Technical University of Denmark

Subjective evaluation of mixing and displacement ventilation combined with a radiant floor system

Krajcik, Michal; Tomasi, Roberta; Simone, Angela; Olesen, Bjarne W.

Published in:
Proceedings of the 22th annual conference Indoor Climate of Buildings 2011

Publication date:
2011

Citation (APA):
Krajcik, M., Tomasi, R., Simone, A., & Olesen, B. W. (2011). Subjective evaluation of mixing and displacement ventilation combined with a radiant floor system. In Proceedings of the 22th annual conference Indoor Climate of Buildings 2011 (pp. 19-24)

22nd Conference

Indoor Climate of Buildings 2011

(1-2 December 2011, Slovakia)

Subjective evaluation of mixing and displacement ventilation combined with a radiant floor system

Michal Krajčík[a,b], Roberta Tomasi[a,c], Angela Simone[a] and Bjarne W. Olesen[a]

a) Technical University of Denmark, ICIEE

b) Slovak University of Technology, Faculty of Civil Engineering

c) DFT- Department of Applied Physics, University of Padova, Italy

1. Introduction

Sixteen subjects evaluated the indoor environment in four experiments with different combinations of ventilation, heating and cooling systems. Two test set ups simulated a room in a low energy residential building with a single occupant under the heating season. The room was equipped either by a ventilation system supplying warm air for heating or by a combination of radiant floor heating and mixing ventilation system. The other two experimental setups simulated an office room with two occupants during the summer period. In one test the room was ventilated and cooled by displacement ventilation. In the other test a radiant floor cooling system was combined with displacement ventilation. The hypothesis was that the displacement ventilation combined with floor cooling could provide good indoor air quality, but it may result in thermal discomfort of occupants caused by vertical air temperature difference, cold floor or draught. The human subjective evaluation was given by the subjects through questionnaires during their three hour exposure. Both MV systems were able to provide a comfortable thermal environment, neutral, during the last 40 minutes when the subjects were adapted on the thermal environment. Both DV systems provided a comfortable thermal environment with thermal sensation of the people slightly warmer than neutral during the last 40 minutes. No significant differences in perception of the thermal environment were observed between the warm air heating and the floor heating system or between the two DV systems.

2. Design of the laboratory experiments

2.1 Subjects

Sixteen subjects, eight males and eight females were selected based on health backgrounds, time availability and background knowledge. These subjects were young adults, mainly students of the Technical University of Denmark, of various nationalities. The clothing insulation varied from 0.8 clo to 1.1 clo for winter conditions including chair and from about 0.5 to 0.7 clo for summer conditions, including the chair.

2.2 Measuring instruments

The experimental measurements were carried out in a full scale chamber with the dimensions 4.2 m x 4.0 m x 2.4 m at the International Centre for Indoor Environment and Energy, Technical University of Denmark. The floor area is equal to 16.8 m^2 and room volume to 40.3 m^3. Only fresh outdoor air was supplied to the chamber, without any recirculation. All walls were adjacent to air-conditioned interior spaces, kept at a temperature close to the temperature in the chamber, thus the thermal transfer was low. Fig.1 shows the experimental chamber and the room conditions during the experiments with displacement ventilation. The chamber includes simulated window facade, which can be set at different surface temperatures to simulate winter or summer conditions and a radiant floor heating/cooling system.

Fig.1 Experimental chamber during human studies with displacement ventilation.

The room air temperature, the operative temperature and the surface temperature were measured continuously. The accuracy of the temperature sensors is in the range of ±0.3°C. HOBO data loggers were used to record the relative humidity (RH) and to store the measurement data. The accuracy of the RH measurements is ±2.5 % for values of RH in the range from 10 to 90 %. Air velocity profile was measured once, towards the end of each experimental session, by hot-sphere. The accuracy of the anemometers is in the range of ±0.02 m/s. The air velocity was also measured continuously in the centre of the room by omnidirectional spherical anemometers located at 0.6 m and 1.1 m above the floor. The accuracy of these anemometers is in the range of ± 0.02 m/s.

2.3 Experimental systems

Each of the four experimental systems investigated in this study is from this moment later on referred to as System A, System B, System C or System D. System A and System B present the two typical ways of heating and ventilation of low-energy residential buildings during winter season i.e. warm air heating by the ventilation system, floor heating combined with mixed ventilation.. System C and System D present combinations of displacement ventilation and radiant floor cooling in a small office in summer season. Summary of physical measurements averaged from last five minutes of each session is given in Tab.1 for each System.

Drawing of the chamber and location of physical measurements are given in Fig.2. During all experimental sessions with mixing ventilation the air temperature and operative temperature profile were measured in position T1 and the air velocity profile was measured in position A1. During half of the experimental sessions with displacement ventilation the air temperature and the operative profile were measured in position T2 and the air velocity profile was measured in position A2. During the other half of the sessions with displacement ventilation the air temperature and the operative temperature profile were measured in position T3 and the air velocity profile was measured in position A3. Air velocity was also measured in the reference point at 0.6m and 1.1m above the floor. The reference operative temperature was measured in the center of the room at 1.1m above the floor (reference point is the blue star in the center of the room in Fig.2).

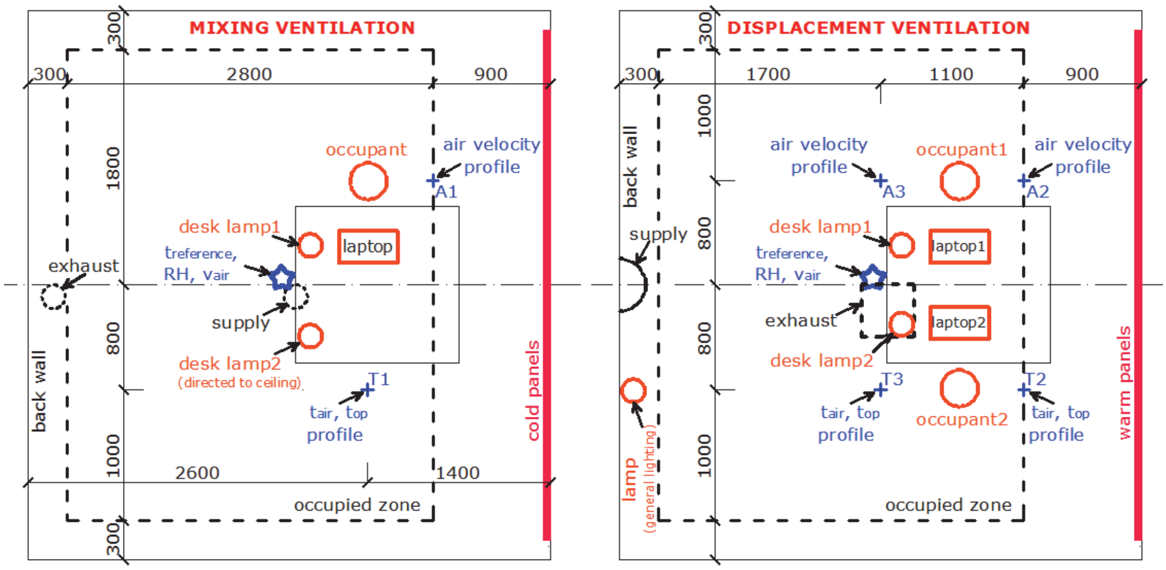

Fig.2 Plan of the experimental chamber. Left: Mixing ventilation. Right: Displacement ventilation.

2.4 Questionnaires

Prior to their first experimental session, every subject was asked to complete a background questionnaire on their self-assessed perception of the thermal environment. Prior to each experimental session the subjects were asked to complete a questionnaire regarding their clothing ensemble. Throughout each experimental session, subjects were asked to complete a questionnaire regarding their perception of the thermal environment, air quality, perception of symptoms and satisfaction with various aspects. Only the results of perception of the thermal environment are presented in this paper. The subjects were also encouraged comments regarding their perception and preferences during the session.

2.5 Experimental procedure

Subjects arrived 10-15 minutes before each session and waited in another adjacent experimental chamber, hereafter called the waiting area. The waiting area was mechanically ventilated with air temperature kept at c.a. 22 °C. While seated in the chamber, the questionnaire on clothing ensemble was distributed and filled in. As the experiments were not primarily focused on air quality assessment, the subjects did not evaluate the air quality immediately after entering the chamber, but as a part of the whole questionnaire about three minutes after entering the chamber. Each experimental session lasted for 180 minutes during which subjects stayed in the room and completed the questionnaires. Subjects completed a total of eight questionnaires starting at 2^{nd}, 30^{th}, 60^{th}, 90^{th}, 120^{th}, 140^{th}, 160^{th} and 178^{th} minute of the session. In between the questionnaires the subjects were allowed to do an arbitrary administration type activity, as for example working on school assignments or browsing on internet. They were not allowed to stand up or adjust their clothing attires.

3. Results

3.1 Physical measurements

Physical measurements (temperature, RH) subjective to descriptive statistics (mean, SD). Summary of physical measurements averaged from last five minutes of each session is given in Tab.1.

Tab.1 Measured indoor environment conditions during the last five of the experimental sessions.

Measured parameters	System A				System B				System C				System D			
	mean	SD	min.	max.	mean	SD	min.	max.	mean	SD	min.	max.	mean	SD	min.	max.
Air temperature (°C)*	22.0	0.3	21.5	22.4	21.9	0.2	21.4	22.1	27.2	0.4	26.5	27.6	27.4	0.3	26.7	27.7
Operative temperature (°C)*	21.9	0.2	21.5	22.3	21.9	0.2	21.4	22.3	26.9	0.4	26.2	27.3	27.0	0.3	26.4	27.4
Temperature of wall panels (°C)	18.0	0.1	17.9	18.2	18.0	0.1	17.8	18.1	30.6	0	30.5	30.6	30.8	0.2	30.6	31.1
Floor temperature (°C)	21.8	0.2	21.5	22.1	23.6	0.1	23.4	23.7	22.0	0.1	21.9	22.1	19.9	0.1	19.8	20.1
Supply air temperature (°C)	27.1	0.1	26.9	27.4	17.1	0.1	16.9	17.3	17.9	0.1	17.7	18.1	24.0	0.1	23.9	24.0
Relative humidity (%)	58	5	51	66	35	5	27	41	34	2	30	37	37	3	33	40

*Measured in the reference point at 1.1m above the floor.

The vertical air temperature profiles are shown in Fig.3. The maximum air velocity occurred at 0.1m above the floor. It reached about 0.15m/s for System B and about 0.1m/s for the other Systems.

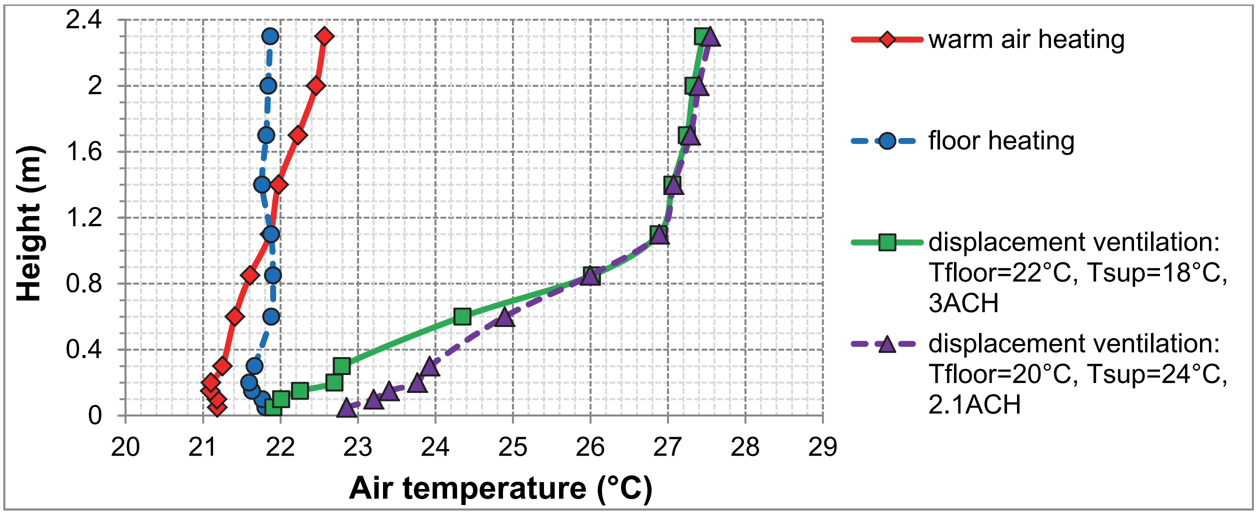

Fig.3 Vertical air temperature profiles for the four experimental conditions.

3.2 Human response to thermal environment

The median, the range and outliers of thermal sensation vote at the start of the session and at the end of the session for the four systems are given in Fig.4.

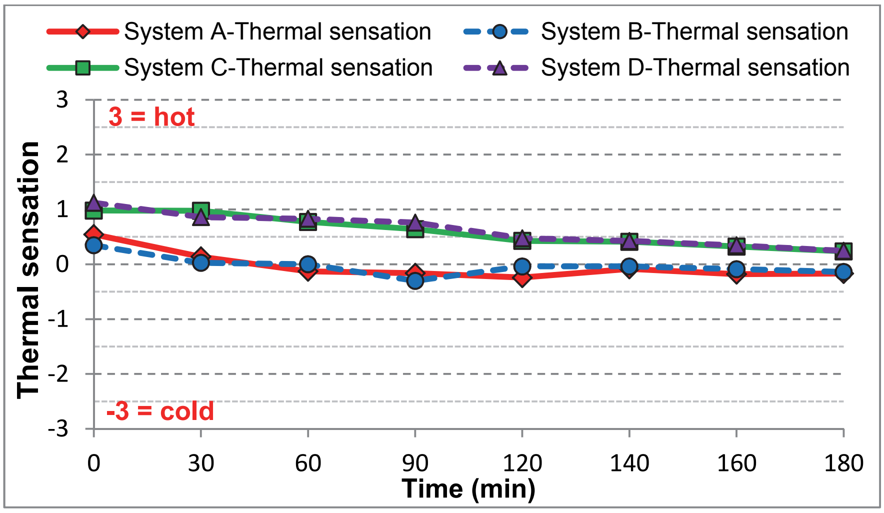

Fig.4 Thermal sensation vote as a function of time for the four systems.

Results of thermal comfort vote at steady state during the last 40 min of the tests are given in Tab.2.

Tab.2 Thermal comfort vote at steady state during the last 40 min of the tests. .

Parameter	System A	System B	System C	System D
Median	1.5	1.2	1.2	1.0
Semi-interquartile	0	0.7	0.8	0
Min.	1	1	1	1
Max.	2	2	2	2

Explanation: 1=very comfortable, 2=comfortable, 3=uncomfortable, 4=very uncomfortable.

In Tab.3 are answers regarding acceptability of the thermal environment. The questions asked were: “Is the thermal environment AT THE MOMENT acceptable to you?” and “If you would stay in this situation DURING THE DAY, would you find the situation acceptable or unacceptable?”

Tab.3 Acceptability of the thermal environment at the end of the experimental sessions.

Parameter		System A	System B	System C	System D
At the moment	acceptable	15	16	15	16
	unacceptable	1	0	1	0
During the day	acceptable	13	15	13	14
	unacceptable	3	1	3	2

Thermal preference vote at the end of the sessions for the four experimental systems are given in Tab.4.

Tab.4 Thermal preference of the people at the end of the experimental sessions.

Parameter	System A	System B	System C	System D
warmer	4	4	1	2
no change	11	11	12	9
cooler	1	1	3	5

The air movement preference at the end of the sessions is given in Tab.5.

Tab.5 Air movement preference at the beginning and at the end of the experimental sessions.

Parameter	System A	System B	System C	System D
more	3	2	6	5
no change	13	14	10	11
less	0	0	0	0

Only for the last two questionnaires for System D the difference in thermal sensation on feet and head was significant ($P<0.05$), when people felt colder on feet than on the head. No significant differences in local thermal comfort between different systems were found.

4. Discussion

The vertical air temperature profiles obtained from human studies agree well with those measured in experimental measurements prior to human studies (Fig.3). The results of physical measurements have been compared to the criteria on local thermal discomfort given in EN ISO 7730 (2005). The air velocity in the occupied zone was always low for the four systems and presents no serious risk of draught. The air temperature was very uniform for System B and only slight temperature gradient was found for System A (Fig.3), both MV systems being in category. The vertical air temperature differences were up to 5K for a sitting person for both DV systems, which still corresponds to category B, although higher gradients are likely to occur at lower floor temperatures and higher temperatures of the warm wall. At the temperature of the floor of 20°C the predicted percentage of people dissatisfied due to cold floor is up to 10 %, which is on the boundary recommended for category A of the thermal environment. For the same condition the percentage of people dissatisfied due to radiant temperature asymmetry is slightly above 10%, being the recommendation for category C of the thermal environment.

The lower TSV in the end of the sessions after three hours of sitting were expected (Fig.4). The TSV in the beginning was significantly warmer than neutral, and it became soon impossible to distinguish from neutral for the two MV systems. For the DV systems the TSV was always significantly warmer than “neutral”. All systems showed the ability to create a comfortable thermal environment towards the end of the sessions (Tab.2). For System D the local comfort on feet improved with cooler feet and also with cooler overall thermal sensation. At the same time people felt the lower legs/feet more comfortable than for System C. The acceptability of the thermal environment improved during the day. People always accepted the thermal environment at the moment, but they were less tolerant to the acceptability during the day (Tab.3). The change in thermal preference corresponds well with the TSV mainly for Systems A, B and C. Due to of almost no perception of local air movement the air movement preference (Tab.5) is likely to be attributed to the thermal sensation and to the air quality. This could explain the tendency from more air movement towards “no change”, mainly for Systems A and C.

5. Conclusion

For the winter conditions the thermal sensation vote for both warm air and floor heating was just below neutral. There was no significant difference in the subjective evaluation of the two systems regarding thermal comfort, preferred temperature, acceptability and air velocity preference. The vertical air temperature distribution was more uniform for floor heating. For the summer conditions there was no difference in the thermal sensation votes for the two systems. The subjects voted a little on the warm side and about 1/3 preferred higher air velocity and/or higher air velocity. With higher supply air temperature and lower floor temperatures, which resulted in a little higher air temperature at the feet, more subjects found the conditions acceptable.

References:

EN ISO 7730, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, European Committee for Standardization, Brussels, 2005.