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Parameters and indicators used in Indoor Environmental Quality (IEQ) studies: a review

Muriel Diaz^{1,2}, Maria Beatriz Piderit², Shady Attia¹

¹ Sustainable Building Design (SBD) Lab, Department of UEE, Faculty of Applied Sciences, Université de Liège, 4000 Liège, Belgium

² Department of Architectural Design and Theory, Faculty of Architecture, Construction and Design, Universidad del Bío-Bío, Concepción, Chile

madiaz@uliege.be

Abstract. Indoor environmental quality (IEQ) is a broad concept, which seeks to define when a built space provides welfare to its occupants. In general, it is defined as the condition of thermal, visual, acoustic and air quality comfort and depends on multiple factors. In the case of school buildings, the relevance of IEQ is related to its effects on the wellbeing, health and performance of the students and teachers. This research summarizes previous studies of IEQ from a multivariable perspective to prove that this research area needs to be further developed. Previous results show that an integrated analysis of IEQ parameters could better understand the IEQ perception of their occupants. Research on IEQ in schools generally refers to one or two aspects of the four. Even the most recent research deals with these topics separately, without using a systemic approach. The reductionism generated by isolating parameters allows us to study a parameter in detail but does not evaluate the environmental quality of the space. This is why new metrics are necessary to describe, assess and compare IEQ in educational spaces under a systemic approach.

1. Introduction

Indoor environmental quality (IEQ) is a broad concept, which seeks to define when a built space provides the necessary conditions for the health and wellbeing of its occupants. In general, it is defined as the condition of thermal, visual, acoustic and air quality comfort and depends on multiple factors, which can be classified into four categories; conditions of the external climate, spatial configuration and the envelope of the building, facilities and activities and factors of use [1]. The importance of IEQ is related to its effects on the well-being and health of the people who use the interior spaces, understanding that the lack of environmental comfort has negative effects on the health of people and on the performance of the occupants. Some relevant negative effects are the lack of focus on a task either in very low or very high temperatures; the sensation of suffocation when the relative humidity of the air is too high; headaches or difficulty to concentrate due to the noise; sensation of tired eyes and glare, in inadequate lighting levels, among others.

Indoor Environmental Quality (IEQ) is composed of four separate but interrelated elements: thermal comfort, respiratory comfort or air quality, visual comfort and acoustic comfort, and the difficulty in evaluating each one of them and as a whole lies in that they are subjective opinions about the quality of a space. When trying to combine the different aspects, this difficulty materializes, as Humphreys [2] explains: if a user qualifies a building as "bad" acoustically, but "good" in lighting, the evaluation of the interior environmental comfort will depend on the relative importance that the user gives (based on to the task, experience, among others) to each factors. This research suggests that people do not negatively evaluate the space based on one deficiency, but that in general they can be indulgent.

In the same publication, which is based on the results of surveys conducted in 26 offices in Europe within the framework of the SCATs project, Humphreys concludes that it is not possible to develop environmental



comfort indexes that are internationally valid and therefore it is better to continue with unitary analyses, although a more positive view will suppose that indexes referring to a specific activity can be developed, which would be equally useful for the design and decision making, although with local application.

Huang and others [3] recognize the difficulty to assess the multiplicity of factors that influence the perception of the environmental quality, since there are complex relationships between different climatic, spatial and psychological factors, from which it can be deduced that this opens a field of research. This field is currently under development and the main findings of this research are summarized in Table 2. Kim and De Dear [4], for their part, state that currently there is no consensus regarding the relevance of the different factors of indoor environmental quality (IEQ) on the perception of comfort of people.

The aim of this research is to present a framework that supports the need for new metrics to describe, assess and compare IEQ in educational spaces under a systemic approach while also defining a theoretical approach to the development of this indicator.

2. Methodology

This review presents a thorough review of journal publications that explore indoor environmental quality in educational spaces at an international level. A systematic review search was conducted using Scopus database, based on the following keywords and restrictions:

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TITLE-ABS-KEY ("learning environment" OR "physical environment" OR "learning space*") OR ("primary school*" OR "secondary school*") AND (Indoor environmental quality)) AND (EXCLUDE (DOCTYPE,"bk") OR EXCLUDE (DOCTYPE,"ed") OR EXCLUDE (DOCTYPE,"er")) AND ( EXCLUDE (DOCTYPE,"no"))
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This search resulted in 258 papers, the selection of paper was further evaluated based on the content of the title and abstract in terms of their scope, with a selection of 158 articles. A basic bibliographic analysis was conducted with Rstudio software [5] using the Bibliometrix package [6]. To further explore the concept of systemic and multicriteria evaluation, research conducted in other building archetypes (University classrooms and offices) was included in Section 3. 2.

3. Results

The systematic review of scientific papers dealing with IEQ resulted in a selection of 258 papers the majority of which is related to Indoor Air quality in classroom, followed by acoustic comfort and visual comfort. Although previous reviews have found that there is much research on thermal comfort in classrooms, few documents that also mentioned IEQ were found in this review.

In Figure 1 the most relevant journals are listed. The leading one is Building and Environment, followed by Science of the Total Environment and International Journal of Environmental Research and Public Health. Figure 2 presents the twenty most productive authors in this area. A description of the methodologies and indicators used for the evaluation of IEQ in classrooms is presented in the next section. To perform this analysis, some papers not included in the search but considered relevant by the authors were included.

3.1. Methodologies and indicators used in the evaluation of IEQ in classrooms

At the international level, there is no consensus on the methods, indicators and equipment to be used for the evaluation of IEQ [7]; the reviewed studies can be classified grosso modo into qualitative, short period quantitative and longer period quantitative studies. Research on school buildings focuses on the classroom unit and evaluates different parameters as shown in Table 1.

Bluyssen et al. [8] evaluated comfort and health levels in school classrooms using data collection tools based on the SINPHONIE research project. De Giuli [9], conducted evaluation campaigns of seven schools near Venice, Italy in springtime. Their subject were 614 children age 9 to 11, who completed a questionnaire about IEQ in the classroom and the impact on their psychological wellbeing. At the time of answering the questionnaires, measurements were collected every 15 seconds. The survey was conducted on paper with the supervision of a researcher, which achieved 87% of response rate. On the other hand, the monitoring of environmental parameters was considered very short. The results showed that noise is the main complaint among students. Another interesting result is that all environmental parameters were evaluated better in alternative schools (Waldorf, etc.) than in traditional schools. One could propose a relationship between the incorporation of dynamic teaching-learning methodologies and the consequent adaptation of classroom use, and greater control and autonomy on the part of students, who could manipulate elements such as windows,

move within the classroom or modify the type of clothing, without affecting the development of the class which would improve your perception of comfort by having greater ability to adapt.

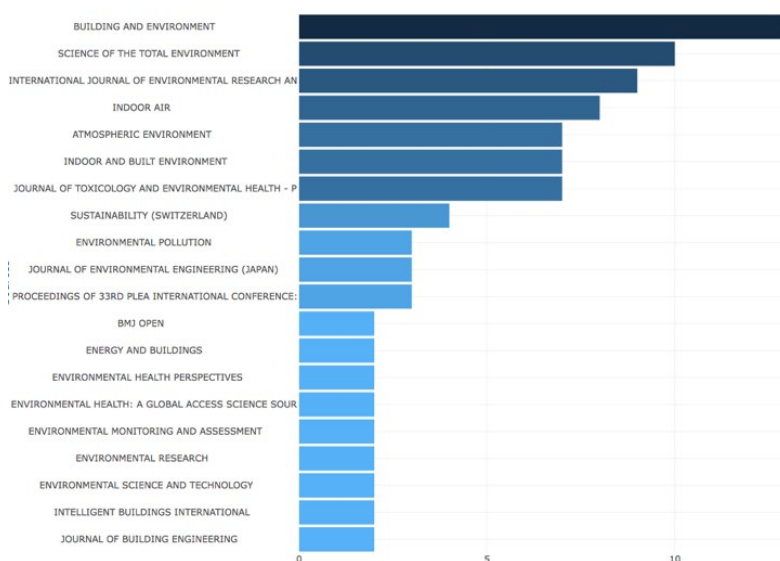


Figure 1. Most relevant journals

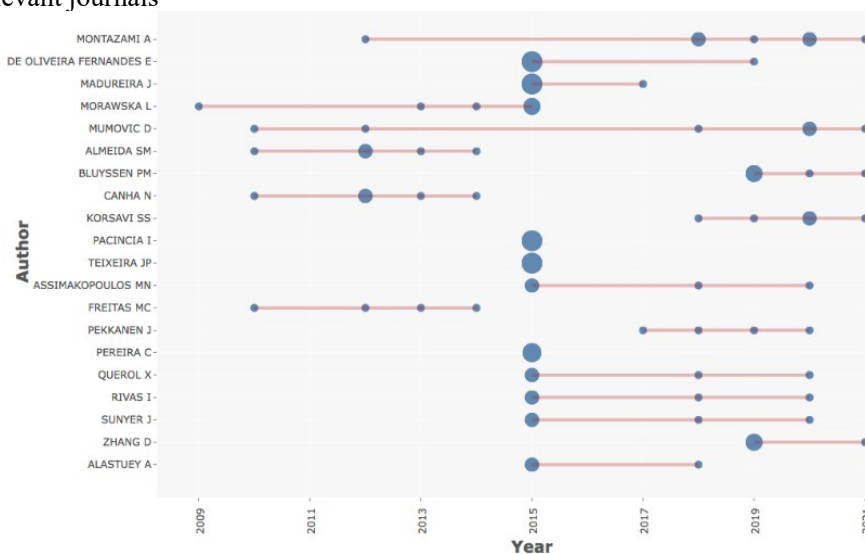


Figure 2. Top authors production over time

Barrett et al. [10] performed surveys and semi-structured interviews with teachers and a photographic survey and description of the space in 153 classrooms in 27 schools. For the spatial definition, researchers defined 30 factors to study based on 18 indicators divided into three design principles (Table 4). The data collected were contrasted with the results of the students' school performance through a multi-level statistical model (MLM). This statistical model was used to find correlations between the spatial and comfort qualities of the classrooms and the performance of the students.

The main result presented is that "... the physical characteristics of the primary schools impact the progress in reading, writing and mathematics". This impact is quite high, explaining 16% of the variation in the overall progress during a year of the 3766 students who participated in the study.

It is noteworthy that the research of Barrett et al. presents an expanded spectrum of factors that influence school performance beyond studies that have focused only on indoor environmental quality (IAQ). Another relevant factor is that, in the case of elementary students, the classroom is very relevant in performance. No direct relationship between the spatial quality of the whole school and performance was found. In general, Barrett's research envisages a relationship between spatial quality, viewed from a holistic perspective and school performance. It is important to point out that the results cannot be extrapolated to other realities. The

authors argue that the relevance of the factors should be linked to aspects of infrastructure quality, cultural and permanence in space, among others.

Table 1: Overview of studies of IEQ in classrooms

Study/protocol	Acoustics	IAQ	Lightning	Temperature	Comfort
Diaz et al., 2021[11] 8 classrooms, 3 days in winter and spring Measurements @30 min	--	CO ₂	--	Radiant Temperature Relative humidity	Not included
Korsavi et al., 2020 [12] 32 classrooms, Measurements @5 min and time-lapse cameras.	--	CO ₂ Air speed	light levels	Air and radiant temperature Relative humidity Air speed	children's sensation votes on the thermal environment, IAQ, visual environment and overall comfort. Developed in [13]
Bluyssen et al. 2018 [14] 37 classrooms. Measurements @15 sec.	--	CO ₂	--	Temperature Relative humidity	Children's Building Symptom index Children's Personal Symptom index Children's Building comfort index
Sadick et al. 2017[15] 32 schools. Sample measurements	Background noise dB(A) Reverberation time (RT60 at 1KHz)	CO ₂	Daylight factor	Temperature Relative humidity	1. Semi-structured interviews to teachers 2. online survey and sample measurements
Toyinbo et al. 2016 [16] 108 classrooms Several weeks of summer.	--	CO ₂	--	Temperature Flow	Questioners to principals of the schools and to students
De Giuli et al. 2012 [9] 28 classrooms. measurements	--	CO ₂	Emin (lux) Emax (lux) On/off Shadings up/down	Air tem Relative humidity Globe temp	51 questions questionnaire
Barrett et al. 2015[10] 27 school. Spot measurements	Noise levels	CO ₂	Illumination levels	Air Temperature Relative humidity	Architectural measurements questionnaire-based interview

3.2. Development of indicators for IEQ

Indoor Environmental Quality has been studied for each of its main aspects (thermal, acoustic, respiratory and visual) separately but the evaluation and understanding of the relations between these factors is a fairly new field.

Multifactorial research has been carried out on a pilot-scale at office buildings [17]. Buratti et al. [18], developed an index that integrates thermal, visual and acoustic comfort in university classrooms. This study included measurements of hygrothermal, acoustic and lighting conditions and at the same time hygrothermal, acoustic and visual comfort surveys were carried out, from which the "Combined Comfort Index ICC" is proposed. The study does not consider the influence that air quality could have on the general comfort assessment. The authors describe it as an evaluation carried out to develop a methodology, so that its replicability is not proven. For more information on multi-domain approaches, Schweiker et al. [19] present a comprehensive review.

4. Conclusions

To define a comfortable space, it is necessary to state a methodology to assess the environmental quality (IEQ) for students and teachers in school classrooms. Such a methodology should consider the four aspects that define IEQ: Thermal comfort, Indoor air quality, visual comfort, acoustic comfort in a systemic manner. There is also a need to define standards that are verifiable. These standards should consider time of exposure, interactions between factors to ensure an educational space that delivers environmental comfort to its occupants.

Research on environmental quality (IEQ) in schools generally refers to one or two aspects of the four. Even the most recent research deals with these topics separately, such as the post-occupational assessment of thermal comfort and its congruence with the existing thermal comfort models [20]. Thermal comfort and air quality, air quality and acoustics, without considering all the factors that influence the environmental quality of the spaces.

It is understandable that the reductionism generated by isolating parameters (thermal, acoustic, air quality, lighting) allows us to study a parameter in detail. But it is relevant to understand that this method does not give us an evaluation of the environmental quality of the space. Therefore, we need metrics that integrate all factors that influence environmental quality and will allow evaluating and comparing educational spaces, understanding that the perception of comfort of people depends on multiple factors that simultaneously define a space.

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