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COMPARISON BETWEEN ANALYTICAL CALCULATION AND EXPERIMENTAL EVALUATION OF ENVIRONMENTAL COMFORT FOR CLASSROOMS HEATED WITH MIXED VENTILATION AND RADIATORS FOR WINTER SEASON

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Abstract: The paper aims to show the difference between static heating system and recirculated air ventilation system for the winter period, calculated analytically and statistically evaluated by the occupants of the room. The thermal sensation will be assessed by the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD).

Key words: Dry bulb temperature, relative humidity, predicted mean vote, predicted percentage dissatisfied.

1. INTRODUCTION

The parameters which define the indoor air quality are: dry air temperature, air velocity in the room, turbulence intensity, relative humidity, the mean air temperature, the occupant activity, and the cloth thermal resistance.

The temperature difference on vertical levels influences the thermal sensation because the human body exchanges energy with the environment and also the human body temperature can be different on the three levels considered for sitting position: knees 0,1 meter, abdomen 0,6 meter and head 1,1 meter.

Also the thermal comfort is influenced by the technical solution chosen, economically, energy efficiency and environment pollution.

This paper presents the evaluation of thermal – hygrometric comfort conditions and the investigation methodology in university classrooms for winter season where the heating is provided with mixing ventilation with recirculation.

The thermal – hygrometric comfort is calculated analytically by the predicted mean vote and evaluated with test filled out by the occupants regarding the general thermal comfort. The results from the two evaluations will be compared.

2. SCOPUL ACTIVITĂȚII

The class has 47 m2 and a volume of 178 m3 and the number of 12 occupants. The space is placed at the ground level surrounded by other classrooms witch are heated. The heat demands of the room for winter is 2,65 kW calculated for Timişoara at -15°C. For the study the mixed ventilation air flow used is q_{SUP}=1350 m3/h corresponding to 7.5 h^{-1} necessary for heating up the room. In figure 1 is presented in 3D view the classroom with the ventilation and the system with radiators.

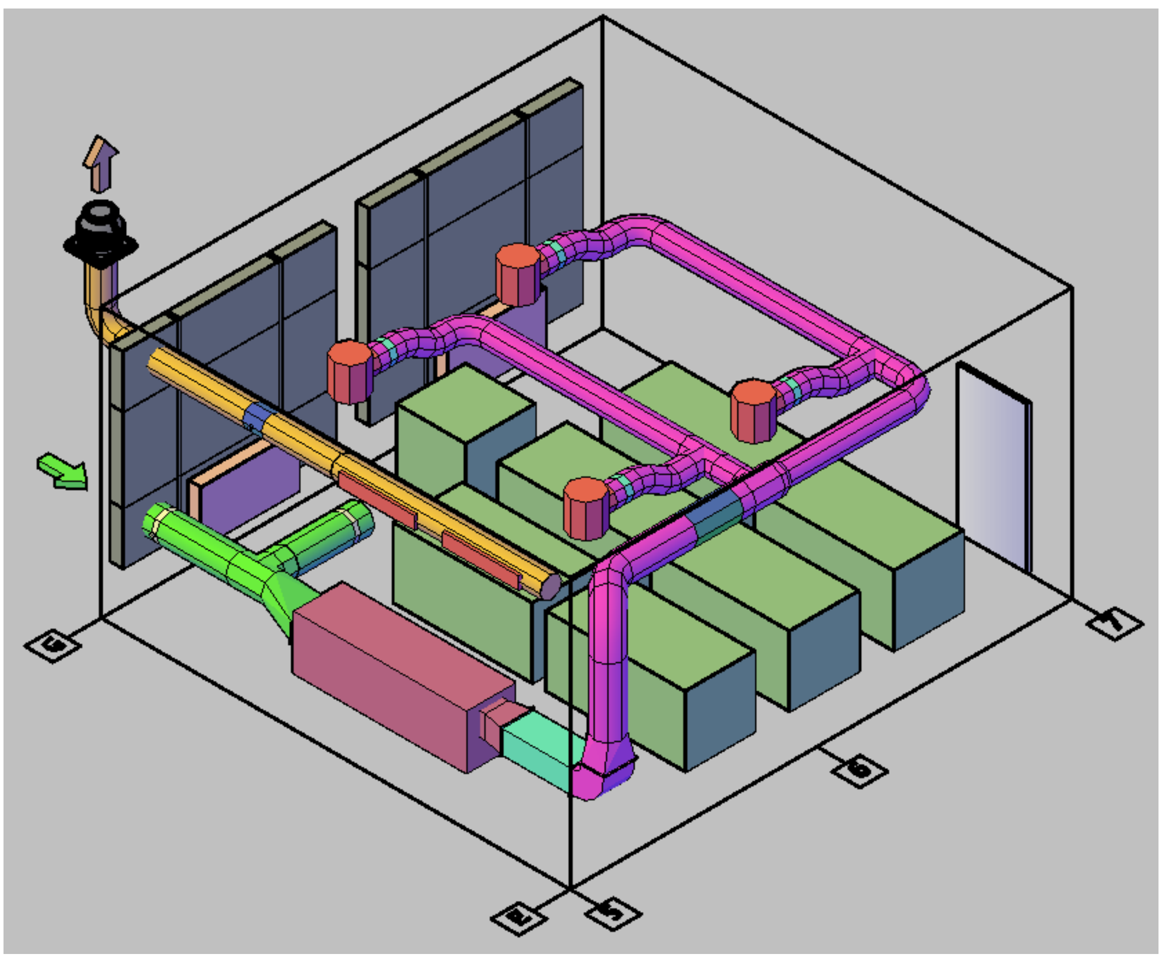

Fig. 1 3D view of the ventilation system for the laboratory (exhaust and supply) and the system with radiators

The actual heating system of the building is with radiators but a problem is setting the inside temperature, so for this case all the measured parameters from radiator heating will be compared with parameters from mixed ventilation and recirculated air heating system.

The air handling unit supplies the treated air in the classroom by 4 supply swirl diffusers with adjustable blades for changing the air pattern for reducing stratification effect. The air handling unit contains a heating coil, bag filter, fan and steam humidifier which is set to maintain in the room a relative humidity of 50%.

The recirculated air is taken from the room and mixed with the fresh air before the air handling unit. The exhaust is with a roof fan connected to a circular duct which has 2 duct grills. The system is in equal pressure.

Also in the drawing at the bottom of the windows are the two radiators. To define the thermal comfort most thermal parameters will be measured and calculated to determine the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD). The calculation formula for PMV is given in equation (1) to (4):

$$PMV = [0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028] \cdot \begin{Bmatrix} (M - W) - 3{,}05 \cdot 10^{-3} \cdot [5733 - 6{,}99 \cdot (M - W) - p_a] - 0{,}42 \cdot [(M - W) - 58{,}15] \\ -1{,}7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) \\ -3{,}96 \cdot 10^{-8} \cdot f_h \cdot [(t_h + 273)^4 - (t_{mr} + 273)^4] - f_h \cdot h_c \cdot (t_h - t_a) \end{Bmatrix} \tag{1}$$

$$t_h = 35{,}7 - 0{,}028 \cdot (M - W) - I_h \cdot \left\{ 3{,}96 \cdot 10^{-8} \cdot f_h \cdot [(t_h + 273)^4 - (t_{mr} + 273)^4] + f_h \cdot h_c \cdot (t_h - t_a) \right\} \tag{2}$$

$$h_c = \begin{cases} 2{,}38 \cdot |t_h - t_a|^{0{,}25} & dacă \quad 2{,}38 \cdot |t_h - t_a|^{0{,}25} > 12{,}1\sqrt{v_{ar}} \\ 2{,}38 \cdot \sqrt{v_{ar}} & dacă \quad 2{,}38 \cdot |t_h - t_a|^{0{,}25} < 12{,}1\sqrt{v_{ar}} \end{cases} \tag{3}$$

$$f_h = \begin{cases} 1{,}0 + 1{,}290 \cdot I_h & dacă \quad I_h < 0{,}078\ m^2 \cdot K/W \\ 1{,}05 + 0.645 \cdot I_h & dacă \quad I_h > 0{,}078\ m^2 \cdot K/W \end{cases} \tag{4}$$

where:

M- Metabolic rate, [W/m^2];

W- Effective mechanical power, [W/m^2];

I_h- Clothing insulation, [$m^2 \cdot K/W$];

f_h- Clothing surface area factor;

t_a- Air temperature, [$^\circ C$];

t_{mr}- Mean radiant temperature, [$^\circ C$];

v_{ar}- Relative air velocity, [m/s];

p_a- Water vapor partial pressure, [Pa]

h_c- Convective heat transfer coefficient, [W/m^2·K]

t_h- Clothing surface temperature, [$^\circ$C]

The calculation formula for PMV is given in equation (1) to (4) and for a precise value it must iterated several times. For the evaluation of results 7 iterations were made.

The PMV also can be evaluated the index from table 1 used for a group of people containing 7 points regarding the thermal sensation scale, based on the heat balance of human body.

Table 1 Thermal sensation scale

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cold	Neutral	Slightly warm	Warm	Hot

The PPD is the prediction of thermally dissatisfied people who feel too cool or too warm. The value of PPD can be obtained analytically from equation (5).

$$PPD = 100 - 95 \cdot \exp[-(0{,}03353 \cdot PMV^4 + 0{,}2179 \cdot PMV^2)] \quad (5)$$

3. REZULTS

3.1 Measurements

The mean dry bulb temperature measured in the room for the heating with mixed ventilation and recirculated air was 26,03°C and for heating with radiators 26,51°C. The measurement duration was one and a half hour and the parameters measured and calculated are presented in table 2.

The occupants were students and their activity level was 1,2 met and the clothing insulation was 1 clo. The group of students was male and female.

The values from table 2 contain the most important aspects like:

- Indoor dry bulb air temperature for the both cases nearly at de 26°C;
- Mean radiant temperature which is almost the same as the indoor dry bulb temperature;
- The mean velocity in the room is lower then the recommended velocity in rooms, being below 0,2 [m / s];
- For the two cases the values results were PMV=0,9 and PPD=22,1 for heating with mixed ventilation with recirculated air and PMV=1 and PPD=26,65 for heating with radiators;
- The operative temperature is almost the same like the indoor dry bulb temperature.

Table 2 Values measured and calculated

Values Measured/Calculated			Radiators	Mean	Ventilation	Mean
t_a	[°C]	1	26,47		25,94	
		2	26,25		26,00	
		3	26,20	**26,51**	25,95	**26,03**
		4	26,12		25,84	
		5	27,51		26,41	
r_h	[%]	1	25,28		48,31	
		2	26,29		48,74	
		3	25,25	**25,76**	48,06	**47,93**
		4	25,25		46,85	
		5	26,72		47,71	
t_e	[°C]	00:30	0,61		10,90	
		01:00	0,76	**0,83**	11,20	**10,94**
		01:30	1,12		10,73	
r_{he}	[%]	00:30	92,68		76,05	
		01:00	92,05	**91,74**	80,57	**77,92**
		01:30	90,48		77,14	
v_a	[m/s]	00:30	0,08		0,13	
		01:00	0,06	**0,07**	0,13	**0,14**
		01:30	0,08		0,15	
t_{mr}	[°C]	00:30	26,55		25,87	
		01:00	26,89	**26,83**	26,22	**26,14**
		01:30	27,05		26,32	
CO_2	[ppm]	00:30	-		709,03	
		01:00	-	**-**	786,80	**746,03**
		01:30	-		742,27	
t_o	[°C]			**26,65**		**26,05**
PMV				**1**		**0,9**
PPD	[%]			**26,65**		**22,1**

In the center of the room is placed the globe thermometer for measuring the mean radiant temperature and the hot wire anemometer for measuring the air velocity in the room.

The indoor temperature and relative humidity was measured in points from 1 to 5 (in the four corners of the benches and in the center of the room) presented in table 2 and in figure 2. Outdoor temperature, outdoor relative humidity, air velocity, mean radiant temperature, and CO_2 level was measured only in one point also showed in table 2. The measurements duration was one and a half hour. In table 3 is presented the synthesis regarding the questionnaires (from Appendix E - ASHRAE standard 55) filled out by the occupants and in table 4 the synthesis from the calculation and questionnaires.

Table 3 Synthesis of general thermal sensation from questionnaires

Occupant nr.	1	2	3	4	5	6	7	8	9	10	11	12
Gen	M	M	M	M	M	M	F	M	F	F	M	M
Heating with mixed ventilation and rec.	+1	+1	0	+1	+3	+3	+2	+3	+2	+2	+1	+3
Heating with radiators	+1	+3	+1	+1	+3	+1	+2	+1	+2	+2	+1	+1

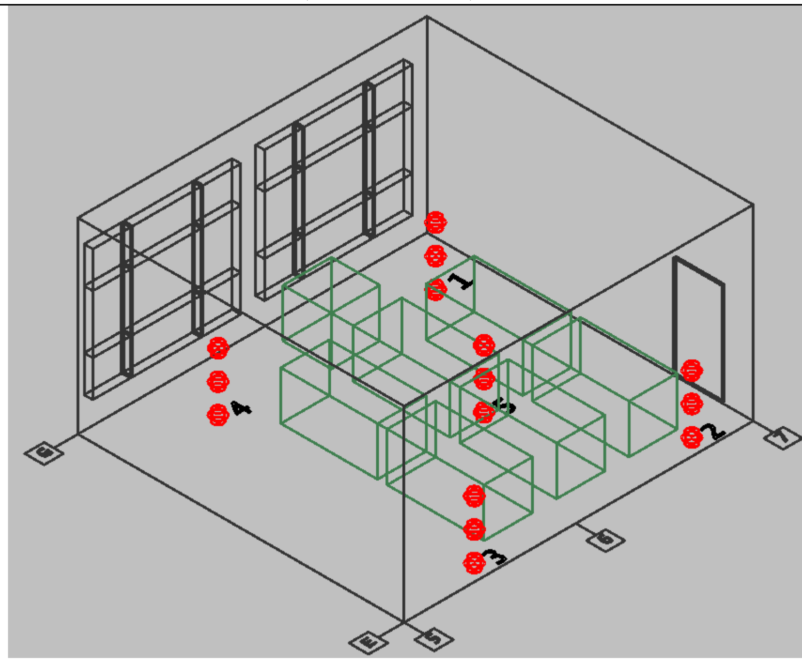

Fig. 2 Position of the sensors in the 5 points and the three levels in the room

Table 4 PMV, PPD and thermal sensation

Values	Radiators		Ventilation	
	PMV	PPD	PMV	PPD
Calculated	1	26,65	0,9	22,1
Questionnaires	Slightly / Hot		Slightly / Hot	

3.2 Measurement results

The distribution of temperatures in both heating systems shows an interesting point of view regarding the temperature gradient and the distribution of relative humidity in the room. In figure 3 and 4 we can see the variation of indoor temperature and relative humidity for the heating with radiators and in figure 5 and 6 for heating with mixed ventilation with recirculated air for a period of one and a half hour.

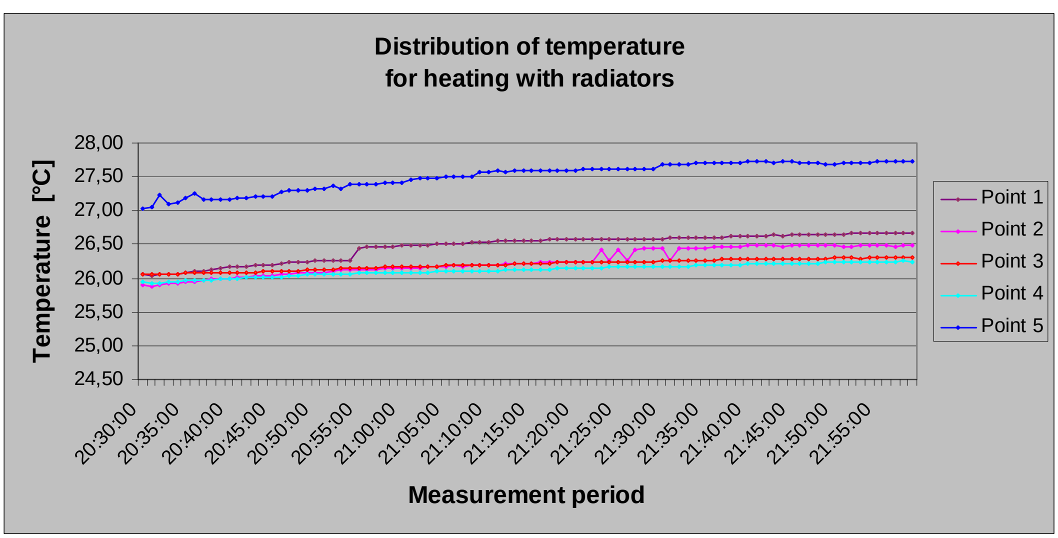

Fig. 3 Variation of mean temperature for the three levels and five measuring points

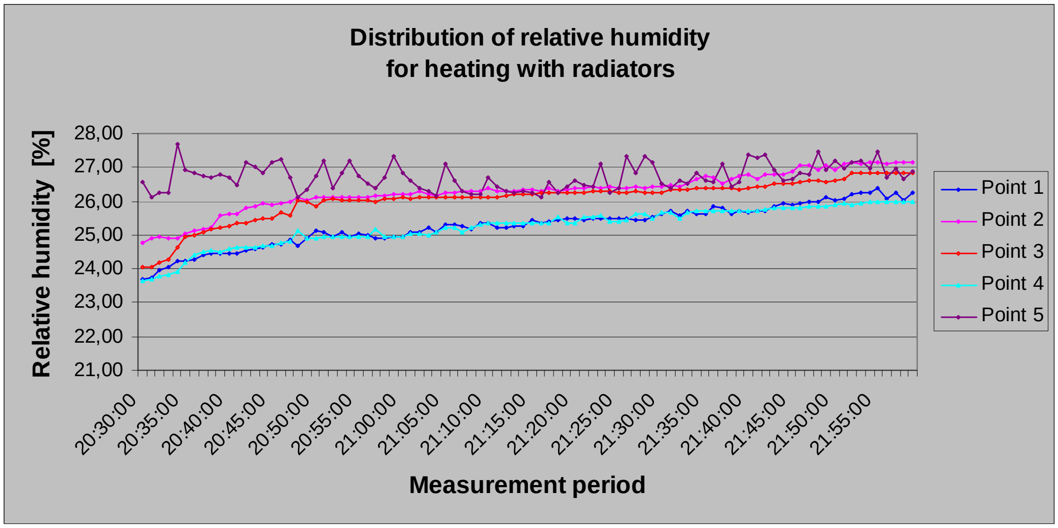

Fig. 4 Variation of mean relative humidity for the three levels and five measuring points

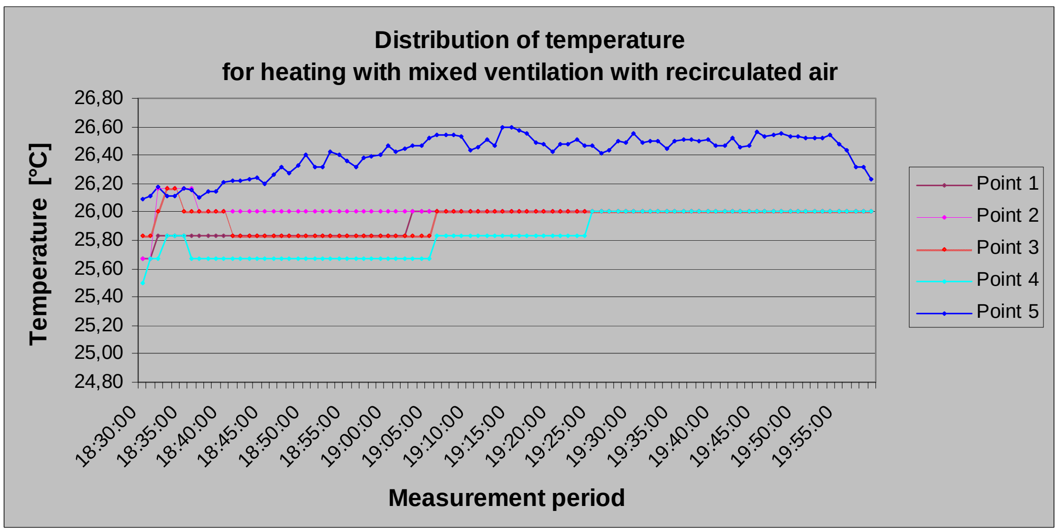

Fig. 5 Variation of mean temperature for the three levels and five measuring points

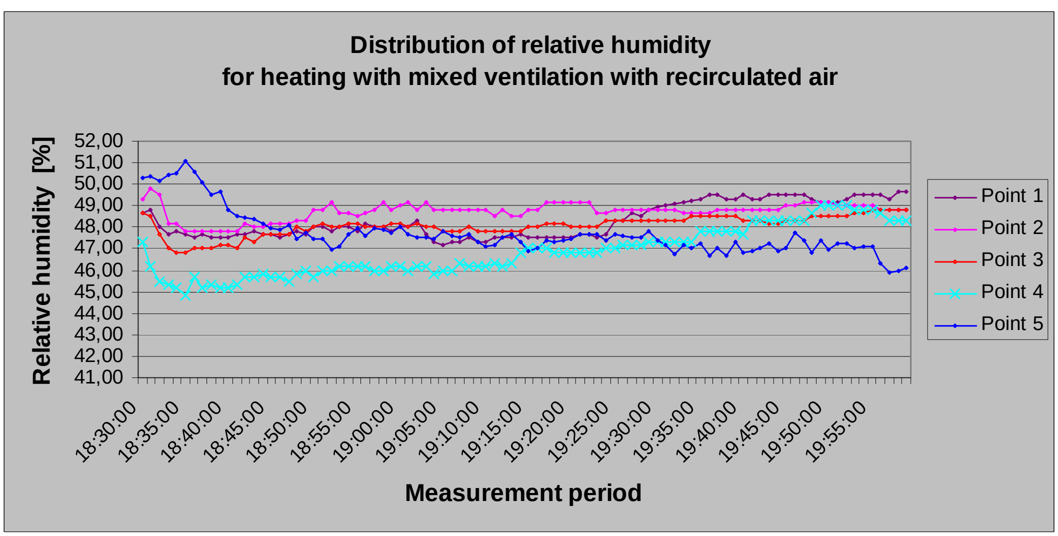

Fig. 6 Variation of mean relative humidity for the three levels and five measuring points

In table 5 we can see that the difference of temperature between the level of knees and the level of head in sitting position. Because point five was between the benches, the indoor air circulation was blocked so the temperature difference at level 0,6 meter and 1,1 meter has a higher value. In the center of the room at height 0,1 meter the temperature wasn't measured because the sensor was not working properly.

Table 5 Temperature gradient for the two heating systems

Measurement	Radiators				Ventilation			
	0,1 [m]	0,6 [m]	1,1 [m]	Δt [°C]	0,1 m [m]	0,6 [m]	1,1 m [m]	Δt [°C]
Point 1	26,29		26,86	0,57	25,82		25,96	0,15
Point 2	25,93		26,69	0,76	25,99		26,03	0,04
Point 3	26,30		26,50	0,20	25,86		26,00	0,14
Point 4	25,95		26,50	0,55	25,80		25,99	0,19
Point 5		26,61	27,52	0,91		26,05	25,96	-0,09

4. CONCLUSIONS

With the measured values of the main environmental parameters was calculated analytically and statistically with the tests filled out by the occupants, the values of PMV and PPD and synthesis in table 4. The results for the both systems are similar.

Neither of heating systems aren't in the thermal comfort zone, it is clear that in the case with mixed ventilation with recirculation the air stratification disappears and the minimum fresh air for the occupant is provided.

The relative humidity for the heating system with radiators is below 30%, meaning a dry air. For a longer period of time the occupants in these conditions could have health problems and also sick building syndrome producing less productivity.

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