Technology concepts for rapid renovation using adaptable lightweight façade systems

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Abstract. H2020 project PLURAL (Plug-and-Use Renovation with Adaptable Lightweight Systems) proposes prefabricated, modular and adaptable lightweight façade systems for rapid renovation of existing buildings providing high-performance, cost-effective and fast renovation solutions. This paper presents the early stage technology concepts of three different core systems representing Plug-and-Use (PnU) building envelope kits. The PnU kits couple the lightweight façade module concept with ecological coating materials, integrated energy systems such as photovoltaics, heating, cooling, and ventilation. The paper describes in detail technical solutions of three innovative core systems and presents real and virtual demonstration buildings. Also shows calculated energy performance for real buildings when one of PnU kits is applied for renovation.

Keywords. Building renovation, energy performance, nZEB, façade panel, HVAC integration.
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1. Introduction

The existing building stock calls for high-performance, cost-effective and fast renovation solutions to significantly decrease energy consumption [1], [2]. The answer to this challenge regarding residential buildings is the PLURAL project, which targets to design, validate and demonstrate a palette of versatile, adaptable, scalable, off-site prefabricated “plug and play” facades accounting for user needs (named “Plug-and-Use” - PnU kits). Technologies integrated in prefabricated panel solutions in the framework of local nZEB requirements need to fulfil requirements for: fast retrofitting process, renovation cost reduction, high level of prefabrication, use of eco-friendly and sustainable construction materials and in total provide high indoor environment quality. All these aspects will be validated in the frame of the PLURAL project for three demonstration sites (called real demonstration) and three additional buildings where the PnU kits will be “virtually” installed accounting for specific design and climatic requirements and their performance will be validated using computational tools (virtual demo sites).

In the second year of PLURAL we present the three basic PnU kits:

- “SmartWall” – a multifunctional prefabricated wall panel,
- “eWHC” – an external prefabricated Wall Heating and Cooling module panel,
- “eAHC” – a prefabricated module with air handling unit with Advanced Heat/Cool recovery system.

The goal of this paper is to present developed technology concepts of above mentioned three different PnU kits. The project is in the stage of preparation of real demonstrations, the paper presents only calculated results for two of them.

2. Overview of the core systems

PLURAL renovation aims to ensure that the retrofitted buildings reach criteria of nZEB, according to each country's nZEB directives. It is important to note that the target level is a comparison of the retrofitted building with the nZEB definition for new buildings. This is because the requirements for retrofitted buildings are often lower.

The PLURAL approach is in line with the EU energy strategies for 2050. Heat losses through the envelope will be minimized through improved insulation of the façade components, reaching U-values of less than 0.23 W/(m^2·K) and building primary energy consumption less than 60 kWh/m^2. In addition, through the installation of the prefabricated panels, the cost of renovation is aimed to be reduced by 58 % and the time of renovation by 50 %. Energy performance, renovation time and costs will be validated via extended monitoring campaigns at the three real demo sites.

Each of the core systems described below has a unique structure; "SmartWall" is a welded steel frame structure, "eWHC" is a timber frame structure and "eAHC" is a stainless-steel line structure.

2.1 SmartWall

The SmartWall is a unique compact versatile prefabricated wall panel, which can be installed externally or internally in existing building envelopes, introducing an innovative and flexible solution for light and/or deep buildings' retrofitting. Fig. 1 illustrates its three basic components, which are the frame, insulation material and finishing layers.

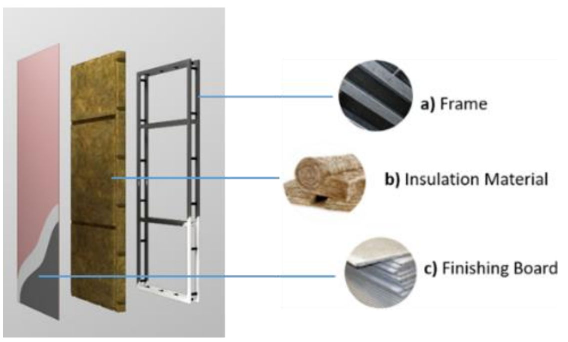

Fig. 1 – Fundamental components of "Smartwall".

The basic material for the frame is steel S245, using lightweight 50 x 50 mm members welded in a frame. The "Smartwall" can be easily manufactured using alternative materials such as timber, industrial plastic, aluminium or carbon fibre. Due to various materials and technologies that can be integrated in the "Smartwall", a large variety of panel sizes with various frame strengths can be designed and manufactured

Among insulation materials possible alternatives are rockwool, glass wool, EPS, cellulose and VIP (backside of a convector). Finishing surfaces differ according to the use of the PnU kit in interior or exterior of a wall. Large variety of boards contains cement, gypsum, fibre, timber, etalbond, etc. Most of the aforementioned boards can also be treated with PCM-multifunctional coatings enhancing their properties with energy storage, self-cleaning, IR reflective, anti-bacterial, self-healing etc., characteristics, produced by project partner AMS [3].

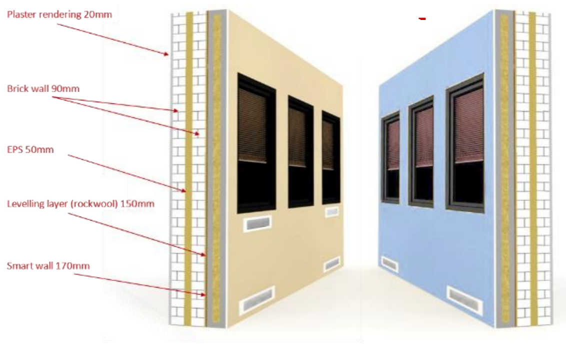

Fig. 2 – "Smartwall" solutions for interior (left) and exterior (right) integration.

The conceptual idea of "SmartWall" PnU kits, is to integrate various prefabricated elements such as windows, doors, and balcony doors, in order to reduce installation time and construction faults during installation. Also, a wide range of technologies for heating and / or cooling could be integrated in the SmartWall, e.g. fan coils, split units, air ducting systems, radiators and convectors. Optional features for exterior "Smartwall" PnU kits are PV panels including local batteries.

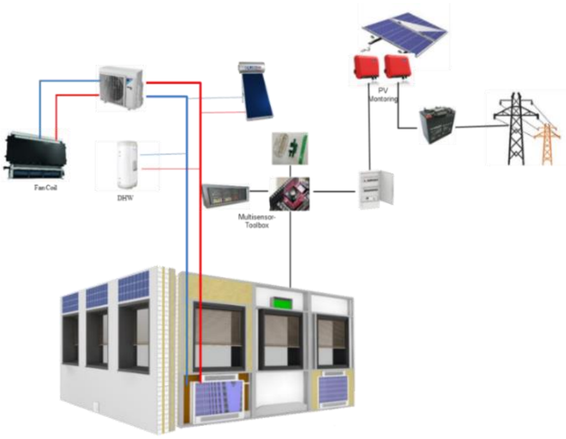

Fig. 3 – General example of "Smartwall" application.

2.2 eWHC

The eWHC PnU kit is specifically designed to be used in colder climatic zones such as continental and alpine. Therefore, the high requirements are set on the thermal isolation properties and airtightness. Fundamental material for the frame is timber because of low carbon footprint, high flexibility in shape, dimensions and variety of connection techniques.

Outer layers serve as load bearing timber and include the main thermal insulation (see parts 1 – 4 in Fig. 4). Next comes a flexible layer made from an insulation material (5). Its purpose is to ensure best and maximum contact of the heating/cooling pipes (8) with the existing façade wall accounting for wall irregularities (7). This enables the element to adapt to uneven sections of the wall. After investigations the most appropriate materials are selected that include the group of organic (wood fibre, sheep wool, hemp wool) and mineral (glass and rock wools) materials. The nut and washer (12), attached to the L-profile via a threaded rod will provide the horizontal force to push the PnU kit against the wall.

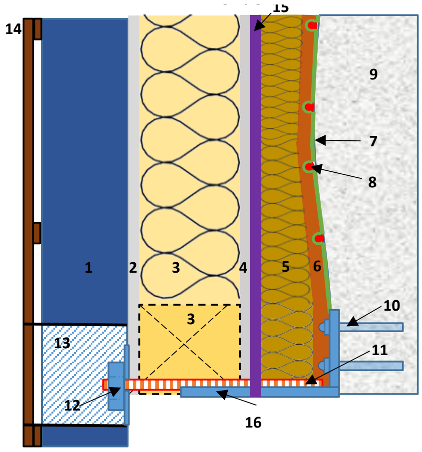

Fig. 4 – Section of “eWHC” kit (1 – insulation + weathering membrane, 2 – upper fermacell board, 3 – beams and insulation, 4 – lower fermacell board, 5 – flexible layer, 6 – soft board, 7 – metal heat fin, 8 – heating/cooling pipe, 9 – original wall, 10 – anchor, 11 – threaded rod, 12 – nut + washer, 13 – access, 14 – outer cladding, 15 – vapor barrier, 16 – L profile).

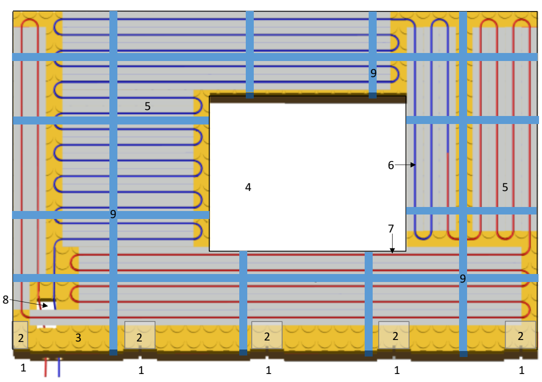

Fig. 5 – Heating layer in “eWHC” kit (view from original wall; 1, 2 – slots and space for L-profile, 3 – soft fibreboard, 4 – recess for a window, 5 – metal fins, 6 – return flow, 7 – supply flow, 8 – opening for pipes, 9 – belts)

The eWHC, as described above, integrates a heating and cooling layer in its composition creating a dynamic HVAC feature. The construction of the heating/cooling pipe network (Fig. 5) is done with standard materials of a radiant floor heating systems. The flexible and structured board (6 – Fig. 4) has slots for the metal fins (7) and the composite heat pipe (8). The metal fins are essential to ensure a sufficient heat distribution throughout the wall.

The “eWHC” PnU kit can easily integrate a local air-handling unit with heat recovery in order to supply fresh air to a single room.

Integration of windows as well as window frame integrated units is possible above or below the “eWHC”. The “eWHC” system is ready to integrate standard types of windows with double or triple glazing configurations depending on climatic zones and local nZEB requirements.

2.3 eAHC

The “eAHC” PnU kit is a ventilated façade prefabricated system that can integrate a large range of functionalities. The base is the system developed by the project partner company Denvelops, composed of vertical stainless-steel guide lines and connectors, that allow to attach and bear the loads of the cladding [4]. The thermal insulation is made of mineral wool and is protected by a weathering layer. Both are attached to the system vertical guidelines in order to achieve the required thermal and water-tightness performance. Thickness 100 mm with declared thermal resistance of 2.90 (m^2·K)/W is considered as the optimum passive measure according to simulations and includes at least 50% of recycled material. The mineral wool is covered by a glass-fibre layer that can protect against mechanical damage.

The cladding of the façade is made with painted aluminium cladding tiles with 1 mm thickness and a resistant powder coating. PV panels are integrated in the façade, replacing locally the final cladding. These panels are composed of 2 layers of tempered glass and amorphous PV cells with overall thickness of 4 mm and width of the module 200 mm. The peak power of the cell with height of 800 mm is 19,4 W.

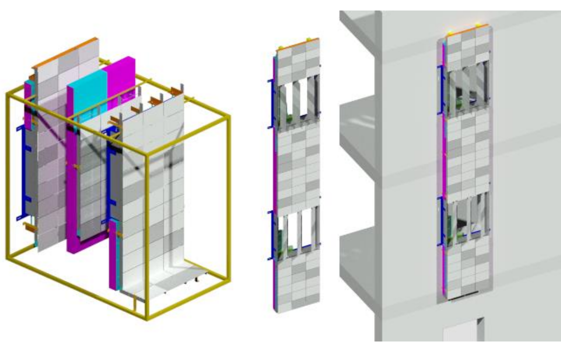

Fig. 6 – Vertical transport and straight frames for installation of eAHC kit.

The main HVAC component integrated in the façade is the “eAHC” ventilation unit. The unit is located in vertical position, thus needs to have a very low depth (160 mm). It contains two stage heat recovery, the first is regular plate heat exchanger, the second is active heat exchanger with thermoelectric modules and provide supply air temperature control. The unit is connected with the interior space via supply and extract channels. Due to maintenance reasons, the ventilation unit must be located next to a window side. (Fig. 7).

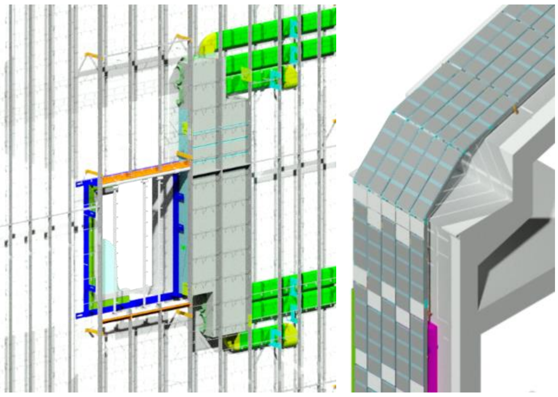

Fig. 7 – Ventilation unit and air channels (left) and PV panels (right) in eAHC kit.

3. Real and virtual demonstration

The PnU kits are planned for real (Table 1) and virtual application (Table 2) to verify their design and performance on various types of buildings in different climate zones in Europe.

Tab. 1 – Overview of real demonstration sites.

Description	Photo
Greece, Athens, Voula *Mediterranean climate (hot summer)* 2 of 10 flats - "SmartWall".	
Spain, Barcelona, Terrassa *Mediterranean climate (mild summer)* 1 block of 2 – "eAHC".	
Czech Republic, Kašava *Continental climate (warm, humid)* Whole building – "eWHC"	

Tab. 2 – Overview of virtual demonstration sites.

Description	Photo
Germany, Berlin *Continental climate* "SmartWall".	
Sweden, Väsby *Boreal climate* "eWHC"	
Switzerland, Bern *Alpine climate* "eWHC"	

Each real demonstration building faces different challenges and objectives given by the local law requirements, owner plans, inhabitants expectations, etc.

3.1 Czech pilot – Kašava

The Czech pilot project in Kašava is a detached double dwelling house built in 1962. Renovation doesn´t include only improving of thermal insulation of external walls and windows and installation of renewable energy sources. The Czech strategy for the building energy efficiency retrofit prefers complex solutions for the whole thermal envelope. PnU kits are not used only on outer walls, but modified prefabricated elements are used on new walls and roof construction. The volume of the roof is changed to improve internal flat distribution and to minimize surface of external thermal envelope. New volume has been designed to avoid thermal bridges that are joined with traditional mode of energy efficiency refurbishment.

Regarding HVAC, the existing gas boiler will be replaced by air-to-water heat pump as heating and cooling source for the wall integrated "eWHC" system. Integration of BIPV system on building's roof is essential to achieve nZEB. Also, each room will be equipped with local ventilation unit with heat recovery.

Tab. 4 – Overview of preliminary energy performance for renovation of Kašava building [5] (green – nZEB criteria passed, red – nZEB criteria failed, need update).

nZEB indicators	Kašava building	Building retrofit	nZEB 2022
Average U value of envelope ($W/m^2.K$)	**0.21**	0.41	0.29
Total delivered energy (kWh/a)	**18579**	44272	34094
Specific delivered energy ($kWh/(m^2.a)$)	**93**	161	124
Total non-renewable primary energy (kWh/a)	**-10943**	46320	19383
Specific non-renewable primary energy ($kWh/(m^2.year)$)	**-39.8**	169	71

Table 4 summarizes the expected energy performance of the Kašava building after renovation with the eWHC PnU kits. It is significant in preliminary design that because of heat pumps replacing old gas boiler and heat recovery ventilation, the overall delivered energy decreased. Furthermore, due to PV system on the roof, non-renewable primary energy fell into negative values.

3.2 Spanish pilot – Barcelona

The Spanish pilot project in Barcelona (Terrassa) is renovation of one of the two blocks of a residential social housing built in 2008. The project is specific for the specific requirements by the building owner in order to improve the management of the building and match with the user needs. These requirements are at technical, social, economic and building controls' level. The final scenario involves renovating the East and West façades of the selected building block using the "eAHC" PnU kit, counting it as an intervention to the thermal envelope, as well as using the roof area facing East in order to install photovoltaic panels for RES production, using the same PnU solution as for the façade, but without affecting the thermal properties of the roof. Important emphasis is on installation of new windows with outer folding blinds and ventilation units for each apartment.

The recent HVAC systems include local electric heaters and electric hot water tanks. According to the building owner, these will not be replaced.

Table 5 summarizes the expected energy performance of the Bercalona building after renovation with the eAHC PnU kits. Main issue for this building is very high portion of non-renewable energy because all electric HVAC. Therefore, the entire energy savings must be provided via active measures in the "eAHC" PnU kits.

Tab. 5 – Overview of energy performance with various PLURAL measures of Barcelona building (green – nZEB criteria passed, red – nZEB criteria failed).

Simulated Cases	Description	EP_{nren} [$kWh/(m^2\ a)$]	EP_{total} [$kWh/(m^2\ a)$]
Base case	Existing building before PLURAL	103	137
PLURAL passive	PLURAL passive solutions (1st and 2nd floor)	**83**	**113**
PLURAL passive + active	PLURAL passive solutions (1st and 2nd floor), active solutions eAHC + PV installation to accomplish regulations	**70**	**105**
PLURAL passive + active nZEB	PLURAL passive solutions (1st and 2nd floor) active solutions eAHC + PV installation to accomplish nZEB for a new building	**38**	**76**

To accomplish local regulations [6] for a building renovation, it is necessary to reduce the consumption of non-renewable primary energy (EP_{nren}) to 12.8 $kWh/(m^2{\cdot}a)$ and total consumption of primary energy (EP_{total}) to 7.6$kWh/(m^2{\cdot}a)$. This will be done through the "eAHC" ventilation unit and PV system. To be an nZEB building in terms of Spanish definition, as for a new building, active measures, especially the PV system, have to reduce EP_{nren} for 44.8 $kWh/(m^2{\cdot}a)$ as well as EP_{total} for 36.6 $kWh/(m^2{\cdot}a)$.

3.3 Greek pilot – Athens

The Greek pilot project in Voula, Athens is a multi-floor residential social dwelling for elderly people built in 1971. Local municipality divide the overall renovation in two stages, mainly for budget reasons, as well as, to minimize tenant's reallocation in other buildings, as the building provides accommodation to elderly people with limited financial capabilities. The 1st renovation stage works in the semi-basement and ground floor have already been completed since September 2020. The 2nd renovation stage is focused on the ETICS installation on all external envelope of the building; roof renovation and insulation; refurbishment of the apartments, common areas, corridors, staircases, lift etc.

Application of the "Smartwall" PnU kit targets to refurbish and upgrade each apartment with recyclable and eco-friendly materials, upgrade all energy systems in order to reduce energy consumption to reach the Greek KENAK nZEB standard (5) and ameliorate the thermal, acoustic and visual comfort of the residents. In order to meet the Greek nZEB standards [7], primary energy consumption should be between 31 and 99 kWh/(m^2·a) or lower. Unfortunately, no data are available at the moment.

4. Conclusion

The target of this paper is presentation of three prefabricated versatile "plug and play" facades (PnU kits) for building retrofit to nZEB level of a new building. The overview presents a path for cost-effective and fast retrofit of buildings which provide very large variety of panel structures with integrated technologies. One or more of the three basic PnU kits is capable to provide a solution for renovation of residential buildings across Europe from Mediterranean to Cold climate.

At the moment are available only calculated data from evaluation according to local nZEB requirements. They indicate abilities of proposed PnU kits. But it is important to notice also limits of energy savings, when the renovation targets only the building envelope. This is seen in the case of Czech demonstration building, which meet requirements for retrofit, but to reach requirements for new buildings deeper optimization of envelope is necessary. In the case of Spanish demonstration building is seen limitation when focus is only on façade and not to existing HVAC systems in the building. This results in significant increase of PV system in façade.

5. Acknowledgement

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6. Appendices

List of PLURAL partners in alphabetical order: Advanced Management Solutions, Agència de l´Habitatge de Catalunya, BG Tec Bergamo Tecnologie Sp.z o.o., Czech Technical University in Prague, Daikin Airconditioning Hellas SA, DENVELOPS TEXTILES S.L., FENIX TNT s.r.o, Institute for Solar Technology SPF of Eastern Switzerland University of Applied Sciences OST, INTRASOFT International S.A, Municipality of Vari-Voula-Vouliagmeni, National Technical University of Athens - Project coordinator, Obec Kašava, Pich Architects, RD Rymarov, RECUAIR s.r.o, The Catalonia Institute for Energy Research, The Catalonia Institute of Construction Technology, ZRS Architekten.

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