Facade 2018 -
adaptive!

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Facade 2018 - Adaptive!

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Contents

S 1

S 2.1

S 2.2

S 2.3

S 2.4

S 3.1

S 3.2

S 3.3

S 3.4

S 4.1

S 4.2

S 4.3

S 4.4

S 5

Preface

Lucerne University of Applied Science and Arts, the European Façade Network and the European research network COST Action TU1403 “Adaptive Facades Network” have joined forces in the organisation of the FAÇADE 2018 – Adaptive! Conference. This international scientific conference - held on November 26-27, 2018 at the culture and convention centre Lucerne (KKL), Switzerland – focuses on adaptive, multifunctional and dynamic building envelopes. It gathers excellent architects, engineers, researchers and representatives from the façade industry to discuss recent façade projects, the advances in the design, new adaptive technologies and future developments in research.

Within the FAÇADE conference series, this is the fifth edition – following the editions in 2010, 2012, 2014 and 2016 - held in Lucerne and organized by Lucerne University of Applied Science and Arts. Within the COST Action TU1403, it follows the mid-term conference held at the TU Munich in 2017. This book provides the proceedings of the FAÇADE 2018 – Adaptive! Conference and, as such, it forms one of the final publications of the COST Action TU1403 with the booklets ‘3.1. Cases Studies’, ‘3.2 Performance Simulation and Characterisation of Adaptive Facades’, ‘3.3. Research and Education’, and the Special Edition Adaptive! of the Journal of Façade Design and Engineering (JFDE), which is dedicated to the conference FAÇADE 2018.

Nearly 60 peer-reviewed papers, published by more than 150 authors from 30 different countries, provide a profound state-of-the-art on adaptive facades. Thirteen high quality papers have been selected by the scientific committee to be published in the special edition of the JFDE journal.

The papers are divided over five subthemes, which address products and materials for adaptive facades, strategies for design, performance assessment, experimental tests and post occupancy evaluation of adaptive facades. Moreover, five keynote presentations provide inspiring projects and ideas for further reflection.

Organising this conference and editing the conference proceedings has once again been an enjoyable experience. We would like to acknowledge all authors for their contributions, the scientific committee members for their valuable comments, our esteemed keynote speakers for their inspiring presentations, and of course, all conference participants for their interest in this event. In addition, we are grateful to our Sponsors Stahlbau Pichler, MHZ and HALIO, as well as the non-profit organisations Suisse Innovation Agency (Innosuisse) and the Swiss association for windows and facades (SZFF) for supporting the organisation of this conference. We also would like to thank the editors in chief of the JFDE journal, Ulrich Knaack, Tillmann Klein, Thaleia Konstantinou and Alejandro Prieto for their great support and the special edition dedicated to the FAÇADE 2018 – Adaptive! conference.

Finally, we would like to acknowledge COST for supporting both the conference and publication of these conference proceedings, and all COST Action TU1403 members for their contributions to make this happen. Particularly we would like to thank science officer, Mickael Pero, and administrative officer, Carmencita Malimban, for their great and valuable support during the course of COST Action TU1403.

We wish you an enjoyable conference and we hope you will find inspiring publications in these proceedings.

Andreas Luible, Susanne Gosztonyi & Stephanie Ly-Ky
Conference Organisers

Andreas Luible, Mauro Overend, Laura Aelenei, Aleksandra Krstic-Furundzic, Marco Perino, Francesco Goia, Frank Wellershoff, Shady Attia, Ulrich Knaack, Uta Pottgiesser, Christian Louter
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An innovative adaptive multilayer façade: evaluation in the test cell LABIMED

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Sustainable energy efficient building policies have shown a significant growth in recent years, deeply changing the way to design buildings. Directive 2010/31/EU prescribes more stringent commitments to increase energy efficiency in the construction sector to achieve EU standards nearly Zero Energy Building (nZEB). New technologies and design solutions need to be developed to meet highest performance levels for components and building envelope systems requirements. However, for advanced hybrid façades there are no established evaluation strategies and characterization methods to assess their energy performances. Evaluation of dynamic behaviour of adaptive façades using full-scale outdoor test facilities can significantly help to overcome these issues contributing to their performance assessment. This paper presents the evaluation of an adaptive multilayer façade by mean of LABIMED, a PASSLINK outdoor test cell at Florence University able to assess energy performances of full scale façade systems through a well-controlled realistic room sized environment equipped with advanced measuring instruments, providing a high quality of output data coming out from the dynamic monitoring test. Furthermore, a detailed description of the Test Cell LABIMED will be shown. Finally, the experimental test performed on a multilayer hybrid façade will be described, discussing the monitoring strategies adopted to evaluate the case study energy behavior.

Keywords: Adaptive envelope, Outdoor Test, Test Cell, Monitoring activities, Energy Performance.

1 Introduction

The building sector has a significant impact on energy saving. European strategies moving towards nearly Zero Energy Buildings (nZEB), as defined by the Energy Performance of Buildings Directive (EPBD) 2010/31/EU, also promoting smart technologies integration in buildings and product innovation in the construction sectore. In this framework, the research in the field of adaptive building components, advanced materials and nanotechnologies, shows a great potential, and lately led to significant results, completely changing the way to conceive and to design the building envelope (Perino 2007; Becker 2014; Aelenei 2014). However, for these advanced façade systems there are no yet established evaluation strategies and characterization methods to assess their energy performances. In many case, in fact, results from traditional laboratory tests are very different from the real operating conditions applied in a full scale building, because they don't take into account the effects due to the changing outdoor conditions (AA. VV. 2015). Therefore, evaluation of dynamic behavior of adaptive façades using full scale outdoor test facilities, can significantly help to overcome these issues, contributing to their performance assessment (Bloem 2007).

This paper shows ongoing research activities carry on an adaptive multilayer façade system SELFIE, developed by Abita Interuniversity Research Centre of Florence University, involving several partners such us research institutes on materials technology and construction industries. The first aim of the research SELFIE (Smart and Efficient Layers for Innovative Envelope) has been the improvement of more efficient architectural solutions, developed to be integrated both in new construction and existing buildings, to achieve high energy efficiency performances and to satisfy

the construction market trend requirements for buildings energy saving and indoor environment quality (Gallo and Romano 2017).
In detail, the first part of the paper presents the design and technology features of a full scale test facility for the Mediterranean area: the Test Cell LABIMED, an outdoor laboratory built to study innovative façade systems under real climatic conditions (Alcamo and Donato 2011; Baker and Van Dijk 2008). The second part is focused on the experimental activities provided for the outdoor test in order to analyse at the full scale the energy performances of an adaptive façade system developed in the frame of SELFIE research.

2 The Test Cell LABIMED

2.1. The project of a test cell for Mediterranean climate

The Test Cell LABIMED was realized in the frame of the research project Abitare Mediterraneo, funded by the Tuscany Region and developed by the Architecture Department of the Florence University jointly with 12 Italian companies of building sector in 2010. The main aim of this project was to create a system in which technological innovation and architectural quality could finding real application in the construction field, increasing energy saving and promoting a close collaboration between manufacturing companies, builders and research centres (Gallo 2014).

Test Cell LABIMED can be considered a significant result of this research. It was realized in order to investigate the overall energetic and thermo-physical performances of opaque and transparent façade systems, testing full scale products by means of dynamic measurements in real climatic conditions.

The advantages offered by using test cells, compared to other methods, depend on the possibility to test full scale envelope systems by means of well-controlled realistic room sized environment equipped with advanced measuring instrumentations, providing a high quality of output data coming out from the dynamic monitoring test (Bloem 2007). Moreover, these reliable data sets can be largely used for data analysis and to validate the most common building energy simulation tools.

The project of Test Cell LABIMED gone arise to the outcomes of the research activities carried out during PASSYS and PASSLINK projects (Baker and Van Dijk 2008; AA.VV. 2015). They were focused on development of agreed quality procedures for full scale test and dynamic data analysis, investigating the energy quality and thermo-physical properties of passive solar building components as: thermal transmittance, solar factor, and behaviour associated to its thermal inertia. Threfore, the test Cell LABIMED has been designed likewise the other EU PASSLINK Test cells, but improvements were achieved to overcome some critical aspects such as: indoor overheating, thermal bridges effects, problems due to infiltrations and heat conductive parts. For these reasons, it was built with a wooden structure in platform frame, where it is possible to integrate an insulated removable wood façade for placing the test sample (Fig.1).

All the envelope components were realized with the same material and had the same thickness (0.30 cm) and same U-value (0.32 W/m2 K). They were provided of wooden external solar shading device to avoid overheating which could affect the accuracy of results during the test.

The test cell was positioned on a rotating system to evaluate differences in building component performances corresponding to different orientations. (Fig.2)


a) b)

Fig. 1. a) The platform frame structure of Test Cell; b) The insulated removable wood façade for placing the test sample.

Furthermore, the LABIMED was equipped only with a heating system and an axial fan, which have the function to heat the air volume of the Test Room and to ensure the indoor air convection in order to reduce interior temperature stratifications. During the test, indoor ambient conditions of test room can be considered homogeneous. The electrical heater warms the air volume inside the test room and the air temperature sensors measure data to compare air temperature profiles at different heights. In order to establish an overall energy balance, the heater can be switched on and off from the data acquisition system and a power transducer measures the power consumption. During the test, the thermal power generated inside the test room by the heater and the heat flux rate through the envelope of the test room are instantaneously measured; the heat flow through the test component may be derived indirectly applying the overall heat balance equation.


a) b)

Fig.2. a) The routable platform to assess dynamic behavior of test sample corresponding to different orientations; b) An external view of the Test Cell LABIMED

2.2. Monitoring apparatus and Data Acquisition System

PASSYS protocol (Maldonado 1993) established highly standardized set of physical test parameters and experimental procedures. Therefore, the minimum set of sensors have been installed inside and outside to the Test Cell in order to monitore and to record all parameters required by PASSLINK method: each sensor is identified univocally by mean of an alphanumeric code which refers to PASSLINK specifications about both its location and type of parameter measured by sensor (Tab.1).

The south wall test sample requires an additional set of sensors (such as: thermocouples, heat flux sensors, humidity sensors, air speed sensors, etc.) depending on the test purposes.

Sensor	Quantity	Position	Parameter Measured	Unit of Measures	Accuracy	Range
Thermoresistance PT100	6	1 for each surface of the test room, 50 cm distance	Air temperature	°C	±0.1 °C	-20°C…80°C
Thermocouples type T	26	5 for each wall, 3 on the roof and 3 on the floor of the test room	Surface temperature	°C	±0.5 °C	-20°C…60°C
Miniature probe	1	Centre of the test room	Relative humidity	%	±0.5 %	0%...100%
			Air temperature	°C	±0.1°C	-20°C…80°C
Globe thermometer (PT100 sensor)	1	Centre of the test room.	Radiant temperature	°C	±0.1°C	0°C…120°C

Table 1: basic monitoring equipment installed inside the Test Cell

The measurement of radiant temperature allows monitoring the comfort indoor, providing some additional information such as data on radiative heat exchanges that take place through the surface of the globe and the inner surface of the test room. Furthermore, during the analysis of the data set, it is possible to suppose a single value of internal surface temperature obtained from the average value of all measured values.

A workstation unit is located inside the service room, it allows to manage monitoring equipment during the test and includes control and measuring devices such as:

- Data Logger which scans and records signals of all internal and external sensors connected. This is also able to control the switching mode (on and off) of the heating system inside the test room.
- Host computer to store all signals into a daily file for the post processing and analysis of data.

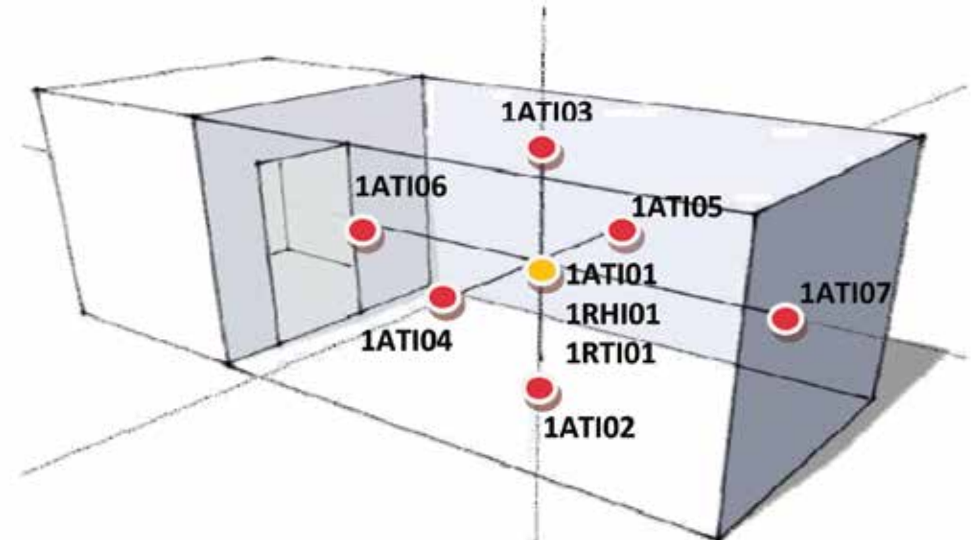


Fig.3. Scheme of Pt100 thermoresistances (1ATIn), globe thermometer (1RHI01) and miniaturized transmitter (1RTI01) located inside the test room

a) b)

Fig.4. Pictures of: a) The globe thermometer to measure indoor radiant temperature; b) The PT100 thermoresistance to measure indoor air temperature

A Data AcQuisition system (DAQ) has been configured using Labview software to acquire data from more than 80 sensors each minute and to manage all the system. An user interface permits to observe graphical profiles of all the monitored signals in real time to verify accurate functioning of all sensors and to identify eventually fails during the test. Moreover, DAQ system allows checking the switching of the heater inside the Test Room and to apply the heating test sequence including those defined by the PASSLINK procedures.

3 The Heat Flux Tiles System

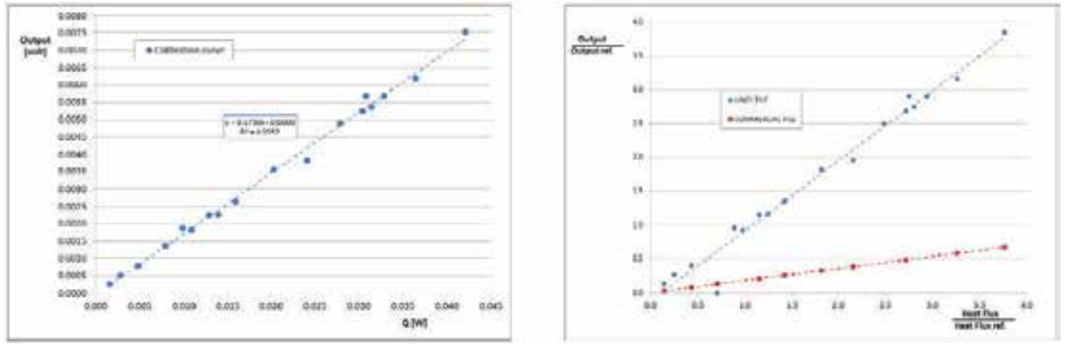
Compared to other PASSLINK Test cells, the main improvement of LABIMED concerns the presence inside the test room of Heat Flux Tile (HFT) sensors (Linden, Dijk, Lock and Graaf 1995) developed from the Industrial Engineering Department of the University of Florence (DIEF) using Peltier cell as sensitive element (with a surface of 1600.00 mm and a thickness of 4.00 mm).
In this innovative technological solution the Perltier cell was applied in the centre of HFT into a filling structure composed of two aluminium layers of 3.00 mm thickness, which have the same overall thermal conductivity as the Peltier cell (λ=0.8 W/mK). Furthermore, according to PASSLINK methodology, a layer of polyurethane foam was applied with the purpose to fill any air cavity behind HFT that would cause errors in the measurement of heat flow. An accommodation to allocate flat cables and connectors needed to wire the tiles in series and to join groups of signals for the measurements acquisition was obtained in the cavity. Therefore, the main feature of this type of sensor was that its sensitive component region and its surrounding area were characterised by the same thermal resistance. In this configuration, it is reasonable to assume the unidirectional heat flow and homogeneous surface distribution of heat flow through the tile and the measure can be considered reliable around the effective surface of the primary sensor up to the edge

The 230 prefabricated HFT sensors covered all the inner surfaces of the test room except the test wall (Fig. 5). In this way, during a test, the thermal power generated inside the test room by the heater and the heat flux rate through the envelope of the test room can be measured instantaneously; the heat flow through the test component may be derived indirectly applying the heat balance equation. Quality and accuracy of measurements data sets depends directly on the precision with which heat flow rate is measured through the envelope of the test room (Erkoreka, Bloem, Escudero, Martin, Sala 2015). Any rapid changes of heat flux measurements may be possible thanks to the small thermal inertia of the tiles.

The calibration values of the mentioned HFT sensors were obtained through laboratory tests (Donato 2016) performed by University of Florence, using a standard calibration device that consists of a hot plate apparatus with a guard ring. Moreover, the sensitivity of this new heat-flux sensor was optimised for the use in the test cell leading to an output signals in the range of mVolts, with high reproducibility of the measurements. (Fig. 6)

a) b)

Fig.5. Overview of: a) the Heat Flux Tiles system inside the Test Room; b) Connection in series by means of flat cables and interface modules to obtaining final signals.



a) b)

Fig.6. a),b)Results of calibration process of UNIFI Tiles in hot plate apparatus with a guard ring and comparison with a commercial tiles.

4 The SELFIE façade test

4.1 Features and operational functions of the façades

The research SELFIE, has been started since April of 2016 with the aim to develop three innovative envelope components that can be assembled, with different geometric configurations in the SELFIE façade (280.0 cm x 280.0 cm). The concept of the three SELFIE components (Tab. 2) foresees several functionalized layers that could be separately assembled depending on the architectural design of the building where they will be installed. In the integrated solutions, the layers considered all together and performances tested as a whole. (Romano and Gallo 2018)

In order to analyze their energy performance, SELFIE system prototypes have been designed and evaluated in the concept phase, by mean of dynamic energy simulation tools considering several operation strategies; in the executive phase, the façade prototype realized with the three innovative components has been tested under real outdoor conditions in the test cell LABIMED.

4.2 Experimental set-up and monitoring results

The prototype of the SELFIE façade, has been installed in the Test Cell since December 2017 with the aim to analyse its thermal performances.

The experimental set-up of the system for winter measurements concluded at the end of March 2018. In these months we analyzed the energy performances of the winter façade configuration, when the ventilation grid was closed. The objective was to investigate the thermal performance of the modules in order to store heat into the air cavity keeping the system warm for a longer period of time and reducing thermal losses from inside to outside.

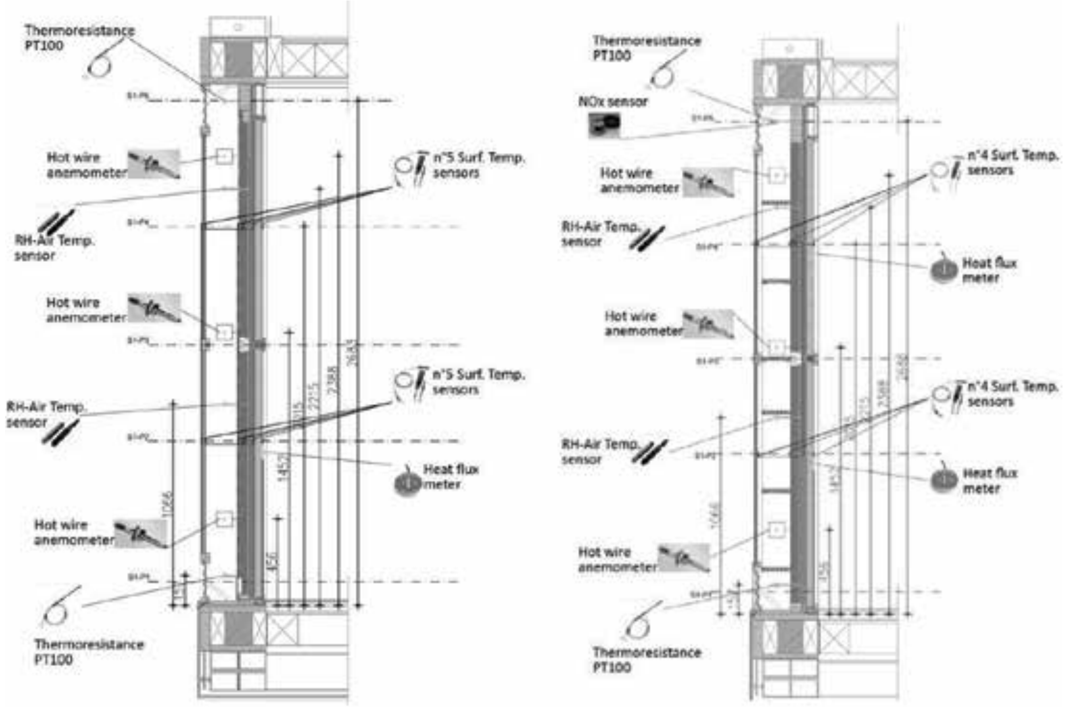
In detail in this paper, we shown the results of the analysis carried out during a monitoring campaign started on 24/02/18 and ended on 18/03/2018.

Type	Description	Operating mode
SELFIE 1	The component SELFIE 1 is an opaque panel composed of following layers from outside to inside: a) An outer glass layer assembled by two simple glass sheets coupled through a Poly Vinyl Butyral (PVB) film merged with nano-materials able to maintain the transmittance of the visible light and to reflect in the IR zone; b) A first internal layer realized with a panel of honeycomb, in the form of a porous ceramic charged with Titanium Dioxide (TiO2) material able to be activated with visible light a purification effect of indoor air; c) An insulated panel of closure applied on a support frame in aluminum thermal break; d) A heat exchanger system is also integrated in order to reduce building energy consumptions in the winter months and increase micro-ventilation in the inner space in the summer months.	In winter, the module is expected to work as a preheating air supply façade: during the day air ventilation grids on the outer surface allow the air to flow into the cavity; the outer glass surface preheats the air coming from outside activating natural ventilation of airflow, which by the effect of TiO2 coating on the honeycomb structure, purifies air that supplied into indoor zones. During the night, module works as a thermal buffer. In summer in the SELFIE 1, air is not exchanged between the inside room and outside, but comes from outside, cross the cavity and then is released outside again to dissipate the heat. Furthermore, the outer glass surface with a low-emission (low-e) coating reflects infrared radiation avoiding overheating.
SELFIE 2	The component SELFIE 2 is an opaque panel composed by following layers: a) An outer layer in Dye-Sensitized Solar Cell (DSSC) photovoltaic panels (PV), to produce renewable energy; b) An insulating layer in porous ceramic tiles integrating Phase Change Material (PCM); c) An insulated panel of closure applied on a support frame in aluminum thermal break.	The expected behavior of this module is to work as a thermal buffer in winter: during the day the DSSC PV panels absorb solar radiation generating heat into the cavity which is stored by the (PCM) during the melting process; when PCM solidifies during the night, the heat into the cavity keeping the system warm for a longer period of time. In summer, with high levels of solar radiation, the SELFIE 2 is expected to work as an outdoor air curtain: air is not exchanged between the inside room and outside, but comes from outside, cross in the cavity and then is released outside again to dissipate the heat. Insulation layer with PCM minimizes the effect of large fluctuations of temperature levels into the building and also shifts the heating and cooling loads to off peak electricity periods.
SELFIE 3 Transparent module	The component SELFIE 3 is a transparent panel composed by following layers: a) A window with thermal break frame with transmittance values of 1.2 W/m2K and a layer with a glass laminated sheet, with self-cleaning external treatment, coupled with PVB in order to maintain the transmittance of the glass visible light and to reflect in infrared; b) An electric venetian blind designed to optimize daylighting inside the building and to reduce thermal overheating phenomena in the summer months.	During winter, the double glazed window reduces heat losses from inside to outside thanks to a total transmittance of 1.2 W / m2K. During summer, the low-e treatment of outer glass reflected Infrared Reflective (IR) light and the solar shading system allows light transmission improving indoor lighting comfort and reducing thermal overheating phenomena.

Table 2: Description and operating mode of SELFIE modules

Forty-two sensors (Fig. 8) were integrated into the test sample during these three weeks, according to the pictures shown in the Figure 7 and connected to a Datalogger to measure each 10 minutes the following parameters:

- 4 thermo-resistances PT100 located behind the inner grids and the upper grids to measure the temperature of the air entering and leaving the gap of SELFIE 1 and SELFIE2;
- 20 thermo-resistances to measure surface temperatures of each layer constituting the three SELFIE components;
- A Nitrogen Oxides (NOx) sensor behind the inner grid of SELFIE 1 (measurement range 0…4000 ppm, accuracy ±0.1 ppm);
- 6 hot-wire anemometers to monitor air flows inside the gap in SELFIE 1 and SELFIE 2 at three different heights (measurement range 0…1.0 m/s, accuracy ±0.02 m/s);
- 4 heat flux meters to measure the thermal flows through the components in W/m2, in the centre of each SELFIE module, facing the indoor environment (measurement range -2000…2000 W, accuracy ±3%);
- A pyranometer located on the vertical plane of the test sample to measure the global solar radiation W/m2.



a) b)

Fig.7. Scheme of the sensors integrated in the SELFIE system prototype: a) SELFIE 1; b) SELFIE 2.

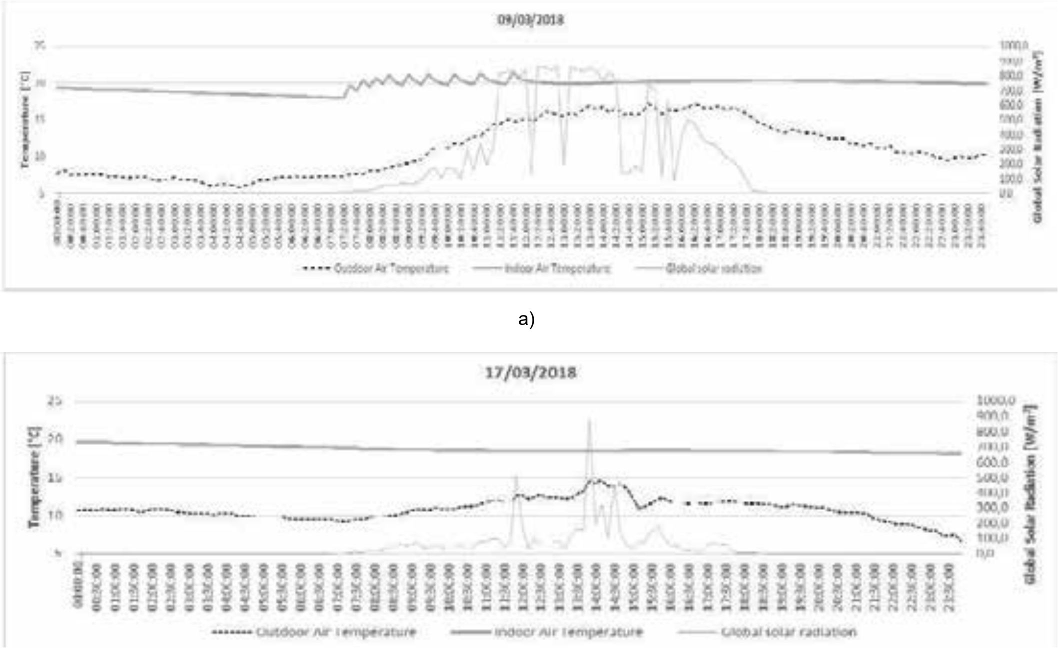
The measured values were compared with data sets from another weather station located on the roof of a nearby university building, 15,00 m height above the ground. The global solar radiation over the plane of test wall was included in the overall balance of heat exchanges that take place between outside and inside through the test cell envelope and the test wall. This data is recorded by means of a pyranometer located on the vertical plane of test sample. The area surrounding the Test Cell is a green area; however, measurement does not take into account the reflected part of solar radiation on the façade due to the grass covering the ground.

The analysis on dynamic behavior of the façade prototype refers to the 9th of March 2018 (sunny conditions) and the 17th of March 2018 (partially covered sky conditions). The heating system was switched on between 7:00 am and 7:00 pm in weekdays (Temperature set point of 20°C) and turned off during the weekend. Comparing Indoor Air Temperature and Outdoor Air Temperature during both the days (Fig. 9), the graphs show that even during nighttime, when the heater is turned off, the indoor temperature never goes down below 18°C. Consequently, the thermal performance of the SELFIE prototype can be considered good, with respect to the reduction of thermal losses in winter, keeping the indoor environment close to comfort conditions (temperature range 18°C-24 °C).

a) b) c)

Fig.8. a) Picture of The SELFIE prototype in the test cell LABIMED;b) overview of sensors installed on inner surface of SELFIE façade (b); overview of sensors installed on external surface of SELFIE façade.

The temperature profiles through the cross section of SELFIE 1 and SELFIE 2 modules are shown in Figure 10 at different hours during two representative days of winter period. As a result of thermal buffer operative configuration, the air temperature inside the air cavity of SELFIE 1 is between 40°C and 50°C during the day, with a temperature difference (ΔT) of 45°C from 9:00 am to 3:00 pm in sunny day conditions. Under overcast conditions, during the day, the air cavity temperature changes between 20°C and 25°C with a ΔT of 15°C from 9:00 am to 3:00 pm. The SELFIE 2 module, during sunny day, shows high temperature on the PV module, in particolar in the period between 12:00 am and 4:00 pm, when the surface temperatures reach values close to the melting temperature of the PCM. The PCM layer works as thermal storage, decreasing the temperature inside the buffer zone by 6°C - 7°C without changing its temperature.

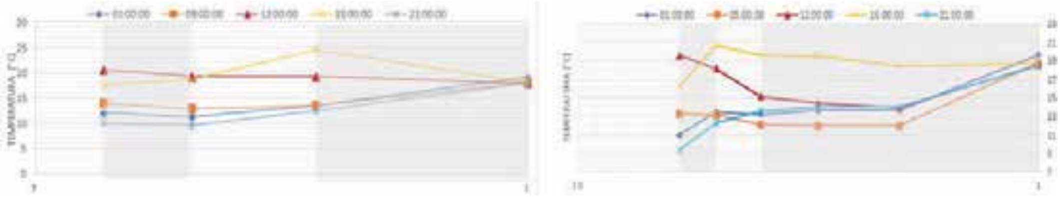


a)

b)

Fig.9. Indoor and Outdoor Air temperature and global solar radiation time profiles during a typical winter period: a) sunny day conditions and b) partially covered sky conditions.

9th of March 2018 (sunny conditions) 9th of March 2018 (sunny conditions)



17th March 2018 (partially covered sky conditions) 17th March 2018 (partially covered sky conditions)

a) b)

Fig.10. Temperature profiles through the cross section of a) SELFIE1 and b) SELFIE 2 compoennts at 9th of March 2018 (sunny conditions) and the 17th March 2018 (partially covered sky conditions)

5 Conclusion

The monitoring results during winter season show a good performance of SELFIE system (specially for SELFIE 2 module integrating PCM) in reducing thermal losses keeping the indoor environment close to comfort conditions also during the night, when the heating system is turned off. The experimental set-up of the system for summer measurements will be concluded at the end of August 2018. Furthermore, we hope to start the overall data comparison in September so to know exactly the thermoigrometric performances of the SELFIE façade in order to eventually improve its design concept.

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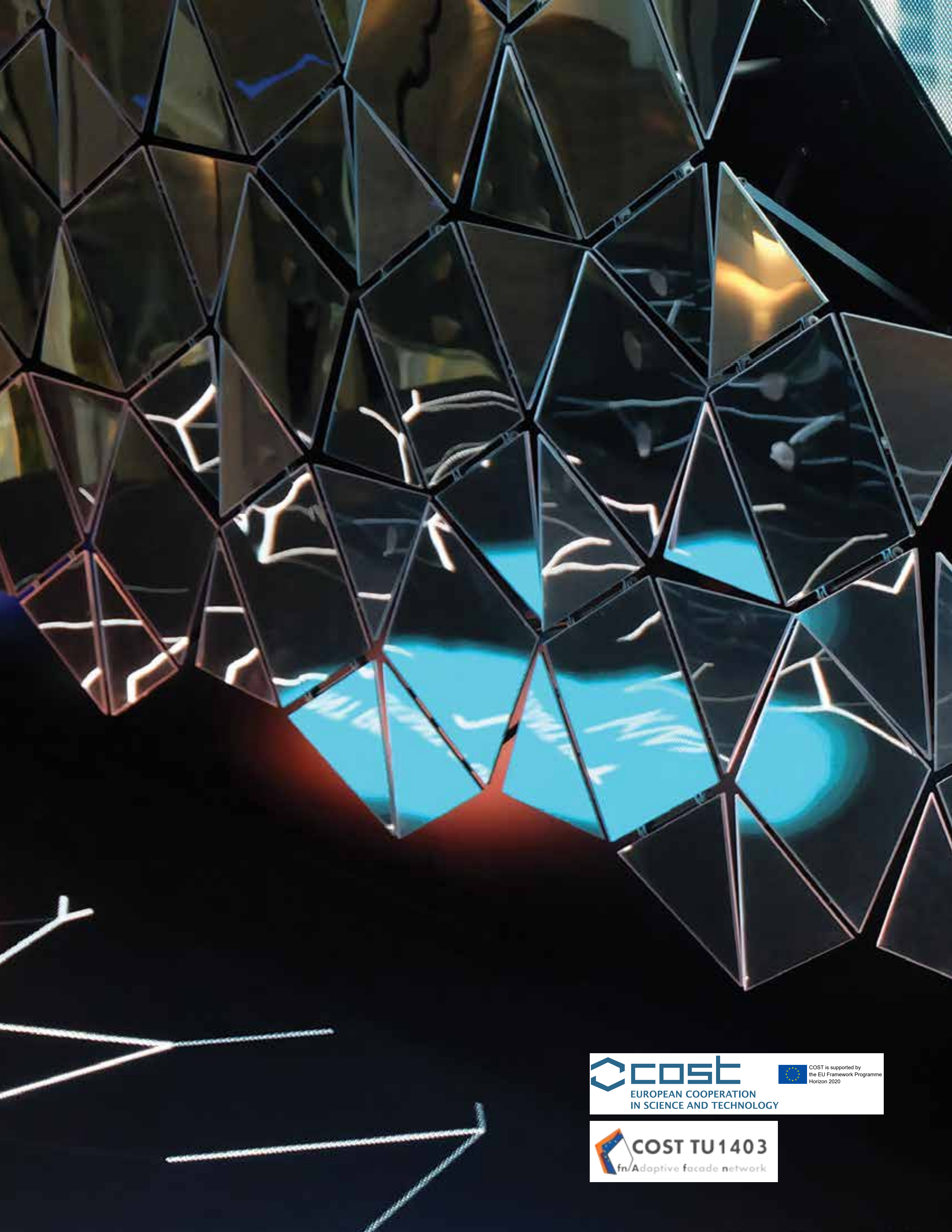
Author Index



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