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THERMAL COMFORT ANALYSES IN NATURALLY VENTILATED BUILDINGS

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Abstract: Global current requirement is to increase thermal comfort in residential and non residential buildings. A field survey was accomplished in a naturally ventilated university classroom in Bucharest, Romania, in winter and spring. Comfort parameters were measured and comfort questionnaires were distributed to the students. Questions were related to thermal sensation of the occupants. This paper compares the experimental results with the occupant's response. It analyzes the variation of Predicted Mean Vote (PMV) and Predicted Percent of Dissatisfied (PPD) with temperature. It is made a comparison between PMV and thermal sensation vote. The results show PMV values different from Thermal Sensation Vote (TSV) values which means there is a poor approximation of indoor comfort. In conclusion the comfort parameters should be reviewed and should be proposed other evaluation methods. Possible explanations are discussed in relation with thermal regime of the buildings.

Keywords: thermal comfort, university classroom, PMV, PPD

1. Introduction

Thermal comfort inside buildings is evaluated by several methods (ASHRAE Standard 55/2010, EN ISO 10551, EN ISO 7730 [1-3]). Many studies, in the recent years, have analysed the thermal comfort in school or university classrooms in different parts of the world, for different climatic conditions and architectural configurations.

As an example, in "Field study on thermal comfort in a UK primary school" [4], there is described the specific thermal response of schools children in Southampton UK. The study included simultaneous measurements of indoor environmental variables and thermal comfort surveys. The results show that children have a different thermal perception than adults. In order to find a correlation between experimental data measured by the instruments and subjective responses given by the occupants, in another paper, [5], the authors showed a comprehensive study undertaken in autumn, winter and spring in classrooms of the University of Perugia, Terni and Pavia, Italy. The paper concludes that were obtained higher values of TSV from the questionnaire than instrumental PMV for the same value of operative temperature.

Experimental research on thermal comfort in the university classroom of regular semesters in Korea was realized in "Experimental research on thermal comfort in the university classroom of regular semesters in Korea" [6]. The target building belongs to School of Architecture of Pukyong National University located in coastal area of southeast Korea. In this location the climate is oceanic temperate. This research is based on the ISO 7730-2005 standard and the Adaptive Thermal Comfort theories. The environmental variables were measured. Thermal sensation vote and a thermal preference vote were investigated at the same time using a questionnaire. This study concludes that the acceptability ratio of thermal environment is slightly different from ASHRAE 55-2004 Standard [7] and it is necessary to more investigate standard range of acceptability of thermal environment in oceanic temperate climate region using larger databases.

Occupants' adaptive responses and perception of thermal environment in naturally conditioned university classrooms in Chongqing, China was analyzed in another study, [8]. In this study is presented the occupants' thermal sensation votes and it is analyzed the occupants' adaptive response of the thermal environment in a naturally conditioned space. The climate in Chongqing has hot summer and cold winter climatic characteristics. The paper conclude that the Chongqing adaptive comfort range is broader than that of the ASHRAE Standard 55-2004 [7] in general, but in the extreme cold and hot months, it is narrower. This can be explained by the thermal conditions in Chongqing in summer and winter are severe. The adaptive behavioural such as changing clothing, adjusting indoor air velocity, etc., as well as psychological adaptation, are important in adapting to the thermal environment.

We can see that the main conditions show that classics evaluation of the parameters of thermal comfort differs from real perception of occupants irrespective of weather conditions and construction of buildings.

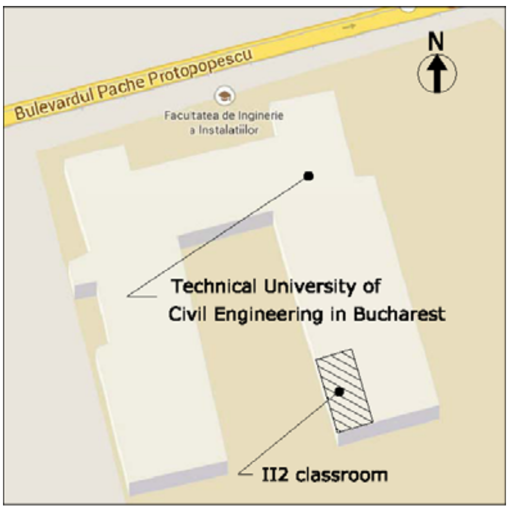
In Romania, which has a continental climate, characterized by winters with low temperatures and summers with high temperatures we cannot find many studies regarding thermal comfort in education buildings.

2. Method

2.1. Studied classroom description

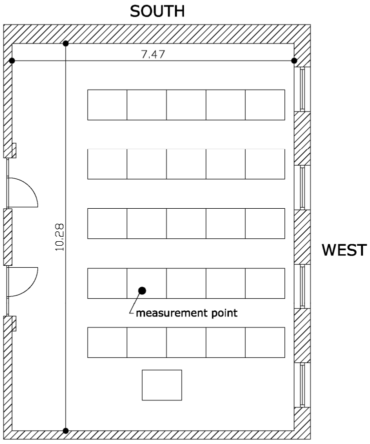
The experimental data presented in this work were collected from measurement campaigns carried out in a University classroom, from Faculty of Building Services of Technical University of Civil Engineering in Bucharest (UTCB), Romania. The building has been constructed at the end of the XIXth century and it was renovated and consolidated in 2003. Its supporting structure is realised 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 [9].

The classroom is situated on second floor of the building, oriented to West toward interior yard of the building, as can be seen in fig. 1 b). In fig. 2 are represented dimensional characteristics of the classroom and a photo inside it.



a) b)

Fig. 1 – a) Position of classroom II2 on faculty façade; b) Position of classroom II2 in university



a)

b)

Fig. 2 – a) Plan of classroom II2 and measurement point; b) Photography of the investigated classroom

The students are aged between 20 and 30 years. They are of both sexes, more boys and attend the course and applications. Some of them have computers with them.

2.2. Measurements surveys

The field study presented here included measurements of the indoor environmental variables correlated with simultaneous questionnaire surveys regarding thermal comfort. The measurements campaign was realized during three months; from 26.02.2014 to 30.04.2014 with a day of measurement on each week (a total of eight days with 22 sets of measurements data). The measurement variables were CO_2, interior air temperature and relative humidity. The measurement point inside the classroom can be seen in fig. 2a).

The instrumentation used for this experiment evaluation was a TSI system with probe for humidity, CO, CO_2 and temperature.

IAQ-Calc™ Indoor Air Quality Meter 7545 made by TSI company is a professional instrument for investigating and monitoring indoor air quality (IAQ) (fig. 3). The 7545 model simultaneously measures and data logs multiple parameters.

Fig. 3 - IAQ-Calc™ Indoor Air Quality Meter 7545

2.3. People questionnaire about thermal comfort

For each set of measurement data, a survey questionnaire was given to each student who was present in the studied classroom. A total number of 174 questionnaires were completed and the time for filling the questionnaire was about 2-3 minutes. The general information requested by questionnaire was: date and time of filling, the floor and the classroom number, 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 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

The data resulted from measurement was interior air temperature and relative humidity, and an estimated value of 0.05 m/s for air velocity and they were processed with CBE Thermal Comfort Tool [10] for finding the PMV value. The mean level of activity and clothing for each measurement set were estimated using the questionnaire results. For a good accuracy of estimated values, instead of using general parameters for metabolic rate and clothing level we used the values obtained from questionnaire.

Values were obtained for comfort indexes Predicted Mean Vote (PMV) and Predicted Percent of Dissatisfied (PPD).

It should be noted that starting from 9th of April 2014 the centralized heating system in university was stopped.

In fig. 4 it is observed that correlation line between instrumental and and questionnaire data found in this experimental campaign is different from ideal correlation line. It is observed that for PMV values less than -0.82 the perception of cold sensation is accentuated beside the predicted thermal sensation. On the other hand, for PMV values more than -0.82, the perception of cold sensation is lower. It results that the exaggeration of the thermal comfort predicted by PMV.

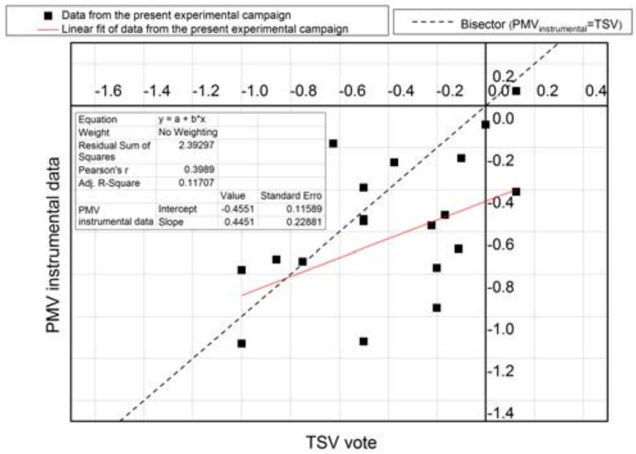
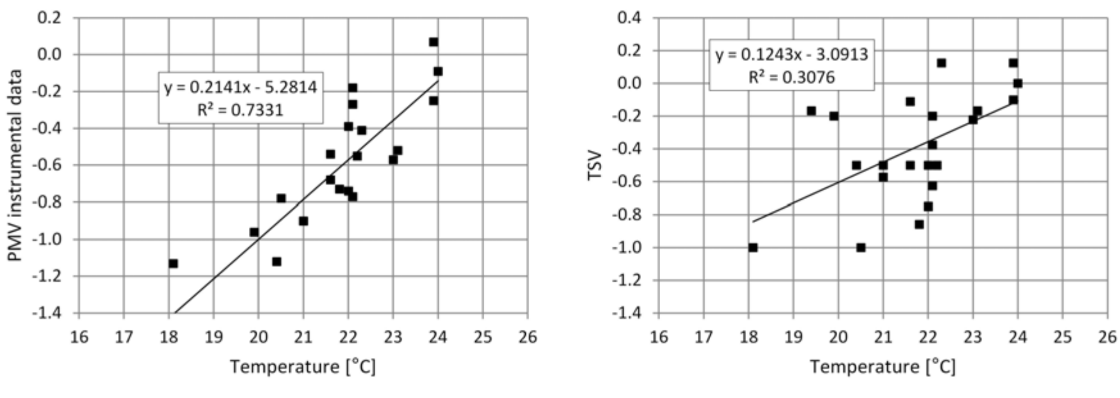


Fig. 4 - PMV of instrumental data versus TSV of questionnaire data



a) b)

Fig. 5 – a) PMV as function of interior air temperature; b) TSV as function of interior air temperature

PMV and TSV are represented as functions of interior air temperature (fig. 5) and a linear approximation of the points was realized. The fitting quality is guaranteed by the index R^2 (the coefficient of determination), for which values of R^2=0.7331 and R^2=0.3076 were, respectively, determined. It is evident that for PMV variation with temperature the fit is better.

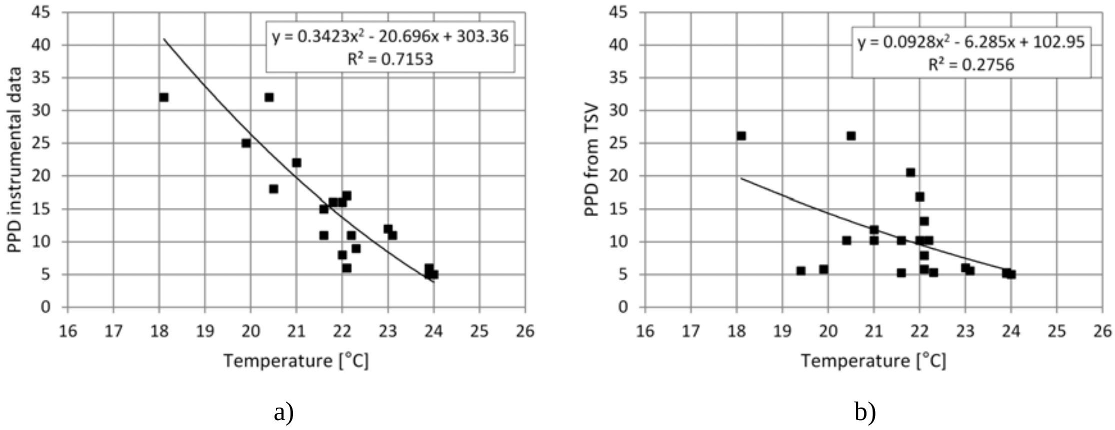


Fig. 6 – a) PPD as function of interior air temperature; b) PPD from TSV as function of interior air temperature

PPD obtained from instrumental data and PPD obtained from TSV are represented as functions of interior air temperature (fig. 6) and a polynomial approximation of the points was realized. For the index R^2, the values of R^2=0.7153 and R^2=0.2756 were, respectively, determined. It is evident that for variation with temperature of PPD obtained from instrumental data, the fit is better.

Table 1

The measurement and questionnaire results for all survey period

No	Date	hour	TSV	PMV	PPD [%]	T [°C]	CO_2 [ppm]
1	26.02.2014	10:00	-0.75	-0.74	16	22	1100
2		10:30	-0.50	-0.39	8	22	1070
3	05.03.2014	10:20	-0.20	-0.77	17	22.1	1045
4		11:00	-0.10	-0.25	6	23.9	1056
5		12:00	0.13	0.07	5	23.9	1178
6	12.03.2014	11:00	0.13	-0.41	9	22.3	1048
7		11:30	0.00	-0.09	5	24	1074
8	19.03.2014	10:30	-0.11	-0.68	15	21.6	895
9		11:30	-0.22	-0.57	12	23	1031
10		12:30	-0.17	-0.52	11	23.1	1048
11	02.04.2014	10:00	-0.50	-0.54	11	21.6	845
12		11:00	-0.63	-0.18	6	22.1	851
13		12:00	-0.38	-0.27	6	22.1	940
14	09.04.2014	10:30	-1.00	-0.78	18	20.5	1221
15		11:30	-0.86	-0.73	16	21.8	1148
16		12:30	-0.50	-0.55	11	22.2	972
17	16.04.2014	10:30	-1.00	-1.13	32	18.1	804
18		11:15	-0.20	-0.96	25	19.9	702
19		12:00	-0.50	-1.12	32	20.4	959
20	30.04.2014	10:30	-0.16667	-1.43	47	19.4	853
21		11:30	-0.57143	-0.9	22	21	1014
22		12:00	-0.5	-0.9	22	21	1049

The measurement and questionnaire results for all survey period, which have been used for the graphics achievement, can be found in table 1.

In figure 7 it is showed the distribution of carbon dioxide concentration in each measurement from all eight survey days. It is observed, in mean, an increase of CO_2 level with the passage of time during the day. The exception is the date of 09.04.2014. We analyzed what happened then and we found that only in that day the measurement instrument position in the classroom was changed. Maybe the number of persons around the CO_2 sensor had a decrease in time. That explains the reduction of CO_2 concentration.

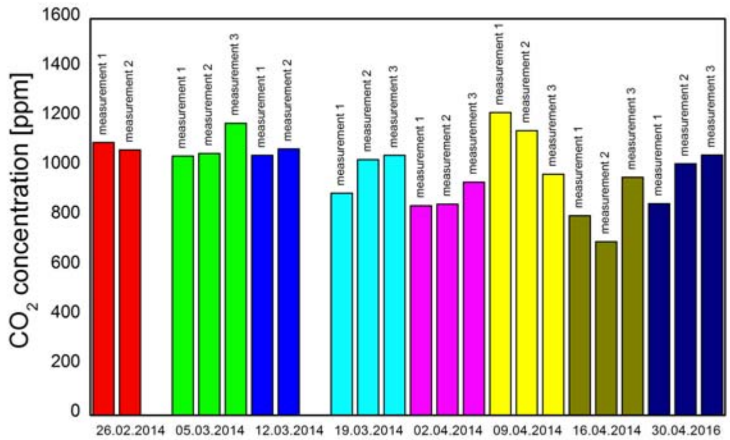


Fig. 7 - Carbon dioxide concentration for each measurement set

According to Romanian standard I5/2010 [11], for an IDA 3 category of indoor air quality (moderate quality of indoor air quality), the CO_2 level must be 600-1000 ppm. We observed that, in more than half of measurements, this limit is exceeded. We found no correlation with thermal comfort.

4. Conclusions

The PMV instrumental data variation is between -1.43 and 0.07, leading to a tendency of "cold" perception. It can be explained by the fact that from 09.04.2014 the centralized heating system in university was stopped. The PPD variation is between 5% and 47%; this shows a high degree of dissatisfaction of the subjects.

The relationship between the experimental data and the questionnaire shows that the discomfort conditions are more intensive perceived by the occupants, in comparison with the predicted values.

The outside temperature was lower than usually temperature for this period. This difference can be seen, for example, for daily mean value of outside air temperature in Bucharest, in April, obtained from AMN (Administratia Nationala de Meteorologie) [12], comparatively with a monthly mean value of outside air temperature for a typical meteorological year of 11.8° C , in Bucharest in April obtained from EnergyPlus weather data [13].

We calculated for all the measurements, the difference between TSV and PMV and we obtained a maximum of 1.26 and a minimum of -0.45. That means a prediction error, a big difference between calculation parameters and people response. This thing is found both in specific literature and in our calculations. It results the need to reevaluate the thermal comfort indices in order to correlate it as much as is possible with the actual values.

The studied classroom represents a natural ventilated one, with no heating or cooling system from the date when the heat was turned off. So an adaptive comfort evaluation according to international standards can be effectuated in a further study in the future.

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