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Protocol for Post Occupancy Evaluation in University Campus Classroom to Improve Indoor Environmental Quality

Ridha Benabdallah[1]*, Toufik Mezerdi[2]

[1,2]LACOMOFA Laboratory, Architecture Department, Mohamed Khidher University, BP 145 RP, 07000 Biskra–Algeria.
benabdallah.ridha@univ-biskra.dz

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Abstract

The healthy indoor environment is the aid that allows us as architects or people interested in well-being to better understand the impact of building occupancy on the occupants' health and comfort. In addition, students' positive education requires creating learning spaces of a good environmental quality. It is also necessary that teachers and students are satisfied with this interior space and physical environment (thermal, visual, sound and air quality, among others) that it represents. Post-occupancy evaluation (POE): a process of evaluating the performance of a building after it has been occupied for a period of time. It has been recognized and recommended as one of the methods used by researchers in the field of indoor environment quality (IEQ).The present paper shows the results of a literature review that aimed at exploring the POE protocols adopted by researchers in order to assess indoor environmental quality in classrooms. Our goal is to propose a robust IEQ protocol to improve indoor environment quality in university campus classrooms; we will present the proposed POE protocol for our research (case study), which will be a synthesis of what has been adopted in the literature. The POE developed for this study will be related to two levels: an objective and subjective short-term evaluation. Furthermore, this protocol will include the way of taking measurements as well as the written questionnaire (students' survey).

Key words: Indoor Environmental Quality (IEQ), IEQ in-situ measurements, Occupant Survey, Post-Occupancy Evaluation (POE), Post-Occupancy Evaluation Protocol.

ABBREVIATIONS

IEQ (Indoor Environmental Quality), POE (Post-occupancy evaluation), POE Protocols (Post-occupancy evaluation Protocols), CO (carbon monoxide), CO2 (carbon dioxide), IAQ (indoor air quality), PM (particulate matters), RH (relative humidity), AT (air temperature), TVOC (total volatile organic compound).

INTRODUCTION

Indoor environmental quality is a perceived indoor experience of occupants in the indoor environment of a building (David et al., 2013). The evaluation of indoor environments quality is a very important research subject for several specialties, in particular: architecture, interior design and mechanical engineering (Sooklee, 2007). This concept consists of several comfort parameters: including thermal, visual, acoustic comfort and indoor air quality.

In addition, the indoor environment quality of classroom can expose a health risk to students (dizziness, heavy head, headache and fatigue), it may sometimes lead to school absenteeism (Turunena &Oluyemi, 2014). In this regard, several studies illustrate that these problems of well-being, health and performance occur in poorly designed educational buildings that provide poor indoor environmental quality in terms of acoustics, indoor air, high temperature and insufficient lighting (Salimat &Halil, 2020). In terms of learning activities, creating a comfortable learning environment has become a necessary requirement, due to its positive impact on students' well-being and success.

POE is an invaluable tool, it is considered as a systematic assessment process to assess the quality of a building's indoor environment, including thermal, visual, acoustic and indoor air quality conditions. (Peixian et al., 2018). For this reason, many post-occupancy evaluations approaches have been applied over the past decades to improve future architectural design. (Galatioto et al., 2014). This approach was discussed in the late 1960s by the study of Sim van der Rijn (from California University, Berkeley) and Victor Hsia (from Utah University). Herb McLaughlin (1975) authored the first publication with the term POE. In 1988, the approach was widely spread by Preiser, Rabinowitz and White wrote (1988) (Peixian et al., 2018).

Based on the above finding, this research deals with this topic and focuses on the indoor environment quality of classrooms. The objective of this paper is to provide the following: (1): an overview of methods and assessment tools (objective and subjective) of the IEQ, (02) a review of the literature on post occupancy evaluation protocols adopted by researchers to improve IEQ in classrooms, and (03) the presentation of post- occupancy evaluation protocol proposed for this study.

MATERIALS AND METHODS

Post-occupancy evaluations (POEs) have been recognized for documenting the well-being (health and comfort) and the perception of the occupants to indoor environment quality parameters such as: thermal, acoustic and visual comfort as well as indoor air quality (Suyeon et al., 2017). It was conducted to define the various correlations between measurable physical indicators of IEQ and occupants' comfort (Kaushik, 2019).

The state of the art is a mandatory process before any scientific research. It was carried out in order to collect everything that has been written on our research subject up to the present day. In this regard, we tend through this review to clarify the methodologies as well as the post-occupancy evaluation protocols by which architects have evaluated the IEQ, and its relationships with comfort, well-being and students' performance in learning environments. This work was conducted by an electronic research of theses and scientific papers referenced in peer-reviewed journals.

Finally, the present work will be concluded by presenting our proposed post occupancy evaluation protocol in order to improve indoor environmental quality in university campus classroom.

RESULTS AND DISCUSSION

Review of Indoor Environment Quality Assessment Methods and Tools

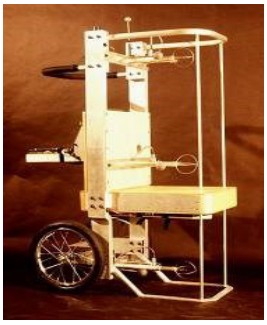
Historically, the concept of indoor environment quality has hardly evolved. A number of authors have done literatures studies such as (Ponti et al., 2015; Frontczak &Wargocki, 2011; Yousef & Arif, 2016 and Bluyssen, 2019). That term has been in discussion since 1999. The following studies are the first works in this field: (Chiang et al., 1999; Chiang et al., 2001; Tarcan et al., 2004; Al-Harbi, 2005; Mui & Chan, 2005; Humphreys, 2005; Gilmour, 2006; Veitch et al., 2007; Dascalaki et al., 2009; Yoon, 2008; Astolfi & Pellerey, 2008; Wong et al., 2008; Bluyssen, 2009; Lai et al., 2009 and Schakib et al., 2010).

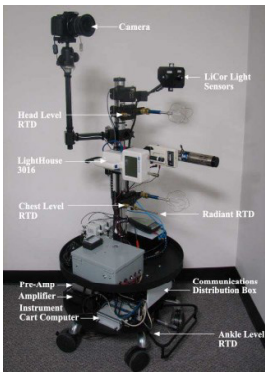
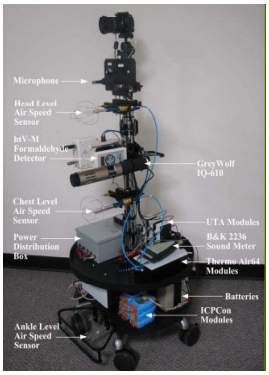
Before delving into post-occupancy evaluation protocols of IEQ, this paper will briefly review the assessment methods presented in literature. The recent literature review has clearly established that there is currently no unified method for assessing indoor environment quality. On this subject, the scientific literature has known two principal methods: an investigation (survey) and experimental, these two (02) methods usually consist of two techniques (objective and Subjective).

Objective Method

Through in situ physical measurements of several indoor environment quality indicators (IEQ), it is applied using measuring sensors and IEQ measurement carts that are manufactured according to international standards (described in research by David et al., 2013 and Peixian et al., 2018). The following table (table.1) represents IEQ measurement carts that have been described by the literature.

Table 1. Pictures of IEQ measurement carts (Source: (Heinzerling et al., 2013 and Peixian et al., 2018)

1st of it's kind (1985)	Benton C, Bauman F, Fountain M. A (1990)	Nicol, J. F. et McCartney K (2000)
	 **Instrumented chair-like cart**	 **SCATs instrumented cart**

Chiang CM, Chou PC, Lai CM, Li YY. A (2001)	Webster T, Bauman F, Anwar G. (2007)	Newsham G, Birt B, Arsenault C. (2012)
 **IEQ cart**	 **UFAD commissioning cart**	 **NICE instrumented cart part 1**
Newsham G, Birt B, Arsenault C. (2012)	Choi J-H, Loftness V, Aziz A (2012)	Kim H, Haberl J. (2012) et Kim H. (2012)
 **NICE instrumented cart part 2**		 **Comprehensive IEQ monitoringcart**

Subjective Method

Through questionnaires (Occupant survey), two types of questionnaires exist for this purpose: in situ at the time of measurement (right now) and overall questionnaires (online or in buildings).

Concerning indoor environment quality parameters, the content of this concept is still being discussed (Claude, 2008; Sani, 2018 and Mujeebu, 2019). In the following table (table.2), we present indoor environment quality parameters and indicators measured in educational buildings (learning environments).

Table 2. IEQ factors and parameters (indicators) (Source: author)

Reference	Method	IEQ Factors and Parameters (indicators)			
		Thermal Comfort	**Visual Comfort**	**Acoustic Comfort**	**QAI**
(Ludmila, 2017)	Measurements and questionnaire	RH Outside air temperature Air temperature Air velocity	Illuminance	Sound level	CO2 level PM2 and PM10
(Mari et al., 2014)	Measurements and questionnaire	Ambient temperature Air temperature	N/A	Noise	Ventilation rate CO2 level

(Toderaşc and Vlad 2016)	Measurements and questionnaire	Outside air temperature Air temperature	Illuminance	Sound pressure level SPL	N/A
(Tahsildoost and Zomorodian, 2018)	Measurements and questionnaire	Air temperature RH Air velocity	Illuminance Daylight factor (DF)	Sound pressure level SPL	CO2 level
(Da Yang et Cheuk Ming Mak, 2020)	Measurements and questionnaire	Air temperature RH Air velocity	Illuminance Illuminance uniformity	Sound pressure level SPL	CO2 level
(M.A.A. Rahman et al., 2020)	Measurements	Mean radiant temperature Air temperature RH Air velocity	Illuminance	Sound level	CO2 level Co
(Varshini, 2015)	Measurements and questionnaire	Air temperature RH Air velocity	Illuminance Luminance	Sound level	CO2 level PM2 and PM10
(Sani, 2018)	Measurements and questionnaire	Air temperature RH Air velocity Radiant temperature	Illuminance Uniformity	Noise Reverberation	CO2 level PM2 and PM10
(Silvia et al., 2017)	Measurements and questionnaire	Air temperature RH	Illuminance	Sound level	CO2 level PM2 and PM10
(Alzahrani, 2018)	Measurements and questionnaire	Air temperature RH Air velocity	Illuminance	Sound pressure level SPL	CO2 level
(Vishnani, 2018)	Measurements and questionnaire	Air temperature RH Air velocity	N/A	Sound level	CO2 level
(Radwan, 2014)	Measurements and questionnaire	Air temperature RH Air velocity	Illuminance	Sound level dB	CO2 level PM2 and PM10 Co TVOC Ozone
(Zuhaib et al., 2018)	Measurements and questionnaire	Air temperature RH	Illuminance	Sound level	CO2 level
(Shailendra et al., 2020)	Measurements and questionnaire	Air temperature RH Air velocity Mean radiant temperature	Illuminance	N/A	CO2 level PM2 and PM10

Review of Post-Occupancy Evaluation (POE) Protocols for Indoor Environment Quality (IEQ) in University Campus Classrooms

Many post-occupancy evaluation studies (POE) have been conducted in literature with a common objective to evaluate occupant's well-being and productivity. In fact, there is little research on POE protocols in university campus classroom. Generally, POE in the field of indoor environmental quality (IEQ) is based on several quantitative and qualitative approaches, by following three methods: the first through in-situ measurements of IEQ indicators; the second by the questionnaires and the third through both (Radwan, 2014; Alzahrani, 2018 and Galatioto et al, 2014).

IEQ in-Situ Measurements in Classroom

This part includes the basics and specific instructions for measuring each IEQ parameter. This procedure provides

detailed information on temporal and spatial accuracy, each indicator with its measuring instruments and assessment protocols as recommended in international standards. In the following, we present the evaluations protocols examined as part of this review.

In the protocol of Radwan (2014), air temperature, humidity and air velocity were measured at three levels according to ASHRAE 55 (2004), feet, chest and head (0, 10m, 0.59m and 0.97m). Acoustic comfort, the sound level (dB) was measured to the height of a student's ear (1.17 m) according to Acoustical Society of America 2010. Concerning visual comfort and indoor air quality, illuminance and CO2 levels, at a height of 0.8 m as determined by Reynolds et al. (2001), this protocol does not provide the required details on the number of measurement points for each indicator. Alzahrani (2018) used an in situ questionnaire and measurements to evaluate IEQ parameters in classrooms (thermal, visual, acoustic and indoor air quality). In this regard, air temperature and air velocity were measured at a height of 0.60 m, humidity at 1.00 m according to ASHRAE-2010 and Dubai Municipality 2010. CO2 level 0.8 m high according to EN15521 2007. Sound level (dB) and illuminance (E) at an altitude of 0.8 m as determined by Navai &Veitch (2003); Tang & Wong (1998) and Moore et al. (2002).These indicators were recorded in three (03) places (front, center and rear), six measurement points in each classroom, then calculating the mean following the procedure used by Awang et al. (2015). Measurements were taken three times in each classroom, morning, mid-day and afternoon. Sani Muhammad Ali (2018), IEQ in-situ measurements protocol was based on the study of Dorizas et al. (2015); Heizerling & al. (2013); Sarbu & Sebarchievici, (2013). Five measurement points "front-left, front-right, middle-middle, rear-left and rear-right to assess thermal comfort and indoor air quality, Three levels were measured for air temperature and humidity (0.10 m, 1.1 m and 1.50 m), this protocol does not specify the height of the CO2 level measurement meter. Nine points front-left, front-middle, front-right, mid-left, mid-mid, mid-right, rear -left, rear-middle and rear-right to measuring illuminance, with and without artificial lighting at a height of 0.75 m, values obtained were then averaged in order to arrive at representative mean illuminance values for each measured space . Three measurement points for acoustic comfort (sound level); at one meter from the table, in the middle and at the rear, at a height of 1.00 m. Erica Cochran et al. (2020), POE protocol to improve the indoor environmental quality (IEQ) in eight school buildings over eight years, between 2012 and 2019.The National Environmental Assessment Toolkit (NEAT) was adopted. For spot measurements, thermal and visual comfort indicators were measured in four and five points for Five (05) min, to account for increased student and teacher movement in classroom.

Questionnaires (Occupant Survey)

A questionnaire is another essential component of a post-occupancy evaluation protocol. Many questionnaire tools have been developed over many decades in the scientific literature among which; Building Use Studies (BUS), Building Assessment Survey and Evaluation Study (USEPA, 2003) and Center for the Built Environment (CBE) that are considered protocols for studying occupant's perceptions and satisfactions in indoor environment (Radwan, 2014; David et al, 2013 and Kaushik, 2019). These protocols have been used in similar previous studies, as an example (Alzahrani, 2018; Sani, 2018 and Vishnani, 2018). In this regard, there are two types of questionnaire: right now questionnaires and overall questionnaires. As such, in the following table (table.3) we present the questionnaires (Occupants survey) examined in this review.

Table 3. Review of indoor environment quality survey (Source: author)

Reference	Survey Types	Dimensions	Measurement Scale	Number of Questions
(Sooklee, 2007)	Overall questionnaire long-term	Participants' demographics Characteristics of personal workspace Satisfaction and performance as related to the IEQ criteria	Likert-type scale 7-point (satisfaction)	36 Questions
(Radwan, 2014)	Overall questionnaire long-term	General information IEQ (thermal, visual and acoustic comfort and indoor air quality), problems and satisfaction	Likert-type scale 7-point (satisfaction)	40 Questions

(Alzahrani, 2018)	Right now at the same time	Participants' demography Acceptance of IEQ factors Effects of IEQ on wellbeing and performance	Human perception Likert-type scale 5-point	28 Questions
(Sani, 2018)	Overall questionnaire long-term	Thermal comfort Visual comfort Acoustic comfort Indoor air quality Clothing and demographics A ranking of IEQ parameters	Perception of IEQ scale 7-point of (comfortable-uncomfortable and acceptability -non-acceptability)	26 Questions
(Natasha et all., 2011)	Right now	Visual comfort Thermal comfort Air movement	Likert-type scale 5-point Perception of IEQ	04 Questions
(Kraus and Nováková, 2019)	Right now immediate evaluation	Air acceptability Odor intensity Thermal comfort Visual comfort Humidity comfort Color comfort Noise load Total satisfaction	Perception and satisfaction	08 Questions
(Nivedita and Parik, 2020)	Right now	IEQ factors thermal, visual and acoustic comfort and indoor air quality	Perception 'various Likert scale'	08 Questions

Researchers about IEQ in school building conducted a number of questionnaires. The development of these questionnaires involved various common questions, the basic questions included in most questionnaires cited (table.3) focus primarily on Students' personal information, perception of the indoor environment quality and level of satisfaction with indoor environment quality (thermal, visual, acoustical comfort, and indoor air quality; and also the overall comfort level)

Post-Occupancy Evaluation Protocol to Improve Indoor Environment Quality in University Campus Classroom

To determine indoor environment quality of selected university's learning environments (classroom), scientific literature has led us to choose post-occupancy evaluation approach in this research. This evaluation process involves several data collection techniques and uses both quantitative and qualitative measures.

In fact, IEQ indicators will be measured through measuring instruments each designed to measure one or more indicators. Measurement will be conducted according to specific evaluation protocols as recommended by standards, these protocols have been used in similar previous studies, as an example (Alzahrani, 2018 and Sani, 2018).

IEQ in-Situ Measurements in Classroom

In situ measurements are dependent on the instrument available to the researcher and therefore have a significant effect on the number of indicators to be measured. In this research, the available measuring instruments are the lux meter, testo 480 and sound level meter. According to the protocols cited above, IEQ measurement cart proposed for this research contains the following instruments: Lux meter is used to determining illuminance; testo 480 to measuring CO2 levels, temperature and humidity, and sound level meter to measuring sound level.

Figure 1. Measuring instruments used (Source: author)

Regarding the measurement points fixed in each classroom, our choice was based on those applied in previous studies, as well as the results obtained in pre-survey. In this regard, we observed the absence of a fixed protocol (number of measurement points and height of location instrument), it was different for each author. According to the protocol adopted by Sani (2018), we will present the following protocol:

Temperature, humidity, and CO2 level will be measured in five 05 points; front-left (F-L), front-right (F-R), middle-middle (M-M), rear-left (R-L) and rear-right (R-R), testo 480 will be placed at a height of 0.6 m above ground to measure humidity and temperature, and 0.8 m to measure CO2 level . Illuminance in classroom will be measured in nine 09 points, front-left (F-L), front-middle (F-M), front-right (F-R), middle-left (M-L), middle-middle (M-M), mid-right (M-R), rear -left (R-L), rear-middle (R-M) and rear-right (R-R), with a height of 0.8 m (as was recommended by Alzahrani (2018) and Radwan (2014). Sound level dB will be taken in three 03 points, one meter from the table, in middle-middle (M-M) and rear-middle (R-M), sound level meter will be placed at a height of 1.00m.

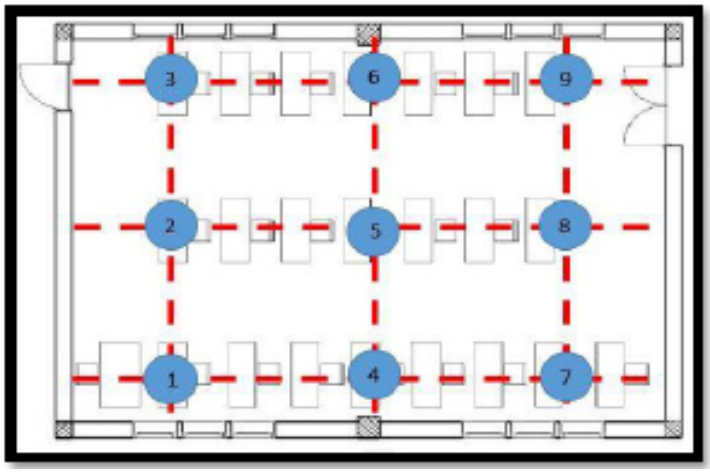


Figure 2. Measurement points: air temperature, relative humidity and CO2 level: p1, p3, p5, p7 and p9; illuminance: p1, p2, p3, p4, p5, p6, p7, p8 and p9; sound level dB: p2, p5 and p8(Source: author)

In the following table (table.4), we summarize IEQ in-situ measurements protocol used in this study.

Table 4. IEQ in-situ measurements Protocol for this study (Source: author)

IEQ factors	IEQ indicators	Measuring instruments	Measurement points	Height
Thermal comfort	Air temperature (°C)	Testo 480	05 points	0.6 m
	Relative humidity (RH %)			0.6 m

Visual comfort	Illuminance (lx)	Lux meter	09 points	0.8 m
Acoustic comfort	Sound level (dB)	Sound level meter(sonomètre)	03 points	1.00 m
Indoor air quality	CO2 level (ppm)	Testo 480	05 points	1.00 m

Questionnaires (Students Survey)

Survey by questionnaire mainly aims to evaluate Students' perception and satisfaction with indoor environment quality factors (thermal, visual, acoustical comfort, and indoor air quality). In addition, the questionnaire suggested in this study is based on the questionnaire of Center for the Built Environment (CBE), as well as dimensions and common questions in similar previous studies such as: (Sooklee, 2007; Radwan, 2014; Varshini, 2015; Alzahrani, , 2018; Sani, 2018; Silvia et al., 2017; Kraus &Nováková, 2019; Tahsildoost &Zomorodian, 2018; Nurul et al., 2017; Zuhaib et all., 2018 and Nivedita &Parik , 2020). Although the "CBE" questionnaire focuses largely on office buildings, it has been adjusted, so that it is suitable for the case of this search. This procedure was based on the interpretation of various questionnaires executed in similar learning environments.

Briefly, the right now questionnaire developed is structured in two 02 parts (dimensions): 01 General information and 02 Indoor environmental quality (IEQ). It consists of Seventeen 17 questions is distributed over nine 09 components. Four (04) distinct dimensions are for thermal comfort, visual comfort, acoustic comfort and indoor air quality. Three (03) dimensions are as follows: 01) satisfaction level with thermal, visual, acoustic comfort and indoor air quality. 02) Indoor environment quality in term of each aspect of comfort (overall comfort). 03) Students' learning and productivity.

Moreover, to ensure that questions are efficient and quick to answer, thirteen (13) multiple choices closed ended questions (multiple choice, Likert scale), three (03) single choice closed-ended questions and multiple response closed-ended questions. Incidentally, the questionnaire includes open-ended -questions, which assist to acquire free answers that may be rewarding. In the following table, we present the concepts, dimensions, types of questions and measurement scales used in this questionnaire.

Table 5. Students survey structure. Concepts, dimensions, types of questions and measurement scales used in this questionnaire. (Source: author)

Concepts and Dimensions		**Type of Questions**	**Number of Questions**	**Measurement Scales**
General Informations		single choice closed-ended questions	Q1, Q2 et Q3	Single answer
IEQ	Perception of IEQ	Multiple choice closed ended questions	Q4, Q5, Q6, Q7, Q8, Q9, Q10, et Q11	Perception 'various Likert scale'
	satisfaction with IEQ (Satisfaction Mean Votes)	Multiple choice closed ended questions	Q12 et Q14	Likert-type scale 5-point
			Q13	Single answer
	Students' learning and productivity	multiple response closed-ended questions	Q15	multiple answer
		Multiple choice closed ended questions	Q16 et Q17	Single answer

CONCLUSION

The scientific literature review indicates that the researchers agreed on the following parameters for developing a post-occupancy evaluation protocol to improve indoor environmental quality in educational Buildings: thermal, visual and acoustic comfort and indoor air quality. Accordingly, the most widely used thermal comfort indicators include: air

temperature, relative humidity and air velocity. In terms of acoustic comfort, sound level dB is the fundamental indicator to assess acoustic environment of the classroom. Visual comfort is often measured minimally with illuminance. To assess indoor air quality, CO2 level and particulate matter PM were the most commonly used indicators. However, CO2 level is still the most important indicator. On this subject, the scientific literature has demonstrated the absence of a unified universal post-occupancy evaluation protocol for the IEQ concerning the way of taking the measurements (IEQ in-situ measurements); this includes measurement points and height of the measuring instruments.

Finally, this paper will provide a comprehensive introduction to POE protocols that will benefit future research and give directions on indoor environmental quality in university campus classrooms.

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