y | Y | N | N | - | 428 |
| PL | FAS | Gdynia | Y | Y | Y | Y | N | Y | Y | Y | Y | Y | Y | Y | - | 120.5 |
| PL | WAW | Nursery | Y | Y | | | | | | | | | | | | 137.3 |

**Figure 4. Energy assessment of the main demonstration cases before the deep renovation**

## CONCLUSION

The demonstration cases being implemented aim to show that through the components offered by P2ENDURE such as the adoption of the integration of innovative technologies for the control of the intervention through the 4M process, it is possible to achieve a 60% energy saving compared to in the pre-intervention state, a 15% reduction in costs and 50% of the time required to carry out the intervention compared to the standards, guaranteeing comfort for the occupants (both in terms of quality of the internal environment and reduced disturbance due to the restructuring operations). The project is closing the third year of research and by still following the 4M scanning method of the phases, it is possible to trace both the already obtained and potential results, and the difficulties emerging (Sebastian, 2018) as introduced in the following paragraphs.

The most interesting results of the first step, Mapping, of the adopted 4M process regard the registered procedure that assists the 3D scan and the subsequent BIM modelling, and the BIM Parametric Modeller application which, by importing the model and breaking it down, acts as a guide with regard to the type and number of interventions to be performed. The limit is the lack of a totally automated method of transforming the 3D point cloud survey into a BIM model. The Modelling phase has produced calculation procedures of the energetic behaviour resulting in a BEM that are also importable in the BIM Parametric Modeller application, even though some interoperability defects still emerge. The first results of the Making phase include the solutions themselves during the assembly in the demonstration cases. The P2Endure consortium has analyses and selected advanced PnP technologies allowing energy efficient advanced deep retrofits on demonstration cases. The main focus was the selection, consolidation, optimisation and integration of innovative PnP prefab components that are necessary to achieve the targeted quality and performance in terms

of energy, cost and time-saving as well as improved IEQ and reduced disturbance during on-site processes. All solutions were presented to the building owners or their representatives. The proposed solutions were confronted with the needs of the end-users where was emerged the request of hard evidence about cost and energy effectiveness of the proposed solutions. The Monitoring phase will begin with completed interventions, also assisted by the devices (e.g. Comfort Eye) already installed and the data of which on the quality of the internal environment, detected before and after the intervention, will certify the outcome of the operation.
The P2ENDURE project is working on building renovation interventions managed in a public-private partnership system, the research is experimenting with innovative methodologies, procedures and technologies within a context in which innovation often has to break down innumerable barriers. Also considering obstacles concerning different existing situations in the EU countries.
The tested 4M modular process adopting series of practical ICT tools is demonstrating its functionality facilitating and optimizing the deep renovation process on each demonstration cases and solving the introduced barriers. The experimentation of the tools and technologies developed in the P2ENDURE project is still ongoing. Despite this is possible summarize that the various ICT tools integrate in the 4M process has contribute to:

- established a solid baseline before renovation;
- facilitated the renovation design process by configuring the suitable PnP / prefab solutions for deep renovation;
- provided BIM-based input for energy calculation / energy simulation of the possible deep renovation designs;
- supported the decision-making at deep renovation, i.e. to decide on the most optimal renovation design, as well as after renovation.

Moreover, the results achieved so far have highlighted its potential, not only in terms of optimization and refinement of the functions emerged in the research project, but also of their significant development, prefiguring its high aptitude for replicability in the various countries of the European Union.

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