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The Sense of Sensors

Marco Imperadori[1], Graziano Salvalai[1*], Federica Brunone[1], Marica Angela Fumagalli[2] and Rossano Scoccia[2]

[1] Department of Architecture, Built environment, Construction Engineering, Politecnico di Milano, Italy
[2] Department of Energy, Politecnico di Milano, Italy
** Corresponding author (graziano.salvalai@polimi.it)*

Sensors are nowadays more and more common in buildings because they are becoming everyday cheaper, reliable and long lasting. Applications inside, outside and in between the built layers are more and more common and therefor the possibility to collect a big amount of data.
However, the question is: does it make any Sense? Huge amount of data does not mean that the building is nicer and works better. Sometime the excess of technology and the presence of these devices ends up in a lack of responsibility by the user and, in some cases, the building does not work better than one without all these invisible measurements.
Thinking and adapting the purpose of the sensors and educate users, on contrary, allow us to have a more interactive building and the possibility to check it very quickly with an app and run it from remote. Thus it is very important to set up what kind of sensors we need and how we collect the data and how we interpret them in a correct and fast way, being data so many and being the user not necessarily an Engineer.
Some experiences will be shown seeing the effect of users and also actual benchmark technologies that allow us to live in an Active House and check it live, than\ks to an app that shows several sensors outputs.
The paper will also show an experimental case study at Politecnico di Milano, VELUXlab, where sensors have been installed for different purposes, since some years, and where the building behaviour has been checked with and without occupants.
Big Data are around us, but sometimes it seems that we forget the basics and the world surrounding us when too much technology seems to substitute our senses.
Finally, the goal is to show that technology and remote sensing is efficient and produces a better living environment only if it does not cancel our singular responsibility and our capability to trust in our senses and in a clever use of our architectures.

Keywords*: sensors, big data, sustainable design, active house, interactive buildings*

INTRODUCTION

Buildings account for 40% of overall energy consumption in the European Union. Increase the energy efficiency in this sector means to contribute significantly in reaching the EU climate and energy targets as well as reducing EU dependency on imported gas and oil, thereby limiting the need for higher electricity production. According to the EPBD Directive 2010/31/EU [1] by the end of the 2020, all the new buildings must be very energy efficient with an annual balance between produced and absorbed energy close to zero [2]. Actually there are no a global definition of nearly zero energy building [3, 4, 5] since each member states must define they own detailed calculation method. The available calculation methods, defined by the standard, focuses currently only on energy demand during operation but a new view that consider a wide environmental efficiency must be introduced in the near future [6, 7]
There are a number of long-term advantages of moving toward ZEBs, including lower environmental impacts, lower operating and maintenance costs, better resiliency to natural disasters, and improved energy security. The following paper shows a case study of nearly zero energy building located in northern Italy with focus on the real operation by means the integration of sensors in the building component for real time tuning.

METHOD

In the current construction practice, there is commonly a big gap between the predicted and the real energy consumption. This paper aims to show the sensors-based upgrade approach on a high-efficiency and smart building. The final target was to prove and validate the retrofit strategies that has been previously studied trough several simulation tools, and applied to a specific case study, VELUXlab in Politecnico di Milano, Bovisa Campus.
According to these purposes, in a first phase of the study, several different sensors and sensored devices has been installed, and interconnected via a wireless network. Thus, all the data has been collected and stored, in order to be analysed through a big data mining process.
This study focuses on specific physical quantities, which provide real time conditions about internal comfort, energy consumption, energy production and their interrelation. Therefore, the selected and installed sensors are able to measure:

- Temperature [°C]: on the envelope as superficial and indoor air-temperature, with thermos-resistor sensors; on systems, as working temperatures;
- Humidity levels [%];
- Heat production;
- Electrical production;
- Electrical consumption;
- CO_2 concentration.

Thus, the mined and patterned data could detect both the real functionality and high efficiency of the building, from the "as-built" status, to its usage phase, with the interaction of tenants.
The second step of this work involves the transposition of all the investigated data and the derived information about the building on a shared platform of augmented reality. This phase has the target to let the engineering knowledge of the project and the quantitative data become visualized qualitative information, more readable and comprehensible also for the common final users of the building. This aim heads to educate occupants to a correct use of a high performance object, in order to maintain and get the maximum from it. Besides, the informed-object that represents the building in a virtual reality could be easily updated, to record and show the improvements of the building features and the changes about its performances during time. Moreover, thanks to a BIM design approach, the availability of data and information in one unique environment facilitates the management of the building and future interventions.

CASE STUDY: VELUXLAB BUILDING

VELUXlab is the first Italian Nearly Zero Energy Building, which is located inside a University campus [8] (Fig. 1). Its design process started in 2011, when VELUX decided to convert the demo-house Atika, into an experimental laboratory of Politecnico di Milano: VELUXlab. The original building was already conceived in its shape and features to be a model home for Mediterranean climate. The scientific supervision of the design team of Politecnico di Milano upgraded the construction into an active prototype and, thus, a real case study for future sustainable buildings.
The retrofit process of the building involved both the improvement of the envelope's layering with new and high performances materials that increased the technical performances of the building case (U-values up to 0,124 W/m^{2}K), and the implementation of systems. Static and dynamic simulations helped to calibrate the design choices to lead through the minimisation of energy needs [8]. They proved the feasibility of high internal comfort levels, high energy efficiency and low environmental impact. The integration of those three principles managed the development of all the modifications that has been introduced during the transformation phase.

Fig. 1. A picture of the building after renovation and localization at Politecnico di Milano, Bovisa Campus

VELUXlab: the first Italian Nearly Zero Energy Building and Active House of a university campus

The main feature of VELUXlab is that it has been conceived and further developed as a real smart and active building. The high performances reached by the construction has been verified by the achievement of the A+ value of the CENED protocol, in 2014, and the Active House label [9]. Thus, it soon represented the first Italian ActiveHouse building inside a university campus. At the end of 2017, indeed, it was officially awarded with the AH label through an external review process. It testify the achievement of high conditions on internal comfort, low energy consumptions and environmental loads (Fig. 2 and Table 1).

Comfortindicators	Value	Category
1.1 Daylight	5,7%	1.0
1.2 Thermal Environment	Better level	1.8
1.3 Indoor air quality	<750ppm	2.0
Energy indicators		
2.1 Energy demand	74,7 kWh/m^2	2.7
2.2 Energy supply	79,7 kWh/m^2	1.0
2.3 Primary energy	11,9 kWh/m^2	2.8
Environment indicators		
3.1 Environmental loads	Good level	2.3
3.2 Freshwater consumption	84%	1.0
3.3 Sustainable construction	Best level	2.1

Tab.1. Active House labelling results, performed by Active House verifier Arch. Eileen Meyer for Active House Alliance, 2017

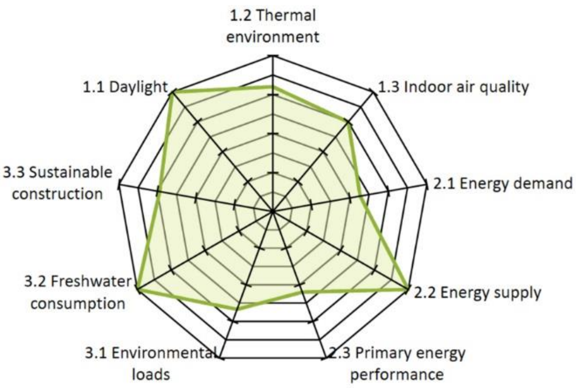

Fig. 2 Active House Radar of VELUXlab, evaluated by Politecnico di Milano design team and verified by Active House Alliance, 2017

VELUXlab Augmented Reality

As a real case study, during its construction and usage phases VELUXlab has been the core of multiple scientific activities and experiments. They involve, as first, the implementation of the project to the augmented reality. The building 3D model, in its geometrical data and non-geometrical information (about material performances and features, e.g.) has been transferred into a virtual environment, freely available: the online platform LAYAR. Thanks, to the support of several file-sharing systems, such as Autodesk A360, the aim of this initiative is double: as a BIM-oriented approach, to have all the data and information directly available in one unique place, useful for the management of the building; on the other hand, to communicate with final users (Fig.3).

Fig. 3 Augmented reality platform used by Ing. Vanossi, the BIM manager of the project

VELUXlab, the sensorized laboratory

Beyond its definition in a virtual environment, VELUXlab has been equipped by a wireless multiple sensors network. They are located both all across the envelope than on systems, in order to have a holist perspective on the building behaviour. Superficial temperature sensors are placed both on internal and external surfaces of walls, roofs and windows of the west wing (Figg. 4 and 5), to investigate the summer performances of a dry layered construction.

All the data provided from these devices, from 2012 till now, has been collected, storage, mined and analysed. This part of the study could be considered as big-data experimental analysis, because the experience deals with three of the 4Vs of big data [10]: (i) Volume, a considerable amount of collected data from 7 selected sensors over a year has been used in the first trial step of the process, with a total amount of 521.148 records from building sensors and 277.888 records from a local weather station; (ii) Velocity, all values are recorded every 30 seconds; (iii) Veracity, sensors may provide inconsistent values due to external unpredictable factors. The collected and already mined records have been uploaded on an IBM platform, to be queried by experts. The second step focused on data-visualization problems: thanks to BIM-based environment, all the scientific results have been transported and integrated to the 3D informated object, already available on LAYAR. Thus, a more user-friendly interface could help the communication between AEC sector experts and users, and their education to deal with a high energy efficiency building, without wasting its big potential (Fig. 6).

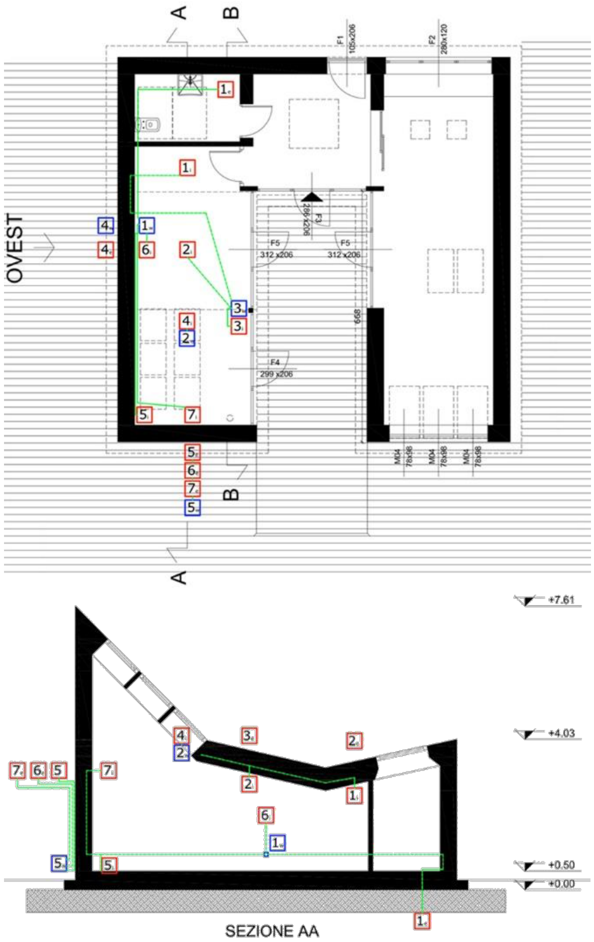

Fig. 4 Location of thermal sensors across the envelope of VELUXlab and their wireless network

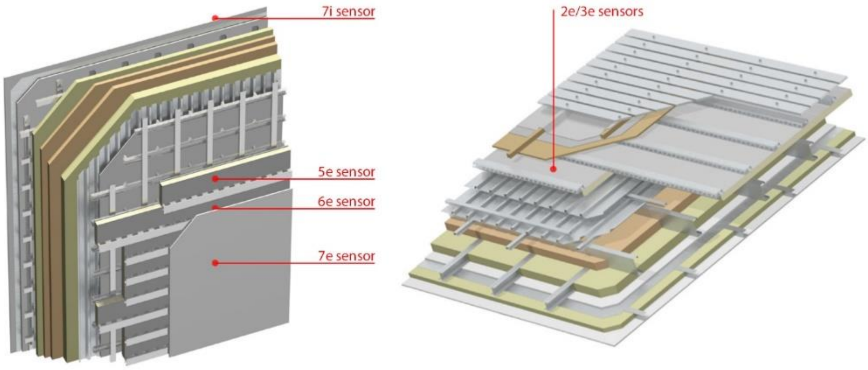

Fig. 5 Location of thermal sensors inside the technical solution of the envelope: wall and roof. The information about the geometrical and material global performances of the technological solution has been transferred on a BIM environment and are currently available on the augmented reality platform

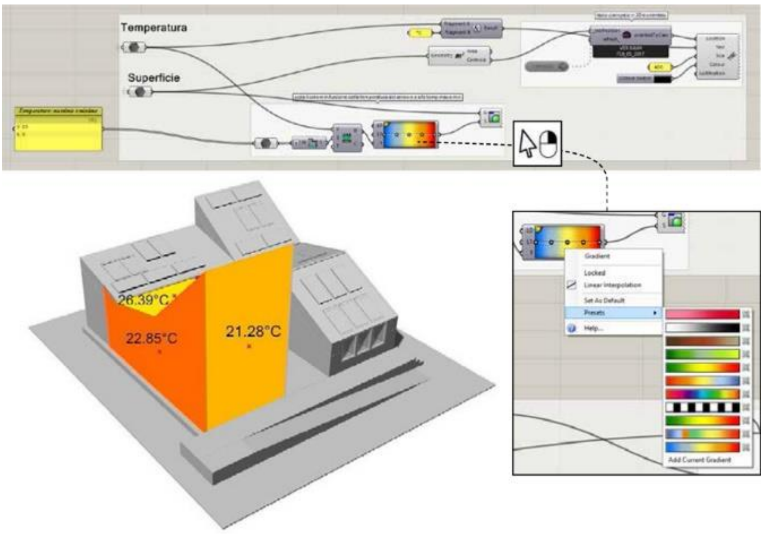

Fig.6 Augmented reality and BIM model implemented with big data derived from sensors network

Since April 2017, the sensor network has been extended with several temperature sensors (Table 2), which measure the temperatures of the internal environment in different positions of the building, in order to study the trend of the internal conditions among different seasons and to evaluate if the comfort conditions are homogeneously granted (Fig. 7).

Internal temperature sensors	
sample time	10 min
accuracy	±0.35 °C from 0° to 50°C
resolution	0.03°C at 25°C

Table 2 Technical features of the internal temperature sensors

Beside this analysis, other several sensors (temperature sensors, heat meters, electrical meters) have been installed on the heating and cooling system, composed of an air/water heat pump, AHU and photovoltaic and solar heating panels.

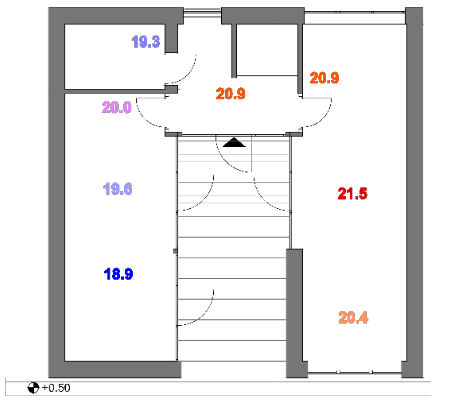

Fig 7 Average internal temperatures measured in different positions of the buildings, on a typical day of winter 2017-2018

In this way, it has been possible to characterize the efficiency of the single components and optimize the control of the system to guarantee the internal comfort and maximize the energetic performance.
Some redundant sensors have been introduced, in order to improve the reliability of the monitoring data.
Moreover, some of the instruments have an internal memory and are battery-powered, in order to assure

the continuity of the data collection, even when the p ower supply is cut off (at least for short periods, as on e day).
The monitoring system is based on a database modu lar structure, which allows collecting simultaneously s everal signals coming from the all sensors, without a limitation on the number of input signals.
The installation of the sensors network has been executed by a team of plumbers and electricians, while the set-up and the maintenance of the monitoring system is provided by a computer engineer, as it is customized and studied for research purposes. Anyway, we are studying an easier interface to improve the accessibility to the monitoring data.
Another collaboration between VELUX, Politecnico di Milano and Beghelli, the Italian leader of artificial lighting, headed to the replacement of the existing lighting system with new sensored and dimmerable LED devices. These energy saving lights could read through single sensor ready-installed on each device the lux-value on working surfaces and then regulate its emission power. They could be also remotely controlled by the central system, and all the data are collected in order to record the total amount of saving energy, compared to a traditional not-sensored/dimmered and LED lighting system (Fig. 8).

Fig. 8 The local control unit of LED devices power and energy savings recorder, placed inside VELUXlab and remote connected to Beghelli Headquarter, Bologna

Furthermore, the integration of the natural light from the roof windows and the artificial light from electronic devices guarantees the internal visual comfort, all year long, and the maximum electrical consumption cut-off. At least, Beghelli provided VELUXlab with another small wearable and sensored device, the Salvavita Beghelli. This device fits the wrist of users and is able to record the their heartbeats and movements. Therefore, in case of a sudden illness, the control unit sends an alarm to the central management office, and calls directly the health emergency services.

RESULTS

The quantitative results of all these experiences could be summarized per each step of the entire work of data analysis.
As first, the investigation about the building behaviour as a dry layered construction set in a Mediterrean climate give several interesting outcomes, both in terms of the methodology and its reliability and in terms of final results. Indeed, the analysis highlights how sometimes the provided data could be significantly inconsistent, because of technical problems on sensors functionality. The possible causes are both related strictly to the devices, and to unpredictable external factors. Due to these reasons, the performed analysis involved just seven temperature superficial sensors, in order to detect at first the consistency of data related just to the envelope performances. The outcomes of the first data-mining process show how some sensors have to be frequently recalibrated, because of the long lasting period of their use. Thus, an average of 65% records could be used to investigate the set problem. However, the validated data prove the achievement of high level of comfort values, inside the analysed space. This preliminary study confirm the capability of dried hyper-insulated wall to have a good behaviour not only during the colder seasons, but also in the hottest one, such as Italian summers. This qualitative evaluation, indeed, is supported by the records: comparing real values to the boundaries of ISO 7730 on inside comfort conditions, it is guaranteed at 70% (Fig.9).

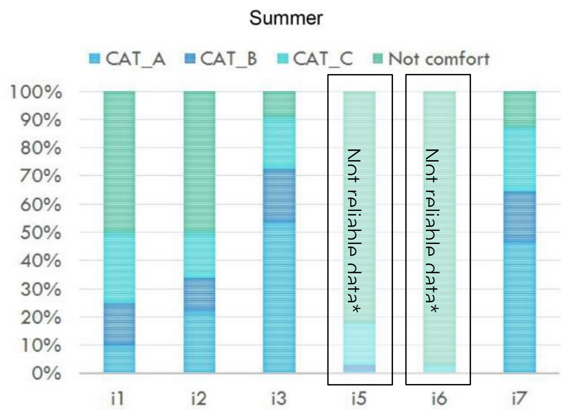

*Fig. 9 BIG DATA analysis results, in summer period, which is the most critical for mediterrean climates. They are compared to the comfort categories defined by UNI 7730; *the i5 and i6 sensors show not enough consistency*

The other part of the study involves the survey and maintenance of systems, both electrical production, from March 2015 to December 2016, than heat/cooling productions, from April 2014 to December 2016. In particular, the sensors survey shows that the PV-energy profile of follows the normal seasonal trend, with high values in the summer, in which it reaches up to 35% of the monthly building requirement, and very low values in winter, due to the scarce solar radiation (Fig. 10).

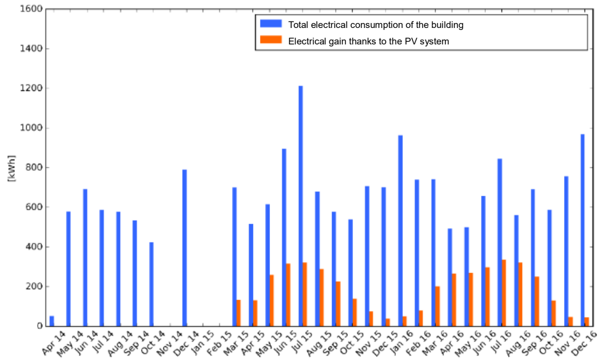

Fig. 10 Monthly values of the total electricity consumption of the building and of the electricity produced by the PV panels

At least, the outcomes about the LED sensored and dimmerable lights show the total amount of energy that has been saved since the installation of new devices. The integration of natural and artificial light allow almost the 80% of energy consumption cut-off (Fig. 11)

Fig. 11 Online layout, freely and remotely available, of the quantitative data about the LED system; the numbers show: a) the total amount of using hours, b) the total amount of energy that would be consumed by the previous traditional system, c) the currently consumed energy by the LED system, d) and e) the saved energy, in kWh and %

Discussion and conclusions

Built environment is artificial. It is something that we create to live but sometimes it is totally anti-natural. In nature, we live by sensing: vision, touch, smell, taste hear and sometimes we feel well when a synaesthesia is present. Can we make our built environment more natural like? Can we have easy sensitive and responsive buildings, which will be, because of this, more sustainable and more comfortable?

Active House is a possible strategy, beyond 2020, which is…tomorrow!

Even if we think to other field of human industry – e.g. automotive, ships, aerospace –, the presence of sensors is increasing and creates more efficient, reliable and safe objects. Would you imagine your car without fuel indicators? Without water pressure, oil levels indicators or others? Nowadays cars can stop by themselves, have speed auto-limited controls, rear cameras view, etc. As this paper has shown, the same methodologies can be applied now into buildings, without being invasive. Thermal sensors, humidity, CO_2, pollution particles, acoustics, fire meters could be controlled easily in multiple platform of data. This big-data are synthetized in graphical outputs, giving us the possibility to learn from our behaviour. Thus, the building could become adaptive, and, in general, active in a technical approach, to challenge quick changes, but also to control the general long-term strategies. Sensors help building to achieve and maintain high energy-efficiency standards, such as the almost 80% of electrical energy saving. In the meanwhile, an efficient data-visualization helps users to understand the functionality of the entire construction and the impact of their attitude, educating them to live in this new generation of buildings.

The grid of sensors incepts data in a big platform, “ad hoc” defined each time, and the BIM process guarantees us to have a quicker control of triple field of action, typical of an Active House: energy, comfort and environment. This is a great leap forward for building industry and architecture. Volumes are no more “passive”, mineral entities. They have an invisible technology inside – very reliable and every day cheaper –, which helps us to live better.

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