Thermal comfort in university buildings – differences between measured values and occupants' subjective evaluation

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Content

1. Introduction

- Definition of comfort: 'that condition of mind that expresses satisfaction with the ... environment' [1].
- Indoor environmental design should assure comfort and health.
- Existing buildings, especially naturally ventilated, have a problem to meet the criteria prescribed through the international standards regarding thermal comfort.
- Reaching the optimal thermal comfort parameters is of a high importance.
- Long period of time spent in inadequate environmental conditions leads to the various health problems.
- Poor IEQ in classrooms is one of the causes of students' productivity loss [2].
- Learning performances decreases 10-14% when effective temperature increases from 24°C to 27, 29°C [3].
- 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 [4].

[1] ***, CIBSE **Environmental criteria for design,** CIBSE Guide, Vol. A, Design Data, Chartered Institution of Building Services Engineers, London, 2006.
[2] **Vardoulakis, S., Dimitroulopoulou, C., Thornes, J., Lai, K.-M., Taylor, J., Myers, I., Heaviside, C., Mavrogianni, A., Shrubsole, C., Chalabi, Z., Davies, M., Wilkinson, P.**, Impact of climate change on the domestic indoor environment and associated health risks in the UK, *Environment International*, *85* (2015), pp. 299–313.
[3] **Seppanen, O., Fisk, W.J., Faulkner, D.**, Control of Temperature for Health and Productivity in Offices Control of Temperature for Health and Productivity in Offices, *ASHRAE Transactions, 111* (2005), pp. 680-686.
[4] **Bajc, T.S., Todorović, M.N., Stevanović, Ž., Stevanović, Ž. Ž., Banjac**, M., Local thermal comfort indices impact on productivity loss in classrooms, Proceedings *BEST 2016 - 1ST International Conference on Buildings, Energy, System and Technology,* University of Belgrade and Society of thermal engineers of Serbia, Belgrade, Serbia, 2016.

2. Standards regarding thermal comfort

1) ISO 7730:2005

- International standard ISO 7730:2005 determines the "methods for predicting thermal sensations and degree of discomfort of people exposed to moderate thermal environments".
- Analytical determination of thermal comfort by calculating PMV and PPD indices (the thermal balance of a whole body) and local thermal comfort criteria.
- Local thermal discomfort: draught, vertical air temperature difference, warm and cool floors, radiant asymmetry.

Table 1. Categories of thermal environment [5]

Category	Whole body		Local discomfort			
	PPD [%]	PMV	DR [%]	PD vert.temp. diff. [%]	PD floor [%]	PD radiant asymm. [%]
A	< 6	-0.2<PMV<+0.2	< 10	< 3	< 10	< 5
B	< 10	-0.5<PMV<+0.5	< 20	< 5	< 10	< 5
C	< 15	-0.7<PMV<+0.7	< 30	< 10	< 15	< 10

[5] ***, *ISO 7730:2005 International Standard - Ergonomics of the thermal environment* - International Organization for Standardization, Geneva, Switzerland, 2005.

2. Standards regarding thermal comfort

2) ASHRAE standard 55-2013

- Defines the conditions that provide thermal comfort.

Table 2. Acceptable thermal environment for general comfort [6]

Whole body		Local discomfort			
PPD [%]	PMV	DR [%]	PD vert.temp. diff. [%]	PD floor [%]	PD radiant asymm. [%]
< 10	-0.5<PMV<+0.5	< 20	< 5	< 10	< 5

3) EN ISO 15251:2007

- Defines the criteria for thermal comfort and methodology for subjective evaluation.

Table 3. Recommended categories of mechanical heated and cooled buildings [7]

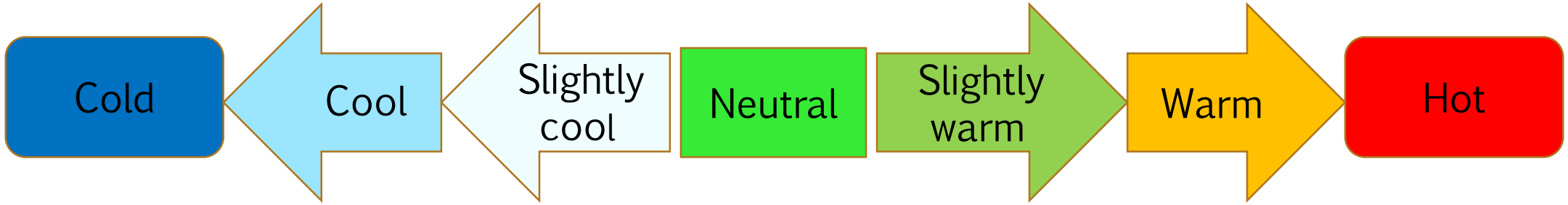
Category	Whole body	
	PPD [%]	PMV
I	< 6	-0.2<PMV<+0.2
II	< 10	-0.5<PMV<+0.5
III	< 15	-0.7<PMV<+0.7
IV	> 15	PMV<-0.7 or PMV>+0.7

[6] ***, *ASHRAE STANDARD 55-2013 Thermal Environmental Conditions for Human Occupancy*, ASHRAE, Atlanta, GA 30329, 2013.
[7] ***, *DS/EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*, European committee for standardization, Brussels, Belgium, 2007.

2. Standards regarding thermal comfort

4) SRPS EN ISO 10551:2008

- Recommends principles of subjective judgment scale construction and conditions of use [8].



- Thermal environment can be described with the following main physical parameters:

1. Air temperature
2. Mean radiant temperature
3. Relative air speed
4. Humidity.

- Thermal comfort is also affected by the personal factors such as:

a) Clothing and
b) Metabolic heat production.

[8] ***, *STANDARD SRPS EN ISO 10551:2008 - Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales*, European committee for standardization, Brussels, Belgium, 2008.

3. Methodology of the research

- Naturally ventilated university classroom
- The research was conducted during four weeks of winter semester
- Predominantly male population, aged about 25 years
- The students' had the typical winter clothing: sweater, shirt, trousers, socks and winter shoes (1.01 Met).
- The physical parameters describing thermal comfort state, such as air temperature, radiant temperature, air humidity, air velocity, etc were measured during four weeks.
- PMV indexes were calculated according to the methodology prescribed within the international standard ISO 7730:2005.

[8] ***, *STANDARD SRPS EN ISO 10551:2008 - Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales*, European committee for standardization, Brussels, Belgium, 2008.

3. Methodology of the research

- New questionnaire was developed according to the international standard SRPS EN ISO 10551:2008.
- The questionnaire had the questions about the physical state of the student, type of the clothing and questions about the thermal comfort sensations.
- 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.

[8] ***, *STANDARD SRPS EN ISO 10551:2008 - Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales*, European committee for standardization, Brussels, Belgium, 2008.

4. Classroom description

•The classroom was South-East oriented.
- 8.12 m long, 6.34 m wide and 3.3 m high.
- one external wall and two windows.
- The total heated area is 51.48 m^2 and the net volume is 169.9 m^3
- The total number of seating places is 30.

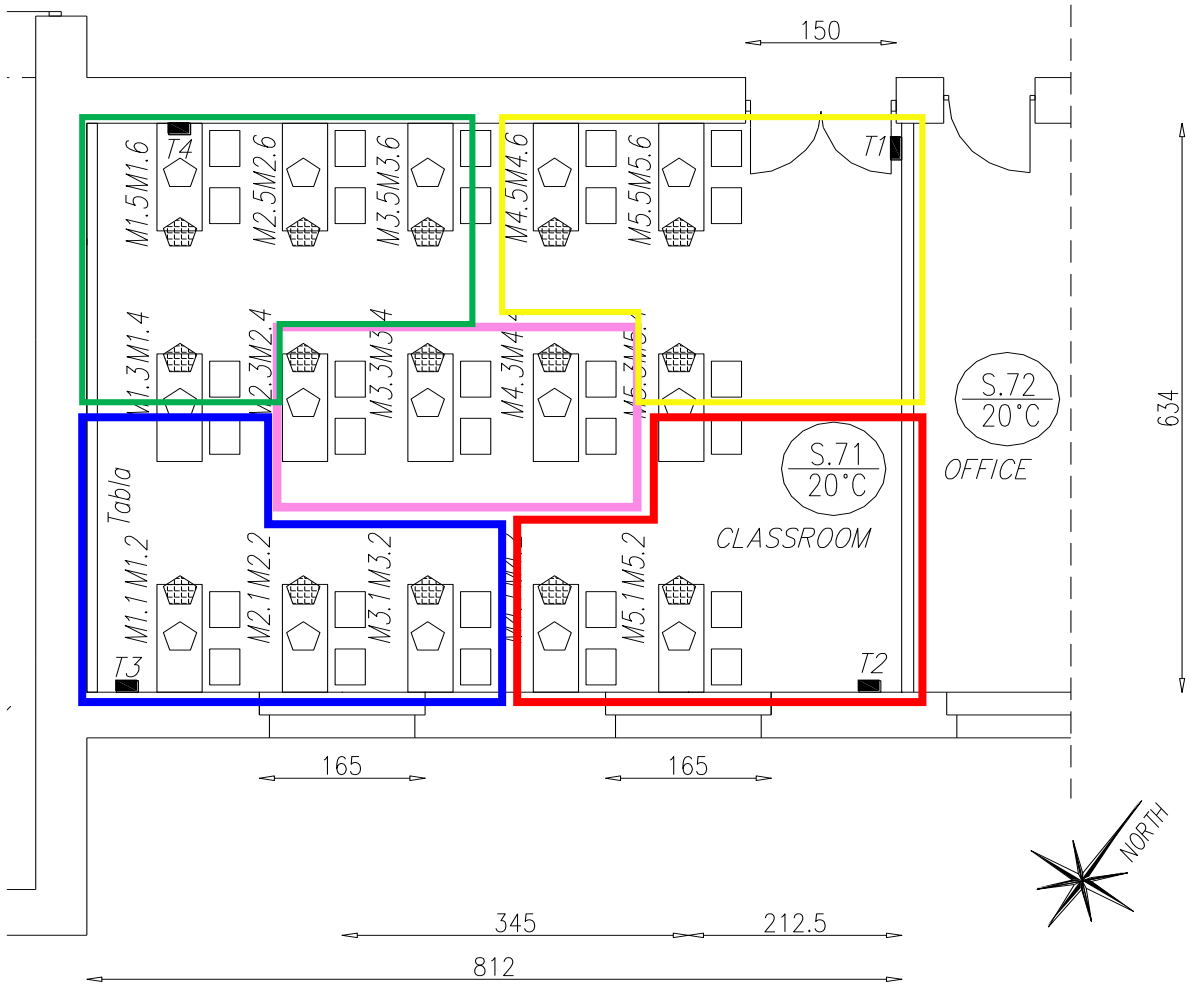


Figure 1. Observed classroom with positions of data loggers

5. 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.
- The votes from students who felt sick were excluded from the final results.
- PMV index was calculated according to the measured data and averaged for each student position.

5. Results and discussion

Table 4. PMV index and thermal sensation votes (part 1)

Position index	Week 1		Week 2		Week 3		Week 4	
	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

5. Results and discussion

Table 4. PMV index and thermal sensation votes (part 2)

Position index	Week 1		Week 2		Week 3		Week 4	
	PMV	TSV (Q)	PMV	TSV (Q)	PMV	TSV (Q)	PMV	TSV (Q)
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
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

5. Results and discussion

Table 5. 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

- The occupants' tend to have about 50 % higher thermal sensations regarding the indoor environment than the actual measured values, expressed through the PMV index.
- The most favorable thermal comfort conditions were marked in second week also by the measurements and by the occupants.
- PMV index ranking showed the most favorable conditions during second week and the worst conditions during the third week.

6. Conclusions

- The presented study showed the similarity between the actual thermal sensation votes and the calculated PMV values.
- 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.
- 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.
- This conclusion is of a high importance during the project design phase especially in educational and office buildings, where the learning and working process, together with the occupants' health are influenced by the indoor environment conditions.

Thank you for the attention!

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