THE IMPACT OF THE INDOOR ENVIRONMENTAL QUALITY ON STUDENTS' PERFORMANCE

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ABSTRACT

The indoor environment quality is a key factor in people's lives, which directly affects their comfort, performance, health and well-being. The main factors that contribute to the indoor environmental quality are thermal comfort, air and lighting quality and acoustics.

This study aims to extend the current knowledge on the impact of IEQ on students' performance. Field measurements on environmental factors were performed in two similar classrooms, with the same number of students engaged in a written examination. Compliance of the indoor environmental parameters with the current standards regulations was performed. Students' performance was quantified by their exam grades. The results of the field measurements show that, in both classrooms, the acoustics and air quality do not fulfil the standard regulations, especially in the case of carbon dioxide concentration which exceeds a lot the threshold limit of 1000 ppm. The outcomes of the study also reveal that in the classroom where the concentration of carbon dioxide is higher, the students scored lower grades, therefore we can conclude that indoor environmental quality has an impact on students' performance.

Keywords: *indoor environmental quality, thermal comfort, air quality, lighting, acoustic*

INTRODUCTION

In recent years, researchers are focused on Indoor Environment Quality (IEQ) evaluation and improvement, since more than 90% of the time people carry out their various activities indoors [1]. Ensuring a high level of IEQ is an essential factor in obtaining healthy environments in buildings. The indoor environmental quality is defined as the interaction between various environmental factors such as thermal comfort, air and lighting quality and acoustic [2], [3].

Thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment" [4]. The most popular way to assess thermal comfort is through the heat-balance approach, which is defined by two indices, the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). PMV index is established from the interaction of four physical environmental parameters (indoor temperature, mean radiant temperature, relative humidity and air velocity) and two personal variables (metabolic rate and clothing insulation). PPD index is defined as the percentage of occupants that could experience local discomfort.

Indoor Air Quality (IAQ), another important environmental factor, is directly associated with the concentration of pollutants and ventilation rates inside buildings and has a high impact on IEQ [5]. A poor IAQ can reduce occupants' productivity and cause health problems [6]. The main factor affecting IAQ is the high concentration of carbon dioxide (CO_2).

A poor lighting quality can cause discomfort, therefore visual comfort is another critical factor affecting indoor environmental quality. In the standard EN 12464-1 [7] are presented the illuminance values that are required to be maintained for a high visual comfort. The study of Heschong [8] regarding the relationship between daylight and human performance, showed the importance of good daylighting, large windows and the possibility of windows openings, on the faster educational progress.

The last factor considered to be crucial and contributes to a high level of indoor environmental quality, especially in offices and schools, is the acoustic comfort. Researchers proved that a poor room acoustic, with excessive noise, reduces peoples' concentration and productivity. In standard EN15251 [9] are presented the acceptable values for the relative loudness of the human ear and of the A-weighted sound pressure levels (dB(A)).

Even though the first steps were made in raising awareness about the importance and influence of the IEQ on the quality of life, many steps must be made to achieve healthy environments. However, in the last couple of years there is an increasing trend in the request for IEQ high quality solutions especially in hospitals, offices and schools to ensure healthy environments and occupants' wellbeing.

Educational establishments such as schools or universities are complex buildings designed to meet the requirements of both teachers and students. An increased level of IEQ is a crucial factor in the intellectual acquisition and proper development of young people. Previous studies reported the IEQ influence on occupants' health, productivity, satisfaction and wellbeing [10-12].

To have a better knowledge on the IEQ impact over the performance of students engaged in different activities, it is necessary to widen the research in this field. Therefore, the purpose of this study is to investigate the effects of indoor environment quality on students' outcomes of a written examination. A case study of two similar classrooms where students took a written examination is presented. Firstly, through this study is assessed the compliance with the regulations of standards [4,5,7,9] and then is investigated if the indoor environmental quality has an impact on students' performance quantified by exam's grades.

METHODS AND MATERIALS

The investigation of IEQ was conducted during winter in one of the educational establishments of the Technical University of Cluj-Napoca, namely the Faculty of Building Services Engineering. The measurements were carried out in a period when the city was affected by fog and the outdoor temperature during the day had a minimum 0˚C value of and a maximum one of +4˚C.

The early ’70s built building, located close to the city centre of Cluj-Napoca, undergone a significant retrofit between 2005 and 2008. The educational establishment is naturally ventilated through windows openings and infiltrations through the building's elements, and is heated during cold seasons with a centralized heating system. The thermal plant prepares and delivers thermal agents to fan coil units mounted on the exterior walls, under the windows made from PVC frames and double glazing. The area of one window is 5 m^2 which facilitates the access of an important amount of natural light. The artificial light inside the building is provided by louvre luminaires with fluorescent lamps. In many classrooms there are vertical blinds, to reduce glare from sun.

The field study of IEQ was conducted in two similar classrooms, where students took a written examination. The classrooms have three exterior walls, have the same orientation and are situated on the same side of the building, one at the ground floor (classroom A) and the other at the third floor (classroom B). The differences between the classrooms are their area, classroom A has 125 m^2 while classroom B has 78 m^2, and the number of windows. The layouts of the classrooms are presented in Figure 1.

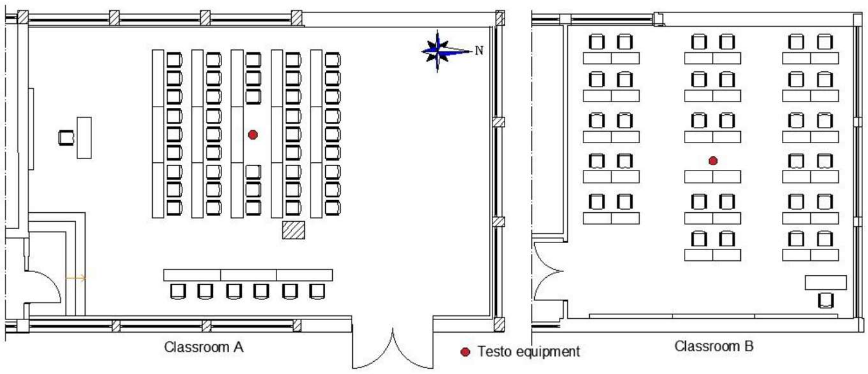

Fig. 1. *Floor plan of the classrooms with the position of the measurement instruments.*

At the research participated a total of 54 people, 27 in each classroom, all students in the first year of the Bachelor studies. Students’ written examination was at the same discipline, with same grade of difficulty and was timetabled between 10:00 and 11:30 AM.

The indoor environmental parameters such as air temperature, mean radiant temperature, relative humidity, air velocity, carbon dioxide concentration, illuminance and sound level were recorder with various instruments. The specification of the apparatus are detailed in Table 1.

Table 1. *Technical specifications of the instruments used.*

Instrument	Recorded parameter	Range	Accuracy
Testo 480 – indoor air quality probe	Air temperature	0 ÷ 50˚C	±0.5 ˚C
	Relative humidity	0 ÷ 100% RH	±1.8% RH
	Air velocity	0 ÷ 5 m/s	±0.03 m/s
	CO2 concentration	0 ÷ 5000 ppm	±75 ppm
Testo 480 – globe probe	Mean radiant temperature	0 ÷ 120˚C	-40 to+1000˚C
GL SPECTIS 1.0+ Flicker spectrophotometer	Illuminance Color temperature Color rendering	0 ÷ 99999 Lux	±3 Lux
Testo 815 – sound level meter	Sound level	32 ÷ 130 dB	±1.0 dB

After the analysis of standards recommendations [4], [5], [7], [9] regarding the placement of the measuring devices, the position of the instruments inside the classrooms was cautious selected (see fig.1). The measuring devices were placed approximately in the middle of the occupied area at height of 1.1 m. In the case of artificial lighting, the measurement grid was selected according to point 4.4 from [7] at a height of 0.8 m. To prevent local influences of the measuring devices, a distance of at least 1 meter was kept away from any possible source (students, walls, windows). Environmental parameters were recorded every 5 minutes.

RESULTS AND DISCUSSIONS

Our field study comprises short-term objective measurements to understand how various factors of the indoor environment can affect students' performance. The followed factors are air temperature (˚C), mean radiant temperature (˚C), relative humidity (%RH), air velocity (m/s), CO_2 concentration (ppm), illuminance (lux) and sound level (dBA).

Indoor thermal environment

The indoor thermal environment can have a meaningful impact on students' performance and well-being and represents an important part of indoor environmental comfort.

For the determination of the physical conditions of the thermal environment in terms of students' acceptability and comfort, the PMV equation presented in ASHRAE Standard 55 [4] was employed. The equation is a function of four environmental parameters (air temperature, mean air temperature, air velocity and relative humidity) and two personal variables (metabolic rate and clothing insulation). Based on the observation method and according to standard's recommendations, the metabolic rate for typical tasks was considered 1 met, while the clothing insulation for typical ensembles totalized a value of 0.92 clo. Further, the PPD equation that predicts the percentage of students who feel dissatisfied with the environment was employed.

The minimum, maximum and mean values of the recorded indoor thermal environment, PMV and PPD are presented in Table 2.

Table 2. *Recorded values of the indoor thermal environment.*

Variables	Classroom A			Classroom B		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Air temperature [˚C]	23	24.1	23.9	22.6	28.1	26.2
Radiant temperature [˚C]	22.8	24.3	24	22.7	28.2	26.3
Relative humidity %RH]	27.2	34.1	31.7	34.3	47.8	40.4
Air velocity [m/s]	0.11	0.12	0.11	0.12	0.13	0.12
PMV [-]	-0.38	-0.03	-0.11	-0.49	1.21	0.6
PPD [%]	5	7.9	5.25	5	35.8	12.6

The PMV-PPD method is widely used by the research community to assess the thermal environmental acceptability for healthy adults. Compliance with the ASHRAE 55 Standard in terms of acceptability and comfort is achieved if $-0.5<PMV<+0.5$ and $PPD<10\%$.

The mean resulting values of the PMV and PPD are presented along with a graphical representation of their intersection and are shown in Figure 2 for classroom A, respectively Figure 3 for classroom B.

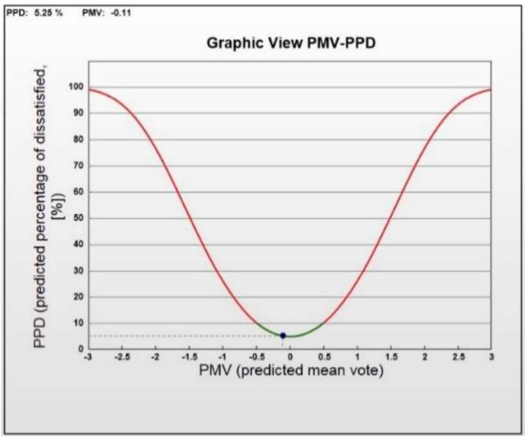

Fig. 2. *Graphic representation of PMV-PPD for classroom A.*

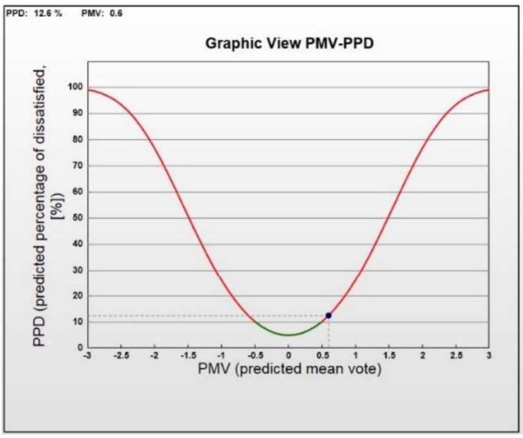

Fig. 3. *Graphic representation of PMV-PPD for classroom B.*

From the above figures it can be observed that the thermal environment acceptability and comfort in classroom A meets the standard recommendations, while in classroom B the upper limit (+0.5 for PMV and 10% for PPD) is a little bit exceeded.

Air quality

The indoor air quality is usually expressed in terms of ventilation required for reduction of air pollutants and CO_2 concentration. The carbon dioxide concentration is mostly affected by occupants' body mass, density and the relationship between it and IAQ has been for a long time researched [13]. In ASHRAE Standard 62.1 [5] are specified the minimum rates of ventilation and the acceptable values for CO_2 concentration for a good indoor air quality. In Figure 4 is shown the evolution of CO_2 concentration in both classrooms.

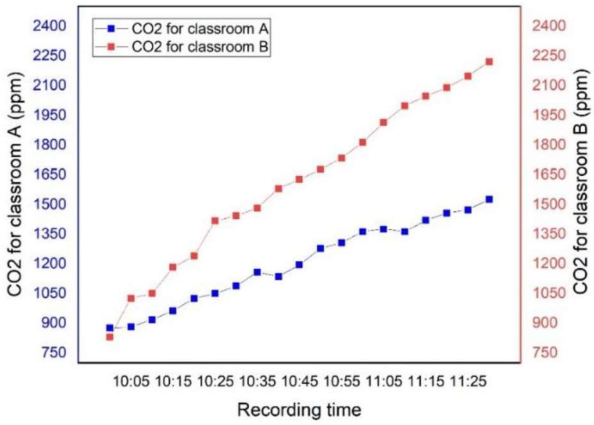

Fig. 4. *Evolution of CO_2 concentration*

The measured CO_2 concentration exceeds in both classrooms the threshold limit (1000 ppm) of the standard [5]. Therefore, the air quality inside both classrooms fails to meet acceptability and can create discomfort, health problems and difficulties in concentration.

One of the reasons for such high values of CO_2 concentration is related to the low ventilation rate. The building is naturally ventilated, thus ventilation is made through window openings and infiltration, but given the fact that measurements occurred during winter and the outside temperature was low (approximately 1.5˚C), the windows weren't opened during the recording timetable. Another cause for such a high concentration of CO_2 is due to the outside fog that affected the city at the measuring time. Cluj-Napoca is a large and crowded city with many factories around it and plenty of cars, so when the fog settles down the outdoor air quality is poor. When the experiments occurred, the outside concentration of CO_2, at 9:50 A.M., was 725 ppm. From Figure 4 it can be observed that in classroom B the concentration of CO_2 is higher and increases more rapidly and that is due to occupants' density. In classroom A the ration between area and one student is 4.62 (m^2/student) while in classroom B is 2.88 (m^2/student).

Lighting quality

Previous researches have emphasized the significance of real-life experiments and acquiring quantitative information due to observable differences between actual operating environments.

During the building's retrofit process, previous bare battens luminaires with two T12 fluorescent lamps of 40W with magnetic ballast, were replaced with louvre luminaires with two T8 fluorescent lamps of 36W - 765, again with magnetic ballast.

The requirements for artificial lighting (illuminance Em, uniformity U0 and color rendering Ra, according to [7] are presented in Table 3 alongside with the recorded values during students' examination. Even though the exams started at 10:00 A.M. and the classrooms benefited of natural light, the artificial lighting was on because the in-site measurements occurred during winter and outside was fog.

Table 3. *Types of activity in educational buildings and lighting parameter.*

Room type	Em [lux]	U0	Ra	Specific Requirements
EN 12464.1 recommendations				
Classrooms	500	0.6	80	Lighting should be controllable
Recorded values				
Classroom A	585.4	0.61	82.1	Lighting is not controllable
Classroom B	510.2	0.64	82.3	

As it can be seen from the above table, the classrooms fulfil the norms requirements. The differences between values are due to the numbers of windows, classroom A having many more compared with classroom B.

Acoustic environment

To analyze the classrooms' indoor acoustic environment the recording of the sound pressure level was every 25 minutes, after the exam started when all the students started to resolve the problems, in the middle of the timeframe and before the time for examination ended. In Table 4 are presented the EN 15251 [9] recommended criteria for the sound level and the results obtained during the measurements.

Table 4. *Recorded values of the indoor thermal environment.*

Zone	EN 15251 recommendations dB(A)	Mean sound level dB(A)
Classroom A	30 ÷ 40	51.5
Classroom B	30 ÷ 40	50.2

The mean sound level in both classrooms was a little above the threshold limits of 40 dB(A), which shows high level of sound pressure, therefore, can induce discomfort for students. The high recorded values of the sound pressure level are due to the outside noise, due to building's placement to the proximity of an intense circulated boulevard.

Impact of IEQ on students' performance

Average grades have been widely used and accepted in almost all schools and universities to measure performance. In our study, we also use the results of the written examination to quantify students' performance.

In both classrooms, students' written examination occurred in the same day and timeframe, at the same discipline, while they were overseen by teachers from other disciplines. The subjects received by students to be solve were the same. The exam papers were then corrected by the teacher in charge with the discipline. The evaluation scale of the grades is from 1 to 10, students pass the exam if they score at least 5. The results of the exams are presented in a comparative graph presented in Figure 5. The grades obtained by students from classroom A had an average on 6.88 respectively 6.07 from classroom B.

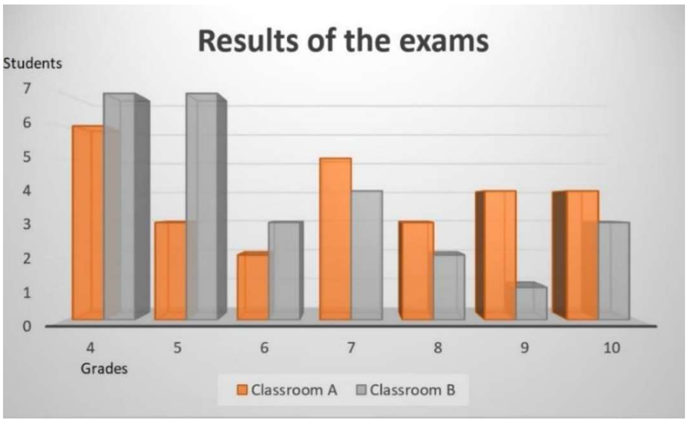

Fig. 5. *Comparative graph with the results obtained*

From the comparative graph, it is observed that students from classroom B received lower grades and the promotability rate is a little bit reduced compared with the students from the other classroom, although at the partial exam undergone in the middle of the semester the results were similar. The explanations of these results could be many starting from students' preparation for the exam, subjects' difficulty, to stress factor and lack of concentration.

By analyzing the results obtained from the recorded values of environmental parameters, the lighting quality in both classrooms meets the requirements of standards [7]. Therefore, one can't relate the low grades and differences in the exam results to this factor. The sound level in both classrooms was above the upper limit of the standard recommendations [9]. The values recorded didn't excessively pass the acoustic threshold limit, so one can state that a small discomfort in terms of noise was present. Regarding occupants' thermal comfort in classroom A the thermal environment is slightly cool respectively slightly warm in classroom B. According to standard recommendations [4], only classroom A meets the requirements of a comfortable and acceptable indoor thermal environment. Previous studies [11,14] have highlighted that a slightly cool environment supports occupants to concentrate to their tasks, whereas a slightly warm environment creates thermal discomfort and focusing issues. In terms of air quality, the measurements revealed that in both classrooms the threshold limit of 1000 ppm [5] was overpassed. Previous studies highlighted that poor air quality, with high levels of CO_2 have direct impact on occupants' concentration, performance, health and well-being [11,13]. Therefore, we can state that a decisive influence on students' performance had the air quality and high concentration of CO_2, especially in classroom B where the results of the exam were lower, and the concentration of CO_2 reached alarming values.

CONCLUSIONS

The indoor environment plays a significant role in people's lives, which directly affects humans` work, quality of life, well-being, environment, energy status and economy.

In this study, the IEQ of two similar classrooms is assessed through measurements of various environmental factors (thermal comfort, air quality, lighting quality and acoustics). The results reveal that classroom A fails to meet the requirements of the standard for air quality and acoustics, whereas classroom B for thermal comfort, air quality and acoustics.

The impact of the indoor environmental quality on students' performance is highlighted especially in classroom B, where students scored lower grades compared to the students from the other classroom, influenced by the high concentrations of CO_2.

The limitations of this study are due to the short-term measurements and the reduced number of students involved. Larger samples of students and long-term measurements are required to fully understand which of the four factors have a strong influence on the impact of IEQ on occupants' performance.

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