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DEVELOPMENT OF A MULTI-SENSOR DEVICE FOR INDOOR ENVIRONMENTAL QUALITY ASSESSMENT

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ABSTRACT

Indoor Environmental Quality (IEQ) assessment in offices is demanded for the analysis of building performances, management of energy consumptions and occupants' well-being, comfort and work productivity. The present work presents the PROMET&O (PROactive Monitoring for indoor EnvironmenTal quality & cOmfort) system, composed by a low-cost and accurate multi-sensor and a tablet for the acquisition, analysis and communication of the quality conditions of indoor environments to different categories of users. Thermal, lighting, acoustic and air quality conditions will be monitored and displayed, through a user-friendly interface, both to the building infrastructures managers and to the occupants, with the further aim of enhancing their awareness and proactive behavior.

Keywords: *indoor environmental quality, overall comfort, multi-sensor device, interface*

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1. INTRODUCTION

The characterization of indoor environments in terms of thermal, acoustic, lighting and air quality domains is the main concern of Indoor Environmental Quality (IEQ), that influences the occupants' health, well-being, comfort and work productivity [1]. The IEQ assessment is based on in-field monitoring of parameters and indexes of the four domains and nowadays intensive long-term monitoring campaigns by means of low-cost sensors, wireless sensor network and cloud software platforms are carried out [2,3]. For example, Tiele et al. [2] developed a multi-sensor for the monitoring of IEQ in working environments. It is a low-cost battery-powered device with an external case of 165 mm × 105 mm × 55 mm. They also developed a rating system of the acquired measurements, that are classified for each parameter as "good", "average", "poor" or "bad" in relation to how much they exceed predefined thresholds. Finally, an IEQ index is calculated as weighted average of the single parameters and its percentage value is printed on a low-power OLED display over the case of the tool. Parkinson et al. [3] developed SAMBA, an IEQ monitoring multi-sensor designed to be located on office desks. Its design consists in two separate units kept together through an ethernet cable. They developed also

a software platform for the reporting of monitored data in a user-friendly solution. The reported IEQ score is calculated based on the hourly averages of measurements for the monitored parameters and on their compliance with international standards.

So far, IEQ monitoring is aimed at a specific research question, e.g., the correlation with energy consumptions or with occupants' comfort and behavior, but a defined strategy to correlate all these aspects is needed. In fact, IEQ strongly influences the Indoor Environmental Comfort (IEC), that is the status in which people feel a sensation of well-being and satisfaction. The continuous collection of occupants' subjective feedback using portable computer or smartphones is possible thanks to the information and communication technology. However, there is not a unique solution universally recognized in terms of number of questions, type of questions and frequency of answer needed [4]. Furthermore, there are contextual, personal and behavioral variables that influence the occupants' perception of the environment and thus alter the reliability of their answers [5] (e.g., building orientation, workstation location, age, country of birth, educational qualification). Often, although physical conditions comply with standard requirements, occupants are dissatisfied with the environment, thus their proneness to meet their comfort expectations alters their behavior with consequences on building energy consumptions [6].

As a step forward the state of the art, the development of a system for the assessment of the relationships between IEQ, IEC, personal, behavioral and contextual variables is promoted. PROMET&O will allow for in-field monitoring of IEQ parameters through the multi-sensor and the collection of occupants' IEC feedback through an ad-hoc developed questionnaire.

The paper is organized as follows: in Sect. 2, IEQ standards are recalled, and the physical quantities to monitor introduced; Sect. 3 provides insight on the PROMET&O system, with a detailed description of the multi-sensor device, the cloud platform and the user interface; concluding remarks and some outlook regarding future works are provided in Sect. 4.

2. INDOOR ENVIRONMENTAL QUALITY MONITORING

Tab. 1 shows the monitored parameters through the PROMET&O multi-sensor device and the thresholds for indoor environments defined by standards and the WELL Building Standard, analyzed for the parameters selection, since a universally acknowledged strategy for IEQ monitoring is not defined yet.

Table 1. Monitored parameters and thresholds set by international standards and the WELL Building Standard.

Parameter	Threshold	Reference
Air temperature	WINTER: (20-24) °C SUMMER: (23-26) °C	ISO 7730:2005
Relative Humidity	(25-60) %	EN 16798-1:2019
Illuminance	Writing, typing, reading, data processing ≥ 500 lx	EN 12464-1:2021
Sound Pressure Level	≤ 45 dB(A)	NF S 31-080
Carbon monoxide	15 min. mean ≤ 100 mg/m^3 1 h mean ≤ 35 mg/m^3 8h mean ≤ 10 mg/m^3 24 h mean ≤ 7 mg/m^3	EN 16798-1:2019
Carbon dioxide (ΔCO_2)	≤ 800 ppm	EN 16798-1:2019
Nitrogen dioxide	1 h mean ≤ 200 µg/m^3 Annual mean ≤ 20 µg/m^3	EN 16798-1:2019
Particulate matter (PM2.5)	24 h mean ≤ 25 µg/m^3 Annual mean ≤ 10 µg/m^3	EN 16798-1:2019
Particulate matter (PM10)	24 h mean ≤ 50 µg/m^3 Annual mean ≤ 20 µg/m^3	EN 16798-1:2019
Formaldehyde	30 min. mean ≤ 100 µg/m^3	EN 16798-1:2019
Total volatile organic compounds	≤ 500 µg/m^3	WELL

3. THE PROMET&O SYSTEM

The PROMET&O system aims at encouraging a pro-active behavior of the buildings' occupants, whilst monitoring the actual IEQ conditions and IEC.

The main blocks the system is comprised of are shown in Fig. 1. Each multi-sensor device measures thermal, lighting, acoustic and air quality conditions, and sends a set of pre-processed data to the cloud platform. All objective data are stored there, and they can be later accessed by users by means of a user-friendly dashboard. The occupants can also provide a feedback on the perceived IEC by compiling a questionnaire. In such a way, objective data regarding the actual IEQ can be merged with IEC data provided by users

to encourage a pro-active behavior. A detailed description of each block is provided in what follows.

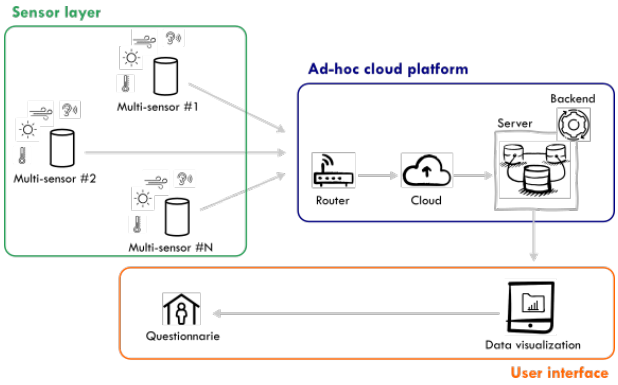

Figure 1. Architecture of PROMET&O system.

3.1 Multi-sensor device

For the proposed system to be effectively exploited in different environments, e.g., offices or houses, the multi-sensor should be a low-cost, compact, plug-and-play and flexible device. The multi-sensor was designed with these objectives, resulting in the architecture shown in Fig. 2.

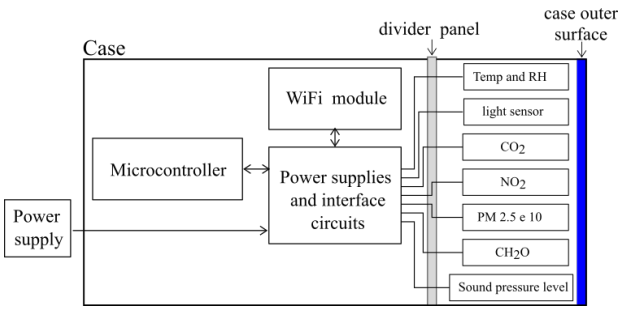

Figure 2. Block scheme of the multi-sensor device.

In order to measure the physical quantities identified in Sect. 2, the multi-sensor is equipped with particulate matter (PM), formaldehyde (CH_2O), nitrogen dioxide (NO_2) and carbon dioxide (CO_2) sensors. Temperature and relative humidity sensors were included to estimate the thermal comfort, whether illuminance and sound pressure level ones for the visual and acoustic comfort as well. Calibration procedures were planned for each sensor both stand-alone and within the external case with the whole components assembled to guarantee the traceability of the measurements provided by the designed multi-sensor [7].

A microcontroller is responsible for acquiring data from the sensors, pre-processing, and sending them to the cloud platform by means of a wireless module. The multi-sensor is powered by the mains through an external power supply to minimize the self-heating issue. The internal volume of the case is divided in two by a panel, which provides both mechanical support and some separation between the sensors compartment and the controller (see Fig. 2). The multi-sensor also includes a PLA case, which encompasses all the electronics. Figure 3(a) reports a photograph of the multi-sensor prototype looking at the sensors compartment. The position of each sensor inside the case has been carefully chosen to avoid cross-interference. All sensors have been mounted vertically, except for the light sensor and the microphone which are located on the top. The external case, which is shown in Fig. 3(b), was designed to maximize the air exchange between the inner case volume and the environment to monitor. Furthermore, a visual feedback about the actual IEQ is provided to the occupants by means of LEDs. The number of turned on LEDs will be proportional to the estimated IEQ in a thermometric-like scale.

(a) (b)

Figure 3. A photograph of (a) the prototyped multi-sensor mounted and (b) of the external case.

3.2 Ad-hoc cloud platform

With the multi-sensor devices sending the measured IEQ data with a time interval as low as 1 second, a reliable and lightweight communication protocol should be adopted. To this purpose, the PROMET&O system exploits the Message Queue Telemetry Transport (MQTT) protocol. It is based on a publish-subscribe paradigm, and it allows for some optimization of the payload. The back-end part therefore includes a broker and a client, which collects the data from the multi-sensors and inserts them in a MySQL-

like database. The data in the database are then retrieved by the front-end part of the platform to be shown to users through a dashboard.

3.3 User interface

The developed dashboard aims at showing to end-users the actual and past physical conditions of the environment they are in, acquire more information on IEQ field (through the "Hints" and "More" sections) and increase their awareness on it and on their role in the enhancement of their IEC. The developed questionnaire allows them communicating their IEC perception for each specific domain. The questionnaire was developed also to acquire personal and behavioral variables to finally analyze and compare IEC with IEQ.
Two campaigns were performed to validate both the dashboard and the questionnaire. Closed questions by means of Microsoft Form and interviews were submitted to a panel of subjects for the evaluation of the ease of navigation, understanding of contents and quality of graphic layout for a greater user engagement [8].

Figure 4. Screenshot of the dashboard. The user can get an indication of the actual IEQ at a glance.

4. CONCLUSION AND FUTURE WORK

The assessment of indoor environmental quality for the analysis of building performances, management of energy consumptions and occupants' well-being, comfort and work productivity is encouraged. This work shows the development of the PROMET&O system, that comprises a multi-sensor, that is a low-cost and accurate device for the acquisition of IEQ parameters, and a tablet, through which subjective feedback on comfort perception are collected by means of a questionnaire and overall data visualization is provided to end-users. The PROMET&O system will be tested in-field in a company open-plan office and this will allow for its validation. The step forward the state of the art is determined by i) the real-time correlation of objective and subjective data, ii) the user's engagement through the dashboard and through the visualization of the IEQ level thanks to the LEDs lighting feedback and finally iii) the aim of promoting energy saving while improving IEQ and IEC.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] I. A. Sakellaris et al.: "Perceived indoor environment and occupants' comfort in European 'Modern' office buildings: The OFFICAIR Study," *Int. J. Environ. Res. Public Health*, vol. 13, no. 5, 2016.

[2] A. Tiele et al.: "Design and development of a low-cost, portable monitoring device for indoor environment quality," *J. Sensors*, vol. 2018, 2018.

[3] T. Parkinson et al.: "Continuous IEQ monitoring system: Context and development," *Build. Environ.*, vol. 149, no. October 2018, pp. 15–25, 2019.

[4] N. Lassen et al.: "Design and in-field testing of a multi-level system for continuous subjective occupant feedback on indoor climate," *Build. Environ.,* vol. 189, p. 107535, 2021.

[5] E. O. Rasheed and H. Byrd: "Can self-evaluation measure the effect of IEQ on productivity? A review of literature," *Facilities*, vol. 35, no. 11–12, pp. 601–621, 2017.

[6] C. fei Chen et al.: "Culture, conformity, and carbon? A multi-country analysis of heating and cooling practices in office buildings," *Energy Res. Soc. Sci.*, vol. 61, no. June 2019, p. 101344, 2020.

[7] A. Astolfi et al., "Development and Metrological Characterization of a Multi-sensor Device for Indoor Environmental Quality (IEQ) monitoring", *Proceedings of 2023 IEEE International Workshop on Metrology for Living Environment*, 2023.

[8] V. I. Fissore et al., "Definition of a methodology for occupants' feedback collection on perceived indoor environmental comfort," *Proceedings of Healthy Buildings Europe 2023*, 2023.