TOPLOTNI KOMFOR U UNIVERZITETSKIM ZGRADAMA – RAZLIKE IZMEĐU IZMERENIH VREDNOSTI I SUBJEKTIVNOG OSEĆAJA KORISNIKA

THERMAL COMFORT IN UNIVERSITY BUILDINGS – DIFFERENCES BETWEEN MEASURED VALUES AND OCCUPANTS' SUBJECTIVE EVALUATION

Tamara BAJC*, Maja TODOROVIĆ
Faculty of Mechanical Engineering,
University of Belgrade, Belgrade

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Istraživanja u oblasti toplotnog komfora u svetu su značajno povećana u poslednje vreme, dok su rezultati u ovoj oblasti za područje Srbije ograničeni. Posebno je značajno pitanje toplotnog komfora i kvaliteta unutrašnje sredine u zgradama namenjenim obrazovanju, sa prirodnom ventilacijom, imajući u vidu uticaj na korisnike koji veći deo vremena borave u ovim prostorima. Takođe je važno naglasiti da toplotni komfor i kvalitet unutrašnje sredine značajno utiču na radne sposobnosti korisnika. Rezultati istraživanja koji su sprovedeni tokom zimskog semestra, u univerzitetskoj učionici u Beogradu, pokazali su da se rezultati merenja i na osnovu njih izračunate vrednosti PMV indeksa i rezultati subjektivne ocene korisnika dobijeni anketom kvantitativno značajno razlikuju. Poređenjem rezultata u okviru četiri nedelje istraživanja došlo se do zaključka da su najpovoljniji i najnepovoljniji uslovi toplotnog komfora, potvrđeni merenjima, takođe markirani kao najpovoljniji, odnosno najnepovoljniji na osnovu rezultata anketiranja korisnika, ali sa različitim vrednostima PMV indeksa.

Ključne reči: *toplotni komfor; PMV indeks; ASHRAE 55; SRPS EN ISO 10551; subjektivna oceana korisnika*

The number of research results regarding thermal comfort worldwide has been significantly increased in the recent period, while the results in this scientific field for Serbia are limited. The question of thermal comfort and indoor environmental quality in naturally ventilated educational buildings is especially important having in mind the impact on occupants who spend the most of their time indoors. Additionally, it is important to emphasize the impact of thermal comfort and indoor environmental quality on occupants' working performances. The results of the research that was performed during the winter semester in a university classroom in Belgrade showed the significant quantitative deviation between the PMV index valu-

* Corresponding author's e-mail: tbajc@mas.bg.ac.rs

es obtained by measurements and the values gathered through the occupants' survey. Comparing the results over a four week period, it has been concluded that the most favourable thermal conditions and also the most unfavourable ones were confirmed by both measurements and the survey results, but with the different PMV values.

Key words: *thermal comfort, PMV index, ASHRAE 55, SRPS EN ISO 10551, occupants' subjective evaluation*

1. Introduction

Satisfying thermal comfort conditions in buildings is one of the most important tasks of efficient building design. A lot of existing buildings, especially the naturally ventilated ones, have a problem to meet the criteria prescribed through the international standards regarding thermal comfort such as ASHRAE 55:2013 [1], ISO 7730:2005 [2] and ISO EN 15251:2007 [3]. Reaching the optimal thermal comfort parameters is of a high importance having in mind that the occupants spend around 90% of their time indoors [4]. Precisely a long period of time spent in inadequate environmental conditions leads to the various health problems, such as the various respiratory infections, Sick Building Syndrome, allergies and other diseases correlated with poor IEQ. According to Vardoulakis et al. [5], the outdoor pollutants but also the indoor allergens and pollutants could be a potential cause of health reactions or diseases. The poor IEQ in classrooms is one of the causes of students' productivity loss. According to the Seppanen et al. [6], the learning performances decreases 10-14% when effective temperature increases from 24°C to 27, 29°C. Further, Bajc et al. [7] researched a correlation between the local thermal comfort and students' productivity loss, and concluded that the students who seated in colder zones of the classroom had a lower productivity loss, then the others seated in warmer classroom zone. The results showed that the productivity loss is lower than 5% when indoor air temperature is in between 22 to 24°C and goes up to 12% when indoor temperature in classroom is up to 26°C. Beizaae et al. [8] researched the difference between the calculated and reported PMV for 16 participant in naturally ventilated office and in their houses in UK. They found that the Fanger's model predicts higher neutral temperature than the actual thermal sensation votes of the occupants.

2. Methodology

The paper deals with a thermal comfort conditions in naturally ventilated university classroom. The research was conducted during four weeks of winter semester among the predominantly male population, aged about 25 years. The students' had the typical winter clothing: sweater, shirt, trousers, socks and winter shoes. This kind of ensemble is evaluated as 1.01 Met, according to [1]. The physical parameters describing thermal comfort state, such as air temperature, radiant temperature, air humidity, air velocity, etc were measured, and PMV indexes were

calculated according to the methodology prescribed within the international standard ISO 7730:2005 [2]. Described methodology is widely used for moderate thermal environments, with a large number of occupants. According to the definition given in Standard ISO 7730:2005 [2], the PMV "is an index that predicts the mean value of the votes of a large group of persons on the seven point thermal sensation scale, based on the heat balance of the human body". The seven point thermal sensation scale varies from -3 for cold sensation to +3 which represents sensation of hot environment. The PMV index can be calculated for different combinations of air temperatures, air velocities, mean radiant temperature, air humidity, clothing insulation and metabolic rate. The same standard defines the three categories (from A to C) of thermal environment according to the prescribed limits for PMV and PPD indexes, while the European standard ISO EN 15251:2007 [3] recommends four categories of buildings (from I to IV).

The methodology of occupants' statistical survey in situ is suggested by European standard SRPS EN ISO 10551 [9], which describes the suitable judgment scales for thermal environment evaluation and gives the instructions for the use of scales. With respect to the suggested methodology, the new questionnaires were developed according to the SRPS EN ISO 10551:2008 [9] and used for subjective evaluation of thermal comfort conditions during the research period. The survey was performed every day, after a relevant number of hours spent in classroom and a minimum 90 minutes in continuity.

2.1. Classroom description

The observed classroom (Fig.1) was located at the Faculty of Mechanical Engineering University of Belgrade. The classroom is 8.12m long, 6.34m wide and 3.3m high. The total heated area is 51.48 m^2 and the net volume is 169.9 m^3. The classroom was South-East oriented with one external wall and two windows. The total number of seating places is 30.

2.2. Statistical survey

The subjective evaluation regarding thermal comfort in the classroom was performed using new questionnaire developed in accordance with standard SRPS EN ISO 10551:2008 [9]. The students' were asked to evaluate the thermal comfort conditions in classroom after a relevant number of hours spent in classroom and minimally 90 minutes. The students' votes were collected within the anonymous survey in order to provide the objectivity of the research. The part of questionnaire dedicated to thermal comfort had a typical thermal sensation scale, with seven values, starting from -3 as cold to +3 for hot environment. The prediction of thermal comfort is usually expressed by using PMV and PPD indexes. The human thermal sensation is usually related to the thermal balance of a whole body. This balance is affected by the personal parameters, such as the activity level and clothing, together with the parameters of the environment, such as mean radiant temperature, air temperature, air velocity and humidity. These parameters can be measured or estimated and then PMV index can be calculated. The thermal discomfort can be estimated by

the PPD index, which can be obtained from PMV. The purpose of this research was to identify the differences between the actual, calculated PMV index and the student' subjective sensations regarding thermal comfort in classroom.

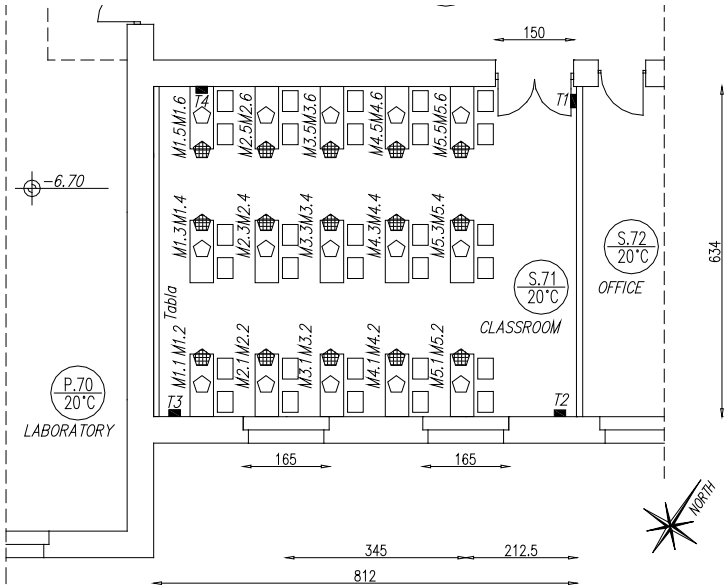

Figure 1. Observed classroom with positions of data loggers

3. Results and discussion

The measurements in classroom were performed every day, during four week period. The results were gathered with step of five minutes between the measurements, and were averaged for every day and every week. The statistical surveys were conducted once per day, after minimally 90 minutes spent in classroom. Averaged results for each week are presented in Table 1. The most important thermal comfort indicator is PMV index, which is averaged for each student position, according to the measured data. Further, the students' thermal sensation votes were gathered using questionnaires (Table 1.) and compared with the measured values. The blank cells for thermal sensation votes represent empty seats in classroom.

The averaged results of PMV index and thermal sensation votes obtained during the research are presented in Table 2.

From the results in Table 2. it can be seen that the occupants' tends to have about 50 % higher thermal sensations regarding the indoor environment than the actual measured values, expressed through the PMV index. This difference is especially noticeable during second week of measurements, when actual thermal conditions in classroom were a slightly warmer than neutral (average PMV=0.29). It is interesting to notice that the most favorable thermal comfort conditions were marked

in second week also by the measurements and by the occupants. This trend is visible for all four weeks. PMV index ranking showed the most favorable conditions during second week and the worst conditions during the third week. The same ranking was obtained with comparison between the occupants' thermal sensation votes.

Table 1. PMV index and thermal sensation votes

	Week 1		Week 2		Week 3		Week 4	
Position index	PMV	TSV (Q)	PMV	TSV (Q)	PMV	TSV (Q)	PMV	TSV (Q)
M1.1	0.42		0.23	1.0	1.05	0.00	0.51	
M1.2	0.42		0.23		1.05		0.51	
M1.3	0.42		0.23		1.05	1.00	0.51	0.0
M1.4	0.68	0.0	0.24	0.0	0.54	2.00	0.78	1.0
M1.5	0.68	1.0	0.24		0.54		0.78	
M1.6	0.68		0.24		0.54		0.78	
M2.1	0.42	2.0	0.23		1.05	2.00	0.51	1.3
M2.2	0.42	1.3	0.23	0.5	1.05	1.50	0.51	0.0
M2.3	0.33	1.3	0.23	0.5	0.70	2.00	0.67	0.8
M2.4	0.33	1.3	0.24	1.0	0.70	2.00	0.67	1.8
M2.5	0.68	1.0	0.24	0.0	0.54	1.67	0.78	2.0
M2.6	0.68	0.8	0.24	1.0	0.54	1.50	0.78	1.7
M3.1	0.42	1.0	0.23	1.7	1.05	1.67	0.51	1.4
M3.2	0.42	1.0	0.23	1.5	1.05	2.25	0.51	1.3
M3.3	0.33	2.0	0.23	1.3	0.70	2.00	0.67	1.2
M3.4	0.33	0.0	0.24	1.5	0.70	2.00	0.67	0.5
M3.5	0.68		0.24		0.54	2.00	0.78	3.0
M3.6	0.68	1.0	0.24	1.0	0.54	1.00	0.78	3.0
M4.1	0.7		0.36		0.59		0.84	
M4.2	0.7		0.36		0.59		0.84	
M4.3	0.33	1.0	0.36	1.0	0.70	1.33	0.67	1.0
M4.4	0.33	1.0	0.39		0.70	1.33	0.67	1.5
M4.5	0.72	0.7	0.39	1.0	0.81	2.00	0.63	1.0
M4.6	0.72	1.3	0.39	1.0	0.81	1.00	0.63	1.0
M5.1	0.7	1.5	0.36		0.59		0.84	
M5.2	0.7	1.0	0.36	0.0	0.59	1.50	0.84	0.0

	Week 1		Week 2		Week 3		Week 4	
Position index	PMV	TSV (Q)	PMV	TSV (Q)	PMV	TSV (Q)	PMV	TSV (Q)
M5.3	0.7	1.7	0.36	0.5	0.59	1.00	0.84	1.3
M5.4	0.72	1.7	0.39	1.0	0.81	2.50	0.63	1.7
M5.5	0.72	0.0	0.39		0.81		0.63	1.5
M5.6	0.72		0.39		0.81		0.63	2.0

Table 2. PMV index and thermal sensation votes comparison

	PMV	TSV	Difference [%]
Week 1	0.56	1.07	48
Week 2	0.29	0.86	66
Week 3	0.74	1.60	54
Week 4	0.68	1.30	48

4. Conclusions

The presented study showed the similarity between the actual thermal sensation votes gathered in situ during the four week period in university classroom and the calculated PMV values obtained by measurement of crucial thermal comfort parameters. Comparison between these values indicated about 50% higher occupants' thermal sensations than the actual measured PMV values. The ranking of the most favorable thermal comfort conditions showed the same trend using measurements and statistical survey. According to this result, the occupants' survey in situ could be an indicator of thermal comfort conditions when the measurements are not possible to be performed. Off course, it is very important to conduct the survey carefully, in accordance with the methodology suggested by standards for precise type of the building and environment.

The higher values of thermal sensation votes gathered through the survey, comparing to the calculated PMV index, indicates that the healthy, young adult male population is affected by high metabolism, thus their preferred indoor thermal conditions are in between the neutral and slightly cool. Similar conclusion was also brought through the previous studies [10-12] regarding thermal comfort and productivity loss in office buildings. This conclusion is of a high importance during the project design phase, in order to provide energy efficient HVAC systems and adequate thermal comfort conditions, especially in educational and office buildings, where the learning and working process, together with the occupants' health are influenced by the indoor environment conditions.

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