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IEQ measurement and assessment tools for Plug-and-Play deep renovation in buildings

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ABSTRACT
This paper presents the approach developed for the monitoring and assessment of Indoor Environmental Quality (IEQ) in the whole deep renovation process aimed at reducing energy consumptions and improving comfort. The research was performed by the P2Endure project, that aims to provide scalable, adaptable and ready-to-implement prefabricated Plug-and-Play systems for deep renovation of building envelopes and technical systems. The idea is to use IEQ as one of the design criteria supporting the decision-making process, included into the holistic renovation process developed by P2Endure and called "4M: Mapping-Modelling-Making-Monitoring". For this reason, a set of Key Performance Indicators (KPI) was selected, with the consequent measurement and calculation methodologies. The KPIs are collected and showed together with the analysis of the different IEQ dimensions (thermal and indoor air quality). The data collection has been investigated extensively, taking into account all possible data sources, measurements and surveys (e.g. special questionnaires for children in schools). In addition to traditional devices, the innovative Comfort Eye sensor is used in the proposed framework. This is a low-cost sensing system capable of measuring thermal comfort together with IAQ, applicable for permanent or periodic monitoring and with low disturbance for inhabitants. The overall procedure is presented, also in relation with the deep renovation process. Then, the application of the measurement and assessment tools in real demonstration cases is illustrated with initial results from the monitoring campaign.

KEYWORDS
Measurement, Comfort, IEQ, Deep renovation, Plug-and-Play

INTRODUCTION

The existing building stock counts 210 million buildings in Europe and 75-90% of these buildings are estimated to still be standing in 2050. Most of Europe's existing building stock – over 90% of the total – has yet to be affected by energy performance requirements[1]. Therefore, the majority of the existing stock is composed by low-performance buildings in terms of energy consumption and IEQ (Indoor Environmental Quality), that will be subjects of renovation in the near future to accomplish 2030 EU targets. Considering that people spend about 90% of their time in indoor environments where microclimatic conditions greatly affect health, well-being and productivity, the renovation approach has to deal with the challenge of reducing the energy use but guaranteeing the optimal comfort. In fact, existing buildings are not able to keep the required comfort conditions because of the poor performance of their envelope and heating/cooling systems (Roaf et al. 2015). Although the renovation is the

[1] BPIE factsheet: 97% of buildings in the EU need to be upgraded

solution to the problem of performance, major attention is provided to the final energy performance and it is very usual that passive buildings design could lead to very tight environments suffering of Sick Building Syndrome. (Yousef et al. 2016) concluded that green building designs don't automatically guarantee that the building designed will be comfortable and will ensure occupants' well-being. Experts recognized and demonstrated that the environmental conditions have a significant effect on building occupants' health, although the general public has only recently started to understand the effect that this relationship can have on their everyday lives and well-being (Sappanen and Fisk, 2006). Detailed analysis and monitoring of building performance during its operations are necessary. In this framework, the EU project P2Endure proposes an innovative approach to buildings renovation, where a set of Plug-and-Play (PnP) technologies are provided within a holistic renovation approach that entails a set of KPIs (Key Performance Indicators) to assess the overall performance under different domains. The IEQ is one of them, and P2Endure developed a dedicated approach for the IEQ measurement and assessment, based on the innovative system called Comfort Eye in conjunction with standard surveying and measurement techniques.

METHODS

P2Endure approach for deep renovation

The P2Endure project is based on a holistic strategy for buildings deep renovation, structured on the 4M approach. The 4M modular process is a stepwise approach for preparing and implementing the deep renovation of buildings making use of PnP based innovative deep renovation products, followed by real monitoring of the resulting performance. The 4M correspond to 4 stages of the renovation process: Mapping, Modelling, Making, Monitoring**.** In this context, the data collection and monitoring before and after the renovation plays a pivotal role to: i) capture the actual real performance of the building and feed the design; ii) verify the compliance with renovation goals with deep Post Occupancy Evaluation. This paper presents the work done to implement tools for the IEQ mapping and monitoring.

IEQ monitoring and assessment protocol

The IEQ monitoring and assessment protocol has been developed starting from the standard EN 15251 (CEN, 2007), as already performed in the previous experience of (Zangheri et al. 2011). The proposed methodology is based on the evaluation of KPIs and benchmarks according to the buildings classification provided by EN 15251 (Categories I, II, III, IV). Different comfort domains are investigated (thermal comfort, IAQ and acoustic comfort) and for each domain a KPI, expressed as percentage of fulfillment of the criteria according to the targeted Category, is used. According to EN 15251, an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit. To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is used. In this way the KPI assigned to each domain is normalized on a 0-100% scale. In addition, a detailed analysis of each domain is performed on measured data to provide insight on building performance and potential pathologies. The scope is the support of the renovation design (before intervention) and verification of renovation results (after intervention).

Comfort Eye

Thermal Comfort is assessed using the predictive (PMV) model. The Comfort Eye is a sensor capable of measuring the PMV for multiple positions in a room. The measuring concept is based on the thermal scanning of indoor room surfaces to calculate the mean radiant temperature with the angle factors method, according to ISO 7726, in function of the room geometry and occupants location. The detailed description of the methodology is presented in

(Revel et al. 2014). The mean radiant temperature is merged with the data (air temperature and relative humidity) acquired by a second sensing node that is placed in the most representative zone of the room. Embedded algorithms allow the calculation of comfort indexes, applying subjective parameters (occupants' activity and clothing insulation) in function of the typical end-use of the building. Furthermore, the second sensing node integrates a CO_2 sensor to provide IAQ monitoring.

Figure 1 The IR scanning device of the Comfort Eye

In the proposed framework, the Comfort Eye is used to measure the IEQ before the renovation to assess the building performance and potential pathologies to be solved in the design phase. In fact, together with comfort and IAQ indexes, information about the thermal performance of building envelope can be extracted from IR thermal maps. The same device is used after the renovation to evaluate if renovation design goal is met.

Surveys

The P2Endure protocol includes the investigation based on surveys to complement the monitoring data collection. This is particularly important in the case of occupants with characteristics that could differ from generic adults (e.g. office worker). In particular, a survey to investigate the thermal sensation of children was specifically created because of the presence of 3 nurseries within the project demonstration cases. Given the age of the interviewed persons (from 3 to 5 years old), traditional questionnaires could not be used. Thus, a graphical questionnaire, based on previous researches in this field (Fabbri 2013; Vasquez et al. 2014), was prepared together with the teachers. The questions asked to children were related to their feeling (hot/neutral/cold), sensation (happy/sad), thermal preference (colder/neutral/warmer), weather (sunny/cloudy/rainy) and clothing. Each question was asked with a set of images, drawn in function of how children could associate the reply with a representative image (Figure 2).

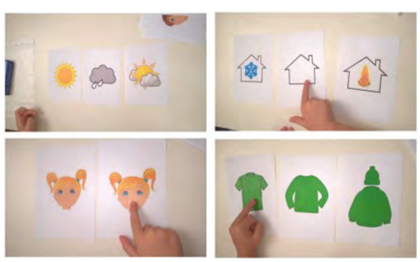

Figure 2 Graphical questions for children interviews

Description of the case studies

The IEQ monitoring protocol has been applied in two real demonstration projects where renovation will be applied. A nursery in Genova, located on the second floor of a two-level building, built in 1930s with concrete structure and non-structural brick walls. A nursery in Warsaw, built in 1983. It is in the southern part of the city and is one of 55 municipal nurseries in Warsaw.

RESULTS

Results from the monitoring in Genova

The thermal comfort and CO_2 have been measured with standard sensors (Deltaohm Microclima HD 32.3A and Deltaohm IAQ Datalogger HD21ABE), compliant with ISO7730 and ISO7726, located in two different rooms. Winter and summer monitoring was one month long each, with an acquisition time of 5 minutes.

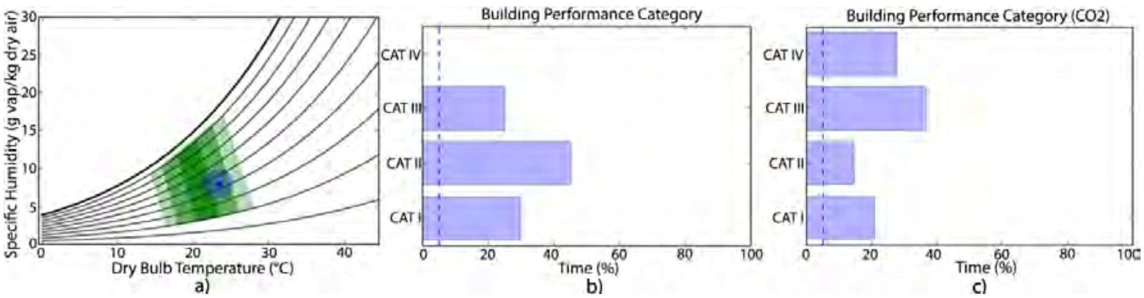

Figure 3 Winter comfort analysis: average operating conditions within comfort zones (a) category compliance of occupied hours for thermal comfort (b) and CO_2 (c)

The detailed analysis of comfort conditions in winter, is reported in Figure 3 a), where the average thermal condition (dark blue dot) is located with respect to comfort zones calculated according to EN15251. The deviation from the average condition (variability) is represented with the transparent blue circle, calculated with Monte Carlo analysis applied to input parameters according to their fluctuation in the time domain. The PMV was calculated with a clothing insulation of 0.9 clo and metabolic rate equal to 1.2 met. The monitoring campaign registered an average PMV of 0.3. The overall thermal sensation is within the optimal comfort range, slightly unbalanced toward warm sensation. The calculation of the percentage of time of building operation within the different Categories is presented in Figure 3 b). For about the 23% the time, the building operated a Category III, which indicates a poor condition. The KPI calculated as weighted average of all the monitored rooms turned out to be equal to 0% for Category II. The indoor air quality has been measured and assessed according to the P2Endure protocol. During winter, windows were mostly kept closed to ensure thermal comfort and the indoor air quality turned out to be poor, the nursery operated mostly as Category III and IV (Figure 3 c). During summer season, both measurements and surveying were performed. Questionnaires were compiled according to the presented methodology, with the support of teachers. A total number of 127 questionnaires were collected presenting a general warm sensation as reported in Table 1.

Table 1 Recap of children surveys in summer

Question	Q1: How do you think is the classroom today?			Q2: When the classroom is (Q1 answ.) how do you feel?		Q3: At this moment you like to feel…		
Reply	Hot	Not hot neither cold	Cold	Sad	Happy	Warmer	No change	Cooler
Number	87	38	3	57	70	20	50	58
Percentage	69%	30%	2%	45%	55%	16%	39%	46%

From the interviews, the warm sensation is prevalent with 69% of replies. This is also confirmed by the higher percentage of children preferring a cooler feeling. At the same time the environmental data were acquired to assess thermal comfort using adaptive model for naturally ventilated buildings, according to EN15251. Measured data turned out to provide averaged operating conditions in the Category III comfort zone, with a variability that brought the building outside that category (Figure 4 a and b). Concerning the IAQ, in summer, the windows were opened and the building presented a very high performance (Figure 4 c).

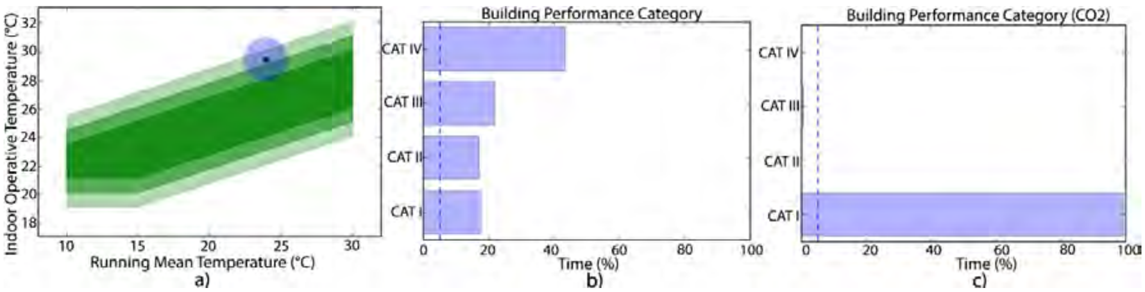

Figure 4 Summer comfort analysis: average operating conditions within comfort zones (a) category compliance of occupied hours for thermal comfort (b) and CO_2 (c)

Results from the monitoring in Warsaw

The Comfort Eye system was applied to Warsaw demo case for testing the first prototype. The installation was performed in March 2018 for 2 days, with an acquisition time of 5 minutes.

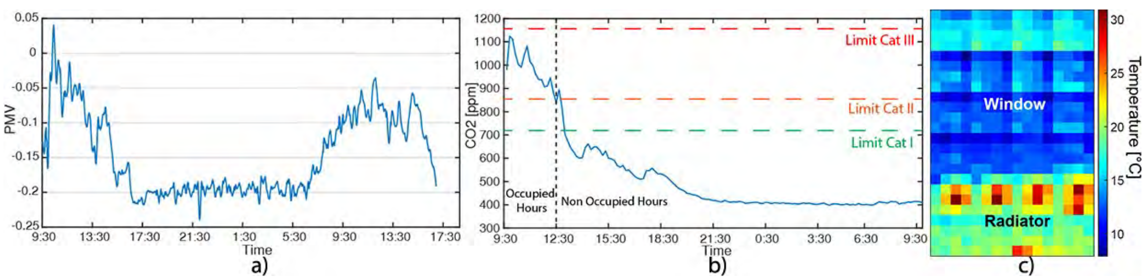

Figure 5 Comfort Eye measurement in Warsaw: Thermal comfort a) CO_2 b) Thermal map c)

Figure 5 a) shows the PMV measured in the room during the test, which turned out to provide an average value of -0.15. The comfort is maintained within the acceptable range, providing a KPI of 100% with the fulfilment of Category II criteria. The CO2 was measured during the two days of testing, but the room was occupied only during the first day. Figure 5 b) shows the CO_2 trend during the occupied and non-occupied period of the first day. The monitoring turned out to provide a poor level of IAQ during the occupied hours with CO2 concentrations always within the Category III, leading to a KPI equal to 0%. Figure 5 c) shows an example of thermal map, provided by the Comfort Eye, where the elements composing the outer wall of the room are measured. The window area is distinguished by a lower temperature (average of 10°C) with respect to the other parts. The opaque element of the wall registered an average temperature of 16°C, providing a strong deviation from the average room air temperature (22.8°C). This deviation, together with the low window temperature, had an impact in terms of radiant temperature. In fact, a mean radiant temperature of 17.8°C was measured near the wall (50cm of distance, not in front of the radiator). This initial investigation suggests a non-efficient building performance since, although thermal comfort is kept within requirements, the air temperature is kept high to balance the cooling effect of the building envelope.

DISCUSSIONS

The presented results reveal the importance of the IEQ measurement in buildings renovation process. The demo cases presented issues that need to be addressed by the renovation design.

In both cases, the indoor air quality is poor, especially in winter, suggesting the inclusion of mechanical ventilation systems. Moreover, the envelope performance monitoring is important to highlight masked pathologies, as the low wall and window temperature that can provide discomfort conditions by strong deviations from the air temperature, or, despite the almost optimal PMV, non-efficient use of energy to keep the building comfortable because of the low envelope thermal performance.

CONCLUSIONS

The proposed paper presents the initial results from the application of innovative IEQ measurement systems in the renovation process. The use of dedicated tools, as the Comfort Eye, can be useful to bring IEQ issues to the attention of the design team. In P2Endure, the monitoring results are going to feed the design of dedicated PnP renovation solutions, as multifunctional panels with embedded ventilation systems. The overall design will thus address not only energy, but also IEQ criteria. After the renovation, the same measurements will be applied to verify the final IEQ result. Finally, the possibility of integrating the measurements all in a unique device, the Comfort Eye, will make easier and less intrusive the monitoring.

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