The Effect of Real-Time Sensing of a Window on Energy Efficiency, Comfort, Health and User Behavior

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Abstract Sensing technologies integration in buildings has grown rapidly. Most of them are connected to platforms for monitoring data and notifying anomalies, but few are integrated within building elements (either for data collection or response). These technologies help regulate HVAC, or detect building systems' failures, but few enable passive sustainable strategies or space maintenance. It is possible to enhance building responsive operation by gathering granular data on passive systems' operation and space occupation by setting a building component, that houses a sensor network. That is, if plugged into Building Information Models, it permits adaptation to unusual climate conditions or abrupt space use [Linked with the following correlated research projects:

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1 Smart Buildings Operation

Industry has shown that data availability can boost the product performance (Brynjolfsson et al. 2011). In the building sector, this can be noted in the application of BIM methodology for managing design information at first instance, however its application in asset management has shown remarkable improvements in terms of operational savings and efficiency (Re Cecconi et al. 2017). To do so within the building operation, in terms of energy and well-being, granular data acquisition is required for monitoring the trend of all or few parameters defining the indoor conditions and provoking human-building interaction.

Shen et al. (2014) have shown energy performance improvements on building energy performance when monitoring in parallel occupancy, illuminance and air temperature at different locations of the room. Additionally, Konis and Annavaram (2017) have studied the influence of studying the occupant interaction when a comfort disruption occurs, which can reach cooling energy savings ranging from ~27 to 90%. Agha-Hossein et.al. (2013) carried out numerous surveys on buildings as post-occupancy evaluation, trying to identify the main reasons for comfort disruption among building occupants, and their magnitude; highlighting visual, thermal, and acoustic comfort plus air quality as highly relevant.

There has been considerable research in identifying what parameters shall be monitored for rating the building performance, the required sensors for acquiring them (together with their sensibility), and how adequate they are as control criteria; however, few researches have been done for understanding their integration within the indoor environment and/or building elements. Hereby, a study is presented on the possibility of predicting the occupant indoor satisfaction and maintaining a healthy and safe environment, by using granular data collected from sensors installed in a window unit. This innovative window unit is intended to work not only as a sensor, but also as a building system actuator able to adjust the local indoor environment, providing to a traditional window unit new functionalities and services.

1.1 Building Smartness Degree

A building can be as smart as any other device, it is perhaps a matter of sensitivity, connectivity and interactivity. The building shall be able to sense any alteration, predict any favorable response and interact with the user for enhancing the response efficacy. Therefore, it shall be equipped with sensor nodes (i.e. smart building elements), and a control algorithm able to dictate its behavior.

For doing so, it's important to know: (1) which type of data is need for providing a comfortable, healthy and safe environment for the building user; (2) how the needed sensor nodes, or network, shall be installed to gather useful data for the devised control algorithm; (3) how these data should be integrated to work in a holistic and unique control logic; and (4) which type of actions it will be able to carry out, or how would it interact with the building user.

The degree of smartness of the new window unit would be established based on the amount of data gathered, the knowledge produced with data collected, and the extent of the action produced by the installed smart system (i.e. extent of the interactivity and/or connectivity with the rest of the building). This smartness has been planned, designed and embodied within the building element by SEEDlab.ABC, in collaboration with Italserramenti, Schneider Electric and University of Brescia.

1.2 Data Collection and Processing

For the data collection it was necessary to understand the main factors for each aspect (i.e. comfort and well-being), that is: (1) for thermal comfort—air temperature and solar radiation (2) for visual comfort—illuminance (3) for respiratory health—concentration of pollutants (e.g. CO_2). Nevertheless, the control logic of the building will function differently if the occupants are present or not, requiring from the building sensitivity to acknowledge this fact.

An initial proposal of the sensor integration is presented in Fig. 1b for obtaining the required data on a south-oriented office space in Milan, Italy. The sensors have a latency of approximately 1 min. Direct measurements are useful, however for some parameters, the sensor becomes expensive and/or impossible to integrate within a building system given its dimensions, requiring some re-engineering for extracting these values from correlation of simple measurements (i.e. the case of radiation). From extracted granular data, correlations can be established from the use of temperature difference between irradiated and non-irradiated surfaces, in Fig. 1a, a matrix correlation diagram is presented with the Pearson correlation method for understanding their similarities.

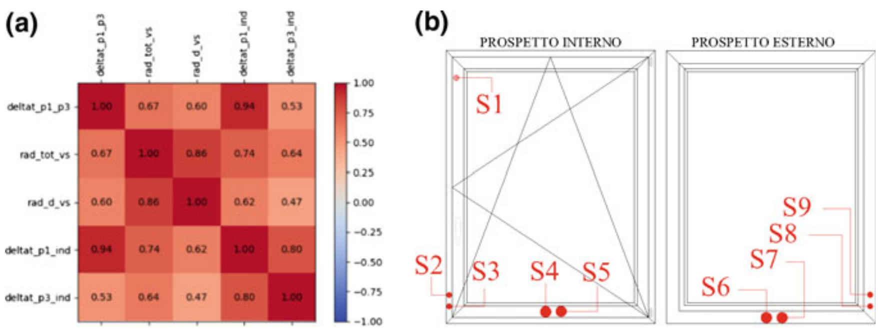

Fig. 1 Results for **a** Pearson correlation test (+1 and −1 corr. strength) between data obtained from temperature probes installed within the window frame; **b** sensor location in window unit

After gathering the required parameters to be measured and sufficient granular data, it was necessary to evaluate the convenience of the sensors and their position, by attempting to give an added value to the collected datum by possible correlated information or avoiding numerous overlapping effects. Thus, different tests were carried out measuring sensor precision and accuracy at different positions and conditions. For instance, analysis on the amount of radiation falling on the window frame, to consider possible alterations due to excess of solar radiation falling on the sensors, the variation of the air temperature values according to the sensor location and the sensibility of these values given the frame material (see Fig. 2).

Not only indirect measurements allow the implementation, and/or complexity reduction, of a sensor node within a building system, the interpretation of the datum is crucial to avoid noise hampering the building performance (Wu and Clements-Croome 2007). For instance, using the results from the Pearson test from Fig. 1a, the data and evidence found from analysis such as the one presented in Fig. 2c, it was possible to neglect the use of a radiometer to determine the amount of radiation falling on the window from external temperature probe readings with reasonable accuracy (see Fig. 3).

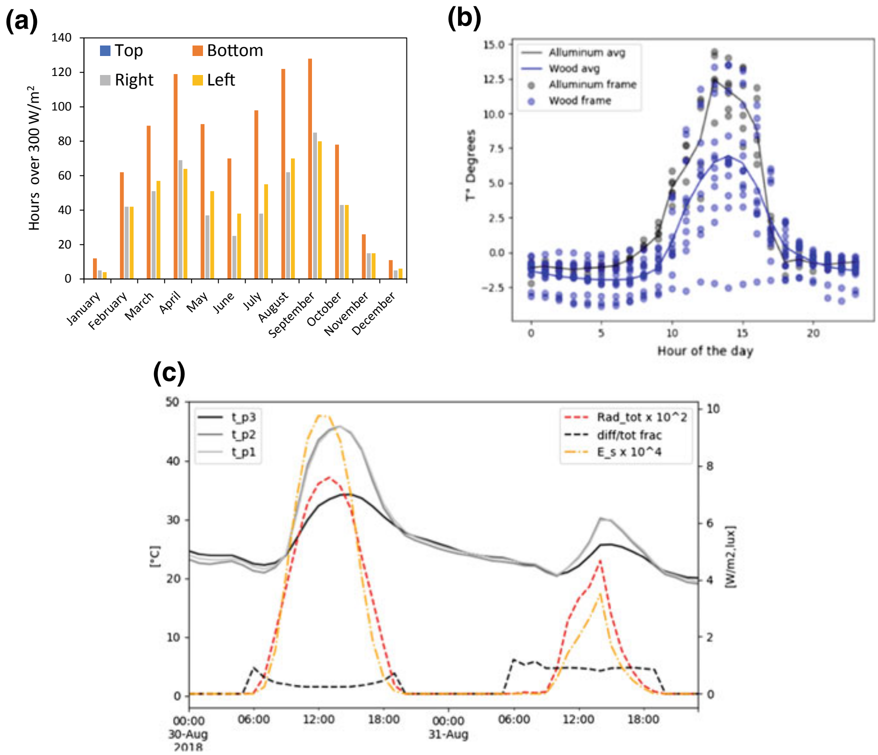

Fig. 2 Data acquisition comparison for **a** frame irradiance intensity; **b** temperature with different window frame; **c** temperature probe at different location, external illuminance and radiation

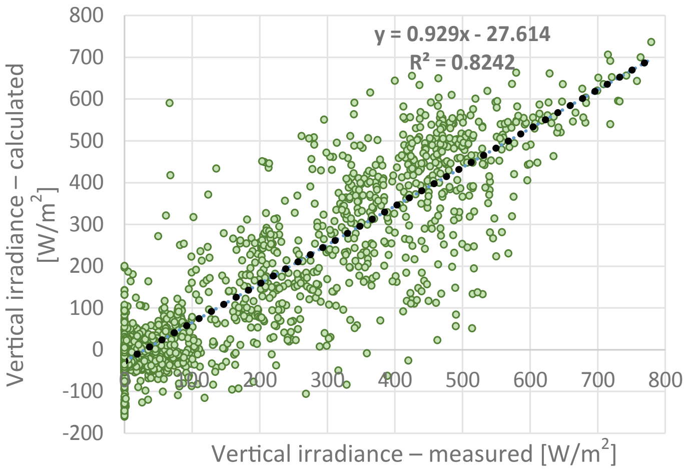

Fig. 3 Comparison between vertical irradiance values on the window obtained from weather files and the ones computed from the correlation found with external temperature measured at the window frame

The use of the minimum quantity of data types for obtaining all required parameters, increases the smartness of the device, and maximises the productivity of the system. That means, faster or immediate connectivity through IoT devices for generating building element adaptions.

2 Conclusions

Sensor integration allows real-time building performance monitoring, enabling immediate intervention when any disturbance occurs. Nevertheless, different data interpretation can be performed by the facility manager or the designer who configures the control algorithm. This will affect the building adaption to climate and the occupant interaction, but the control algorithm could try to benefit from this feedback and adjust the initial control settings.

The integration of sensors within building elements eases the proper data acquisition, data interpretation and, if wanted, reduces the need of an external online platform for managing and storing data, because all the system controller could be integrated within the building element.

Further studies are foreseen to reduce the need for other sensor, such as the passive infrared (PIR) motion sensor, by extracting the room occupancy from air pollution readings as has been attempted by Meyn et al. (2009).

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