E2VENT – design and integration of an adaptable module for residential building renovation

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Abstract

The paper presents an innovative approach to the retrofitting of the adaptive ventilated facade module developed in the EU project E2VENT. The E2VENT innovative facade module is targeted to Optimal Adaptability and Heat Exchange for the refurbishment of existing buildings and is composed of two main parts: an adaptable smart modular heat recovery unit (SMHRU), which is adjustable to work within the ventilated facade cavity, is able to recover heat from ventilation air, and can preheat ventilation air in winter while precooling it in summer; and a latent thermal heat energy storage system (LTHES) which is based on phase change materials fitting in the cavity and is complementary to the SMHRU.
Following a brief introduction of the E2VENT project, the integration of the new technology at the building scale, and analysis of the foreseen design issues in terms of interfaces and facade singularities shall be discussed.
The paper will discuss how the systemic managing of these issues at the design level is vital in preventing inconsistencies between parts and helps with the design team working process.

Keywords

building facade retrofitting, ventilated facade, design integration, heat recovery, PCM, air renewal

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1 INTRODUCTION

Buildings, and more specifically those in the housing sector, are responsible for 40% of EU energy consumption and 36% of the EU CO2 emissions (BPIE, 2015). In 2010, Energy Performance of Buildings Directive (EPBD 2010/31/CE) required all new buildings constructed from 2021 onwards (public buildings from 2019 onwards) to be nearly zero-energy buildings (NZEB). However, in the last five-year period, the construction of new buildings is decreasing and the building sector is currently being led by the renovation of existing buildings (57% share of turnover of the sector) and energy renovation is playing a key role as a stabilizer of the building sector. In fact, the energy renovation market in the EU28 was estimated to be about **EUR 109 billion in 2015**. With respect to existing buildings, EPBD requires that member states must improve their national plans for the gradual transformation of these buildings into NZEBs as well as their long term strategies for mobilizing investments in the renovation of the national building stock, and quicken the pace of implementation. Rehabilitating the existing building stock into more energy efficient buildings remains one of the main difficulties to be overcome, even more so when the targets are as high as they are with the NZEB.

Of the existing European building stock, a large proportion (approximately 34%) of the suburban multi-storey residential building stock was built in the 60s and 70s, when there were either few or no requirements for energy efficiency. These buildings are characterized by:

- High energy loss through the envelope and high energy consumption;
- Poor aesthetics, and a need for maintenance;
- Low indoor air quality mostly related to humidity that can lead to a deterioration of the end user's health;
- Traditionally, the refurbishment of an existing building to current standards and levels of comfort is costly and time consuming.

Many different approaches to these issues have been presented and major references can be found in recent literature as well as in dedicated contexts such as sector conferences and symposia (e.g. Advanced Building Skins - ABS, International Conference on Building Envelope Design and Technology – ICBEST, etc.). Major contributions are promoted by the EU Commission itself through dedicated funding within the current and past framework programs (i.e. FP7, HORIZON 2020). The latest review of ongoing and past funded PPP projects was released in March 2016 and is available at the European portal for energy efficiency in buildings (www.buildup.eu). Novel technologies for the retrofitting of buildings have been proposed in terms of thermal insulation (e.g. AEROCOINs[1], LEEMA[2]), multifunctional envelopes (e.g. ADAPTIWALL[3]), coating systems (e.g. COOL-Coverings[4]), energy management systems (e.g. AMBASSADOR[5], BEAMS[6]), monitoring systems (e.g. CETIEB[7]) and so on.

Focusing on those projects that specifically target the retrofitting of residential buildings, the following are worth mentioning:

- The **MeeFS**[8] project, launched in January 2012, develops an innovative, energy efficient, multifunctional facade system for retrofitting, geared towards the residential building sector.
- **EASEE**[9] project targets residential buildings with cavity walls, which require facade retrofitting for improving the insulation and energy efficiency, and reducing the energy demand while preserving the facade original appearance. For this purpose, the project has developed a tool-kit for energy efficient envelope retrofitting of existing multi-storey and multi-owner buildings.

- **HERB**[10] project has developed innovative energy efficient technologies and solutions for retrofitting and performance monitoring of typical residential buildings in EU countries. Technologies adopted for such retrofitting include various insulation materials, smart windows, surface coatings, and integrated heat recovery panels. Energy efficient solutions have foreseen the application of LED and light pipes, energy efficient HVAC such as natural ventilation, passive heating/cooling, heat pumps integrated with heat recovery and thermal storage, and renewable energy systems based on solar thermal and photovoltaics.
- The **RETROKIT**[11] project targeted multi-family residential buildings and has developed and demonstrated multifunctional, modular, low cost and easy to install prefabricated modules. These modules are integrated with a system able to deal with aspects such as heating, ventilation, cooling, electricity and ICT and comprise a window element accompanied by a technical box including HVAC systems and an interface for building services (ducting, piping) installed on the existing facade.

In comparison with the aforementioned projects in this field, the E2VENT project develops a cost effective, highly energy efficient, low CO2 emission, replicable, low intrusive, systemic approach for the retrofitting of residential buildings, which can achieve remarkable energy savings through the integration of an innovative adaptive ventilated facade system. The main components of the E2VENT system are represented in Figure 1.

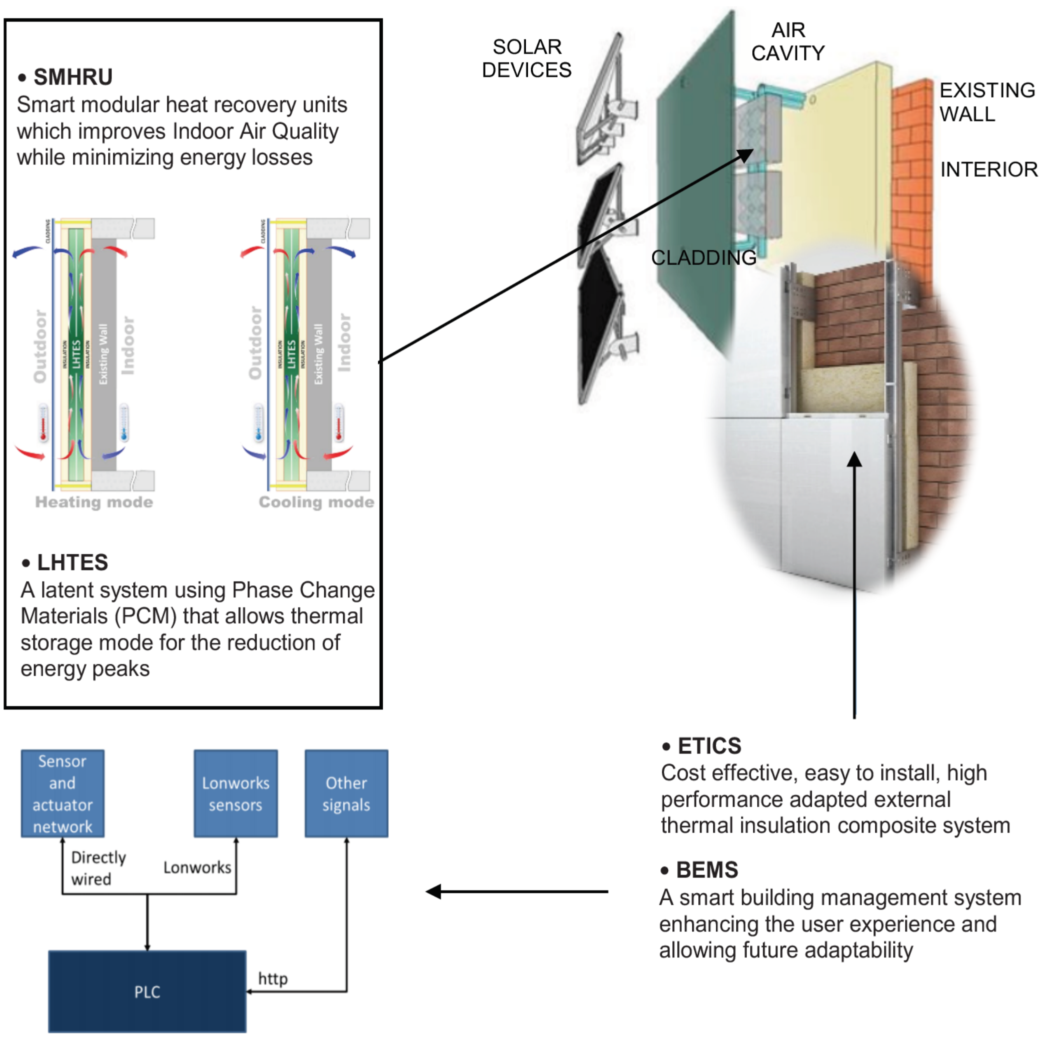


FIG. 1 concept of E2VENT retrofitting solution for the building envelope.

The Smart Modular Heat Recovery Unit (SMHRU) aims to preheat inlet ventilation air in winter and precool it in summer, thus allowing a great reduction in energy consumption.

Such air heat exchangers for ventilation already exist but are not designed for this specific use. Here, the main development has been in adapting the component to allow it to fit within the air cavity of the ventilated facade. The first SMHURU prototype can fit within a 200mm thick box measuring 1600 x 500 mm, resulting in a total weight of about 30 kg.

The Latent Heat Thermal Energy Storage (LHTES) system improves the capacity of the building to store heat. In this way, storing this heat during the day and rejecting it during the night allows for the cooling of the building. Such a system has already been developed by Nobatek (Dugué, 2016) and integrated in two experimental buildings called Napevomo and Sumbiosi, which were built for the international competition Solar Decathlon Europe 2010. The first LHTES prototype fits in a box measuring 2500 x 800mm, with a thickness of 200mm, giving a total weight of about 100 kg.

The developed technologies will be integrated into the ventilated facade, and a real time intelligent facade management system based on meteorological methods of forecasting will control the operation of the system, leading to decentralised electricity production and enabling the energy (electrical and thermal) demand of the building to maximise re-usage. It will inter-operate with existing or latest state-of-the-art Building Energy Management Systems to achieve optimum energy efficiency by reducing primary energy needs, CO_2 emissions and peak loads, assuring at least the same comfort levels required by Member States Building Codes, at an affordable price.

Aside from the difficulties related to the specific development of the new technologies, which happen at the component scale, the project has to provide an integrated solution for the facade retrofitting that is aesthetically pleasing and allows for efficient assembly and maintenance procedures. To this aim, the study of the interfaces of the components and the installation process come to be of critical importance, since different approaches may lead to completely different results. Therefore, the engineering behind the assembly and the architectural detailing of the E2VENT solution are also priorities of the project, and should allow the achievement of the following objectives:

- To fabricate the system as a **modular** ventilated facade system, from the point of view of an **industrialized concept**, avoiding onsite installation errors and losses of performance.
- To produce the system with innovation criteria, analysing new products as perforated metal profiles for the substructure, new anchorage designs with thermal brake and new materials as low emissive superficial treatments for cladding components.
- To develop the system keeping in mind **easy and affordable access for maintenance** of all technologies and components.
- To develop the system with a degree of high adaptability in order to allow it to **adapt to different scenarios or climate zones.**
- To design the system from a sustainable point of view, allowing energy efficient production and using **materials and components with a high value in life cycle analysis**.
- To improve the aesthetic of the rehabilitated building, increasing its economic and social value.
- To **increase the durability** of the envelope and raise the life expectancy of the rehabilitated building.

The paper shall then present the schematic procedural approach that developed within the project to overcome the issues related to the integrated design of the E2VENT system.

2 PROCEDURAL APPROACH FOR THE INTEGRATION OF A NOVEL ENVELOPE COMPONENT

The design integration process developed within the E2VENT project can be seen as a specific application of the Integrated Design Process concept expressed by Larsson (2002) or those proposed by the International Energy Agency (IEA, 2013). The process is follows a four step procedural approach:

1. Definition of the **typical system configurations;**
2. Exposition of **components parameters and interfaces;**
3. Development of the **control strategy** (building energy management system);
4. Definition of **assembly and disassembly** procedures.

The following sections discuss each step further.

3 DEFINITION OF THE TYPICAL CONFIGURATIONS

3.1 TYPICAL FACADE CONFIGURATIONS

The assembly of the E2VENT system depends on several aspects of the retrofitted building facade. These aspects are mainly related to the shape, geometry and proportions of elements in the facade such as window dimensions, storey heights, boundary conditions etc. For instance, the two different facade morphologies in Figure 2 imply different possibilities in terms of optimization of the system.

(a)

(b)

FIG. 2 different distribution of the LHTES and SHMRU components according to two different facade morphologies (red rectangles are representing possible locations of the LHTES/SHMRU modules).

Therefore, in order to define the assembly strategy, it is necessary to determine the configurations to be studied according to the most frequently recurring types of the target building stock.

Starting from these considerations, the most often recurring facade components whose variations we need to take into account have been identified and categorized as follows:

- In relation to the building´s **external appearance** (window dimension and position, access doors, number of storeys in the building, possible relationship of the facade to the roof, municipal regulations, rainwater gutters, air conditioning and other HVAC units, exhaust stacks);

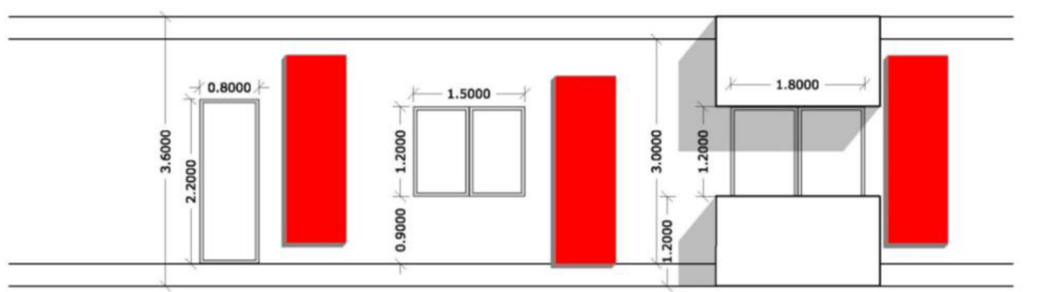


FIG. 3 three main categories of elements influencing facade morphology, being doors, windows and balconies (red rectangles are representing possible locations of the LHTES/SHMRU modules).

- In relation to the **building interiors** (occupancy of the apartments, presence and position of radiators or other existing climate-regulating devices. Types of window framing, presence of window shutters, presence of floor plinth);
- In relation to the **existing facade´s construction methodology** (superficial layer, wall material, wall thickness).

E2VENT architectural integration is also strongly related to the existing architectural characteristics to be refurbished in the building.

The infinite architectural possibilities may be reduced when the following recurring aspects are considered:

- The finishing material is based on aluminium shapes.[12] That allows variability in shapes and colours. This also allows the creation of large modular surfaces with small joints between.
- The necessity to guarantee the air flow from outside the cavity.
- The minimum thickness requirement for the overall system is 20 cm.

Based on these considerations, some possible facade design assemblies are provided hereafter.

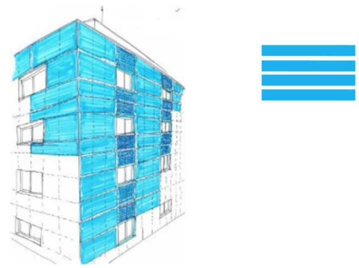
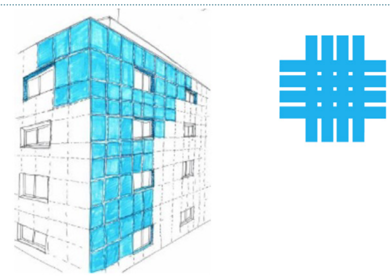
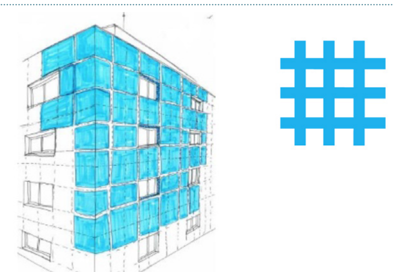
Integration Model 1.A. -The panels are disposed on a horizontal orientation. -Even if the joint between the panels is minimum this modularity already defines an architectural composition. -The air supply areas are solved with specific micro-perforated panels that at the same time allow the maintenance from the window of the E2VENt units.	
Integration Model 1.B -The panels are disposed on a vertical orientation. -Even if the joint between panels is minimum this modularity already defines an architectural composition. -The air supply areas are solved with specific micro-perforated panels that at the same time allow the maintenance from the window of the E2VENT units.	
Integration Model 1.C. -Small square panels are disposed –The air supply and the maintenance can be done from the aluminium frame that E2VENT system includes on the window details solution.	
Integration Model 1.D. -The possibilities to use big aluminium plates 150cmx320cm allow creating big surfaces and locating the air supply and maintenance panels on the window frame.	

TABLE 1 Architectural integration models – case 1: flat facade building (light blue elements are representing plain cladding elements while dark blue ones are representing perforated elements to allow air exchange from LHTES and SHMRU with the outside of the cavity) – hand drawings by Pich Aguilera Arch.

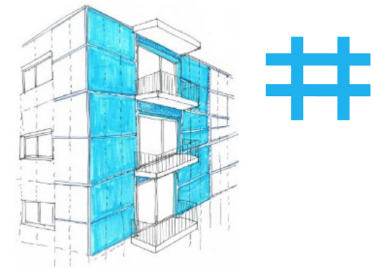
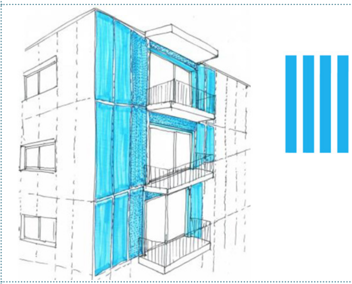
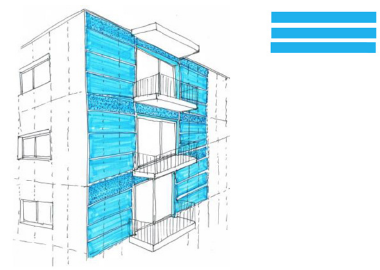
Integration Model 2.A. -The existence of some balconies could become a possibility to facilite the maintenance tasks.	
Integration Model 2.B. -The possibilities to use big aluminium plates 150cmx320cm reduce the colocation cost at the same time it's easy to incorporate the other E2VENT element (SMRU, LHTES).	
Integration Model 2.C. -The panels are disposed on a horizontal orientation. -Even if the joint between panels is minimum this modularity already define an architectural composition. -The air supply areas are solved with specific micro-perforated panels. -At once this surfaces singularity allows architectural different composition possibilities.	

TABLE 2 Architectural integration models – case 2: facade building with balconies (light blue elements are representing plain cladding elements while dark blue ones are representing perforated elements to allow air exchange from LHTES and SHMRU with the outside of the cavity) – hand drawings by Pich Aguilera Arch.

Additional considerations could also arise from the orientation and boundary position (in isolation or in common walls with other buildings) of residential buildings since these aspects may also influence the definition of typical configurations. However, we will not discuss these aspects further here in order to keep the focus on the methodological approach rather than on a detailed analysis of all the possible scenarios.

3.2 SINGULAR POINTS

In the detailed design of a facade it is important to identify those particular points which require specific details and may affect, locally or globally, the choice of the assembly. These points are referred hereafter as "singular points" in the facade design.

Several singular points have been identified in order to classify them in an abacus of typological details highlighting the critical aspects related to each one and providing the range of possible solutions according to the expected scenario. With reference to a generic target building, Figure 4 and Table 1 respectively show the location on the facade and the reasoning behind the development of each singular point solution.

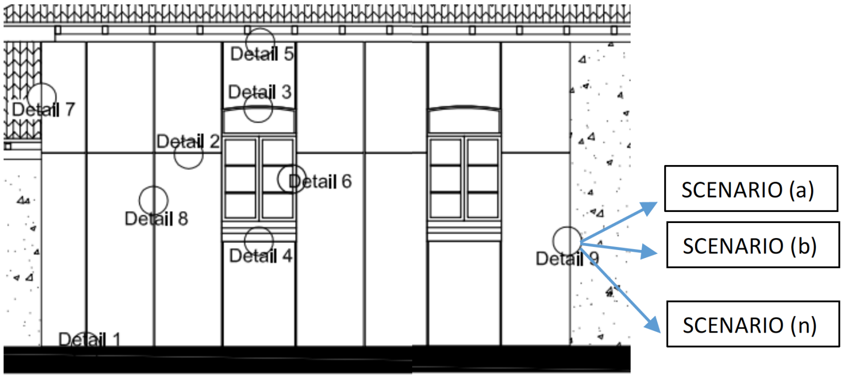


FIG. 4 example of singular points on a generic facade and analysis of their implications.

DETAIL	DESCRIPTION	POSSIBLE SCENARIOS	SPECIFIC ISSUES
#1	Interface between the E2VENT system and the base wall	a Planar ground level	...
		b Slope at ground level	...
#2	TOP-DOWN interface between two facade modules	c. Modules aligned on the same plane	– Need to develop air- and watertight details – Need to allow easy assembly and replacement procedures
		Modules not aligned on the same plane (e.g. curved facade shape)	As for scenario a. If only a local issue then see also detail #7.
#3	Facade edge as outline of curved/irregular shapes	...	– Need to develop a new finishing element at the facade edge – Need for a cut-to-measure facade module
#4	Window sill/lintel	...	...
#5	Interface between the facade and the roof eaves	a. No overhanging eaves	Need to develop a new finishing element at the - facade top edge (coping)
		b. Overhanging eaves with t>E2VENT thickness	– Need for a cut-to-measure facade module – Need to provide an efficient solution for the air extraction
		c. Overhanging eaves with t<E2VENT thickness	See issues for both scenarios a. and b.
#6	Window jamb	As for window sill/lintel	...
#7	Facade corner	a. End of E2VENT intervention	Need to develop special facade modules
		b. To comply with E2VENT intervention on the other side of the facade	Need to develop special facade modules
#8	SIDE-SIDE interface between two facade modules	a. Modules aligned on the same plane	– Need to develop air- and watertight details – Need to allow easy assembly and replacement procedures
		b. Modules not aligned on the same plane (e.g. curved facade shape)	As for scenario a. If only a local issue then see also detail #7.
		c. ...	...
#9	Interface at the edge of the refurbished part of the facade	a. Refurbished part to end against a perpendicular not-refurbished facade portion	– Need for a cut-to-measure facade module – Need to develop air- and watertight details
		b. Refurbished part to end in the middle of the same facade portion (i.e. not in correspondence of a morphological discontinuity)	– Need to define a new finishing element at the facade side edge – Need to lower the thermal bridge as much as possible
		c. ...	...

TABLE 3 Singular points and possible related design scenarios (examples).

4 EXPOSING ELEMENT DESIGN PARAMETERS AND CONNECTIONS AT DIFFERENT SCALES

The E2VENT project sees the parallel development of novel technologies and novel components which generates the criticality of maintaining the consciousness of the whole system as long as the work on each component is progressing. This means that each part of the system must be aware of:

- restraints coming from the whole system design (e.g. total expected thickness, system functionalities, etc.);
- restraints coming from the interfaced components (e.g. weight of the LHTES to be made known for the anchoring development).

Restraints are thus determined, in turn, by exposing for each E2VENT component: 1) **interfaces** with other E2VENT components - component scale, and with the building - building scale (Pavitt, 2002), and 2) all the relevant geometric, material and performance **parameters**. To this aim, the approach adopted by the E2VENT project was to create a live database called Design Integration Matrix (DIM).

Besides its main scope, the DIM will contain multidisciplinary information which are also useful in order to:

- provide an overview of global geometry;
- make explicit the interfaces and ensure compatibilities;
- propose, criticize, debate and make some decisions in order to be able to fix some parameters (the total width for example);
- compile and validate the information arising from and feeding into the modelling (mechanical and thermal);
- record the system development history.

Table 2 shows the list of parameters that have been collected, shared and constantly updated throughout the project, forming the previously defined DIM.

DESIGN INTEGRATION MATRIX			
Overall system	size	**Air cavity**	thickness
	thickness		expected air flow speed
	weight	**Insulation layer**	size/type
	cost		thickness
LHTES	size/material		weight
	thickness		cost
	weight		thermal conductivity
	power supply	**Insulation layer around the LHTES case**	size/type
	air flow rate		thickness
	PCM		weight
	holes		location
	cost		cost
LHTES	integrated devices	**Insulation layer**	thermal conductivity
	interfaces	**Cladding**	size/material
SMHRU	size		thickness
	thickness		weight
	weight		joints
	power supply		maintenance (freq.? cost?)
	expected operational flow-rate	**Interfaces**	building structure
	energy savings		building MEP systems
	cost		framings and windows
Anchoring for the cladding	size	**BEMS**	cabling
	spacing		power supply
Anchoring for LHTES and SMHRU	material/weight		accuracy
	cost		resolution
	strength		users control
	anchoring points		interfaces
	spacing		combination with existing energy systems (e.g. PV, solar, etc.)
Details	sealants and fillers		cost
	balconies	**Aesthetics**	internal finishing
	windows		external finishing
Expected performance	strength	**Industrialization process**	production
	thermal insulation		assembly
	linear thermal bridges		
	energy savings		
	acoustic insulation		
	air- and Vapour tightness		
	fire resistance/reaction [REI/class]		
Expected performance	durability		
	sustainability		

TABLE 4 Design integration Matrix – list of collected parameters

5 BUILDING ENERGY MANAGEMENT SYSTEM

The Building Energy Management System (BEMS) is the set of devices and procedures used to turn what could have been a passive solution for facades into an active set of different elements. The BEMS obtains data from the environment through the use of sensors, and utilising behaviour procedures, schedules, and pre-set parameters makes decisions in order to optimize costs and/or energy savings by means of handling the E2VENT solution (via controllers) and the HVAC elements of the building (depending on the case).

5.1 SELECTION OF SENSORS AND CONTROLLERS

There is a strong connection between the use of sensors to gather data from the environment of the system and the controllers used to modify the working parameters of the system and, generally speaking, they have to overcome certain issues that are raised during the design procedure, the prototype testing, and finally during the demo testing. We can divide these issues into four categories: **commercial, assembly, maintenance** and **end of service**.

5.1.1 Commercial features

The components used for the implementation not only have to fulfil their purpose in terms of technological features, but also have to be affordable and available on the local market. These are not small issues, and as such will limit the selection of devices that can be used in the final solution.

5.1.2 Assembly

There is a differentiated treatment dealing with the sensors and controllers in terms of assembly issues. Sensors and their ancillary equipment can operate almost independently from the rest of the E2VENT infrastructure, and the single problem in this is where to place the sensors and which paths the cables should follow in order to minimize their impact within the general structure, to avoid undesirable interferences and facilitate maintenance.

The controllers are a different matter, as long as they are the backbone of the interactive part of the system. They have to be developed at the same as the other parts of the prototype, and they are strongly dependent on the components chosen for the controls, specifically the dumpers and fans.

Optimizing hardware assembly and cable paths is also needed in order to achieve smaller size components (the first BEMS prototype requires a free box of 60x60x20 cm – see Fig. 5 – optimized components should be less than half that size and will be placed within the LHTES or SMHRU case).

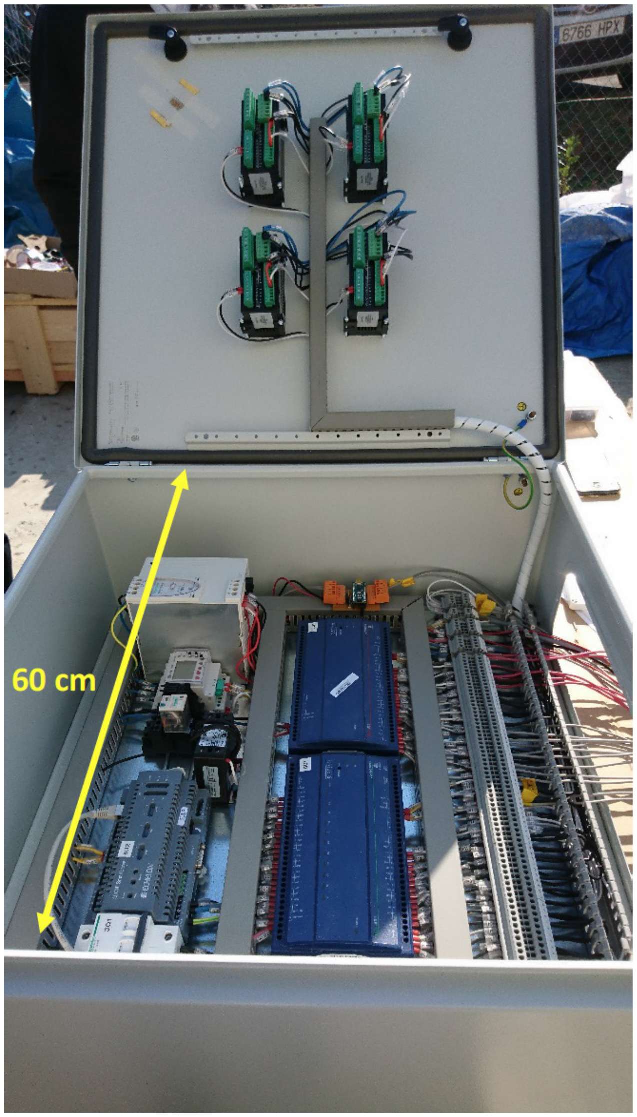


FIG. 5 First BEMS of prototype for the control of the LHTES and SHMRU (assembly by CARTIF). Image by D'Appolonia.

5.1.3 Maintenance

There are some maintenance considerations, which can be summarized in three main features: a correct positioning that can facilitate access to the elements so that they can be easily replaced; the price of the element to be periodically changed; and the skills necessary to properly perform the maintenance process. Also taken into account in other situations were issues such as the use of the alarm service of the BEMS in order to help detect whether any element needs to be checked or replaced, and the detection of failures in the signals from the controllers, or in the sensor values.

5.1.4 End of service

During the E2VENT project, the treatment of the residual parts of the system are considered to be part of the LCA and LCC analyses. They are included in the evaluation of the energy impact of the system in the different actuations.

5.2 INSTALLATION OF THE MONITORING AND CONTROL SYSTEM

In the initial approach of the project, the systems will be used as proof of concept. In order to achieve this, several configurations and programs will be used and tested for best performance and correct operation of the systems, and information on the inlet and outlet temperatures, external weather conditions and forecast previsions has to be gathered. Initially, a net-based monitoring system will be deployed inside the building to determine the internal conditions, temperature, relative humidity and CO2 concentration. Many other temperature sensors and actuators must be installed on the SMHRU and LTHES in order to know when to act on the ventilators, dumpers and other active parts of the technologies. A Programmable Logic Controller (PLC) will be installed and programmed to function as the brain of the system.
During the installation phase of the sensors, actuators and PLC there could be several issues, as discussed earlier.

Two options are considered for the placing of the installation of the control system. The first is installing the cabinet inside the building, but many wires must be run the PLC to the sensors and actuators. The advantage of this solution is that the PLC could be easily updated.

The second consists of installing the cabinet of the control system inside the ventilated facade. In this case, some wires must run from the building to the facade but they are fewer than in the first case. While this is an advantage, changes in the programming of the PLC will be more complicated.

Once the system becomes completely functional, the control system should be installed in the facade, and then other challenges could be addressed, such as the maintenance or the end of service for the product.

6 ASSEMBLY OF THE WHOLE SYSTEM

Some major considerations regarding aspects that may influence or constrain the components have been examined and are briefly recalled hereafter.

Assembly (and disassembly) process is considered both:

- at the installation stage and;
- in terms of maintenance operations.

Regarding the installation stage, limitations are imposed upon single components in terms of weight, in order to make lifting and moving objects at the working site as simple as possible. Moreover, to comply with manoeuvrability requirements, both during the installation stage and in case of maintenance, modularity is another characteristic that has been incorporated into the system and this, in turn, has determined a min-max spacing for the anchorage.

The anchorage system of the LHTES and SHMRU, which is unlike the one for the cladding elements, has been designed considering a different possible bearing structures layout and trying to make the installation as easy as possible. Such an anchoring system is thus composed of two L-shape aluminium profiles that support the LHTES and SHMRU cases at both sides and can transfer their weight directly on to the wall or just to the beams/slabs when the wall does not have the required bearing capacity. Due to the weight of the assembled LHTES unit, around 100 kg, the two L profiles have been shaped to allow the fixation of the modules in two steps through a hang & lock mechanism: 1) lifting and hanging of the module; 2) calibration and final fixation through the tightening of few bolts. The assembly system also allows for dilatation and other joint movements in between old and new materials. The pictures in Fig. 6 show the concept and a few details of such an anchoring system from the installed prototype in Anglet.

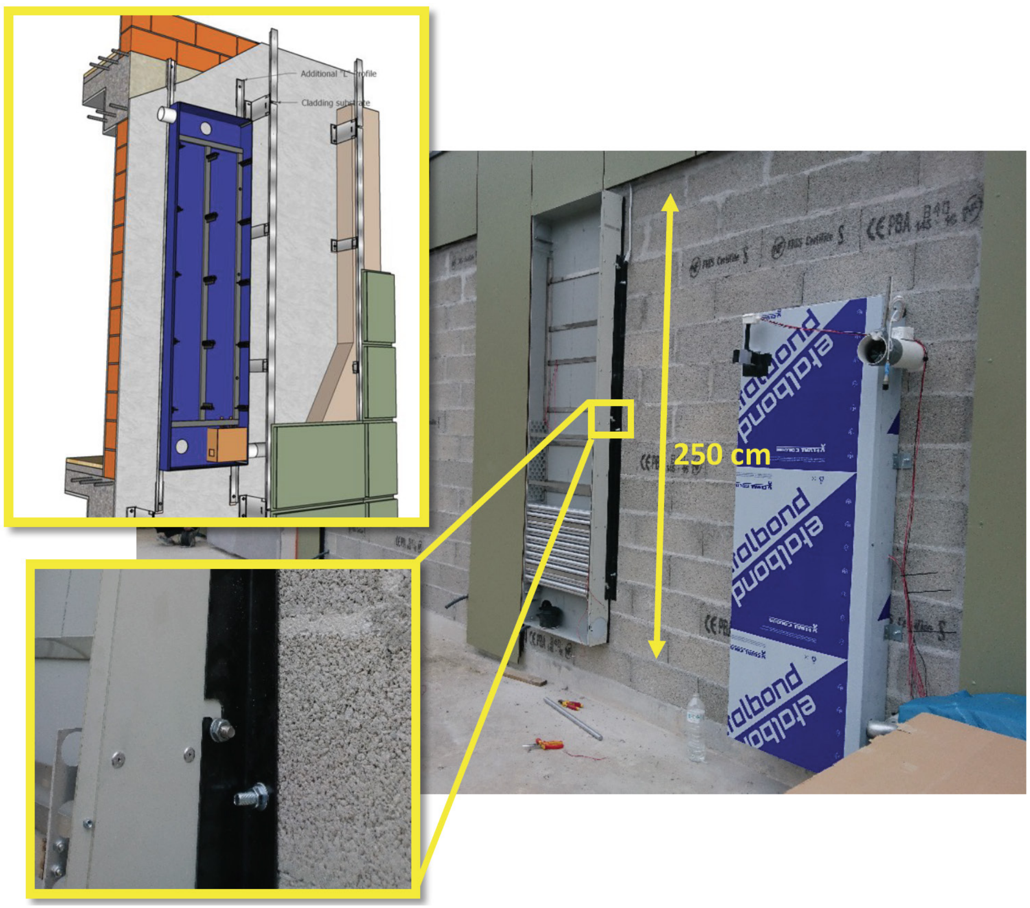


FIG. 6 Prototype installation at the Nobatek testing facility in Anglet, France. Images by D'Appolonia.

One of the most challenging decisions in terms of maintenance is whether to allow access to the single components from inside or outside the building. Any intervention from the inside has to be mindful of the users, while on the other hand, maintenance from the outside could be more expensive in cases where access to a high floor level is required.

However, in terms of maintenance, replacement of air filters and substitution of the fan are the most important points to be evaluated with regard to the frequency of their maintenance requirements. The substructure and cladding will be treated instead as per common ventilated facade installations. Regarding the integration of the LHTES in the E2VENT system, there is a possibility of condensation during cooling mode, therefore in humid climates it might be necessary to introduce a system for condensation disposal.

7 CONCLUSIONS

The E2VENT project focuses on the development of an innovative solution for the retrofitting of the building envelope. Specifically, the proposed solution is represented by a ventilated facade system that provides an increased thermal insulation coupled with a mechanical system for air renovation and heat recovery inside the building.

In such a research project, there is a tendency to place a major emphasis on those components that really represent the innovative part of the proposed solution, i.e. the LHTES and the SMHRU. While this is, of course, reasonable to some extent, there is a risk of underestimating the importance of managing the combination and integration of the single technologies under the project's unique initial vision.

The present work shows the systemic approach that the E2VENT project adopted to solve the design integration issues, and aims to highlight all the arisen technical and procedural aspects that have had direct or indirect impacts on the development of single components.

Endnotes

1. http://aerocoins.eu, last accessed on 23/02/2017.
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12. It is worth mentioning that the possibility to substitute the component materials to the local ones could be preferred at some point, for instance in order to reach sustainable and Km 0 products. However, a discussion about the rationale behind the choice of materials is outside the scope of this paper.

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