Assessment of thermal comfort in lecture room by chosen calculation methods

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Abstract. The proper level of comfort conditions is one of the main goal when designing HVAC systems in buildings. It influences our self-being, our health and productivity. Thermal comfort is a complex issue and relates to indoor air parameters and personal factors. The publication presents the outcome of the research undertaken in one of the lecture room at Wroclaw University of Science and Technology, Poland. It consisted of measurements of comfort parameters, questionnaire survey and PMV and PPD calculations based on different approaches.

1 Introduction

The proper level of comfort conditions is one of the main goal when designing HVAC systems in buildings. It influences our self-being, our health and productivity. The background theory was introduced by Fanger in 70's and since then it was evaluating [1, 3, 5]. Fanger indicated that "thermal comfort is the condition of mind that is satisfied from indoor conditions" [3] and is a complex issue that strongly depends on indoor air and personal parameters. Fanger [1, 2, 4] defined the comfort indices: Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) that are commonly used to described indoor environment and are a background of the European Standard PN-EN ISO 7730 [3]. The literature presents the number of studies on the comfort assessment in offices [6–8] and lecture rooms [9, 10].

The paper presents the part of the research undertaken in one of the lecture rooms at Wroclaw University of Science and Technology, Poland. It is focused on comparing PMV and PPD indices calculated by using three different codes based on European Standard 7730 and individual thermal sensations. This research was accomplished under the final BSc project.

2 Object of interest

The research was conducted in the lecture room no. 58 in C-6 building of Wroclaw University of Science and Technology, Poland. Wroclaw is located in Central Europe. The winter external and mean design temperatures are -18°C and +7.9°C respectively.

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The investigated room is dedicated for 100 students and located at the ground floor of the three-story building from middle of 1970s'. The room area is 103.3 m^2 and height diminish from 3.77 m at the front to 2.66 m at the back of the room. It has only one external wall with about 24 m^2 of double glazing windows faced north-west. Other walls are between heated spaces of 20°C and 8°C (entrance hall). Due to the lack of building documentation, the thermal transmittance coefficients of the investigated room were taken from the literature as presented in Table 1. The U-values were assumed following [11, 12] and took into account building retrofit in 2000s'.

Table 1. U-values [W/(m^2·K)].

Wall/Window	Required U-value	Calculated U-value
External wall	1.16*	1.16*
Internal wall	no requirements*	2.114
Slab	no requirements*	0.732
Ground floor	no requirements*	0.324
Windows	2.6**	2.6**

*PN-74/B-034042 [12], **technical requirements of buildings [11].

The room (Fig. 1) is equipped in water central heating radiators and mechanical ventilation system. During the test days the fans were switched off, thus the room was considered as naturally ventilated.

Fig. 1. The investigated room.

The above data was used to calculate (in OZC software) the surface temperatures (t_i) of surrounding walls and windows. The calculations were based on temporary indoor and outdoor temperatures and U-values. The room radiant (t_r) temperature was obtained following the given equation *(1)* (where A_i is a surface of the wall):

$$t_r=\Sigma(t_i \cdot A_i)/\Sigma A_i \quad (1)$$

3 The research

3.1 Measurements

Two comfort parameters: the air temperature and relative humidity were measured by an indoor air quality data logger Rotronic CL11. The temperature accuracy of the meter is ±0.3K and relative humidity is 2.5% RH. Therefore the meter can be used for comfort measurements purposes. The second device used for measurements was SensoData5500 by Sensor Electronic. This is the data logger especially dedicated for indoor comfort investigations and thus following parameters were measured: the dry bulb temperature, wet bulb temperature, air velocity and its turbulence, atmospheric pressure. Additionally personal parameters were defined in the logger to calculate PMV and PPD values. The accuracy of main parameters are: for temperatures ±0.1°C, relative humidity ±2%, air velocity ±0.02 m/s.

The measurements were conducted during four test days:
1st test day: 28th Oct 2016, between 13:15 and 15:00;
2nd test day: 6th Nov 2016, between 11:15 and 13:00;
3rd test day: 9th Nov 2016, between 13:15 and 15:00;
4th test day: 14th Nov 2016, between 17:05 and 18:45.

For all test days Rotronic CL11 was used to collect the measurements. Additionally on 9th of Nov also SensoData5500 was utilized. The collected data was a background to calculate two thermal comfort indices, namely Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) following the standard in PN EN ISO 7730 [3].

3.2 The survey

The aim of the survey was to compare PMV values with an actual level of satisfaction from the indoor environment declared by students. It was estimated based on the respondent's Thermal Sensation Vote (TSV) that corresponds to thermal 7-point sensation scale described in EN ISO 7730 [3]. In this investigation the scale was narrowed to 5 points, namely: -2 (cool), -1 (slightly cool), 0 (neutral), +1 (slightly warm), +2 (warm).

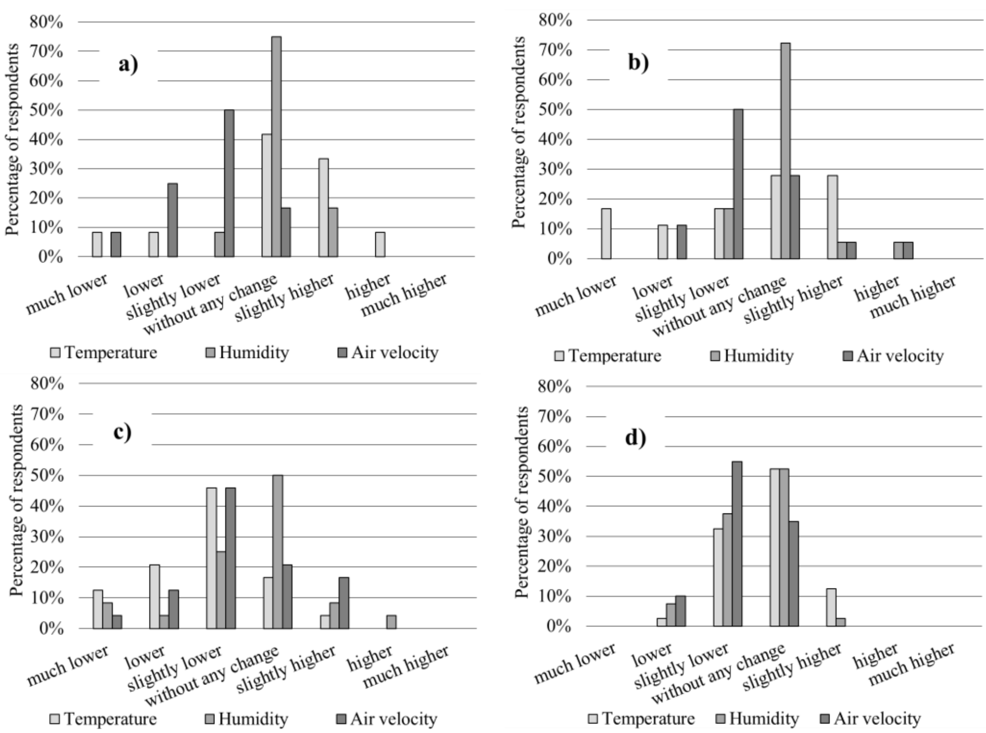

Fig. 2. Respondents' expectations of indoor parameters for: a) 1st, b) 2nd, c) 3rd, d) 4th test day respectively.

The survey was conducted on 94 students on 4 test days as mentioned in point 3.1 of this paper. The average age of the respondents was 24 years. The occupancy of the lecture room varied between 12 and 40%. The indoor air temperature varied between 19°C and 29.6°C. The average indoor temperature during all test days was 24.4°C that is above the design temperature defied by the regulations [3, 1111]. The external temperature during the experiment varied between: 0.5°C and 13°C. To avoid the influence of external conditions on students' thermal sensations during the survey the questionnaires were handed to students at the end of each lecture. The survey form consisted of number of questions related to comfort and discomfort issues, individual sensations, self-being, state of mind and overall conditions of individuals. Only chosen answers were analyzed in this publication. The respondents' TSV for every test day are presented in Fig. 6.

Both air parameters and personal factors influence the individual thermal sensations thus the survey consisted also questions regarding the expectations of indoor air parameters, namely the air temperature, the relative humidity and the air velocity in the investigated room (Fig. 2) in comparison to indoor conditions.

As one can notice the individual sensations vary depending on the day and hour of the survey. The students expectations corresponds well with their TSV. However interesting is their perceptions of very high indoor temperatures during the first test day. Data with the measured indoor temperatures is presented in Table 2.

4 Data analysis

4.1 The indoor air temperature

The data of external air temperatures, minimum, maximum and mean indoor air temperatures for all test days are presented in Table 2. It shows that during the lecture, even if small group of students occupied the room the variability of indoor air temperature was very high: from 1.7°C to even 5.6°C.

The lowest of 19.3°C recorded by Rotronic CL11 was on 6th Nov at 12:21 and the maximum temperature of 29.6°C was recorded on 28th Oct at the beginning of lecture. During the 3rd test day additionally more sophisticated equipment — SensoData5500, with higher accuracy was used to measure thermal comfort and indoor room parameters. Thus the records from both devices were compared. Both devices were located away from students to avoid their influence, however some effect of droughts occurred and caused lower air temperatures or higher velocities around the sensors. Unfortunately, due to technical problems, the data from the 4th test day could not be read out from the device.

Table 2. The temperatures of indoor and outdoor air for the all test days.

No.	Date, hour	External air temperature, °C	Indoor air temperatures, °C		
			Minimum	Maximum	Mean
1	28th Oct 2016 13:15–15:00	13	26.7	29.6	28.4
2	6th Nov 2016 11:15–13:00	10	19.3	24.9	22.8
3	9th Nov 2016 13:15–15:00	5.5	21.1	22.8	21.9
4	14th Nov 2016 17:05–18:45	0.5	Not available		

Comparing the measurements the difference in outcomes between the devices is interesting. The authors expected similar trends and small discrepancy between values of air temperature, especially that the equipment was placed close to each other and before the measurements the readings were validated. Finally, during the 3rd test day, the change in this parameter differs significantly depending on the device. This variability of the internal air temperature measured by Rotronic and SensoData5500 is presented in Fig. 3.

4.2 PMV and PPD

The Rotronic CL11 was used to measure the values of indoor parameters, namely air temperature and humidity. These data was a background to calculate the Predicted Mean Vote (PMV) and thus Predicted Percentage of Dissatisfied (PPD). The formula for PMV requires the introduction of several additional indoor parameters, like air velocity and radiant temperature. It is necessary to take into account also personal factors, namely the metabolism rate (related to human activity), and clothing thermal insulation.

The air velocity in the room for the experiment proposes was assumed to be 0.2 m/s following the literature [2]. The average radiant temperature was calculated from the equation (1). The personal parameters, namely Clo and Met were estimated following [3]. The metabolism rate was estimated to be 1.2 met as for sedentary activity. The clothing insulation was determined to be 1.00 clo. The values of personal parameters were also used for measures taken by SensoData5500 to allow the comparison calculated PMV and PPD.

There are few possibilities to calculate PMV and PPD indices. They can be obtained from tables available in [3], by readings from the thermal comfort logger or by creating own macro based on a code defined in annex to EN ISO 7730. In the paper the outcomes from two written codes were compared, namely the code by A. Schwitalla (written with accordance with [3]) and the macro created by the author — M. Wesołowska — especially written for the purpose of this research and slightly modified compared the annex of EN 7730. The corrections were required to achieve more accurate results (compared to individual votes as presented at Fig. 6) and concerned "+" and "-" signs and some corrections in numerical values of the original code proposed in annex to [3].

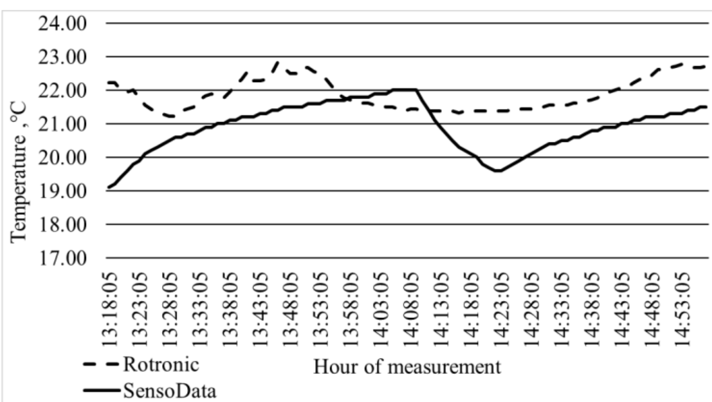

Fig. 3. The trend of the indoor air temperature recorded by Rotronic and SensoData5500.

For the 3rd day additionally the data from SensoData5500 logger was analyzed and compared with calculations. The minimum, maximum and mean values of PMV and PPD for all 3 test days are presented in Table 3. The code written by A. Schwitalla states as code 1, by M. Wesołowska — as code 2, SensoData5500 outcome — as code 3.

The authors decided that it is important to check how the discrepancy in the loggers' readings (presented in Fig. 3) influence calculated PMV and PPD. The results are presented in Fig. 4 and Fig. 5. As one can notice the divergence is significant — the calculated indices with SensoData5500 input gives much higher results than when input from Rotronic CL11 is applied. The calculations based on Rotronic CL11 need more assumptions and that would be reason of discrepancies, however, following Fig. 3 and the variability of measured room air temperatures also validation of measured parameters is needed. Therefore further research in this area and on the bigger number of samples need to be done and will be the subject of the next publication.

Table 3. The comparison between results obtained by different way of calculating the PMV and PPD.

	Code 1 by A. Schwitalla		**Code 2 by M. Wesołowska**		**Code 3 by SensoData5500**	
	PMV	**PPD, %**	**PMV**	**PPD, %**	**PMV**	**PPD, %**
1st test day						
Minimum	0.7	16.2	1.2	33.4	-	-
Maximum	1.4	47.7	1.4	45.2	-	-
Mean	1.1	33.0	1.3	40.8	-	-
2nd test day						
Minimum	-1.0	5.0	0.9	21.5	-	-
Maximum	0.2	24.0	1.0	27.9	-	-
Mean	-0.2	8.4	1.0	24.9	-	-
3rd test day						
Minimum	-0.46	5	0.86	20.57	-1.1	5
Maximum	0.04	9.5	1.62	57.39	0	30.5
Mean	-0.32	7.57	1.06	29.39	-0.25	7.20

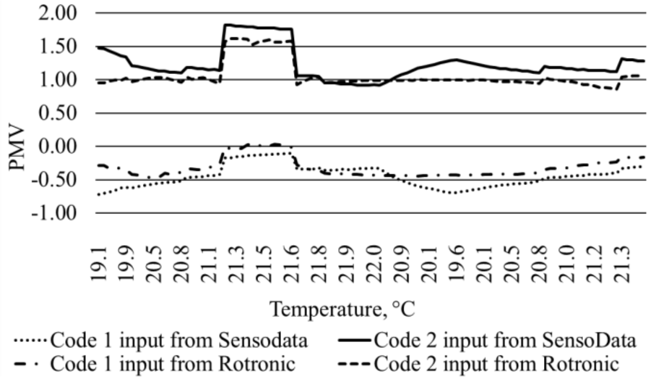

Fig. 4. The comparison of PMV calculated for 9th Nov by code 1 and code 2 with input data from SensaoData 5500 and Rotronic loggers.

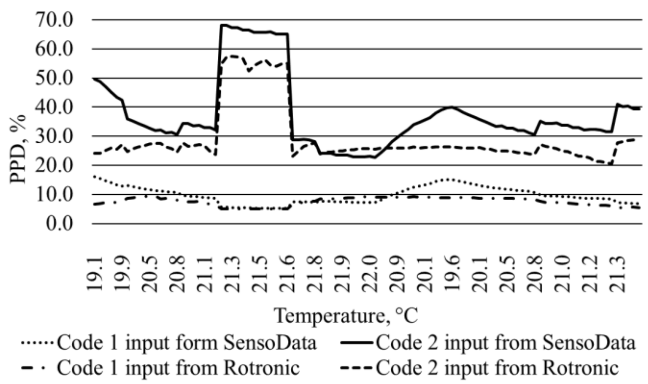

Fig. 5. The comparison of PPD calculated for9th Nov by code 1 and code 2 with inputa data from SensaoData 5500 and rotronic loggers.

To check the convergence of the results achieved by written codes 1, 2 and 3 with individual sensations the additional analysis was undertaken. The outcome of the considerations is presented in Fig. 6.

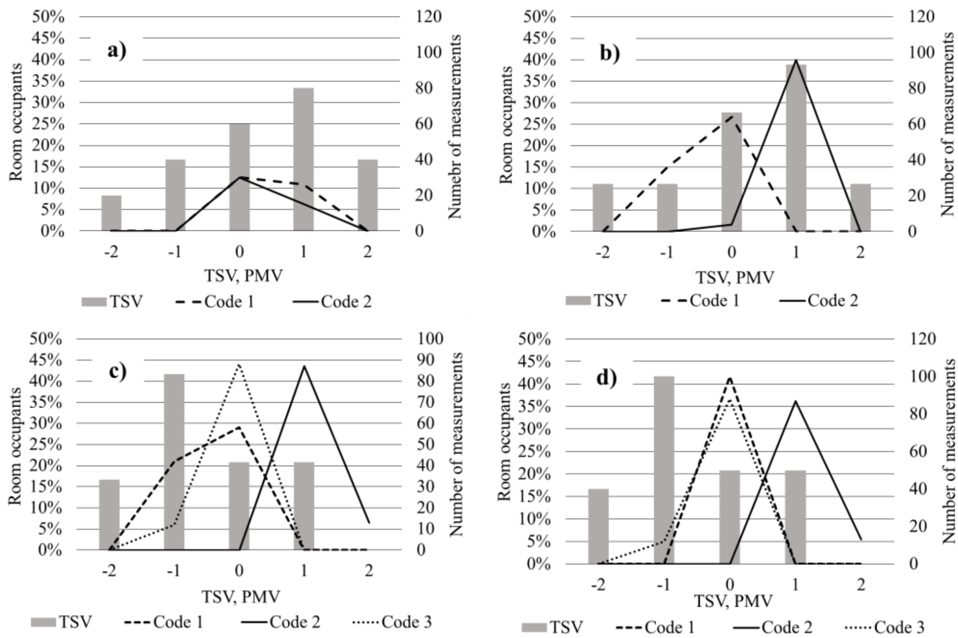

Fig. 6. The convergence of the results achieved by codes 1, 2 and 3 with individual sensations (TSV) for: a) 1st day, b) 2nd, c) 3rd (input from Rotronic CL11), d) 3rd day (input from SensoData5500).

The analysis of the above charts (Fig. 6) indicates that for the 1st test day both codes 1 and 2 are convergent with the individual sensation of room occupants. For the second day better is the code 2 corrected by the Author of the article and for the 3rd day the code 1 corresponds with the data obtained from SensoData5500 however both are shifted to neutral conditions when occupants felt rather slightly cool. Again the further research is needed on the bigger population to confirm that the corrections implemented to the code by M. Wesołowska are reasonable.

5 Conclusion

The paper presents the analysis of 4-day investigation of the comfort conditions in the university lecture room. The indoor parameters were measured by two devices: Rotronic CL11 and multimeter SensoData5500. The individual sensations were examined on the basis of the questionnaire survey and compared with calculated PMV — thermal comfort indicator. Predicted Mean Vote was calculated threefold following the computer code 1 — written by A. Schwitalla, code 2 — written by the co-author of this paper (slightly modified with respect to the original code) and code 3 — obtained from the measuring device SensoData5500.

The data obtained from both devices, despite the fact that were located next to each other, gave significantly different results and thus inconsistent values of calculated PMV.

The code 2 was consistent with TSV only during the 2nd day of survey. Also two other ways of PMV calculations failed to described properly the individual thermal sensations of investigated students.

The respondents' individual sensation varied depending on the day and hour of the survey. However the students expectations mostly corresponds well with their TSV. Interesting is their perceptions of very high indoor temperatures during the first test day.

The undertaken research indicates the complexity of the thermal comfort studies and the need of further investigation of the subject.

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