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IMPACT OF INDOOR ENVIRONMENTAL CONDITIONS ON STUDENTS INTELLECTUAL PERFORMANCE

BY

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Abstract. In this article the main objective was to find out what is the impact of the indoor environmental quality on intellectual performance of students. In order to find out this, several experimental campaigns were necessary. During six tests the indoor conditions were changes from “ideal” comfort to high noise indoor space or low air quality. During each experimental test multiple volunteers students performed intellectual activities. For each test the indoor conditions (sound pressure level, illuminance, air temperature, CO_2 level, etc.) were recorded with several equipments. Moreover, the students answered a small survey on the indoor conditions. It was found that low light level and low air quality have a significant impact on their performance that was reduced by 36%. During the test that simulated good indoor conditions most of the students (90%) answered all the questions in time and their performance was good.

Key words: indoor environmental quality; educational buildings; intellectual performance.

1. Introduction

The amount of information gained by students in the educational system is defined by a range of variables. Some are well known such as native

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intelligence and personal motivation, teaching methodology for teachers and other educational resources that the student may receive. If the mentioned aspects are important yet, there is another important factor in the intellectual development of students: the indoor conditions in the classroom (Technical Article, 2009; Stolz *et al*., 2008; Vinciullo, 2008).

The educational environment is the environment in which the student learns and which includes on the one hand the *ambient physical environment* - desktop, lighting conditions, noise, vibration, solar radiation exposure, air quality, microclimate (temperature,humidity, air draft) and on the other hand - *the social environment* (AESSM, 2014).

The relationship between indoor environmental quality in schools and the focus of the students, as well the the impact of the environment on the health and well-being have received increased attention in Europe since 1980, when in the European countries began a process of elimination of several materials that were found to affect the health of pupils.

Europe's population spends more than 80% of their time indoors. Because indoor air quality is generally worse (2 to 5 times) than outdoor air quality, this has a major impact on the health and quality of life. The students and the staff in schools and colleges spend much of the day inside. A healthy environment at school can thus directly improve the health of both children and their intellectual capacity, thereby promoting effective learning and also can contribute to the development of healthy adults.

Indoor environmental quality in schools can be influenced by a number of factors, including traffic in the immediate vicinity, the heating and ventilation system (*e.g*. naturally or mechanically ventilation). All these factors need to be considered ase they are responsible to a great extent by creating favorable condition or less favorable indoor environmental quality (Sinphonie project, 2011). The microclimate in schools must maintain the thermal equilibrium of the students, to ensure a good thermal comfort environment which will lead to an increase in attention and memory capacity during hours of study (EPA, 2012). The project aims to analyze the intellectual performance of students in different indoor comfort conditions. The performed measurements will determine which is the case most favorable to intellectual performance of students in different indoor comfort conditions and which is worst situation from this point of view. It will also achieve, with graphic charts the comparison between different situations of indoor environmental comfort. Using the experimental testing it was possible to give a verdict on the influence of indoor environmental factors on the intellectual performance.

2. Experimental Campaign

In order to test the impact of indoor conditions on intellectual performances a classroom was instrumented in the Faculty of Building Services Bucharest. The classroom was situated at ground floor and it's dimensions are 9 m length with 6 m wide. The classroom height was 3.5 m and therefore it's volume was calculated to be 189 m^3. The classroom has an external wall orientated West but the trees and surrounding buildings do not allow any direct solar radiation to enter inside. Due to this fact during most of the classes the luminaires are always turned on.

The equipments that were used during the experimental campaign will be presented in the following lines. The most accurate device for measuring indoor climate came from the manufacturer TESTO and it was used as a reference in the calibration process for the other CO_2 Meter Data Loggers. Using the TESTO 480 we had acces to measure multiple parameters in the same time as: relative humidity, air temperature, illuminance level, air velocity, CO_2 level, dew point temperature and globe temperature. The CO_2 Meter Data Loggers were used as measuring instruments able to measure concentrations of carbon dioxide CO_2, the relative humidity (inside and outside) and air temperature (indoor and outdoor) for multiple hours. We have used 12 individual dataloggers spreaded in different positions of the classroom in order to a have a correct view on air temperature, humidity of CO_2 levels distribution.

The accuracy of the loggers was of ±20 ppm ±1% from the measured value (CO_2 levels), ±0.4ºC (air temperature) and ± 3% for the relative humidity. Measuring the sound level and time reverberation within the classroom was carried out by means of a sound level meter manufacturer by Svantek. The model is SVAN 957, a class 1 precission sound meter with the capability of recording the entire noise spectrum. The illuminance level was measured with TESTO 480 but also with the luxmeter LT YK-2005LX (accuracy of ±4%).

2.1. Experimental Protocol

The work is based on the experimental study conducted on a group of students, by performing logical tests similar one with each other (same degree of difficulty). The tests were made to solve by the students in different controlled indoor condtions. The time of each test solution was 5 min. The speed and accuracy of students in these tasks was measured and used to indicate their performance and intellectual ability to think properly and quickly in such different environment circumstances. The final purpose was to find if whether- and how-physical factors influence educational efficiency.

The tests were conducted under different conditions in terms of interior comfort, such as: low level illuminance, high noise threshold, high air

temperatures, low air temperatures, high concentrations of carbon dioxide and the reference test was applied under ideal indoor comfort. These ideal conditions were based on the current Romanian and European standards on comfort (Shaughnessy *et al*., 2006).

The TESTO 480 and the sound meter were placed centrally in the front part of the classroom as it is illustrated in the following image (see Fig. 1).

a *b*

Fig. 1 – *a* – The equipements placed in the front part of the classroom (TESTO 480+SVANTEK 749); *b* – Photo during the tests.

During the experimental campaign we have used different methods to change/control the conditions like:

a) the use of an air heating system to increase the air temperature;

b) the use of an artificial noise source to reproduce outdoor traffic;

c) the use of extra light bulbs in order to increase the illuminance level.

The experimental campaign was conducted in collaboration with a group of fourth year students. The experimental study consisted of the students performing similar logical tests given in different indoor comfort conditions. Each test consisted of five simple questions relating to arithmetic or logical problems and the maximum allowable test time was 5 minutes. The correct answers of the questions were rated by two points with 0 as starting point. The speed and accuracy of students in these tasks was measured, as well as the indoor conditions.

The logic tests were given under different conditions from the point of view of comfort inside with the following sequence:

- **Test 1** – low level of illuminace;
- **Test 2** – high sound pressure level;
- **Test 3** – high air comfort temperature ;
- **Test 4** – low air comfort temperature;
- **Test 5** – ideal indoor comfort conditions ;
- **Test 6** – high concentrations of carbon dioxide.

2.2. The Indoor Environmental Conditions

The Indoor Environmental Quality in the classroom was different for each of the six tests . The experimental campaign began at 9:00 and the first test was done under low illuminance level (50 lux). This value was obtained only with the daylighting level wich of that hour of the test was low. Even if the 50 lux seems a too low value and even unreal, we must point out that during another study on indoor conditions of multiple old rural schools this was a common value, therefore seems logic to test it. To have a higher sound pressure level inside the classroom (around 60 dB) we have used an artificial sound with an external noise source.

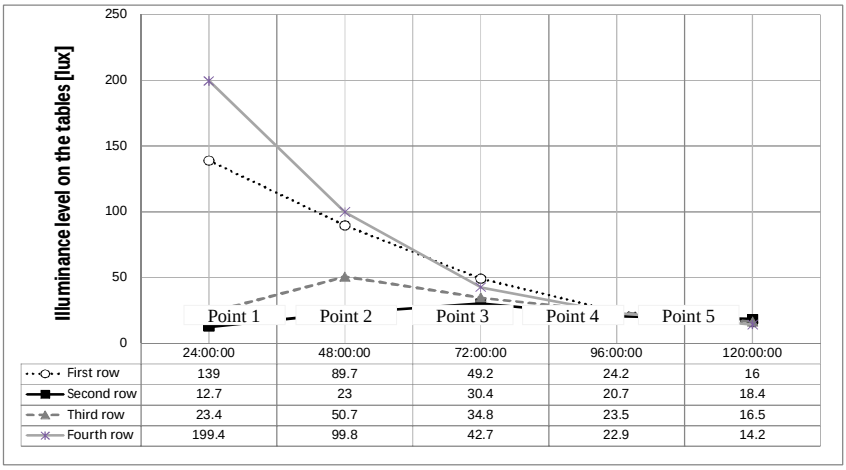
The third test was carried out with a temperature above the comfort level of around 22ºC. To create this environment, two heaters were used and in a few minutes the temperature was increased by 3ºC, reaching 25ºC. This increase was facilitated as the air infilitrations from the windows were reduced using paper adhesive tape. In order to decrease the air temperature we have we have used a controlled air flow with the temperature from outside wich at that moment (02 March 2014) was low (less than 10ºC), therefore we have rapidly deacresed the indoor temperature to 18ºC…19ºC. The ideal conditions were controlled and in good agreement with the recomanded values from EN 15251. The last test was done under higher CO_2 levels (1800-2000 ppm) than the ones recommended (800…900 pp). To reach such higher values was easy as any outside air flow was stoped and therefore the CO_2 from the occupants accumulated very fast.

3. Results and Analysis

During the first test the indoor conditions did not vary as the air temperature was situated in the range 22.1ºC…22.5ºC. The relative humidity values were in the range 34.8 to 34.4% while the CO_2 levels were maintained between 602 ppm to 687 ppm. The slight increase of 0.4ºC was due to the internal heat gains (30 occupants), as well as the CO_2 level. The respondents next to the window had a greater illuminance level than the one located on the opposite side. An uniform illuminance level was almost impossible to achieve. The data measured are traced in Fig. 2 where the data from 20 points is found.

The students who were positioned near windows had a higher level of illumination, however the study shows that they have not achieved better results than the students located in a even more disadvantaged position in terms of the level of illumination. The recommended value for optimal comfort is 400 lux.

The volunteers student had a scoring average of 49.29% for the test – very poor results considering the average of the other tests as these will be presented in the following pages.



	24:00:00	48:00:00	72:00:00	96:00:00	120:00:00
First row	139	89.7	49.2	24.2	16
Second row	12.7	23	30.4	20.7	18.4
Third row	23.4	50.7	34.8	23.5	16.5
Fourth row	199.4	99.8	42.7	22.9	14.2

Fig. 2 – Illuminance levels measured in different points and rows (A, B, C, D) of the classroom (20 point measurements).

A second experimental campaign was given in terms of a high level of noise. This study was conducted after the first test and began at 9:06 and lasted five minutes. The air temperature was still under good comfortable values of 22.4 ºC…22.7ºC similar to the first test. The artificial light was turned on and all conditions were ,,perfect,, except the noise level which was situated between 61.06 dB (back of the classroom) to 65.89 dB (front of the classroom). This small difference was due to the proximity of the noise source located in the front of the classroom. The 4 dB difference are not perceived by the human ear therefore we can consider that all subjects were tested in almost uniform conditions. The results of the test were considerably higher with an average of 78.02%. The lowest value recorded was 42.5% and the highest 95%. During the third test the air temperature was increased up to 25ºC while the rest of the parameters were kept at ideal values (low noise, low CO^2 levels, high illuminance level). The students appreciated to be too hot inside. The temperature was uniform in the classroom with a value of 25.2ºC…25.3ºC (12 measurement points). The results of the test showed that the performance of the students was situated at 77.08%. What is interesting to mention is that one student obtained 43.3% during this third test while he obtained 65.8% for the second one. This is only one particular case but is a proof that the test results depended mostly on the indoor conditions and not on the routine of taking the logical tests, as these were similar. For the fourth test the air temperature was

reduced from 25.2ºC…20.5ºC. All occupants appreciated to be to cold for them, however their score was 80.45% higher with 3% than the one during higher air temperatures.

The fifth test was done under ideal conditions of comfort. It is hard to state what are the best ideal conditions as most of the occupants have subjective opinions on the air temperature. However, they all stated that these were the best conditions among all test and therefore this test was considered as reference. The noise level was kept under 32 dB, the average illuminance in the classroom at 435 lux, the indoor air temperature at 22.1ºC and the CO_2 levels under 800 ppm (clean air). The results of the test showed a performance of 93.08%, the highest of all. The last test was done under high CO_2 levels, overpassing 1,600 ppm. The test indicated a performance of 56.26%. In the following table the indoor average conditions during the six tests are summarized:

Table 1

Indoor Environmental Condtions During the Test

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Temperature, [^{o}C]	22.5	22.7	25.2	20.5	22.24	22.9
Relative humidity, [%]	34.59	34.85	33.74	34.1	34.6	41.02
CO_2 concentration, [ppm]	654.68	780.84	925.2	813.5	896.5	2,078.2
Illuminance level, [lux]	47.6	436.1	436.1	436.1	436.1	436.1
Sound pressure level, [dB]	29.85	62.59	29.47	29.75	29.12	28.56

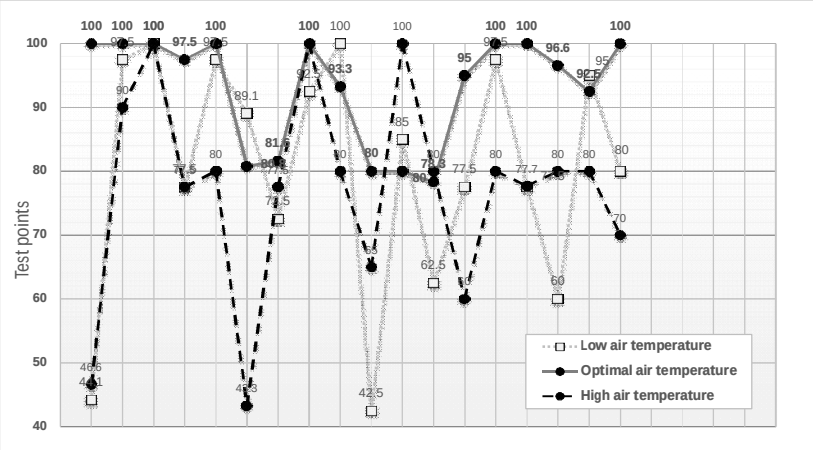


Fig. 3 – Test results for different students under low, optimal and high air temperatures.

It may be noticed from the above chart in Fig. 3, the test results of students characterized by a high level of interior comfort are much better in this

test recorded minimum grade of only 7.83, with 3.37 more than the average of the lowest scores obtained in the other two tests.

The students have obtained from experimental test carried out under ideal indoor comfort top grades compared to other tests carried out at temperatures too high or too low compared to the limit of comfort.

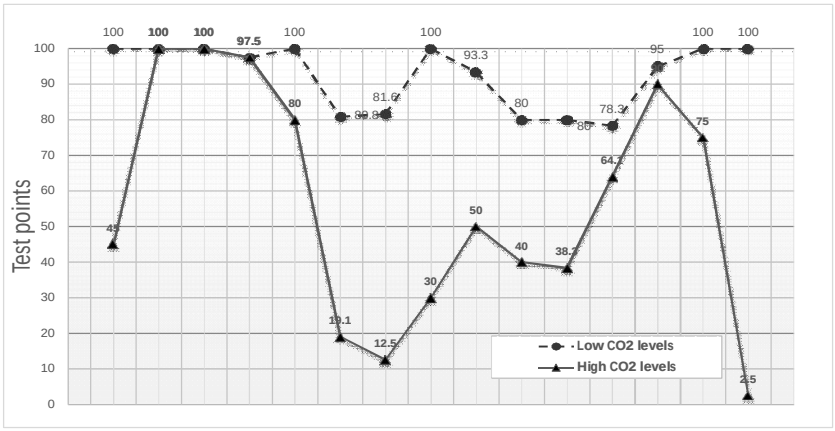


Fig. 4 – Test results for different students under low and high CO_2 concentrations.

In Fig. 4 are plotted the results of multiple students under two indoor conditions: low and high CO_2 levels. With the exception of two students who scored 100% under both conditions the rest had lower results under higher CO_2 levels. This is a proof that air quality affects the majority (> 75%) of the students.

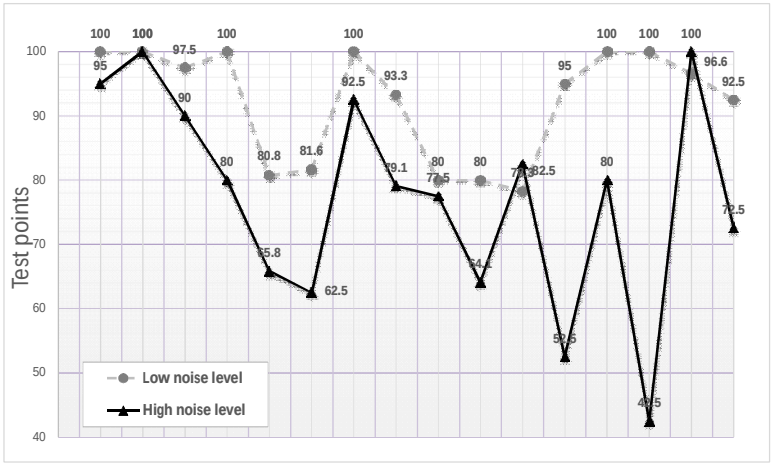


Fig. 5 – Test results for different students under low and high noise levels.

When it comes to performance under high noise level it can be concluded (see Fig. 5) that noise may affect the concentration of students as most of them scored lower by 25% by comparison with the case with no noise. A summary of the results is done as follows:

- **Test 1** – low level of illuminace; Score: 49.2%;
- **Test 2** – high sound pressure level; Score: 78%;
- **Test 3** – high air comfort temperature ; Score: 77%;
- **Test 4** – low air comfort temperature; Score: 80.4%;
- **Test 5** – ideal indoor comfort conditions ; Score: 93%;
- **Test 6** – high concentrations of carbon dioxide; Score: 56.2%.

As a conclusion it can be stated that the air quality and illuminance level have the greatest impact on the intellectual performances. At the end of each test the students respondended to several questions about the environment.

Table 2
Survey Study About the Indoor Conditions During the Tests

	Questions	Answers	Test1 %	Test2 %	Test3 %	Test4 %	Test5 %	Test6 %
1	What is your opinion on the indoor temperature?	Too cold	0.0	0.0	0.0	0.0	0.0	0.0
		Cold	13.3	0.0	0.0	61.1	22.2	26.7
		Perfect	80.0	82.4	22.2	38.9	66.7	73.3
		Hot	6.7	17.6	77.8	0.0	5.6	0.0
		Too Hot	0.0	0.0	0.0	0.0	5.6	0.0
2	What is your opinion on the air quality?	Very clean	0.0	0.0	0.0	16.7	5.6	0.0
		Clean	73.3	64.7	55.6	72.2	72.2	40.0
		Not clean	20.0	35.3	44.4	11.1	22.2	53.3
		Not at all clean	0.0	0.0	0.0	0.0	0.0	6.7
3	Do you have sufficient light on the desk?	Plenty	0.0	82.4	50.0	50.0	50.0	13.3
		Sufficient	6.7	17.6	50.0	50.0	50.0	80.0
		A little	53.3	0.0	0.0	0.0	0.0	0.0
		Very little	33.3	0.0	0.0	0.0	0.0	6.7
4	How was the acoustic during the test?	Very loud	0.0	23.5	0.0	0.0	0.0	0.0
		Loud	6.7	64.7	0.0	0.0	11.1	6.7
		A little loud	46.7	11.8	44.4	66.7	55.6	73.3
		Not loud at all	40.0	0.0	55.6	33.3	33.3	20.0

By doing a little analysis of the responses that students gave in the questionnaire questions received, we can see that most participants felt the indoor conditions more or less exactly with what we wanted to simulate. For example during test 1, 53.3% of them considered that there wasn't light on their desk and 33.3% that the light is very low.

4. Conclusions

From the experimental study it was noted the importance of indoor environmental quality in classrooms. This was determined from the results obtained during six tests of indoor comfort by volunteers students. They have achieved much better performance when solving simple logical questions under ,,ideal,, indoor comfort compared to other tests. During the tests, the accuracy was noted both from the student's responses and efficiency in terms of time to solve the test. These facts underline the importance of the indoor environment has the intellectual capacity of students. Among all test we must mention the one were the students were solving the test under low light. Almost none of the students solved the test or their time response was to high.

A similar test, which was aimed at evaluating the impact that lighting has a high level of performance achieved by the students , was conducted in 1999 in three school centers. This study showed that students in classrooms with a high degree of illumination had significantly higher results on tests of mathematics and reading . Increasing students' performances in tests that have high levels of illumination were statistically significant – 20 % better than the normal situation So, the lighting can greatly influence student performance , as demonstrated in this research work (Shaughnessy *et al*., 2006).

During another test we have tested the influence of a high noise level on the ability of students to solve the test. The simulated noise level was set to 62.73 dB (as it is the case during spring autumn season when the windows are opened and the outdoor noise is let inside), exceeding the allowable limit noise for the school, which is 35 dB. The results of the experimental campaign showed that students have achieved up to 15.06 % weaker scores under high noise compared to a good acoustic comfort. A similar test was conducted in 2001 by Steffan Igor Knez and Hygge [6], with a group composed of women and men. There found a high level of speed in solving tests during high noise conditions , but also a very low accuracy in correct answers.

Other experimental tests consisted in the analysis of students performances under low and high air temperature. They had scores of 16.00% weaker during the test conducted in high temperature conditions compared to the one when the air temperature was kept at very comfortable value. On the other side, during low temperature, students results obtained 12.63% weaker performance compared with the same ,,ideal,, thermal comfort. In a similar study conducted by Wargocki and Wyon in 2006 on a group of pupils aged between 10 and 12 years, they noted the influence of indoor temperature on intellectual capacity. The results showed that the optimal temperature can raise students' academic performance by up to 14% (Schneider, 2002).

It also demonstrated the influence of high concentrations of carbon dioxide on intellectual performance of students. The average concentration of carbon dioxide present in the room during the experimental study was 2,078 ppm, exceeding three times the allowable limit of comfort inside interior rooms for the educational buildings. The results of this test showed that the results obtained students were lower by 36.82% as compared to the test done under a clean air (800 ppm concentration).

Poor performance of students in an environment with a high concentration of carbon dioxide has been demonstrated by Barbara Wauman in three countries of Scandinavia: Denmark , Sweden and Norway. On this study it was noted that a healthy indoor environment in terms of indoor air is beneficial to students' health and for their educational performance (Earthman *et* al., 1995). Other studies related the same conclusions (Shendell *et al*., 2004; Lagercrantz *et* al., 2000; Myhrvold *et* al., 1996).

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IMPACTUL CALITĂȚII MEDIULUI INTERIOR ASUPRA PERFORMANȚELOR INTELECTUALE ALE STUDENȚILOR

(Rezumat)

Scopul articolului este de a analiza performanța intelectuală a studenților în diferite condiții de confort interior. Acest aspect a reprezentat mereu o condiție a calității educaționale şi a formării profesionale a acestora. Un mediu interior nefavorabil pentru elevi şi studenți va conduce către o pregătire deficitară a acestora, diminuând capacitatea intelectuală şi atenția în timpul cursurilor. Viteza şi precizia studenților în aceste sarcini de lucru simulate au fost măsurate, iar datele colectate au fost utilizate pentru a indica performanța intelectuală. Testele logice s-au desfăşurat în condiții interioare diferite, precum: condiții „ideale" de confort interior, iluminare slabă, zgomot, temperatură depăşind limita superioară de confort, temperatură scăzută, concentrație mare de dioxid de carbon.

A fost înregistrată şi analizată performanța individuală a studenților prin punctajul rezultat din testele celor şase condiții de confort interior, determinându-se, astfel, ambientul propice performanței intelectuale a studenților şi, totodată, conjunctura cea mai defavorabilă. Au fost realizate, de asemenea, grafice comparative între situațiile diferite de confort ale mediului interior, făcându-se analize şi studii pe baza rezultatelor obținute.

Din studiul experimental s-a putut constata importanța pe care o are calitatea mediului interior în sălile de clase în care studenții îşi desfăşoară activitatea. Acest lucru s-a determinat în urma rezultatelor dobândite la testele de confort interior de către studenții voluntari. Aceştia au obținut performanțe mult mai bune la testul realizat în condițiile ideale de confort interior față de celelalte teste. La acest test s-au remarcat atât acuratețea răspunsurilor studenților, cât şi eficiența din punctul de vedere al timpului de rezolvare al testului.

S-a putut observa ponderea ridicată pe care o are nivelul de iluminare asupra capacității de gândire şi concentrare a studenților. Acest indice de confort interior a avut impactul cel mai mare asupra rezultatelor obținute de către studenti, aceştia având cele mai slabe rezultate la testul realizat în condițiile unui iluminat redus. Studenții au

obținut la acest test un punctaj cu 43,79 % mai slab față de testul desfăşurat în condiții ideale de confort interior.

Rezultatele celei de-a doua campanii experimentale arată că studenții au obținut rezultate cu până la 15,06% mai slabe la testul cu nivel ridicat de zgomot față de testul realizat în condiții ideale de confort interior.

S-a demonstrat, de asemenea, influența concentrației ridicate a dioxidului de carbon asupra performanțelor intelectuale a studenților. Nivelul mediu al concentrației de dioxid de carbon prezent în sala studiului experimental in timpul celui de-al şasele test a fost de 2 078 ppm, depăşind limita admisibilă a confortului interior pentru încăperile interioare destinate sistemului educational, valuarea admisibilllă fiind de 800 ppm. Rezultatele acestui test au arătat că studenții au obținut rezultate mai slabe cu până la 36,82% față de testul realizat în condiții ideale de confort interior.