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Sensor based IoT architecture for the indoor well-being

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Abstract

Indoor Environmental Quality (IEQ) has led to an evolution in the construction practice and building design. Up to now, the main research objectives in this field relate to the performance optimization of the structures, involving the energy saving - fuels and CO2 consumption - and environmental comfort issues in order to achieve a greater sustainability of the built environment. In light of the recent upheavals brought about by the SARS Cov 2 pandemic, attention to IEQ has shifted from the topic of building performance to that of people safety in closed environments. Therefore, living and working environments can greatly contribute to the safety of users and also contribute to improving their health state. This paper deals with the design of an IoT application for the construction sector suitable to both in human health protecting and building efficient energy functioning. In fact, thanks to a combined user-environment monitoring system, it is possible to manage the indoor environmental conditions according to the user psychophysical state and the IEQ parameters, dynamically detected over time. The research shows how, through a sensor network, it is possible to communicate the monitoring data with the automatic activation of environmental control devices such as controlled ventilation and daylighting systems.

Keywords: indoor well-being; adaptive design; wireless sensor network; environmental monitoring; Internet of Things (IoT)

1. Introduction

It is widely recognized that people spend between 80% and 90% of their lives indoors, be it their home, workplaces or leisure places (Zao et al, 2004; Fard et al.,2021; Klepeis et al., 2001; Schweiker et al., 2020). In the last few decades, the issues that arise from this incessant mutual relationship between man and environment have been primarily concerned with the theme of energy saving, then sustainability challenge took over (Clyde Zhengdao, et al., 2022). Keeping these priorities together with the objectives of protecting the built environment from a seismic and energy point of view has sanctioned the beginning of research aimed at optimizing performance, where optimization was precisely the means to keep together often conflicting needs: conservation structures, their adaptation and maintenance, environmental and economic expenses and investments (Machairas et al., 2014; Longo et al. 2009).

All these issues necessarily had to be measured to some extent with the human factor, to which attention was paid through mainly socio-cultural analyses (Sood et al., 2020) and indoor comfort analyses (Fanger, 1972). International Standards refer to

Fanger Indices and are based on predictive systems calibrated on essential environmental parameters (relative humidity of the air, radiant temperature, air speed) and general human parameters through correction coefficients that take into account the type of activity carried out in the environment (metabolic ratio) and the type of clothing worn (clothing level) (Fanger, 1972; Ashrae, 2020). Recently, several studies have shown how these models, and among them the adaptive model (Dear and Brager, 1998), were useful in the design phase, but insufficient to guarantee real well-being in the building, optimizing energy consumption required to achieve it: this mainly depend on individual sensitivity highly variable from person to person, from context to context (Mahdavi et al., 2020; Rupp et al. 2018; Pigliautile et al., 2020; Chinazzo et al., 2018). For this purpose, personal comfort models were born, less generalized and referring to the conditions of the individuals involved in the analyses (Jinhua et al., 2022; Zhihao et al.,2022) and more accurate models have been realized through the use of wearable sensors (Liu et al., 2019; Choi et al., 2012; Jayathissa et al., 2019).

The healing environment literature (Rossi and Lent, 2006; Sullivan et al., 2014; Schweitzer et al. 2004) lacks the detailed models and tools built for indoor comfort but provides some interesting insights. Among these it is a priority to mention a work on the definition of healing, described as a series of adaptive mechanisms - self-induced or externally induced - to re-establish a balance and a physiological functioning of a system (Phillips and Blackburn, 2016). Medicine teaches us that this is what happens to our human body, to animals and to nature as a whole. In this case, the system that we must maintain in a healthy balance is the User-Environment System (UES).

This work presents the design of an IoT application in buildings for triggering adaptive and self-healing phenomena of the UES when it comes out of its equilibrium and health state. Thanks to a network of sensors it is possible to connect the UES and activate automatic compensating mechanisms in the building structure to restore or maintain its status by controlling the Indoor Environmental Quality (IEQ) monitoring air particles and composition, temperature, humidity, light, etc. These building compensations are implemented thanks to architectural and technological devices integrated in the building's envelope for IEQ management, such as ventilation chimneys and light pipes, connected to the UES and therefore real-time responsive.

2. Validations from previous studies

Previous studies carried out on several buildings through on-site monitoring combined with the use of dynamic simulations verified the functioning of architectural and technological devices integrated in the structure envelope for building performance optimization. IoT and cloud platforms for data collation and verification guarantee to achieve maximum energy savings maintaining comfort condition through the management of environmental parameters such ad relative humidity and air temperature (Laurini et al., 2021; De Vita et al., 2018; see Fig. 1).

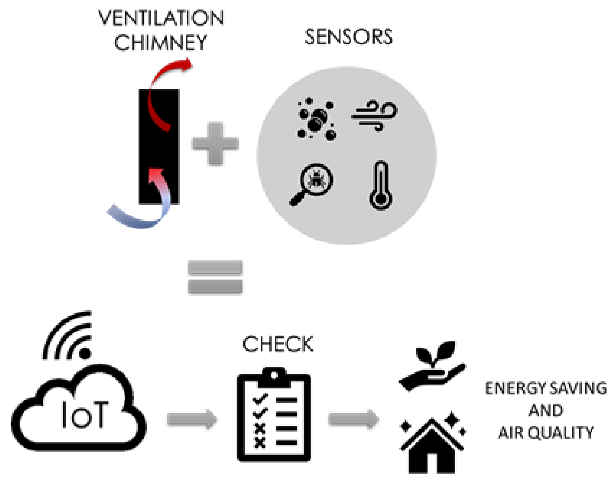

Figure 2. Benefits from Ventilation Chimney and IoT integrated in the building envelope

An application in this area was carried out in Poggio Picenze (AQ), Italy, through the application of a ventilation chimney and the monitoring of the IEQ before and after the device activation: following its opening and closing, comfort and discomfort levels were obtained respectively (Laurini et al., 2021). Another validation concerns the IoT application to the monitoring of IEQ of a sport pavilion before and after envelope interventions: monitoring data and dynamic simulations carried out validated the performance optimization from both the energy saving and indoor comfort point of view (De Vita et al., 2018).

Further studies were carried out in the field of workers safety in construction sites: through the use of smart wearable technologies was passible to improve the operation's security (see Fig. 2). One of these wearable tools is the Smart Safety Belt: a resistant and comfortable belt capable of detecting air quality, noise, vibrometric, hygrometric parameters, accelerometers for the detection of accidental falls and sensors for the detection of physiological data (body temperature, heart rate, etc.).

The monitoring data makes it possible the assessment of the risk linked to the interaction between the workplace and the physical conditions of workers both during normal working activity and in the event of an accident. The transmission of data allows to identify the parameters of the environment and the physical state without accessing the places at risk. The knowledge of the environmental parameters allows to immediately activate the rescue and identify the "near misses", reconstructing their dynamics and allowing to prevent future risks (de Rubeis et al., 2019; De Rubeis et al., 2017; Muttillo et al., 2020).

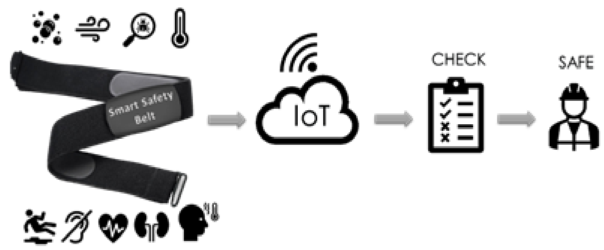

Figure 2. Wearable sensors for workers safety

3. Proposed architecture

In order to talk about indoor well-being, the measure of comfort must be overcome by new models and tools, which include not only generic environmental and personal parameters, but also quantitative polluting measures as well as psychophysical parameters of the users to be put into practice. In this new scenario, the research perspective is finding relationship between collected data not with the aim of "optimizing" the design but with the aim of safeguard both for environment and people.

Therefore, the research scope is to enhance Smart Buildings in favor of indoor well-being through the use of facility management combined with the Internet of Things, allowing real-time automation with remote control of all the parameters that contribute to define a healing environment.

The innovation of research lies in the application of IoT technology not only for the environments monitoring but also for the UES dialogue, able to modulate the parameters and the activation of specific procedures that provide as the first input data, the sensory data detected in the users. In this regard, the buildings with the highest technological potential are included, such as the Grid-interactive Efficient Buildings (GEB), highly efficient buildings in terms of consumption that use the IoT for better consumption management (Neukomm et al., 2019; Moncef and Xin, 2020). Integrating IoT with an Internet of Healthcare Things (IoHT), these buildings could be equipped with a sensor network that verifies the real-time comfort of the occupants. Communicating with the built environment, sensors allow a continuous verification and management of indoor well-being and ad hoc IEQ parameters, defining a new kind of buildings: Grid-Interactive Healthy Buildings (GHB, Figure 3).

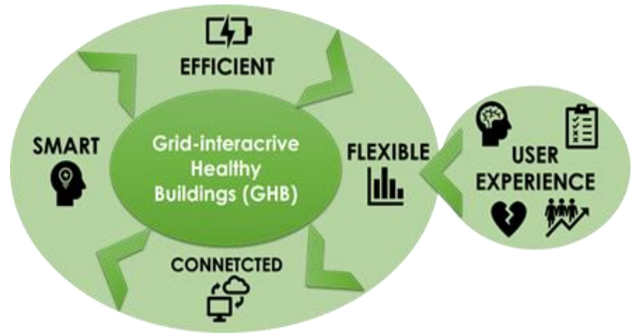

Figure 3. Defining the Grid-Interactive Healthy Buildings (GHB)

GHBs make it possible to generate a virtuous circle (see Fig. 4) which, in addition to guaranteeing the health of users, dynamically contributes to energy savings through the management of thermohygrometric comfort thanks to the containment of the use of air conditioning and heating systems, which are mainly responsible for fuel and CO_2 consumption.

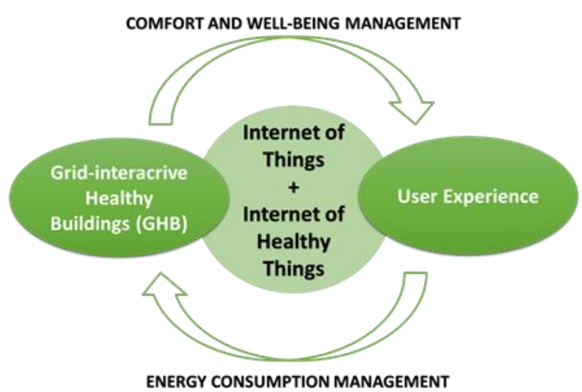

Figure 4. GHB energy and comfort virtuous circle

3.1. Node architecture

Building Health Monitoring (BHM), a process for the identification of general conditions, periodically collects data from suitable sensors that allow to characterize the general health status of a building such as the structural condition (de Rubeis et al., 2019;

De Rubeis et al., 2017; Muttillo et al., 2020). Therefore, this monitoring will provide information on the structure condition in a short time, and, for infrastructures and civil structures, it is necessary to assess performance and health status. For this work we took advantages form an already developed architecture, an Internet of Things (IoT) system for SHM to find possible damages and to see how the structure behaves over time where we added several sensors (temperature, humidity and particles) connected to the node microcontrollers (see Fig. 5).

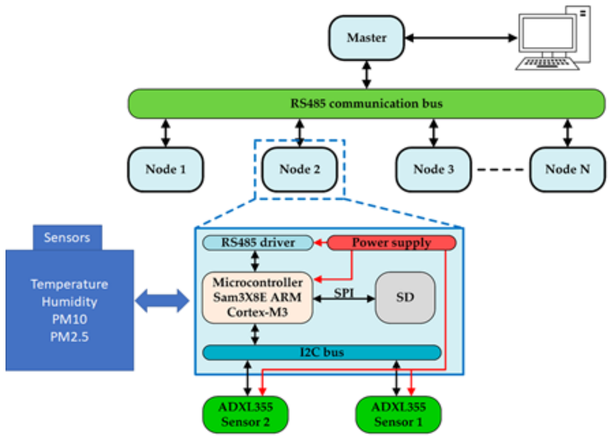

Figure 5. GHB energy and comfort virtuous circle

As in (de Rubeis et al., 2019), the datalogger is able to acquire the data coming from the nodes through RS485 communication and synchronize acquisitions and has an internal memory to allow for the post-processing of the collected data.

4. Discussion

The use of the Internet of Things is now very widespread: thanks to the IoT, every connected and communicating object uses an information exchange technology between the objects and the system, becoming able to acquire data and exchange information. The combination of IoT and Health Management (IoHT) represents an evolution in the use of these technologies, improving comfort and user experience, transforming the way spaces are lived and interact with one's own reference systems.

The collection and analysis of environmental and body data allows intelligent and optimized control of the environments in order to program operations with a reduction in energy consumption and an increasingly higher level of indoor comfort based on the real sensations of the occupants by dimensioning the management based on the average occupancy: this fact represents the new frontier of the innovative personal thermal comfort models, making them operational while the structure is in use.

Another important element is prevention: continuous monitoring allows us to understand any health threats or discomfort levels in advance, making possible an immediate intervention through the activation of compensative measures.

The results obtained to date from the research form the basis for implementing the monitoring and dynamic simulation models. This would allow both to perfect the design of high-performance buildings such as GEBs and, above all, to equip them with healing environments defining a new generation of healthy and inter-active environments (GHB). Furthermore, the application of IoT to UES makes the built environment truly adaptive, capable of reacting to external and/or internal changes.

5. Conclusions

The aim of this research is to target the Grid-interactive Efficient Buildings (GEB) directly connected to the health and comfort parameters of the users through IoT application. In GHBs, IoT and energy management represent the architecture of all energy resource optimization solutions while maintaining the indoor well-being and comfort of the occupants over time.

The IoT architecture designed in this work makes it possible to carry out human activity tracking in order to adjust the parameters according to real needs through an interactive and connected database.

The objective of the research implies not limiting the good management of the environments to parameters monitoring but to combine them with the sensations and the state of well-being of the occupants, creating an active response *ad personam*, so that each environment is tailor-made to users who lives it. Finally, in addition to the positive effect on human health, an increase in the resilience of the built environment is generated as well as energy savings due to the improvement of indoor comfort.

The design of such healthy and sophisticated environments, from the point of view of both sensor technology and networks and architectural/construction environmental devices, must be supported by project models and dynamic simulations of the performance required by the structure from the first step of the design process and, at the same time, by a constant monitoring of the living space during use.

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