COMPARISON OF THE THERMAL ENVIRONMENT IN ROOMS WITH CHILLED BEAM AND RADIANT PANEL SYSTEMS

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Abstract

Compared with convective systems radiant systems explore the advantage of influencing the mean radiant temperature for maintaining similar thermal conditions at lower room air temperature in heating mode and higher room air temperature in cooling mode. In some manufactures catalogues, the difference of the mean radiant temperature between radiant and convective systems is claimed to be as high as 2-3 ^{o}C. The difference between radiant system with ceiling installed pannels combined with mixing air distribution and convective system of chilled beams was studied with regard to the mean radiant temperature and radiant temperature asymmetry in a mock-up office at different internal load in both heating and cooling modes.

The operative temperature and the radiant temperature asymmetry were measured at four locations and three heights in the occupied zone. The radiant temperature asymmetry was measured in three directions: vertical direction between floor and ceiling, and two horizontal directions respectively parallel to walls.

The difference in operative temperature measured at 1.1 m height measured with the two systems under the same conditions and at same locations was insignificant (about 0.15 ^{o}C). The operative temperature was more or less uniform over the occupied zone and there was not any significant difference in the operative temperature measured with the two systems. The radiant asymmetry was lower than 5.5 ^{o}C in all measured cases. The difference in the radiant temperature asymmetry measured with the chilled beam system and the radiant panel system was also small.

Keywords: thermal comfort, operative temperature, radiant panel, chilled beam

1 *Introduction*

Present standards (EN ISO 7730) specify requirements with regard to general thermal comfort, operative temperature, vertical temperature gradient, radiant temperature asymmetry and draught discomfort for achieving thermally confortable environment in occupied zone of rooms. According to Babiak et al. (2007) compared to the convective cooling system the radiant panel cooling system can achieve the same level of operative temperature at a higher room air temperature. In some manufactures catalogues, the difference of the mean radiant temperature between radiant and convective systems is claimed to be as high as 2-3 ^{o}C. The reported difference in the mean radiant temperature is based in measurements in empty room with maximum heating demand.

However in modern offices, the situation is different when the heating and cooling demands are moderate and the surface temperature of the radiant panel is close to the room air temperature. In cooling applications, the radiant panel temperature can not decreased below 16-18 ^{o}C because of the condensation risk. For heating, the surface temperature of about 30 ^{o}C is high enough to cover the maximum heating demand.

The difference between radiant and convective systems with regard to the mean radiant temperature and radiant temperature asymmetry was studied in a mock-up office at different internal load in both heating and cooling modes. The results are presented in this paper.

2 *Methods*

Experiments were conducted in a mock up of an office room with dimensions 4.6 m x 2.8 m x 2.65 m (L *x* W *x* H). A chilled beam system (2300 (L) x 300 (W)) and a radiant panel system (2 x 3000 (L) x 600 (W)) were installed and studied. A radial air supply diffuser was installed between the radiant panels. In Fig.1, there is shown test arrangement in the simulated office.

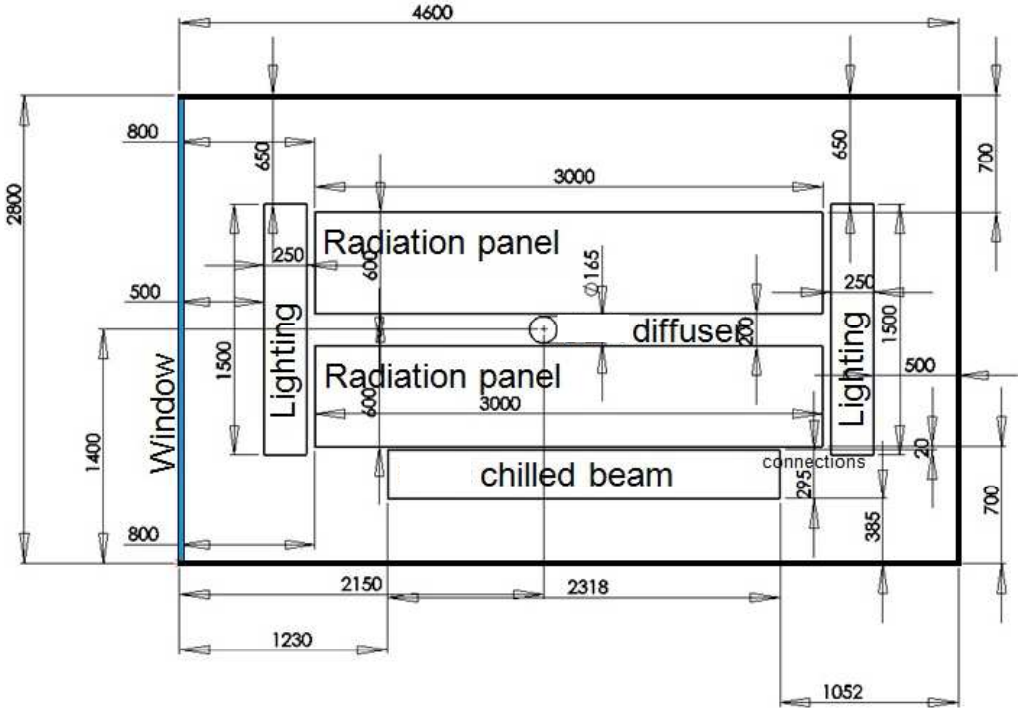

Figure 1. Set-up of the two systems studied.

The performance of the systems was evaluated under winter and summer conditions in both maximum heating/cooling conditions and typical mid-season conditions in an office. The heat load used in the measurements comprised a PC (120 W), lighting (116 W) and a heated dummy (72 W) simulating an occupant. In the maximum cooling condition, heat gain from direct solar radiation was simulated by heating 3.0 m² area of the floor close to the window by electrically heated foil (120 W). The heat load from the window was 215 W (maximum cooling case) and 143 W (moderate cooling case) (surface temperatures of 32 °C and 30 °C). In the winter conditions, adjustable temperature of the simulated window was introduced. The window surface temperature was –15. 2 °C in the cases without internal heat gains (heat loss 208 W). The transmission loss of the structure was 90 W. When the internal heat gains where introduced, the window surface temperature was decreased to 13.3 °C (heat loss 276 W). With the heat gains, the tramission loss was 199 W. In Fig.2, there is presented the locations of heat sources, the simulated window, radiant pannels, the supply valve, the chilled beams and the exhaust valve are indicated in Fig. 1 and Fig. 2.

The operative temperature and the radiant temperature asymmetry were measured at four locations in the occupied zone of the room. The operative temperature was measured at 0.1, 0.6 and 1.1 m above the floor. The radiant asymmetry was measured in three directions: vertical direction between floor and ceiling, and two horizontal directions respectively parallel to walls. The locations of measurements sensors are presented in Fig. 3.

The operative temperature was measured by Thermal Comfort Meter. The operative temperature measurement range is 5 ÷ 40 ˚C and the accuracy of operative measurement is ± 0.3 ˚C . The radiant temperature asymmetry was measured by radiant asymmetry sensor with measurement accuracy ± 2 ˚ C (in the range 0 ÷ 30 ˚ C). The water flow rate was measured with Krohne

Electromagnetic Flowmeter IFC010 with accuracy less than ± 1% of the readings. The airflow rate was measured with differential pressure transmitter Furness Controls FCO33 with accuracy less than ± 0.5% of the readings. The air flow rate was measured with a measurement unit (MSD-100).

The experiments were conducted at winter and summer conditions. In the summer case the room air temperature was kept at 26 ˚C in the reference point at the height level 1.3 m above the floor. In the winter case, the room air temperature measured was kept at 21 ˚C. When supply air flow rate was introduced, it was in both radiant panel and active chilled beam cases 25 L/s (2.0 L/s per m^2).

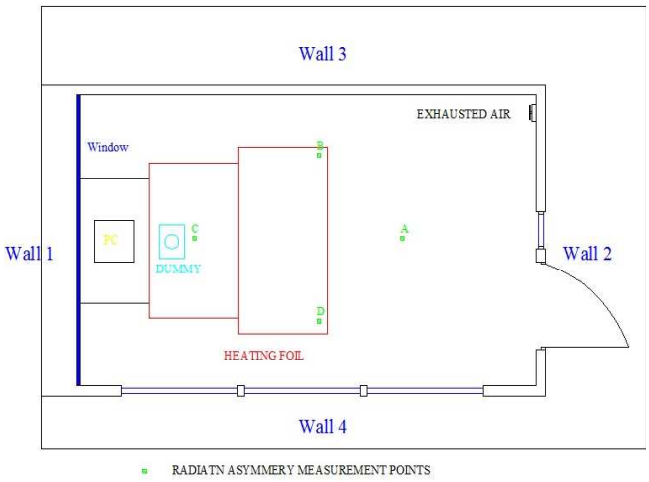

Figure 2. Locations of the heat sources, window and exhaust air diffuser in the room.

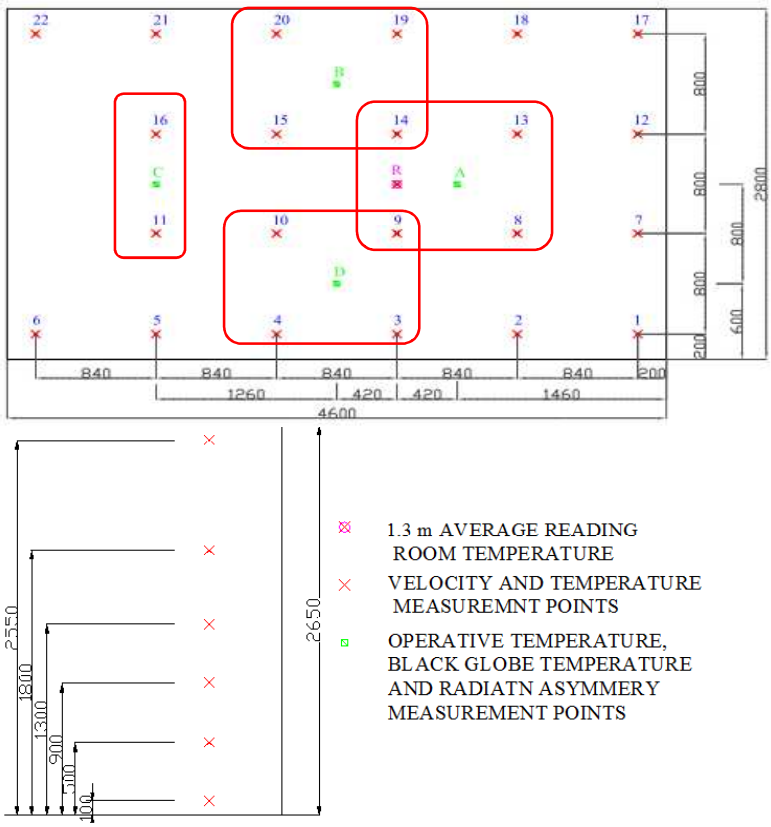

Figure 3. Measurement locations and heights in the room.

The experimental conditions during the experiments are listed in Table 1. The cooling capacity was varied between 35 W/m$^2_{,floor}$ - 50 W/m$^2_{,floor}$. In the cooling mode a reference case with radiant cooling panels but without supply of ventilation air was measured. In heating mode, the heating capacity was varied between 17- 24 W/m$^2_{,floor}$. With radiant panel system, for the case with the maximum heating capacity (24 W/m$^2_{,floor}$) measurements without supply of ventilation air were performed as well.

Table 1: *Measured cases and experimental conditions (RP= radiant panel, CB=chilled beam and WSA= without supply air).*

Case	Water Temperature in/out, ˚C	Water Flow rate kg/s	Temperature of supply air, ˚C	Specified Heat gain profile
RP 29 W/m^2 WSA	Cooling: 14/18	0.022	-	Maximum internal load Note: 265 W (24 W/m2) transmission loss through the walls
RP 50 W/m^2	Cooling: 14/18	0.022	17	Maximum internal load
RP 35 W/m^2	Cooling: 14/18	0.011	17	Part load
RP 24 W/m^2 WSA	Heating: 33.5/28.5	0.014	-	No internal load
RP 24 W/m^2	Heating: 33.5/28.5	0.014	21	No internal load
RP 17 W/m^2	Heating: 33.5/28.5	0.010	21	Maximum internal load
CB 50 W/m^2	Cooling: 16.8/20.9	0.022	17	Maximum internal load
CB 35 W/m^2	Cooling: 21.4/ 23.4	0.022	17	Part load
CB 24 W/m^2	Heating: 33.0/28.1	0.014	21	No internal load
CB 17 W/m^2	Heating: 29.6/26.1	0.014	21	Maximum internal load

3 Results

In Fig 4, the difference between the air temperature and operative temperature measured at the 1.1 m at the locations A, B, C and D (Fig. 3) in the occupied zone in the cooling mode case is shown. In the comparison of the operative and room air temperatures, the reference room air temperature is calculated from the closest air temperature sensors from the relevant operative temperature measurement point. The used reference room air temperatures calculation are marked with red circles around the operative sensors in Fig. 3. With the radiant panel system (RP), the room air temperature was in average 0.3 ºC higher than operative temperature in the case of maximum cooling load condition (50 W/m^2). Close to the dummy (at point C), the room air temperature was 0.35 º C higher than the operative temperature. With lower heat gains (35 W/m^2), the room air temperature was at the measured points was either higher or lower than the operative temperature. On an average, the room temperature was 0.13 º C lower than the room air temperature. The difference increased (up to 0.7 ºC) in the case with radiant panels when ventilation air was not supplied. With the chilled beam system (CB), the room air temperature was in average 0.15 ºC lower than the operative temperature in the case with maximum cooling load (50 W/m^2). Close to the dummy, there was not any difference and the room air temperature was the same as the operative temperature. With lower cooling load (35 W/m^2), there was on average 0.2 º C difference between the room air and operative temperatures. Thus, the radiant panel gave on average 0.15 º C lower operative temperature than the chilled beam systems. Close to the dummy, there was higher difference: radiant panel system gave 0.35 º C lower operative temperature than the chilled beam system.

In Fig. 5, the difference between room air temperature and operative temperature in heating mode is shown. With the radiant panel system combined with mixing air distribution, the room air

temperature was on average higher 0.16 ° C than operative temperature in the maximum heat demand condition (17 W/m^2). With the chilled beam system, in the maximum heat condition, the difference was about the same level (0.1 ° C). Respectively, with lower heat demand case (17 W/m^2), the difference was 0.06 ° C with the radiant panel system and 0.25 °C with the chilled beam system. The temperature difference in the case with radiant panels increased (up to 0.4 ° C) when the ventilation air was not used (Case RP 24 W/m^2 WSA).

Both in heating and cooling mode when the supply air flow rate was introduced with the radiant panel system, the difference between the room air and operative temperatures reduced. This indicates that the jet and convection loads mixed the room space and influenced on the surface temperature of the walls.

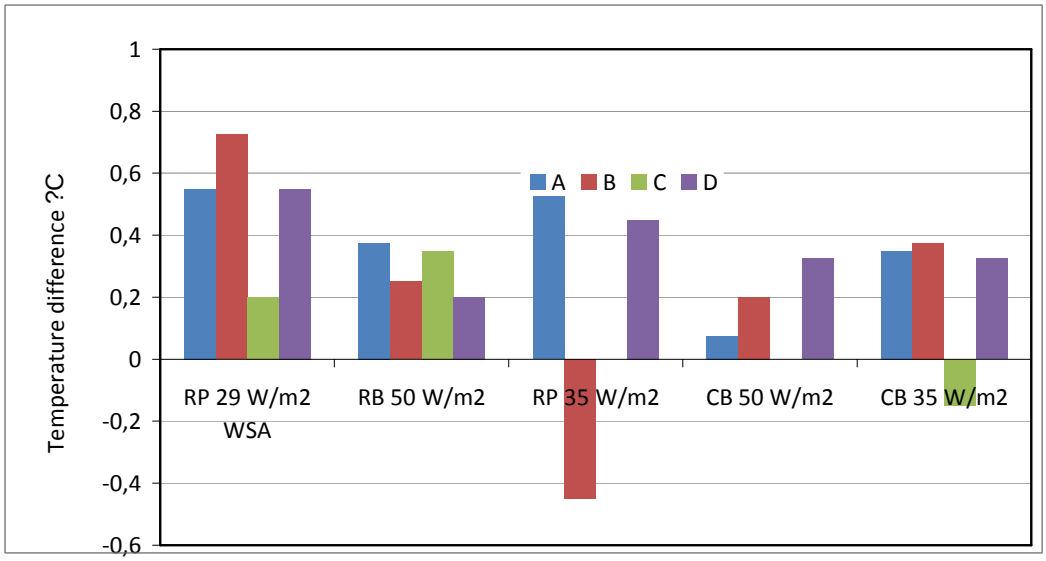

Figure 4. Difference between room air temperature and operative temperature measured at A, B, C, D at 1.1 m level above the floor in cooling mode cases. (WSA=without supply air)

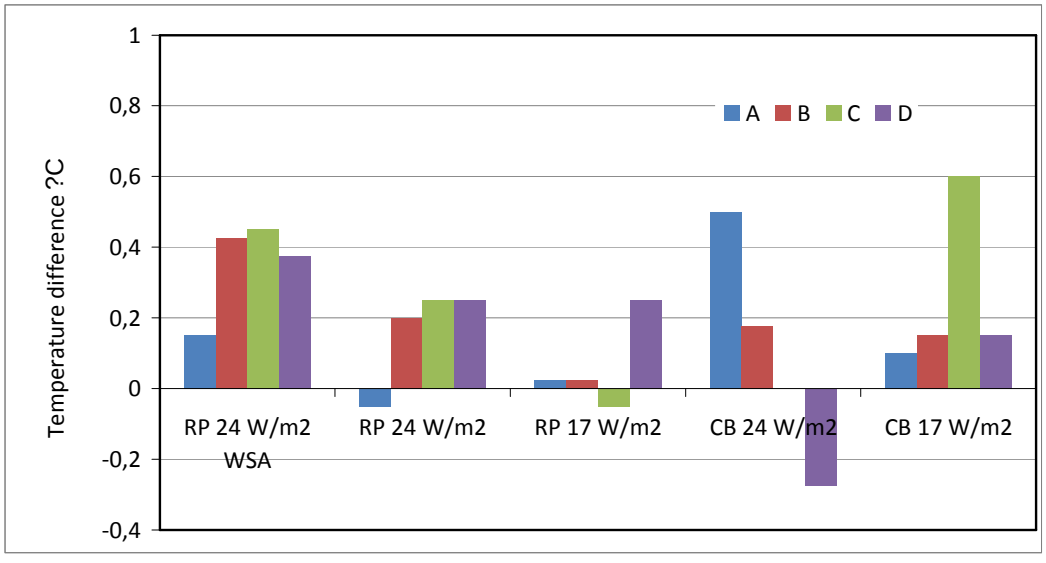

Figure 5. Difference between room air temperature and operative temperature measured at locations A, B, C, D at 1.1 m level above the floor in heating mode cases (WSA=without supply air).

Radiant temperature asymmetry was measured in three directions: between floor and ceiling, and direction respectively parallel to walls 1 and 2 and walls 3 and 4 (Fig. 2). In Figs. 6 and 7 radiant temperature asymmetry between floor and ceiling and between wall 1 (with heated window) and wall 2 is shown in the heating and cooling conditions respectively. In the cooling mode, the radiant symmetry between floor and ceiling was below 5.5 ^{o}C in all measured cases (Fig. 6). The radiant temperature difference was less than 2 ^{o}C for all measured locations except location C which most probably was influenced by the heated dummy. Between the floor and the ceiling the radiant temperature asymmetry was below 2.5 ^{o}C (Fig. 6). In heating mode, the radiant asymmetry was below 3 ^{o}C in all studied cases (Fig. 7).

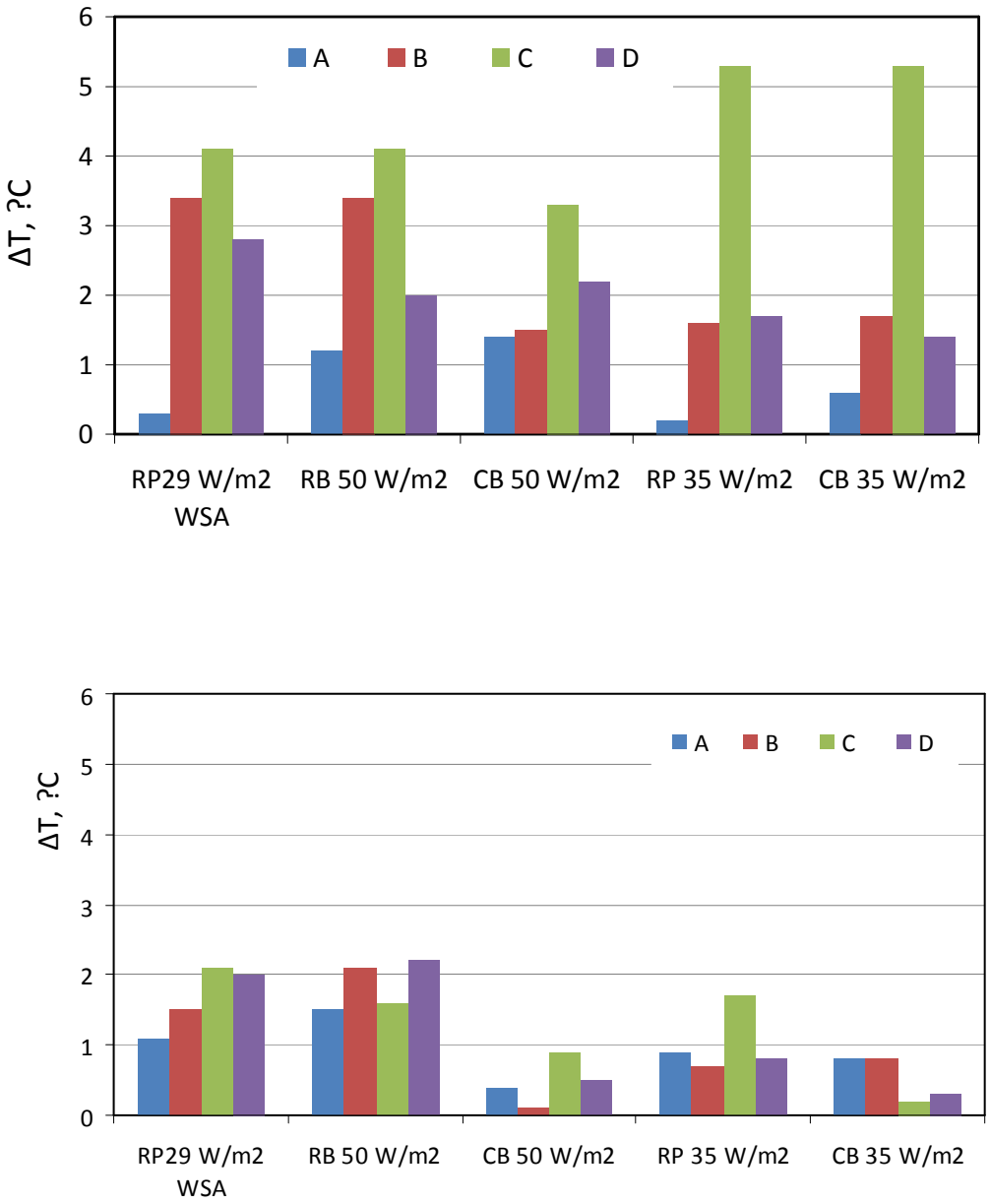

Figure 6. Radiant temperature asymmetry measured in the cooling mode cases (Table 1). Upper figure: asymmetry between wall 1 and wall 2; Lower figure: asymmetry between floor and ceiling (WSA=without supply air).

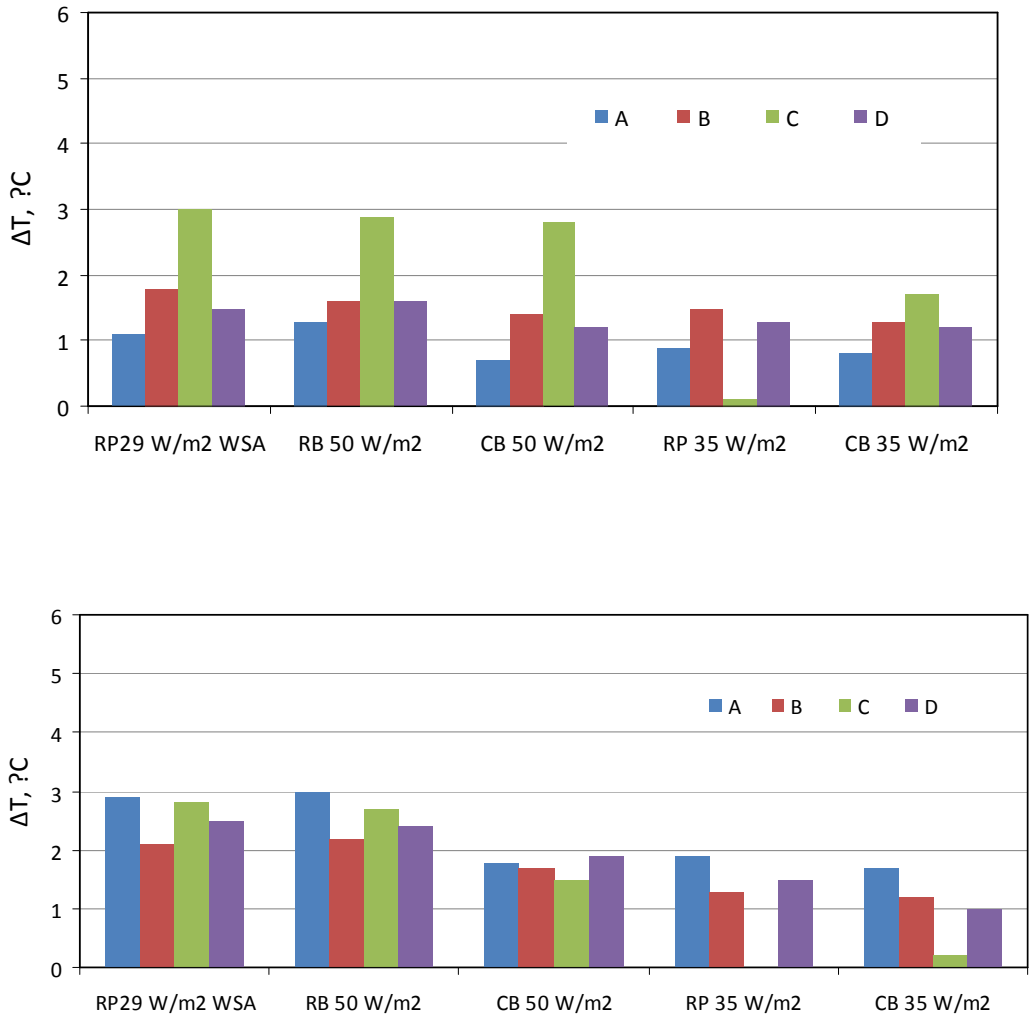

Figure 7. Radiant temperature asymmetry measured in the heating mode cases (Table 1). Upper figure: asymmetry between wall 1 and wall 2; Lower figure: asymmetry between floor and ceiling (WSA=without supply air).

4 Discussion

The results of the present study do not validate the reported in the literature advantage of radiant cooling systems in providing operative temperature 2-3 ^{o}C lower than air temperature in comparison with mixing air distribution systems. The results of this study showed that the difference between the operative temperature and the air temperature was much lower. In the cooling mode the maximum difference for the radiant panel system combined with mixing air distribution was 0.35 ^{o}C and an average difference was only 0.2 ^{o}C. Results showed also small difference between room air temperature and operative temperature with the chilled beam system. Thus, there was no significant difference on the operative temperatures with the radiant panel and chilled beam system.

The stated in some manufactures catalogues relatively large difference of 2-3 between operative temperature and air temperature in rooms with radiant cooling/heating panels has been obtained without presence of heat sources and airflow introduced by mechanical ventilation. In occupied spaces

thermal plumes and the ventilation flow influence substantially the air distribution and promote air mixing which has an impact on the mean radiant temperature and thus on the operative temperature. The present results show that air mixing is also achieved in rooms without mechanical ventilation due to the thermal plumes generated by heat sources. In the room with radiant panels and without heat sources and flow generated by mechanical ventilation the difference between the room air and operative temperature is higher. This however is not the case in occupied spaces.

In the measurements of the present study were performed with the highest heat load of 50 W/m^2_{floor}. In case of higher heat load (70-90 W/m^2_{floor}) for radiant cooling systems, the difference between the operative temperature and the air temperature may be higher. The office layout will affect the air distribution and thus may have effect on the performance of the radiant cooling systems and in general on occupants thermal comfort. In open layout concepts, the results could be different.

5 Conclusions

The average difference in operative temperature measured with the radiant panel and chilled beam systems under the same conditions and the same location in the occupied zone were small (less than 0.35 ^oC). The operative temperature was more or less uniform over the occupied zone. The difference between the operative temperature and the air temperature in the case of radiant cooling panels combined with mixing ventilation was not much different than in the case of chilled beams. The radiant temperature asymmetry was lower than 5.5 ^oC in all measured cases. That fulfils the demands of present

6 Acknowledgement

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7 References

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