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This is the peer reviewed version of the following article:

Original

Building Management System and Data Sharing Platform for Passive Cooling Strategies Assessment and Users' Awareness Increase: Design and Application to a Social Housing Context in Italy / Di Giuseppe, Elisa; Maracchini, Gianluca; Latini, Arianna; Bernardini, Gabriele; D'Orazio, Marco. - STAMPA. - (2024), pp. 309319.225-309319.235. (15th KES International Conference on Sustainability and Energy in Buildings, SEB 2023 Bari, Italy 18 September 2023through 20 September 2023) [10.1007/978-981-99-8501-2_21].

Availability:

This version is available at: 11566/328014 since: 2024-03-20T21:45:31Z

Publisher:

Springer, Singapore

Published

DOI:10.1007/978-981-99-8501-2_21

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Building Management System and Data Sharing Platform for passive cooling strategies assessment and users' awareness increase: design and application to a social housing context in Italy

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Abstract. The development and application of Building Management Systems (BMS) provide different benefits, related to optimizing real-time building monitoring and analysis, understanding users' behavior towards systems and components, collecting data to reduce the performance gap in building energy models, and also promoting users' awareness based on automation and control systems and feedback solutions. This paper deals with the design and application of a smart, wireless, reversible and low-impact BMS, integrated into two existing social housing buildings, selected as demo cases in the European "LIFE SUPERHERO" project. The information obtained from installed sensors (outdoor and indoor environmental conditions, occupants' behavior, roof performance) is stored in a server, thus allowing researchers to access data in real-time, and to carry out analyses related to the indicators and objective of the project itself (e.g., reduction of cooling energy consumptions, comfort optimization, etc.). Raw and processed data are then reported in a web-based Data Sharing Platform, called "HUMAN-BEHAVIORS monitoring data SHARING" (HU-BES) that provides qualitative and quantitative user-friendly data representation to specialized and un-specialized end-users, such as designers, stakeholders and occupants. Both the BMS and HU-BES are developed to be flexible tools that can be further integrated depending on the evolution of the project, for example, by adding other sensors or showing different performance indicators.

Keywords: Building monitoring system, Data Sharing Platform, LIFE SUPERHERO project, ventilated clay tiled roof.

1 Introduction

Building Management Systems (BMS) are useful tools to measure the overall building performance also considering the occupants' behavior impact [1–4]. They exploit computer-based control systems and monitoring elements installed or even integrated within the building (in its components and systems). Automation rules are usually implemented to regulate building's equipment as well as to inform decision-makers and designers about the building status [5]. Final application domains are mainly oriented to energy consumptions, occupants' comfort, maintenance tasks (e.g. predictive approaches and failure detection), occupants' safety in emergency conditions, building operation and scheduling [3, 6, 7]. Thus, beside automation tasks, the information acquired by the sensors deployed in the built environment is useful, for example, to [1, 3, 8, 9]: analyze the characteristics and performances of building components under different conditions (e.g. climatic, use-related); understand occupants' behavior and their interaction with new technologies; thus, better verify the real performance of buildings depending on their occupancy; calibrate and validate energy simulation building models to minimize the performance gap between predicted and measured data; diffuse feedback solutions, e.g. with via Data Sharing Platforms (DSP), to increase the awareness of both end-users (occupants) and stakeholders (designers, facility managers, contractors, owners and decision-makers).

In this general context, some of the most critical issues for BMS application to building operation is represented by indoor air quality and occupants' comfort, which are strongly interconnected and linked to the envelope and building systems characteristics, and strongly affecting energy consumption [9]. In view of climate change and temperature raise, also affecting urban heat island, summer is becoming a critical seasons in Europe, due to the increasing cooling demand and related energy consumptions [1, 3, 10, 11]. Passive cooling strategies in the building envelope could support the balancing and optimization of this dichotomy, thus providing significant benefits especially in building retrofitting and in specific occupants' conditions (e.g. those related to energy poverty) [11–13]. Nevertheless, the assessment of these solutions by using BMS is one of the fundamental tasks to support their effectiveness assessment, also in respect to occupant behaviors and lifestyle [1, 12]

The project LIFE19 CCA/IT/001194 "SUPERHERO - SUstainability and PERformances for HEROTILE-based energy efficient roofs" moves towards buildings performance improvement in this context, and aims to promote the use of ventilated and permeable clay tiled roofs (VPR) based on innovative air permeable tiles (called "Herotiles") as envelope passive cooling strategy in existing and new buildings [14]. One of the project's actions relies on the installation of a "Herotiles-based Roof" (HBR) on two existing multi-story social housing buildings placed in Reggio Emilia (Italy), characterized by poor energy quality and comfort. The objective of the action is to demonstrate the easy and cost-effective realization of HBR while entailing high energy and environmental performance.

In view of the above, this work aims to define a BMS and implement it in the building project demonstrators, and also to design and test a Data Sharing Platform (DSP), called "HUMAN-BEHAVIORS monitoring data SHARING" (HU-BES). In particular, HU-BES

collects and shares monitoring data coming from the BMS with expert and not-expert end-users and stakeholders, by using different indicators that are focused on the impact of roofs on the building performance and users' environmental awareness.

2 Methodology

The work is organized in two phases: the definition of BMS requirements and architecture by using a smart, wireless, reversible and low-impact network of real-time sensors, to be applied on the LIFE SUPERHERO buildings (Section 2.1); the definition of the DSP requirements and its preliminary development, which essentially relies on the identification of users' and the related definition of indicators (Section 2.2).

The BMS has been applied to two existing multi-story buildings built in 1980, located in Reggio Emilia, Italy (**Fig. 1**). The envelope is made of prefabricated concrete panels with double-glazed windows. The floors are composed of reinforced concrete slabs without insulations, while the flat roofs are made of a prefabricated reinforced concrete slab ("Predalles") with metal cladding.



Fig. 1 The two social housing demonstrator buildings of LIFE SUPERHERO project in Reggio Emilia (Italy)

2.1 BMS requirements

The BMS architecture should fulfil two different levels of requirements. General requirements represent the first level, and, in particular, concern the following conditions, which can be assumed according to existing guidelines [1, 8, 15–21]:

- 1) sensors' network should be non-invasive (in terms of visibility and usual environments fruition) and reversible, thus not affecting occupants' daily life as well as other stakeholders' actions (e.g. operation and maintenance on building systems and components, and related common interventions);
- 2) sensors' network should be easily and freely further implementable and integrable to meet specific needs of the project;
- 3) sensors and routing devices should have a wireless data transmission, to reduce the need of wiring, which affects adaptability and reversibility of the BMS application;
- 4) sensors and routing devices should also be durable and easy to maintain, since they should remain active for years after the end of the project;
- 5) BMS database should have a high data storage capacity, due to the necessity to ensure a long-term data collection and storage without data losses;

- 6) the whole BMS should provide the possibility of checking, consulting and analysing the recorded data both in-situ (when devices are directly connected to a laptop), and online, by an external server (when the connection is provided by Ethernet. This server should dialog with the DSP).

The second level concerns the specific goal underpinning LIFE SUPERHERO project [14]. In detail, to demonstrate the impact of the VPR solutions, this level is related to the detection of the roof thermal performance (roof surface temperatures and heat fluxes) and of occupants' energy use and behavior before and after retrofitting the building with the HBR. Thus, the low-impact wireless sensors measure [18–22]:

- 1) for each monitored room where long-term occupancy is expected (i.e. living rooms and bedrooms):
 - a. occupant presence in the room, windows opening activity, AC activation (occupants' behavior). In particular, living rooms are supplied with ACs to obtain homogeneous scenarios;
 - b. air humidity and temperature, illuminance, CO₂ levels (Indoor Environmental Quality);
- 2) for each roof pitch, corresponding to the monitored room: surface temperature probes and heat flux meters;
- 3) for the buildings site: weather station.

According to the actual buildings' occupancy, a total of 11 rooms (in five attic flats) and the behavior of 2 occupants (in one apartment) should be monitored in the first building, while a total of 12 rooms (in five attic flats) and the behavior of 9 occupants (in three apartments) should be monitored in the second one. The monitoring period entails 3 summer seasons between 2021 and 2024. In particular, the project schedule entails monitoring the buildings as it is and after the HBR installation, it was hence essential to develop an integrable BMS.

2.2 DSP requirements

The DSP has to be designed to meet the following conditions [1, 3, 4]: (1) being linked to the BMS monitored data, using a (quasi) real-time approach; (2) adopting an interactive and user-friendly interface for internal (i.e. researchers and partners of the project) and external users; (3) sharing monitored data to promote public and stakeholders' awareness; (4) differentiate the outcomes depending on the target audience to provide the highest comprehension; (5) allowing the integration of data analysis methods and other supervised approaches using quick-to-apply calculation methods starting from collected data; (6) allowing data export depending on the end-users' requests; (7) being focused on the main goals of the LIFE SUPERHERO project. Thus, HU-BES has to be developed as an interactive web-based platform and designed to monitor, quantify, and share the environmental benefits obtained by the HBR in terms of increased climate adaptation, (thanks to the reduced internal and external surface temperatures reached) and mitigation (thanks to the reduced air conditioning use and related GHG emissions). HU-BES should also provide qualitative and user-friendly data representation to un-specialized users (e.g. icon-based), as well as quantitative data (e.g. analytical results),

to specialized stakeholders. Thus, the resulting indicators should be filtered depending on the target audience entering the platform.

3 Results and discussion

3.1 BMS application

The installation of LIFE SUPERHERO BMS was concluded in June 2021 in both social housing demo buildings. Considering the requirements defined in Section 2.1, the BMS is based on four modules (**Fig. 2**): (1) the Data Acquisition module including all sensors with their power supply; (2) the Wireless Communication system for data transmission to the Gateway (LoRaWAN protocol), collecting data from indoor sensors and weather station; (3) a Radio Communication system (Zig-Bee 2.4 GHz) for roof data transmission from slaves configured devices to a master for data storage; (4) the Server module, which connects data from wireless and radio communication systems to the DSP. In addition, due to their position in the building, the roof sensors also provide a local data storage to avoid data loss due to unpredictable faults of dataloggers placed in a critical environment as the roof. **Table 1** summarizes their main characteristics of the installed sensors.

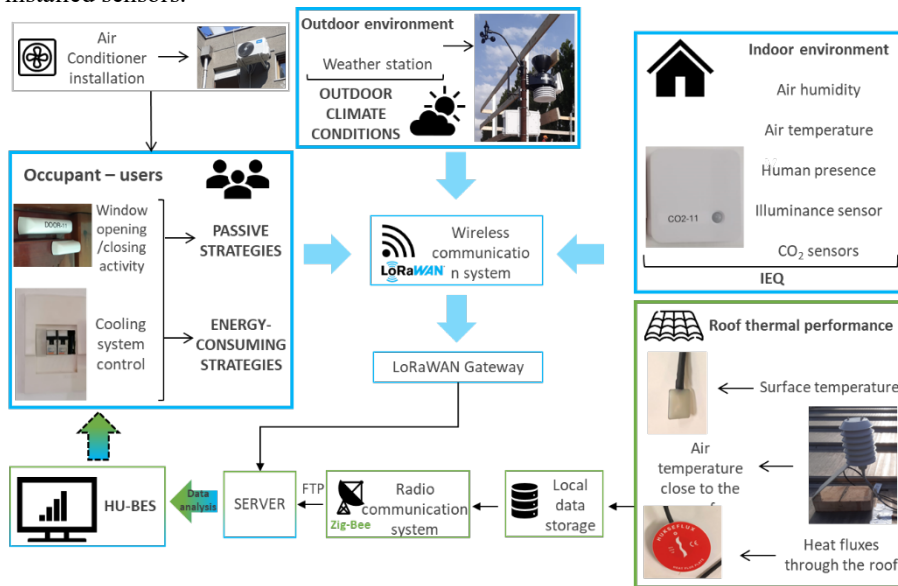


Fig. 2. Overall BMS architecture. In detail, the data acquisition modules have a rectangular bold perimeter, in green for the roof-related part, and in cyan for the other parts.

Table 1. Technical specifications of the installed sensors and monitoring system

Sensor type	Installed sensor	Location	Acquisition rate	Measurement range	Accuracy
Air temperature				-40...65 °C	±0.2 °C
Air humidity				1...100%	±2 %
Solar radiation	Weather Station	Roof of building#2	5 min	0...1800 W/m ²	±5 %
Rain gauge	WS100LRW/SR			1000 mm/hr	0.2 mm
Wind direction				0...360°	±5°
Wind speed				1...322 Km/hr	±3 Km/hr or 5 %
Air temperature				0...50 °C	±0.2 °C
Humidity	ELSYS ERS CO ₂	Each monitored room	5 min	0...100% RH	±2 % RH
CO ₂				0...2000 ppm	±50 ppm / ±3 %
Light				4...2000 lux	±10 lux
Open activity sensor	ELSYS EMS Door	Each window	5 min / At use	±2.0g (accelerometer)	16 mg/digit (sensitivity)
Energy counter	ORNO OR-WE-514	Each monitored living room	5 min	-	class B according to EN 50470-3
Air temperature near the roof surface	LSI-Lastem DMA033.1	0.3m height from the roofs surface	10 min (average)	-50...70 °C	±0.15 °C
Surface temperature	LSI-Lastem DLE124	Contact outdoor roofs surface	10 min (average)	-50...70 °C	±0.15 °C

The LoRaWAN WS100LRW/SR weather station by DAVIS Instruments is installed at 1.5m height on the roof of one of the two buildings to monitor the local outdoor climate conditions (air humidity and temperature, global solar radiation, wind velocity and direction, rain).

ELSYS ERS CO₂ sensors are wall mounted in the living rooms and bedrooms of the monitored attic flats and record indoor environmental parameters quantities (air humidity, indoor air temperature, illuminance, CO₂ emissions, and human presence). Occupants' windows opening/closing activity has been detected through ELSYS EMS Door, small-sized sensors mounted on windowpanes. The indoor environment and door monitoring devices are equipped with a battery power supply. The occupants' energy use for cooling was also measured through a MID-certified ORNO OR-WE-514 module energy counter. This system, together with a URSALINK UC1152 LoRaWAN antenna, was placed in the living room of each monitored apartment. These systems are not supplied with a battery since they should monitor live equipment.

As for the weather station, all these devices are equipped with LoRaWAN communication systems, and they send data to a unique LoRaWAN gateway iStation Kerlink, which embeds 4G worldwide connectivity using a SIM.

The roof thermal performance is detected in two orientations (north and south facing). LSI-Lastem E-log 515.1 dataloggers are used to acquire, store and display data from the connected sensors. A Master/Slave configuration is adopted: a unique Master (located indoor in the common parts of one of the two buildings, to ensure easy access for maintenance) receives data from two Slave devices, one for each monitored roof. Each slave is connected to a couple of sensors, one for each monitored room placed under the roof: (a) the LSI-Lastem thermo-hygrometers DMA033.1 with anti-radiant shields allows measuring air temperature close to the roof surface (about 0.35m height); (b) the DLE124 PT100 sensors allows monitoring the outdoor surface temperature. LSI-

Lastem Mini-DIN R-log ELR510.1 dataloggers are used to acquire and store the indoor ceiling surface temperature through LSI-Lastem EST124 and the related heat flux by using HFP01-05 sensors by Hukseflux. Each of the four configured Slaves acquire and send the measurements via radio to the Master. All the Dataloggers acquire measurements each minute, and their mean values and standard deviation values are stored every 10 minutes. The Master and the Slaves are all equipped with battery power supply, while the Slaves placed outdoors are not directly connected with the building power line, but their batteries are supplied with a photovoltaic panel, located on the roof, one. Finally, the Master is connected to a router, to grant sending data to a remote Server via a File Transfer Protocol.

3.2 HU-BES definition

The data collected through the BMS are sent to the HU-BES platform through the server, using a real-time approach, and depending on the sampling frequency of the sensors (see **Table 1**). HU-BES is based on a web-app, actually in the phase of preliminary development and internal validation. The platform shows raw data and allow their download for the activities performed by the work group researchers, but also provides calculated performance indicators related to the project's goals to other HU-BES possible target users. Such indicators hence aim demonstrating HBR benefits in limiting heat entering the building, thanks to the passive disposal of solar heat through ventilation/transpiration. **Table 2** illustrate exemplary indicators, related to HU-BES end-users. Unexpert HU-BES end-users are represented by general public and stakeholders (e.g. buildings owners, facility managers), while specialized ones refer to building designers. These typologies of target audience will enter the platform with different login credentials, while a further short summary of the monitoring data could be offered by linking the BMS, HU-BES and the website of the project.

Table 2. HU-BES platform: exemplary indicators (actual release) and related target users

indicators	un-specialized end-users	specialized end-users
total heat incoming from the roof during a specific day and/or a period		√
maximum, minimum and average values of some of the monitored parameters:		
outdoor air temperature	√	√
solar radiation		√
indoor air temperature	√	√
reduction of cooling energy consumption in the monitored flats after the installation of HBR	√	√
reduction of CO ₂ emissions at the end of the project after the installation of HBR	√	√
reduction in the maximum roof covering surface temperature	√	√
reduction in the maximum roof slab internal surface temperature	√	√

Depending on indicator typology, end-users can select a specific assessment period, ranging from the available summer seasons data until the end of the project. Some indicators will be specifically based on the comparison of data monitored in two different summer periods (before and after the HBR installation). In this sense, the indicators related to the reduction of cooling energy consumption, CO₂ emissions and roof temperatures will be available after the HBR installation. These data could hence support the end-users' awareness in respect to the HBR implementation, but this approach could be also useful to provide a more wide picture of energy issues and cooling demand, and thus to increase awareness about the impact of "energy-related behaviors", in a direct and real-time way (e.g. considering occupants or building owners).

Fig. 3 shows the proposed preliminary graphical interface of the HU-BES platform, which is currently under development. It is worth noticing that the indicators in **Table 2** are not exhaustive, and additional ones will be developed also considering the general key performance indicators established in the project.

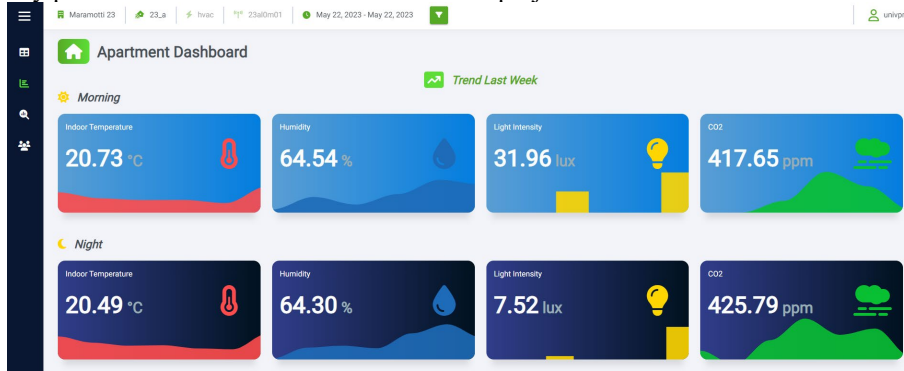


Fig. 3. Preliminary graphical interface of the HU-BES platform

4 Conclusions and remarks

This study provides the design of a Building Management System and of its linked Data Sharing Platform for the assessment of passive cooling strategies in existing buildings, and the increase of users' awareness, according to an action of EU LIFE SUPERHERO project. The overall system architecture is defined, by pointing out the requirements of both BMS and DSP from a general to a project-specific point of view, also according to previous standards and literature. In particular, the application to social housing buildings requires a non-invasive BMS, while the planned future renovation of the attic floor, through the HBR installation, requires a future integration of sensors, without altering the overall BMS architecture. At the same time, the DPS takes advantages of a web application to provide an interactive and user-friendly interface, and then to ensure the highest dissemination of information on the HBR performance and users' behavioral changes. Future steps of the work include the final implementation of the DPS with selected performance indicators, its public access, its continuous maintenance and updating, the dissemination and sharing of the best practice.

Acknowledgement

This work was supported by the Project LIFE SUPERHERO (LIFE19 CCA/IT/001194) “Sustainability and Performance for HEROTILE-based energy efficient roofs”, performed with the contribution of the European Union’s LIFE Programme “Climate Change Adaptation”.

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