EXPERIMENTAL AND THEORETICAL THERMAL COMFORT ANALYSES IN HIGHER EDUCATION BUILDINGS IN BUCHAREST

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Global current requirement is to realize building comfortable and with low energy consumption. The thermal comfort studies are characteristic to each building type and from specific climate. A field survey was therefore carried out in winter, in a university building in Bucharest, Romania. A campaign of measurements and a questionnaire survey has been undertaken. The measurements results and the subject's response were compared. At the last part of the study a numerical analysis was done in order to optimize the energy consumption of the building keeping the thermal comfort in acceptable limits.

Keywords: thermal comfort, university classroom, PMV, PPD, TSV, COMFEN software

1. Introduction

Environment in a university classroom should be kept comfortable even at the cost of high energy consumption for heating and cooling as conditions in the classroom can significantly improve learning motivation and performance. However, the energy consumption should be reduced, current standards targeting both reducing energy consumption and indoor thermal environment acceptability.

The method often used to investigate the human thermal comfort is to measure the indoor environmental parameters and to quantify them using the thermal comfort indexes, Predicted Mean Vote (PMV) and Predicted Percent of Dissatisfied (PPD). At the same time Thermal Sensation Vote (TSV), which represents the actual response received from those who are in the evaluated

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thermal environment, is compared with the thermal comfort indexes. More than that, the adaptive human thermal comfort evaluations can be undertaken in the months in which the building is not mechanically conditioned, using specific standards (ASHRAE Standard 55, EN ISO 15251 [1-2]).

Human thermal comfort investigations are characteristic to the region in which the university is located because each country and even more, each area, has its specific climate. In a study realized in the last period [3], the authors analyze the thermal comfort in a university of Korea where the climate is temperate oceanic. In order to calculate PMV, there are four environmental variables measured (dry bulb temperature, black bulb temperature, air velocity, relative humidity). The questionnaires are used in order to find the thermal sensation of the subjects.

In other paper [4], it is investigated the thermal comfort in classrooms and offices of Harbin, a city located in the northeast of the Republic of China. Climate is characterized by long and cold winters. Measurements were performed in spring and winter. It was found that the neutral temperature is different from summer to spring, that shows the human thermal adaptability. The authors propose a decrease of indoor temperature in winter but still keeping constant thermal sensation vote that would lead to energy savings.

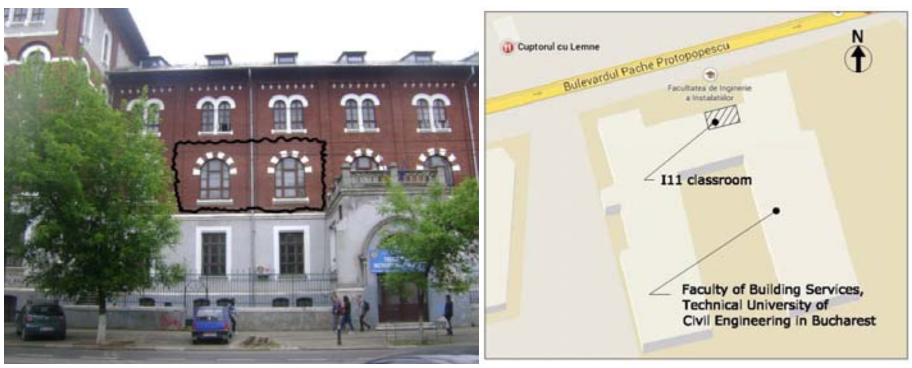
A more complex approach is found in a buildings energy simulation, used to evaluate the thermal comfort. Such kind of evaluation is used in the paper [5]. Buratti analyzes the thermal comfort indexes and the energy performance in a lecture hall of the Faculty of Engineering, University of Perugia. The study consists of two parts: an experimental investigation and a numerical analysis, realized in unsteady regime. The simulation was done using the ENERGYPLUS and TRNSYS software. The simulation results obtained using both software were in accordance and the authors validated their results with the measurements and optimized windows in terms of thermal comfort. The authors conclude that the implementation of the models of heat transfer in unsteady regime is a very powerful tool in the design of buildings: many different solutions can be investigated and the most appropriate design solutions can be selected thanks to simulation results.

There is still a need for studies on thermal comfort in educational buildings of Romania. It has a continental climate characterized by low temperature in winters and high temperatures in summers. The aim of this paper is to realize a thermal comfort study in these conditions.

2. Method and procedure

2.1. Building description

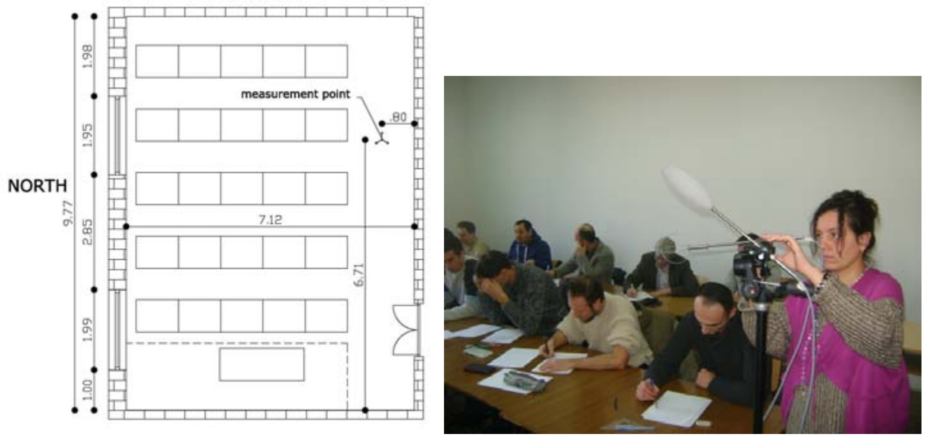
The experimental data presented in this work were collected from a measurement campaign carried out in a university classroom, situated in Faculty of Building Services of Technical University of Civil Engineering in Bucharest (UTCB), Romania. The building has been constructed at the end of the XIXth century and it was renovated and consolidated in 2003. Its supporting structure is realized from reinforced concrete and its walls are built from red brick. The windows are operable, double glazed, with wood frames. A central heating by gas provides hot water for the heating systems with steel radiators beneath the windows. The University is situated in Bucharest, Romania, climatic zone II, according to climate zoning map of Romania [6].



a) b)

Fig. 1 – a) Position of classroom I11 on faculty façade; b) Position of classroom I11 in university

The classroom is situated on the first floor of the building and is oriented to Nord on main façade, situated on Pache Protopopescu Avenue, as can be seen in fig. 1 a) and b). In fig. 2 are represented dimensional characteristics of the classroom and a photo inside it. The classroom height is 3.96 m. It has two big windows with a special form of arch. The room has two radiators, one under each window. Radiators are classical, provided with elements. When the measurements were done, 36 neon lamps worked in class, plus natural lighting through the windows. The windows had no blinds.



a) b)

Fig. 2 – a) Plan of classroom I11 and measurement point; b) Photography of the investigated classroom and the measurement device

2.2. Measurements of the environmental variables

The thermal comfort parameters were evaluated with the ComfortSense device, a system for measurement according to International Standard ISO 7730 [7]. The ComortSense sensors positioning on the stand can be seen in fig. 2 b).

Although ConfortSense measurement system is used in many applications to see which the comfort level at each work station is, in this case there was only one measurement point, fig. 2 a). It was a continuous measurement that lasted 3 hours. It was obtained the instantaneous value for: Operative Temperature, Relative Humidity, Temperature, Velocity, Turbulence Intensity, and Draught Rate. In addition to instantaneous values, ConfortSense software also provided average values for the main index of the thermal comfort, PMV and PPD.

The estimated values (chosen in the ConfortSense software) were 0.73 clo for the clothing level (clothing items were selected and the program calculates the amount) and 1.4 met for the metabolic rate. The positioning heights of the probes on the measurement stand of ConfortSense were: for the operative temperature and air velocity probe – 150 cm, the relative humidity sensor sat on the chair, located near the main frame. The inclination angle for the operative temperature probe was 30° from vertical, when it stimulated a sitting person, as is the case of I11 class measurements, where the majority of occupants were sitting at desk. According to the provider recommendations the position for the air velocity probe is vertical, fig 2 b).

The study was conducted on February 02, 2014. Measurements began at 10:05 in the morning. In the room there were 35 people, including 23 students who pass an exam. At 10:20 there was no student in the room because it was a pause. The students returned in the room after ten minutes of break. Around 11 o'clock they started to leave the place.

2.3. People questionnaire surveys

Survey questionnaires were given to the students who were present in the studied classroom. They were given three sets of questionnaires, around 10:15, 11:15 and 12:00. A total number of 93 questionnaires were completed and the time for filling the questionnaire was about 2-3 minutes. The general information requested by questionnaire was: the date and time of filling, the floor and the classroom number, the information about the person who had completed the questionnaire (name, age and sex). For the assessment of the thermal sensation, the subjects have to chose an option on the ASHRAE 7-points rating scale and they also have to choose the thermal preference at the time of completion. They had to answer about the acceptability of the thermal environment and about the local thermal discomfort. The questionnaire included a checklist with clothing items for people to choose from. They had to specify the activity they had been doing in the last 15 minutes before the moment of questionnaire filling.

3. Results and discussions

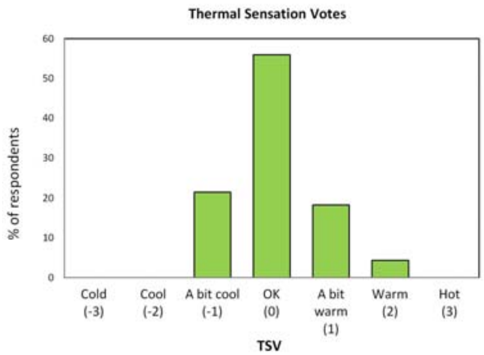
3.1. Questionnaire surveys and measurements

After analyzing data from questionnaires we obtained the values from tab. 1. We realized the graph on the fig. 3 using the data in the tab. 1. It shows the distribution of the thermal sensation votes and thermal preference votes for the entire sample. It can be seen that the TSV are centered on ‘0’ (OK), with a little shift toward warm thermal sensations. The TPV votes are centered on ‘0’ (No change), with an apparent shift toward colder preference. Overall, the subject’s response was balanced against neutral position throughout the study.

Table 1

TSV and TPV mean for all survey period for each category

No. respondents	No. resp. [%]	TSV	No. respondents	No. resp. [%]	TPV
0	0.00	Cold	0	0.00	A lot colder
0	0.00	Cool	4	4.30	Colder
20	21.51	A bit cool	23	24.73	A bit colder
52	55.91	OK	51	54.84	No Change
17	18.28	A bit warm	14	15.05	A bit warmer
4	4.30	Warm	1	1.08	Warmer
0	0.00	Hot	0	0.00	A lot warmer
93	100.00		93	100.00	



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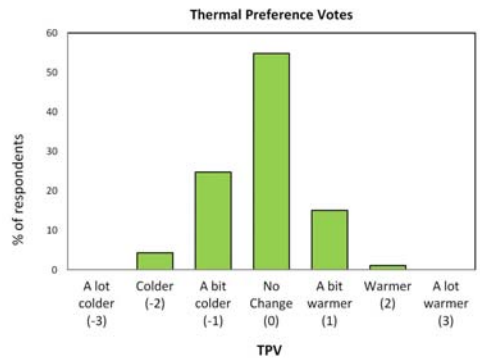


b)

Fig. 3 – a) Relative frequency of TSV votes from all the surveys; b) Relative frequency of TPV votes from all the surveys

The percentage distribution of the age groups is presented in fig. 4. It is observed a very close value for age category 40-50 years and for age category 30-40 years, followed closely by category 24-30 years. At great distance, with a value of 2.14%, is the category 50-54 years.

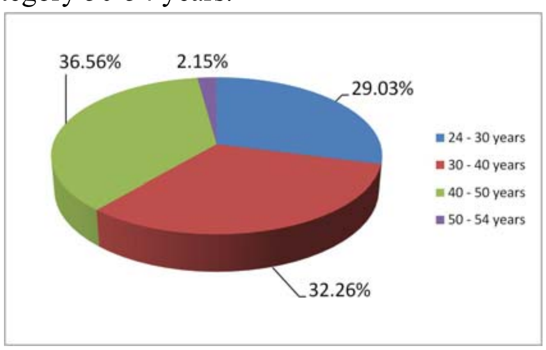


Fig. 4 Percentage distribution of the age groups

TSV and TPV vote repartitions on age range are represented in fig. 5. It is observed, in fig. 5 a), in the age category 40-50 years, the biggest percent of people that feel ‘OK’. In the category 24-30 years, a percent of 37.04 % feels ‘A bit cool’ and a percent of 51.85% feels ‘OK’. An equal percent of 40.74 % can be seen in fig 5. b), from the age category 24-30 years, from preferences, ‘A bit warmer’ and ‘No change’. The biggest percent of people that prefers ‘No change’ can be found in the category 40-50 years. The results obtained for the category 50-54 years are not discussed because this category is represented only by two peoples. It is not relevant to distribute those two peoples on the TSV and TPV category.

From measurements with ComfortSense device we obtained instantaneous values for the thermal comfort parameters. In tab. 3 the comfort indices, PMV and PPD, obtained from measurements, mean for all survey period, are presented in comparison with TSV obtained from questionnaires given to the people. In the expression PPD as function of PMV, ec. 1, formulas (2.5), page 29 of [8], we substitute PMV by TSV and obtained the value 'PPD from TSV' which can be also found in tab. 3.

$$PPD = 100 - 95 \cdot \exp[-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)] \qquad (1)$$

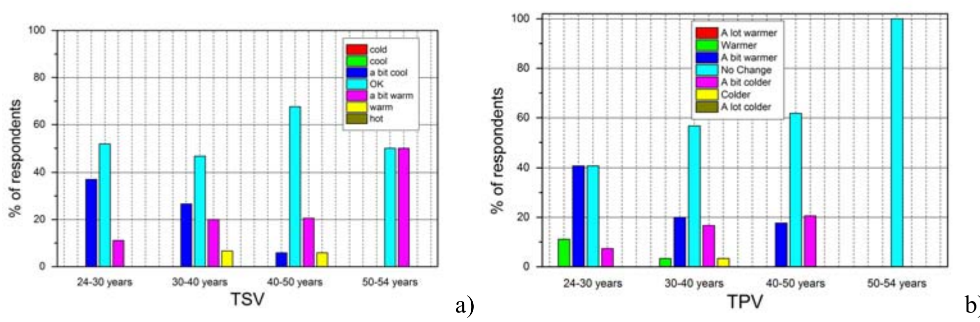


Fig. 5 – a) TSV votes repartition on age range; b) TPV votes repartition on age range

Table 2

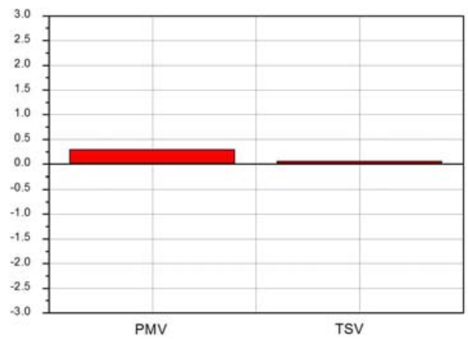
ConfortSense measured and processed parameters, means for all survey period

Operative Temperature [C]	22.71
Relative Humidity [%]	40.13
Temperature [C]	24.02
Velocity [m/s]	0.04
Turbulence Intensity [%]	112.73
Draught Rate [%]	0.00
Predicted Mean Vote []	0.30
Predicted Percent of Dissatisfied [%]	6.88
Mean Radiant Temperature [C]	21.95

Table 3

Thermal comfort indices and thermal sensation parameters

PMV	TSV	PPD	PPD from TSV
0.30	0.06	6.88	5.00



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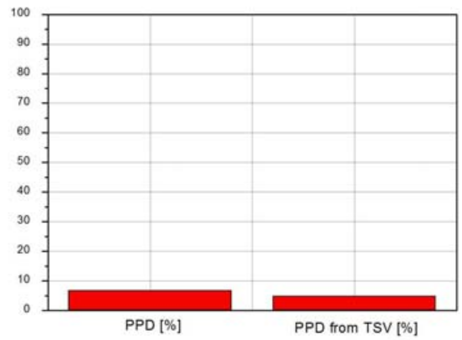

b)

Fig. 6 – a) Comparison between TSV and PMV; b) Comparison between PPD and PPD obtained from TSV

In accord with tab. 5.2.1.2-1, page 12 of [9], the value 6.88 % of PPD set Class B for thermal comfort, so in compliance with this standard. The value of 5% for PPD from TSV set Class A for thermal comfort. As can be seen in tab. 3 and fig. 6 a) between PMV and TSV is a difference of 0.24 that represent the prediction error. The Fanger comfort indices represent the result of an estimation model, so they are not equal with the real response of the subjects. But the difference, the prediction error, is good to be small, like in our case.

In fig. 7 it is shows the operative temperature variation in time for the studied period. This graph is realized from 4000 of instantaneous values recorded by the ComfortSense device. The measurements began around 10:00 am. In the figure we can observe a slow decrease with the temperature that reaches a minimum around 4000 s. This can be explained by the fact that around 11:15 there was no student in the classroom, and their gradual departure explains the gradual decrease with the temperature. Then all the students entered in the classroom and we are witnessing to a phenomenon of the operative temperature increase caused by two facts. On one hand the internal gains increased due to the large number of people and on the other hand a heating occurs due to the increasing of the outside temperature and implicitly of the internal temperature.

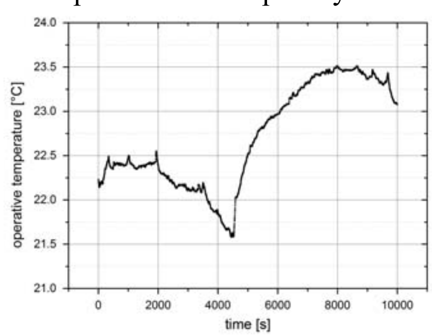

Fig. 7 Operative temperature variation in time for studied period

3.2. Numerical simulation

In the second part of the study of thermal comfort in the classroom I11 from Faculty of Building Services of UTCB, we realized a numerical simulation in order to calculate the thermal comfort indexes. For this purpose it was elected COMFEN [10] software. It is a software developed by LBNL (Lawrence Berkeley National Laboratory), designed to assess the façades of buildings in terms of energy efficiency. COMFEN provides a work environment intuitive, easy to use by the user and which focuses their attention on key variables in the design of façades. Behind it, however, lays Energy Plus, a sophisticated analysis engine that dynamically simulates the effects of input variables on energy consumption, the peak load and the thermal and visual comfort.

In paper [11], the authors noted that despite the fact that currently the emphasis is more on building evaluation software, there are design software too, used since the early stages of the project. From all of these, we quote COMFEN, characterizing him as made to work as a data manager and using an external detailed assessment tool that is Energy Plus.

For the study of the thermal comfort in the classroom I11 it was chosen last available version of the software, COMFEN 5 Beta (5.0.8 - May 17.2013). As input data in the program it had entered the classroom dimensions: height - 9.36 m, length - 9.77 m, width - 7.12 m. Orientation was selected by North. To simulate the external walls was built a structure of old red brick of thickness 50 mm. In agreement with MC001/2, page. 240, tab. 2.8 [12], the internal gains caused by the lighting are of 9 W/m2 and for internal gains due to equipment it was chosen the value 5 W/m2. The number 35 was chosen for the people situated in the class at the measurement moment. Fig. 8 shows the above mentioned data, and a front view of the classroom façade. The windows have a special form, an arch form. The software COMFEN can allow input only for rectangular windows. To solve this problem we use an equivalent rectangular window with the same width and the same area. The complete position of the windows in façade was specified, the type for windows was chosen double glazed with wood frame. The type for building was chosen school (classroom). The climate data for Bucharest, Romania were given in specific EPW format.

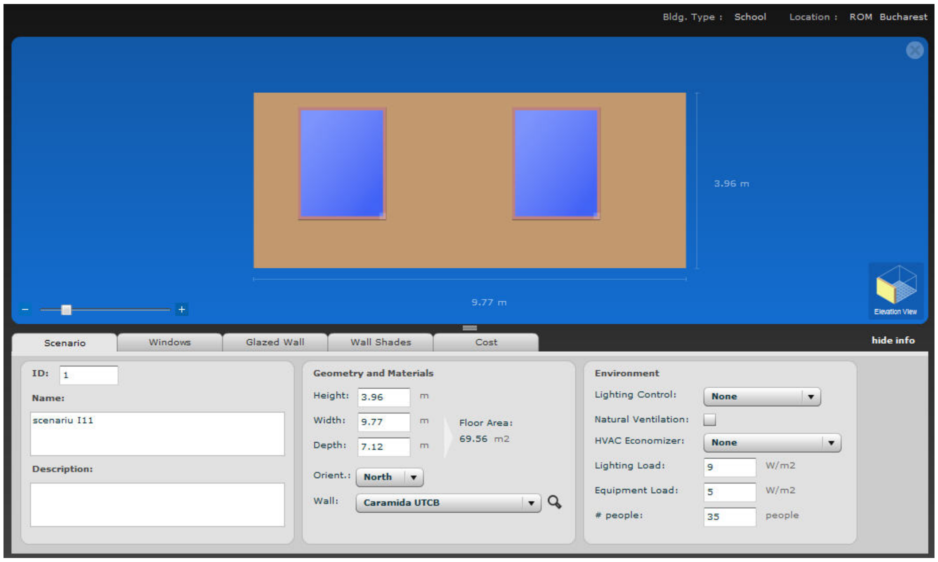

Fig. 8 Frontal view of I11 classroom and input data

Table 4

PPD for two internal temperatures

Hour	10	11	12	13
Internal temperature of 24°C	5.02	5.05	5.11	5.08
Internal temperature of 21°C	10.03	9.72	9.34	9.09

After the introduction of all above mentioned data we realized that it was no field to specify the internal air temperature. That happens because COMFEN is software for design which uses the design temperature. To solve this problem it was used the EnergyPlus direct launch interface, fig. 9. We edited the IDF file (the input file for EnergyPlus) and interchanged the value of 21°C with the real temperature of 24°C which was in the classroom. We study the EnergyPlus manual and we find that from all EnergyPlus output files, the ESO output file contains the interest parameters. In our case the parameter is PPD. In tab. 4 is presented the hourly values for PPD in February 15, 2014.

The measurements were conducted between 10 am and 1 pm. The PPD mean value for this time interval is 5.40%. As can be seen in tab. 3, for the measurement results we have PPD=6.88%. The difference is very small. There are many factors that may cause the difference between measurements and simulation. We specify only one of them, the climate data in the simulation are obtained from a computed characteristic year, not for real climatic data. It can be considered as the numerical outcomes are validated by measurements, for difference of only 1.44%.

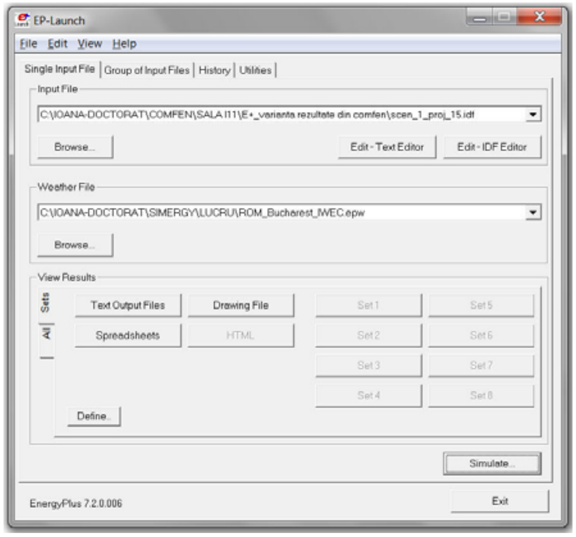

Fig. 9 Interface for direct EnergyPlus launch

In this case we might see how PPD varies if the exterior wall will be insulated, if the type and size of windows will be change or if the interior temperature will be modify. We chose to change the indoor air temperature to 21 °C. It represents the design temperature. The obtained values are show in tab 4. In this case we obtained a value PPD=9.55%. It is about 1.8 times higher than the PPD = 5.40% obtained when the internal temperature was 24 ° C. In accord with tab. 5.2.1.2-1, page 12 of [9], the value 9.55 % of PPD sets the thermal comfort in comfort class B, so in compliance with this standard.

4. Conclusions

Using the data obtained from the questionnaire results we can conclude that the thermal sensation votes (TSV) and thermal preference votes (TPV) distributions are almost symmetrical to neutrality and ‘No change’ preference. The biggest percent of ‘OK’ votes and ‘No change’ preferences are fined at the age range 40-50 years. The value of 6.88 % for predicted percent of dissatisfy (PPD) computed with measurements data, sets the classroom in thermal comfort class B, according to ASHRAE 55 standard. The difference between PMV and TSV, that means prediction error, has a value of 0.24.

From the studied classroom was realized a numerical model. The results were validated by measurements. With this model we change the temperature from 24°C to 21°C. The PPD comfort index is still in comfort class B. A decrease of internal air temperature means energy saving.

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