The SELFIE façade system. From Smart Buildings to Smart grid

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Abstract. The aim of the SELFIE (Smart and Efficient Layers for Innovative Envelope) project was to develop novel adaptive envelope systems for nZEBs, within the framework of a smart city, in order to facilitate the exploitation of RES at building scale and simultaneously decrease the energy consumptions and improve indoor environmental quality in non-residential buildings.

The process of designing innovative technological systems, capable of integrating smart materials and novel technologies, into the new construction and/or renovation of buildings, will be described in this paper. The objective is demonstrated how it is possible transferring know-how from different production sectors aimed to reduction of environmental impact of the built environment of our cities.

Keywords: Adaptive façade, nZEB, Renewable energy, Smart building, Smart materials

Introduction

A shared definition for Smart Cities might still lead to extensive discussions among experts, covering many areas related to energy technology development, environmental issues, politics and socio-economic aspects. Furthermore, following the outlines of the Smart Cities and Communities Initiative of the European SETPlan, Smart Cities are clearly focused on the promotion and dissemination of a new generation of innovative, intelligent and energy-efficient buildings: smart buildings and energy-efficient interactive buildings. In particular, the latter represent the next generation of buildings, where energy efficiency is not exclusively achieved by a single building but rather involves the entire energy infrastructure network of the city, and where buildings represent essential and strategic nodes for exchanging of production of energy (Arbizzani, Civiero, Ortega Madrigal and Serrano Lanzarote, 2015).

A smart built environment requires energy-system-responsive buildings ready to meet the needs of electricity, district heating and cooling grids and the broader energy system. Buildings are smart when they optimize the interplay between individualised consumer settings and physical energy flows e.g. in heating, cooling and ventilation systems. (De Groote, Volt, Bean, 2017)

In this context, what role will innovation in systems and components play in the future? Will we be able to change existent technological systems and develop innovative products in order to influence the building market or create new ideas capable of changing the lifestyle of people within the framework of smart city and/or smart building concepts? The answer to these questions is to achieve a sustainable good quality construction as an ongoing process starting with the new characteristics and opportunities for enterprises and to develop new components, such as adaptive envelopes, with high efficiency in order to satisfy the construction market and meet user demand for high-performance (Gallo, 2014).

For decades, architects and building scientists have envisioned the possibility of the envelopes of future buildings replicating human skin's adaptive response to changing environmental conditions (Davis, 1981; Wigginton and Harris, 2002). Advances in material technology and building automation systems are drawing these parallels between adaptive envelopes and the intelligent response of human behaviour and skin to environmental stimuli, seen as an increasingly feasible way of regulating energy flows through a building's thermal barrier in a controlled manner that promotes energy reduction and occupant comfort. Michael Wigginton and Jude Harris (2002) in their text on Intelligent Skin define this concept as an active and dynamic control system capable of regulating the interchange of energy passing between the inside and outside of an environment, ensuring an excellent level of comfort through the possibility of automatically varying the building's structure. A large number of sensors can regulate the system with precision, transforming the building into a smart building. The variability of the façade system makes it possible to regulate heat and light energy flows through its conformational layers, and has defined an evolution in research linked to phase change materials, advanced glass surfaces, such as electrochromic and/or photochromic glass, or mobile (horizontal and vertical) external screening systems.

The concept of the smart building is, therefore, closely linked to that of the smart façade, as the façade itself is the main element capable of changing its structure to ensure the required performances, emphasizing its resemblance to human skin. With these complex and multi-layer envelope systems, there is always the possibility of manual or automatic control so that the energy flows passing through them can be managed efficiently. The envelope thereby becomes a real organic system connected to the building's central control system and to the air conditioning system, which can be compared with the human artery system (Romano, 2011).

Moreover, the targets set by the Energy Performance of Buildings Directive 2010/31/EU and Energy Efficiency Directive 2012/27/EU on the energy performance of buildings, the rising cost of fossil fuels in recent years, as well as high emissions and tiny air pollution particles have led to the development of a new generation of smart buildings for a new generation of smart cities.

In this legislative and cultural contest, in Italy to overcome these barriers and driven by the scenarios presented by the European Community, the Italian Ministry of Education, Universities and Research and the Regional Administration of Tuscany funded a research project named SELFIE. It aimed to develop synergies between industrial companies, builders and research centres to increase competitiveness in the building sector and meet European and Italian standard requirements. The project aimed to increase energy savings in the Mediterranean climate, focusing

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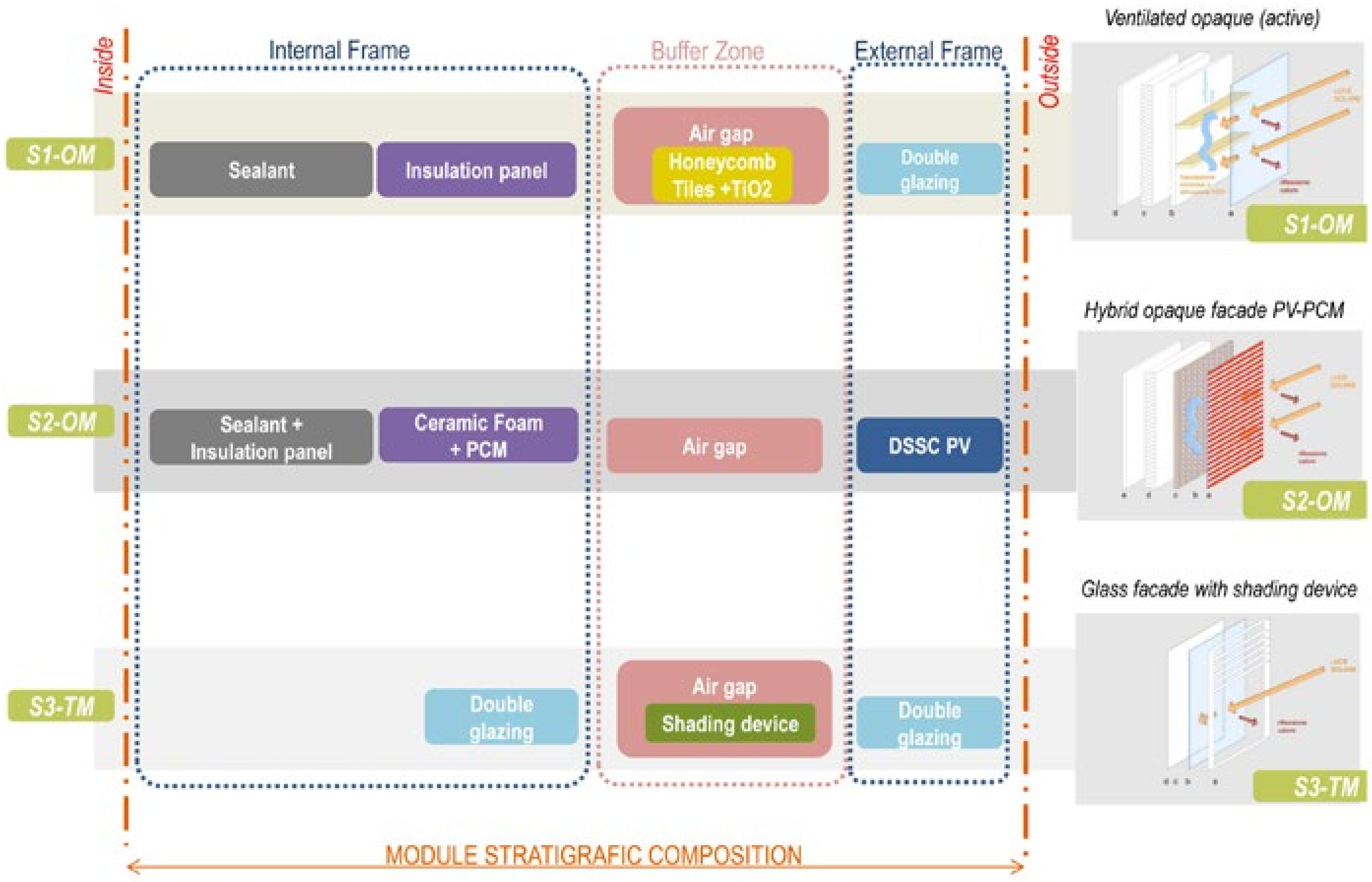


01 | Diagram showing the stratigraphic composition of SELFIE Modules

on summer comfort, developing and testing innovative envelope solutions. The research, in fact, is mainly focused on the design, testing and prototyping of innovative components for adaptive building envelopes, able to decrease energy consumption in line with the nZEB target for existing and/or new buildings located in South Europe.

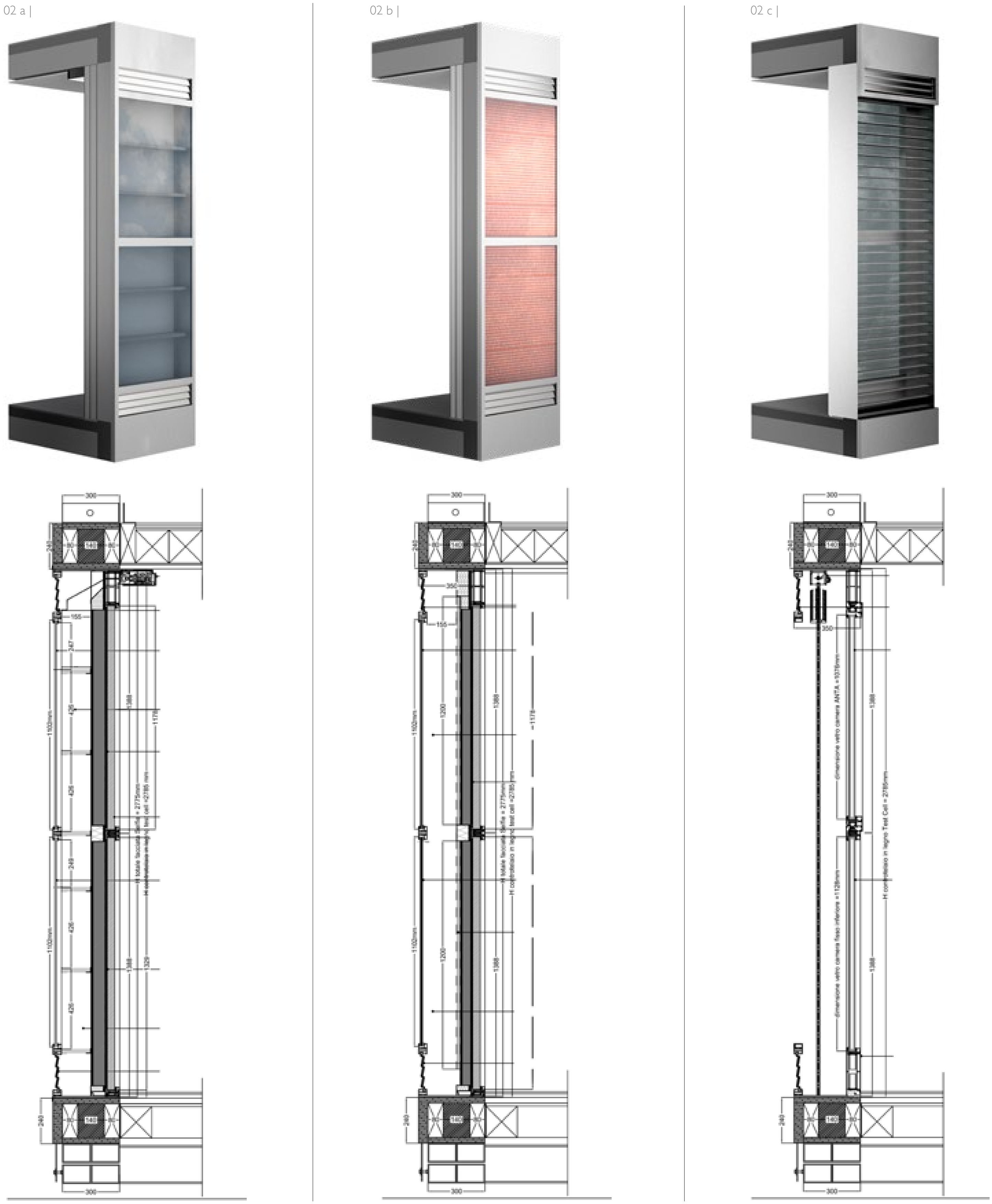
For these reasons, the aims of this paper is to describe the process of designing innovative technological systems, , capable of integrating energy savings, smart materials and novel technologies, that can be combined into the new construction and/or renovation of buildings in smart cities located in the Mediterranean area.

The SELFIE research project

The SELFIE components were elements for a vertical envelope with advanced environmental characteristics that could easily be adapted to different types of buildings and different construction systems, capable of meeting environmental compatibility requirements in terms of Life Cycle Analysis, enabling reduced energy consumption and the lowering of greenhouse gases on a global scale.

SELFIE building components actually meet the new requirements dictated by the environmental crisis, which increasingly calls for the scaled down use of conventional energy resources and consequently fewer climate-altering emissions in the air. As a result, advanced technical components are required for use in both new builds and restructuring and redevelopment projects.

The possibility of integrating energy production technologies in the façade system (such as photovoltaic modules) and innovative materials capable of integrating dynamically with the climatic conditions makes the three envelope components assembled in the SELFIE façade prototype particularly suitable for future integrations in smart urban contexts. These are highly innovative technological solutions able of transforming new and/or existing buildings into autonomous built environments from an energy and dynamic point of view thanks to the presence of interactive materials and systems.



02 | a) SELFIE 1: render and technological detail
b) SELFIE 2: render and technological detail
c) SELFIE 3: render and technological detail

The three components of the SELFIE façade system

The three prototypes of the SELFIE façade system, modular, dry assembled and combinable, designed to measure 92.5x140 cm, and can be configured into different geometric dispositions (Fig. 1).

As part of the research, we project six modules (two for each type identified by the project) aggregated within a double skin façade prototype, measuring 280x280 cm.

Each component appears as a double-frame structure allowing different layers assembled and multiple and specific functions of each layer to be combined. In particular, the internal frame accommodates elements designed to perform thermo-acoustic insulation and closure functions; while the external frame accommodates the surface closure layers exposed to atmospheric agents.

The general aim of the research was to develop envelope components that make it possible to assemble façade that integrate innovative materials and system solutions that can be incorporated into renewable energy generation systems.

SELFIE 1. Ventilated opaque façade

The aim of the façade component SELFIE 1 (Fig. 2a) is to reduce heat dispersion to the outside in order to contain energy consumption in both summer and winter. It contains an integrated system made up of ceramic honeycomb panels treated with photocatalytic paint, which contributes to air purification in the buffer zone.

The mainly "passive" function of the component provides for the integration of "active" elements (ventilation grills and heat exchangers) in order to exploit the winter greenhouse effect and ventilate the confined environment with sanitized air drawn in from the air gap between the internal opaque closure and the external transparent closure (Barbosa, Ip 2014).

The SELFIE 1 functional layers from the outside to the inside:

1. Laminated glass with PVB (Poly Vinyl Butyral) and IR (Infrared Reflective) coatings.
   This is a laminated glass sheet 12.76 mm thick, with a self-cleaning external treatment, coupled with PVB for greater mechanical resistance. The PVB is made of nanocomposite IR reflecting materials to reduce overheating phenomena inside the air chamber.
2. Mobile ventilation grills
   These are two aluminium outlets (h 18 cm, l 8.64 cm), positioned in the lower and upper part of the external layer, with horizontal slats that rotate on their axes thereby opening and closing the air gap according to the external climatic conditions and the need to reduce or increase the thermal transmittance of the component.
3. Air gap
   This is a buffer zone, 15.5 cm thick, for the passage of air from the outside to the inside in winter and from the outside to the outside in the summer months.
4. Ceramic honeycomb panel loaded with TiO2 (Titanium Dioxide)
   These are ceramic honeycomb panels measuring 15x15x2 cm surface treated with TiO2, aligned horizontally inside the air gap in six parallel rows. This geometric configuration ensures the air is purified as it passes through.
5. Thermo-acoustic insulation panel
   Internal closure and support layer, made up of an "ALU-Silent" composite thermo-acoustic insulating sandwich panel formed of an outer sheet of powder-coated aluminium, an inner sheet of tray-shaped aluminium and insulating layers made of self-extinguishing EPS (expanded polystyrene), drywall sheets and polyethylene a wool mattress produced from recycled bottles PET (Polyethylene terephthalate), total thickness 11.50 cm.
6. Three-way heat exchanger
   A small-scale three-way heat recovery aeration system, installed in the top part of the inner layer. This system, which has been altered with respect to market solutions, has been designed to optimize air conditioning in the indoor environment in the winter months thanks to the possibility of using purified air heated by the greenhouse effect in the air gap. In the summer, to avoid overheating in the air gap, the exchanger works as a fan directly expelling exhausted air from the confined space to the outside.

SELFIE 2. Hybrid opaque façade

The façade component SELFIE 2 (Fig. 2b) designed with the aim of:

- reducing heat dispersion to the outside in the winter months thanks to the presence of a thermo-acoustic insulating panel, identical in thickness and characteristics to that used in SELFIE 1;
- increasing thermal inertia in the summer months thanks to the presence of a panel made from an aluminium frame, vertically infilled by two glass sheets filled on the inside with ceramic foam loaded with PCM (Phase Change Materials). (thickness 2 cm);
- producing renewable energy thanks to the presence on the outer layer of an innovative DSSC (Dye-Sensitized Solar Cell) photovoltaic panel which produces electricity irrespective of its orientation (kWp: 0.028).

The component's performance is optimized by the presence of a buffer zone between the photovoltaic panel and the panel containing PCM, in which the speed of the passing air flow can be regulated thanks to the presence of mobile grills placed at the top and bottom of the façade system.

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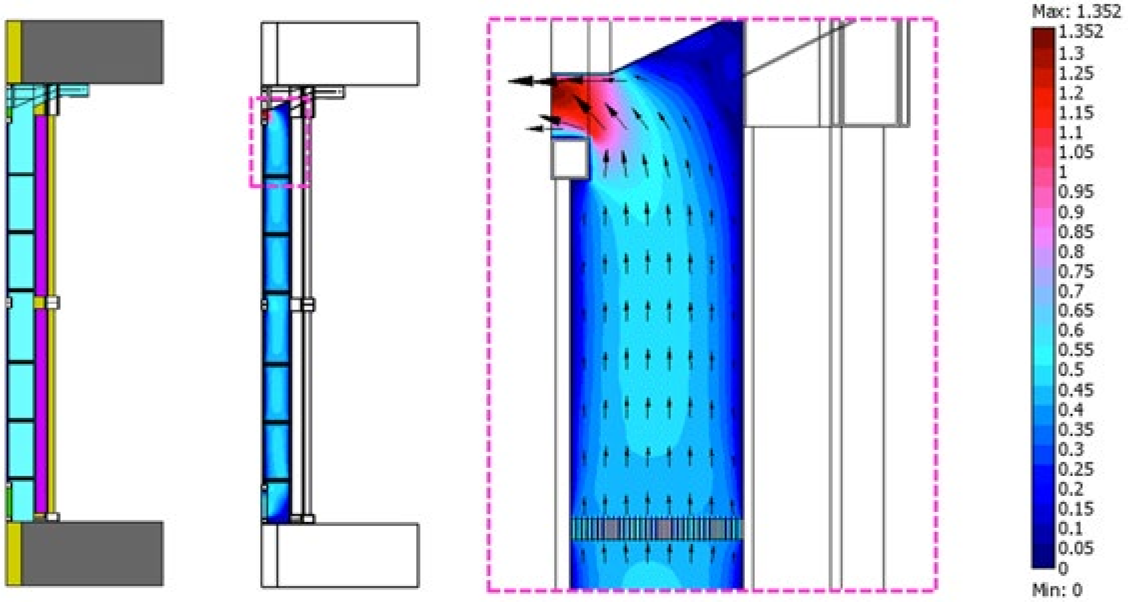

03 | Selfie 1. Stationary analysis of the motion fields (m/s) of air flows inside the air gap in the daylight hours of the summer months. Authors: prof. Carla Balocco, ing. Giuseppe Petrone (DIiEF)

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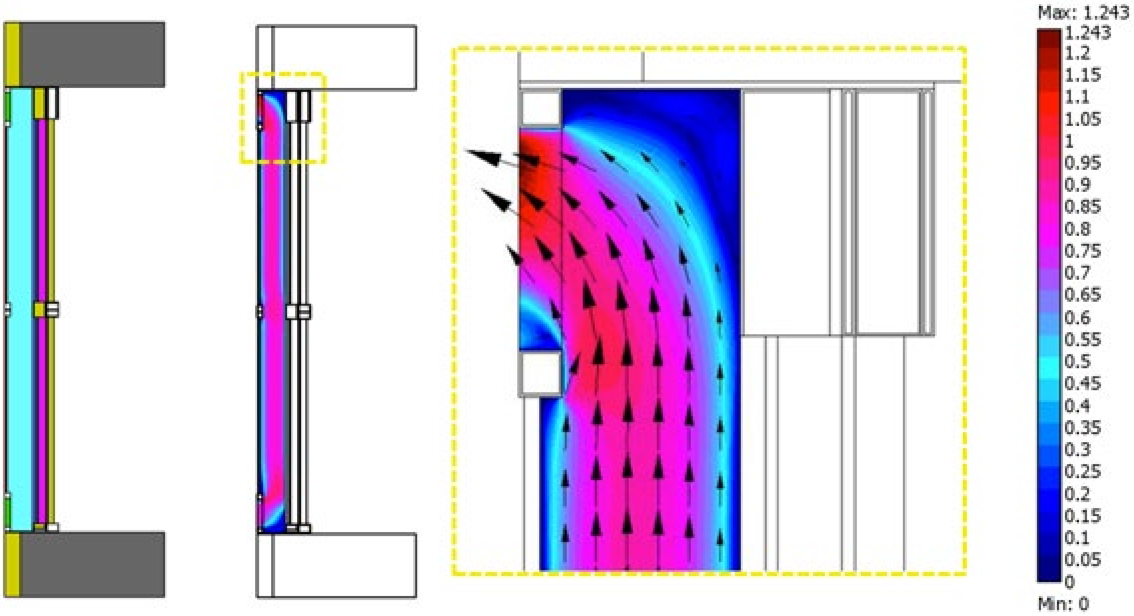

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SELFIE 3. Glass façade with screening

The SELFIE 3 (Fig. 2c) façade component designed to control incident solar radiation, limiting the passage of the thermal component (thereby avoiding summer overheating) and controlling the light component (to ensure good natural lighting in the confined spaces throughout the year).

The external sheet of the system is made of laminated glass with an integrated layer of PVB treated with IR coatings, mounted on an aluminium frame with thermal break. A solar screen created with motorized aluminium blades is positioned outside to further reduce indoor overheating in the summer months.

Simulation and analysis in design phase

In the concept stage, for the three SELFIE components and the façade prototype constructed with them, CFD (Computational Fluid Dynamics) and FEM (Finite Element Method) simulations were made using a multi-physics approach in steady and dynamic conditions (Favoino, Goia, Perino, Serra 2016). In particular, researchers from the UNIFI DIEF (Florence Industrial Engineering Department) operating unit developed solid two-dimensional models of the SELFIE components, against which to analyse the resolution of the motion and temperature fields inside the air gap, concurrently with reference meteoclimatic electrical transients. (Balocco, Petrone 2017)

The models made it possible to assess the thermophysical and energy performances of the system as the geometric-functional configurations varied during the design phase, providing input on fundamental design details, such as the width of the buffer zone and/or the size and positioning of the ventilation outlets.

The simulations conducted in the preliminary phase, allowed us to verify the façade performances in terms of heat dissipation during the summer season (ventilation flow rate, thermal power extracted for ventilation, thermal flow transmitted to indoor environments, periodic thermal transmittance), and in terms of energy containment and how the system operates as a passive solar element during the winter season (thermal buffering, periodic thermal transmittance, thermal flow dispersed from the indoor environment, free solar contribution to indoor environments). (Darkwa, Li, Chow, 2014).

The results obtained have highlighted, as in the SELFIE 1 and 2 (Fig. 3, Fig. 4) the ventilation rate of the cavity, is the wall working fundamental parameter useful to control the optimal transfer of the heat received by the external façade in the summer season. In particular, experimental data analysis has proved that mechanical ventilation is necessary in the SELFIE 2 in the presence of a radiant barrier effect of the wall during summer nigh-time. In this component, in particular, the energy benefit due to the phase change materials (PCM) has been studied in order to discharge the storage effect of the external and internal heat, through night ventilation.

Referring to the thermal flux transferred to the indoor environment, the results show that thermo-physical behaviour of the three SELFIE systems during winter conditions is very similar. Analysing results obtained for winter, it must be considered that when the external air temperature is lower than the internal one, there may be appreciable values of the incident solar radiation; this fact guarantees the natural convection inside the air cavity and then the chimney effect (with natural draft due to the air density differences, i.e., the effect of buoyancy forces). The chimney effect is also present without important values of the incident solar radiation because, in any case, the air warms up assuring the natural draft in the cavity. From the thermal exchange point of view, the total heat losses through the building components of each SELFIE system are not favourable, but the advantage consists of vapour condensation removal.

In the next few months, the SELFIE façade prototype will be tested to assess the performances of the component in a real application (Abitare Mediterraneo outdoor test cell) (Fig. 5) to compare them with the results obtained in the preliminary phase through the CFD and FEM simulations.

Material	Density	Thermal Conductivity	Specific Heat at Constant Pressure
	kgm^{-3}	Wm^{-1}K^{-1}	Jkg^{-1}K^{-1}
EPS	32	0.03	1700
Concrete	2200	1.8	880
Ceramic/TiO$_2$	2100	1.63	1016
PET	1380	0.28	1050
Plasterboard	1900	0.20	840
Aluminium	2800	200	900
Air	pR-1*I-1	0.026	1010
Ceramic foam/ Decanoic acid	1179	$0.789^{(S)}\div0.627^{(L)}$	1500
IR Glass/DSSC Glass	2410	0.937	840

TAB. 1 | Thermophysical properties of the materials integrated in the SELFIE components

Conclusion

Cities already consume 75% of global energy resources and account for 80% of emissions. By 2050, 66% of the world's population will live in cities. Cities are faced with these challenges, as well as the high expectations of citizens, severe budget constraints, and the need to attract jobs and investment. It follows that in order to become more efficient, sustainable, liveable, and attractive, cities need to become smarter.

Sector agencies define a smart city as cooperation and information sharing across sectors and systems to achieve sustainable outcomes. Information comes from connected devices, and today 45 per cent come from smart homes and smart commercial buildings. According to recent estimates, the total number of connected devices will grow from 1.1 billion in 2015 to 9,7 billion in 2020.

Many European cities are already beginning to create digital infrastructures that collect, manage, and analyse data from connected assets. Government agencies and wider groups of stakeholders are using "digital hubs" to gain new operational insights enable a more predictive approach and, in turn, improve the efficiency and quality of services.

Within this framework, the SELFIE project research shows how innovation within a project, company and occupational industry provides the opportunity to achieve significant benefits, and in a smart city it is a requirement for continued existence. In addition, in an effort to catalyse innovation in environmental building performances, the impetus for SELFIE will not be to simply create new building products for the built environment, but to develop enabling technologies that can engage in seeking a balance between aesthetics and efficacy.

The right number and the extensive professional expertise of the partners involved in the SELFIE research project, will guarantee its success and the actual possibility of developing new conceptual and operational tools to support the innovation process in the smart city and adaptive envelope field in order to promote nZEB buildings as envisaged in EU directives and the European SETPlan.

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05 | SELFIE façade prototype being monitored at the *Abitare Mediterraneo* test cell in Florence

Research developed thanks to MIUR (Ministry of Education, Universities and Research) and Tuscany Region (FAR-FAS 2014).
Official in charge for Tuscany Region, dott. Lorenzo Bacci.
SELFIE project has been declared effectiveness for the industrial development of the building sector, since the results obtained, in terms of technological solutions developed, are an industrial attractiveness into local scenario.

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