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A study of CO_2 influence on student activity in classroom

Studiul influenței conținutului de CO_2 asupra activității studenților în școli

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Rezumat. *În aceasta lucrare se prezintă un studiu realizat asupra parametrilor principali care determină confortul ambiental într-o sală de seminar. Confortul termic interior a fost determinat pe baza indicilor PMV si PPD. Parametrii măsurați în acest studiu sunt următorii: temperatura aerului, temperatura medie radiantă, viteza aerului, umiditatea relativă și conținutul de CO_2. Dintre aceștia, concentrația de CO_2 a fost aleasă pentru a se determina modul în care influențează activitatea studenților. Eficienta acestei activitati s-a calculat cu ajutorul notelor obtinute la orele de seminar. În final se propune un model de estimare al influenței conținutului de CO_2 asupra randamentului activității studenților.*

Cuvinte cheie: confort ambinetal, indice PMV, indice PPD, corelație

Abstract. *This paper presents a study of the main parameters which determine the environmental comfort in a seminar room. Indoor thermal comfort was determined based on the PMV and PPD indices. The parameters measured in this study are: air temperature, mean radiant temperature, air velocity, relative humidity and CO_2 content. Of these, CO_2 concentration was chosen to determine how they influence students. Their efficiency was calculated using the grades obtained in seminar classes. Finally, we propose a model to estimate the influence of CO_2 content considering students activity.*

Key words: environmental comfort, PMV index, PPD index, correlation

1. Introduction

Indoor air quality in schools not only affects the health and comfort of students, but it can also affect their productivity and has an influence on efficiency of learning and attention during classes, with repercussions on performance and social costs. There are many studies on the thermal comfort conditions in offices and the consequences of workers productivity [1], [2], but less on students and their performance during school hours. Students spend most of their time in schools; they don't have the possibility to chance the room. This doesn't happen for an employee, because he could change his job in case he is not satisfied with the indoor climate conditions. Several studies [3] have demonstrated that if someone lives in a comfortable environment, performance and productivity increases.

A very important factor of air quality in schools is the CO_2 concentration level. An increased level of CO_2 in schools affects students' health, decreases their learning performance and their efficiency. The studies realized by Smedje et al. [4] have reported air quality in schools in Sweden as being improper, CO_2 content increased by reducing the intake of fresh air and mental performance of students in secondary school decreased. Most of available data showed that higher CO_2 concentrations in classrooms are associated with an increased frequency of health symptoms, an increas of absenteeism of students and a decrease in students learning performance and staff productivity [5-9].

Bakó-Biro et al [5] analyzed the air quality in schools in the UK using CO_2 as an indicator of ventilation, and showed how it affects mental tasks. This research provides strong evidence that the low rate of ventilation in classrooms significantly reduces students' attention and vigilance, negatively affecting memory and concentration.

Coley and Greeves [6] a reduction of the power of concentration with approximately 5% through an increase of the CO_2 level fron an average of 690 ppm to an average of 2909 ppm.

Shendell et al [7] in studies carried out in schools in Washington and Idaho concluded that increased levels of CO_2 concentration is associated with decreased attention and increased absenteeism. Based on measurements of CO_2 content, there was estimated a ventilation rate <7.5 l / s person for at least 50% of the classrooms, the minimum rate specified in many regulations and standards.

In the recent studies performed [10,11], the CO_2 content in some academic classrooms in Timisoara, was found a rather large level compared to the recommended level ($CO_2 \leq$ 1000ppm over the outdoor air level), resulting a quality class IDA4 of indoor air, compliance with SR EN 13779:2007 [12].

It is noted that to produce optimum efficiency is not necessarily optimal thermal comfort conditions, and this is supported by a number of studies where subjects performed mental activities at air temperatures in the range 20 to 30 °C [13]. The insurance of the thermal comfort conditions must be in correlation with energy consumption.

To measure thermal comfort, literature mentions [14], [15] tags: PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied Index). PMV is an index that shows the mean value of the votes for a large group of people in a 7-point thermal sensation scale (figure 1). Standard equation for calculate PMV index is based on six factors (air temperature, mean radiant temperature, air velocity, humidity, activity and clothing).

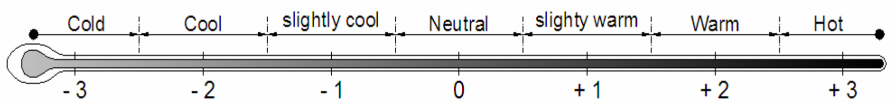

Fig. 1. Seven-point thermal sensation scale

PMV index is expressed by P.O. Fanger, variant (after processing) is simplified, according to:

$$PMV = \left(0.303 \cdot e^{-0.036 \cdot M} + 0.028\right) \cdot L \tag{1}$$

where:

M - metabolic rate, or heat produced by the human body. Metabolic rate in sedentary activity (school) for a person is considered to be 1.20 Met;

L - Heat load - defined as the difference between internal heat produced and heat loss through evaporation and transpiration by environment.

PPD is the index that establishes a quantitative prediction of the proportion of people who are dissatisfied with feeling too cold or too hot, relationship calculation is:

$$PPD = 100 - 95 \cdot \exp\left(-0.3353 \cdot PMV^4 + 0.2179 \cdot PMV^2\right) \tag{2}$$

2. Working conditions

The study was realized in Timisoara, located in the western part of Romania with a temperate continental climate, with an average annual outdoor temperature of 11.1 °C. The experiment was realized in a period of 2.15 h (8:00 to 10:15) during the summer months from June to July.

The mean values of outside parameters during the measurements can be consulted from Table 1.

Table 1

The mean values of outside parameters during the measurements

	time	t_{ext} [°C]	φ_{ext} [%]	$vair_{ext}$ [m/s]	CO_2 [ppm]
Summer	07:50	20.2	71.5	0.37	373
	10:30	26.4	53.6	0.31	381
Average values		23.28	62.82	0.34	377

The seminar room where the measurements were made is on the ground floor of the Faculty of Civil Engineering University "Politehnica" of Timisoara, a building with 6 floors, built in 1982. The room has an area of 67.50 mp and a height of 3.70 m, with a single external wall oriented to the east.

To provide a lower temperature inside, during the summer we use a VRV air conditioning system. This air conditioning system consists of a DAIKIN outdoor unit model RSX8K, where are connected three indoor units mounted to the ceiling, including a model FXYSP63K and two models FXYCP25K, each indoor unit model is equipped with a wired remote control BRC1D52 model.

During the experiment there were monitored the following parameters: air temperature, mean radiant temperature, air velocity, relative humidity and carbon dioxide content (CO_2). To determine PPD and PMV comfort index after Fanger model was estimated occupants activity as 1.2 met (69.84 W/m2) and thermal resistance of clothing of 0.5 clo (0.078 m2 ° C / W) for girls and 0.6 clo (0.094 m2 ° C / W) for boys. For determining thermal resistance of clothing were used tables contained in ASHRAE 55-2004 and ISO 7730 standards, considering their mean value.

The measurements of indoor climate parameters were made using Testo 350 measuring instruments connected to a sensor for measuring CO_2 concentration, sensor for measuring velocity (hot wire), humidity and temperature, and black globe to determine the radiant temperature.

Installation of sensors for measuring temperature, speed and humidity was made only on one level to a height of 1.10 m to the floor and the sensor for measuring CO_2 concentration at a height of 0.10 m to the floor - Figure 2.

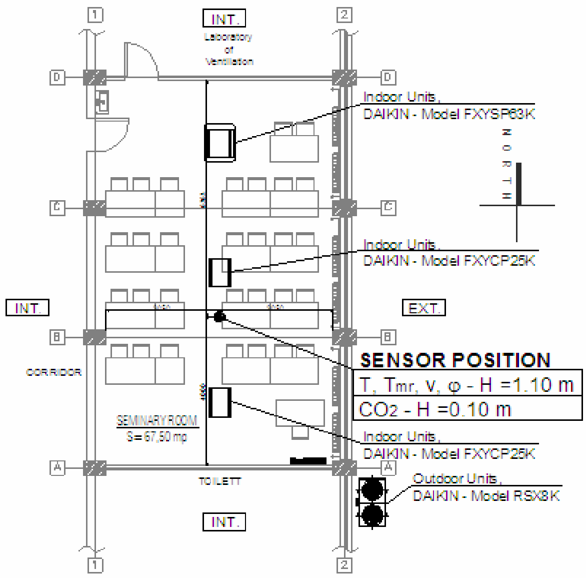

Fig. 2. Plan of seminary room and sensor position

During experiments we chose a total of 18 subjects comprising 11 boys and 7 girls, those were students in second and in third year in the Department of Civil Engineering and Building Services, "Politehnica" University of Timisoara. All students subjected to the tests were in a good health.

The experiment

At the beginning and at the end of measurement interval each subject received a questionnaire in which he expressed his opinion on climatic conditions in the room.

There have been several series of experiments, each complying with the following three cases:

1. Room without air conditioning worked and without pause - "NC" - Non cooling;

2. Room air conditioning worked without a break and with an interval of 50 minutes after the start of measurements - "NC + break";

3. Hall worked with air conditioning (break is irrelevant because conditioning installation keeps constant temperature in the range of ± 1 ° C) - "C" – Cooling

3. Climatic parameters measurements

The measurements purposes in the classroom without air conditioning, in case of break or no break was to see what is the influence of temperature variations, respectively the content of CO_2.

In figure 3 it can be seen that the temperature showed a constant increase enough sharply from 22.4 °C to 28.9 °C when the air conditioning did not work and kept a constant value in that case when the air conditioning was turned on. The temperature decreased during the break with approximately 1.5 °C, in all this time the room was empty.

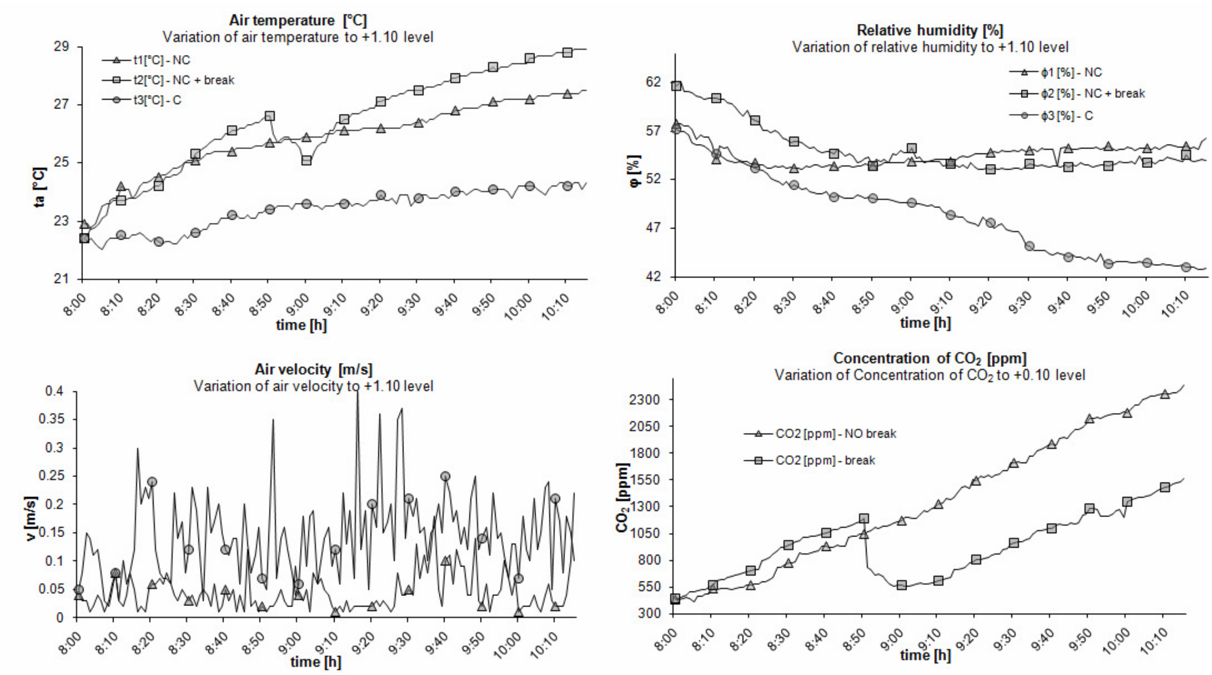

Fig.3. Variation of climatic parameters

The variation of indoor air relative humidity was in the limits (30% -70%) of comfort according ASHRAE standard 55. In the first case when the air conditioning didn't work the relative humidity showed a sharp decline in the first 35min. to around 54 % and then kept a constant value. During the break when the windows were opened for ventilation, the relative humidity showed a small increase due to a higher humidity level outside. In case of the air conditioning operation, relative humidity showed a steady decline from 57.2% to 42.9% in a period of 2.15h. Large variation of the interior humidity at the beginning of the measurements was due the fact that it had rained during the previous nights.

Air speed in the room was quite low, almost insignificant in the case of the air conditioning malfunction with an average value of 0.045 m/s and of 0.145 m/s due to air conditioner operation.

Considering that the room is not equipped with mechanical ventilation we can see, in figure3, how much the CO_2 concentration increased above the permissible, reaching to a value of about 2400 ppm> 1000 ppm within 2 hours, compared to the situation when everyone left the room during the break, ensuring fresh air by opening windows. In the case when the room was ventilated during the break, CO_2 concentration decreased significantly, reaching at the end of 2 hours a value of approx. 1500 ppm. Please notice the role of classrooms ventilation during breaks.

At the beginning of each measurement at an interval of 10 minutes, after the students came into the room and were accommodated with indoor climate, each student completed a questionnaire to express the sensation of thermal comfort perceived by each part perceived sensation on indoor air quality. PMV index was calculated for the same conditions with two different methods. A subjective method based on the method of ASHRAE responses based on the 7-point scale of sensation, and a second mathematical calculation method according to the calculation procedure of ISO7730.

A summary of the results by gender and response time is presented in Table 2.

Table 2

Summary of mean values for the PMV objective, respective PMV subjective

		Start		Finish	
		PMV - objective	PMV - subjective	PMV - objective	PMV - subjective
F	NC	-0.07	Slighty warm – item „1”	0.89	Warm – item „2”
	NC+break	-0.32	Slighty warm – item „1”	0.29	Warm – item „2”
	C	-0.65	Slightly cool– item „-1”	-0.29	Slightly cool– item „-1”
B	NC	0.13	Neutral – item „0”	1.02	Warm – item „2”
	NC+break	-0.1	Neutral – item „0”	1.39	Slighty warm – item „1”
	C	-0.42	Slightly cool– item „-1”	-0.08	Slightly cool– item „-1”

From Table 2 it can be seen that girls are more sensitive than boys to variation of climatic parameters.

4. Model for estimating CO_2 influence on student activity

In this case was chosen a linear regression model. Equation that forms the basis linear model has the following form:

$$p(x) = a * x + b \quad (3)$$

For CO_2 concentration we chose this model because the concentration of relationship between x and p(x) is linear in this case. The data that led to these results can be seen in Table 3.

Based on data in Table 3 were determined three regression models for students' performance depending on CO_2 concentration in the room. The first model taken into consideration the data were obtained in part 1 experiment, while the second model was considered the data obtained in part 2 experiment. (Figure 4)

Table 3

Average student results at each part and CO_2 concentrations during the seminary period

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10
Part 1	8.76	8.79	8.72	8.72	8.63	8.74	8.80	8.79	8.59	8.80
CO_2 - part 1[ppm]	792	573	732	785	1717	889	439	968	2184	693
Part 2	9.31	9.35	9.17	9.39	9.11	9.26	9.24	9.13	8.95	9.32
CO_2 - part 2[ppm]	1030	866	1949	572	1853	1601	1575	1830	2129	1064

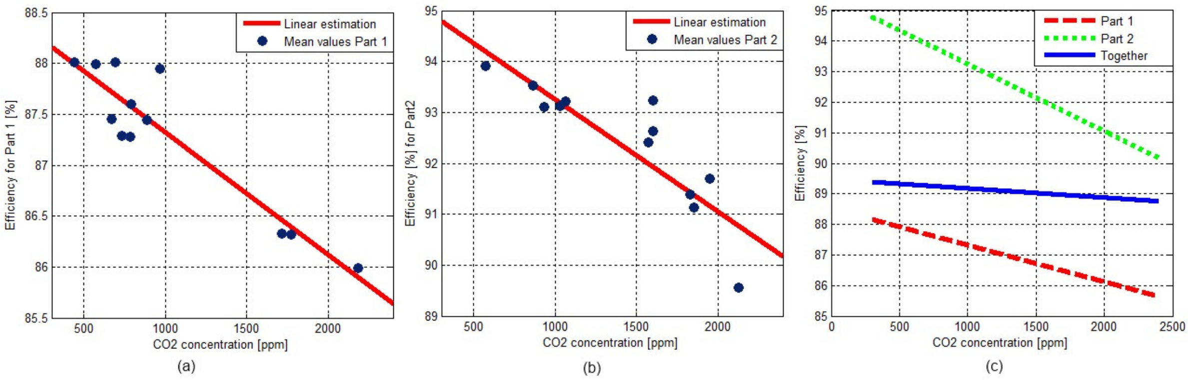

Fig 4 Estimation of efficiency for: a) part 1, b) part 2; c) together based on CO_2 concentration

Finally it was proposed a model that includes both results (part 1 and part 2) and that approximate student's efficiency in CO_2 concentration. This model has the following form:

$$Efficiency_{CO_2} = -0.0003 * x + 89.48 \quad (4)$$

Validation of this model was made in other two seminars .Thus, the proposed model provides an error of 2.2% as it concern the determination of students' efficiency during the seminar depending on the CO_2 concentration.

5. Conclusions

This article is based on a study that follows how indoor climate parameters influence students' performance of activity in the classroom.

The study was taken in a seminar room on the ground floor of the Faculty of Civil Engineering from the Polytechnic University of Timisoara, during the summer. To determine the efficiency of students during each seminar, students were tested theoretical (by mathematical calculation) and on graphic representation of results.

The first part of the article shows the variation of indoor climate parameters. For each seminary the following parameters measured indoor climate: temperature, relative humidity, velocity of air and CO_2 concentration.

In the second part of the article there were proposed models to estimate the efficiency of the work undertaken by students based on the results of these two tests.

Calculation of model is based on a method that uses the approximation method by a simple linear regression.

Relationship between mean thermal sensation and percentage of thermally dissatisfied subjects was in fairly good agreement with prediction by PMV/PPD model.

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