IMPACT OF THE AIRFLOW INTERACTION ON OCCUPANTS’ THERMAL COMFORT IN ROOMS WITH ACTIVE CHILLED BEAMS

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ABSTRACT

The interaction of flows in rooms ventilated by active chilled beams and its importance for the air distribution and occupants’ thermal comfort is studied in a full-scale room experiments. The impact of the supplied flow rate of primary air (1.5 L/s/m² and 3 L/s/m²) and the heat load strength (50 and 80 W/m²) on the thermal environment generated in the occupied zone was in the focus of this study. Two thermal manikins, two desk computers, two artificial windows with controlled heat load and ceiling lights were used as heat sources. Comprehensive database of mean speed and air temperature field, draught rating in the occupied zone was collected. All of the experiments represented summer conditions. The room temperature was maintained at 24°C. The results show that the heat load and the supplied flow rate have substantial impact on the air distribution in rooms with chilled beams. The non-uniformity of the thermal environment and the risk of draught discomfort increases when the heat load and the flow rate of the supplied primary air increases.

KEYWORDS

Airflow interaction, active chilled beams, thermal comfort, draught discomfort

INTRODUCTION

The use of chilled beams for ventilation of office buildings increases due to their ability of removing higher heat loads in more energy efficient way than other office ventilation principles (REHVA Guidebook 2006). Chilled beams supply primary outdoor air which induces room air. The induced room air passes a water-air heat exchanger installed in the chilled beam, mixes with the primary air and is supplied back to the room. Special devices installed in the chilled beams allow for regulation of the amount of induced room air.

Air distribution in rooms with active chilled beams is result of complex interaction of ventilation flow from the beams with the convection flow generated by heat sources, occupants, warm/cold window surfaces, office equipment. The airflow distribution depends on several factors, including arrangement of chilled beams, supplied airflow rate and momentum flux, lay out of workplaces, strength and location of heat sources, etc. Only limited studies on the air distribution in rooms with chilled beams is reported in the literature [2, 3, 4]. The impact of the airflow interaction in rooms with active chilled beams on occupants’ comfort needs to be studied.

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This paper addresses the effect of air flow rate supplied from chilled beams and heat load in rooms on the non-uniformity of the thermal environment and the risk of draught discomfort.

METHOD

Experimental facilities

Measurements were performed in a full-scale test room, with size of 5.4 x 4.2 x 2.5 m (height). Two thermal manikins were used to simulate people in the room. The surface temperature of the manikins was controlled to be identical with the skin temperature of person in state of thermal comfort. The manikins represented an average female body size. They were dressed with clothing typical for office type work, i.e. underwear, trousers, blouse, etc (total clothing insulation was 0.7 clo). The manikins sat behind desks simulating seated person performing office work. Two computers and two table lights were used as additional heat sources. Windows heated by solar radiation were simulated by two heating panels (attached at one of the walls). The size of the simulated windows was 2.0 x 1.8 m. Several smaller heating panels were placed on the floor when high heat load was simulated (Figure 1). Four chilled beams were installed on the ceiling. The lay out of the chilled beams, the desks with the thermal manikins, the windows and the heated panels on the floor is shown in Figure 1.

Experimental conditions

The experimental conditions are listed in Table 1. The impact of the flow rate of primary (outdoor) air was studied at 1.5 L/s/m² and 3 L/s/m². The amount of the room air induced through the heat exchanger of one chilled beam in the case of the lower flow rate of primary air was estimated to be 37 L/s. The total amount of air entraining the room from one chilled beam was 46 L/s. For the higher flow rate of primary air (3 L/s/m²) the amount of induced room air for one chilled beam was calculated to be 72 L/s and the total supply flow rate was 89 L/s.

Experiments at two heat load levels, 50 W/m² and 80 W/m² were performed. The flow rate of the fresh air supplied through each chilled beam was 1.5 L/s/m², e.g. total flow rate (including induced air was 46 L/s. Heated panels placed on the floor as shown in Figure 1 were used to increase the heat load to 80 W/m². The heat generated by different sources is listed in Table 2.
Table 1. Experimental conditions

<table>
<thead>
<tr>
<th>Primary airflow Rate, L/s/m²</th>
<th>Heat load, W/m²</th>
<th>Temperature in the room, °C</th>
<th>Temperature of the supplied air, °C</th>
<th>Surface temperature of windows, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>50</td>
<td>24.1 ± 0.2</td>
<td>21.3 ± 0.3</td>
<td>43.3</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>24 ± 0.2</td>
<td>22.3 ± 0.2</td>
<td>39.2</td>
</tr>
<tr>
<td>1.5</td>
<td>80</td>
<td>24.2 ± 0.2</td>
<td>18.9 ± 0.3</td>
<td>41.6</td>
</tr>
</tbody>
</table>

Table 2. Distribution of heat load

<table>
<thead>
<tr>
<th>Heat gain from windows, W</th>
<th>Heat gain from PCs, W</th>
<th>Heat gain from thermal manikins, W</th>
<th>Heat gains from floor panels, W</th>
<th>Heat gain from lightning, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x345</td>
<td>2x30</td>
<td>2x75</td>
<td>0</td>
<td>116</td>
</tr>
<tr>
<td>2x345</td>
<td>2x50</td>
<td>2x75</td>
<td>740</td>
<td>116</td>
</tr>
</tbody>
</table>

The air temperature in the test room, measured in the occupied zone at 1.1 m above the floor, was almost constant 24 ºC (Table 1). The lay out in the room and the lay out of the chilled beams were not changed during the experiments.

**Measurements**

Velocity and temperature measurements in the occupied zone were performed. The velocity sensors were placed at 0.1, 0.6, 1.1 and 1.7 m above the floor (required in ISO standard 7726 1998, ASHRAE Standard 55 2004) at 35 measuring locations as shown with dots in Figure 1. In this way velocity (in fact air speed) and temperature in 140 points in the room was measured. Because of obstructions (tables, manikins) measurements in some of the locations were not performed. The standards (ASHRAE Standard 55 2004, ISO standard 7726 1998) define the occupied zone to start at distance 0.6 m from the walls. Nevertheless in this study measurements at locations 0.1 m from the walls were performed in order to obtain better overview of the air motion in the room.

Comprehensive velocity and temperature measurements in a plane above the thermal manikins (defined in Figure 1 with a black line) were performed as well (the results of these measurements are not included in this paper).

Two multi-channel low velocity thermal anemometers with eight omnidirectional transducers each were used to measure mean velocity (in fact mean speed), turbulence intensity and temperature. The velocity sensors were spherical with a diameter of 2 mm and the temperature sensors were shielded against radiation. The measuring period at each point was 3 min. Twenty-three resistance thermometers were used for measuring inlet and outlet water temperatures, inlet and outlet air temperatures in every chilled beam, surfaces temperatures of the walls and air temperature in the room. All sensors were connected to a computer and temperatures were recorded every 6 seconds by a data logging system. The sensors were calibrated before the experiment start. The measurements were performed under steady state conditions.

**Data analyses**

The air speed and temperature measurements in the occupied zone were used to analyse and compare the impact of the studied factors on the air distribution and thermal comfort in the occupied zone. Two indices were calculated with the obtained data: the ADPI index (Air Diffusion Performance index) and the Draught rating (DR) index (ASHRAE Standard 113 2005). The measurements above the manikins were used to define in detail the velocity and temperature field and to study the interaction of
the flow supplied from the chilled beams and the thermal plumes above heat sources.

RESULTS AND DISCUSSION

Average, maximum and minimum values for the velocity, temperature and draught rating in the occupied zone obtained from the analyses of the collected database are listed in Table 3. The values are taken from all of the measurement location for each of the studied experimental conditions.

Table 3. Minimum, maximum and average temperature, velocity and DR in the occupied zone.

<table>
<thead>
<tr>
<th>Flow rate L/s/m²</th>
<th>Heat load W/m²</th>
<th>Vmax m/s</th>
<th>Vmin m/s</th>
<th>Vave m/s</th>
<th>Tmax °C</th>
<th>Tmin °C</th>
<th>Tave °C</th>
<th>DRmax %</th>
<th>DRmin %</th>
<th>DRave %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>50</td>
<td>0.348</td>
<td>0.062</td>
<td>0.162</td>
<td>24.9</td>
<td>23.2</td>
<td>24.0</td>
<td>34.1</td>
<td>2.9</td>
<td>13.8</td>
</tr>
<tr>
<td>1.5</td>
<td>50</td>
<td>0.201</td>
<td>0.034</td>
<td>0.1</td>
<td>25.4</td>
<td>23.2</td>
<td>24.3</td>
<td>17</td>
<td>0</td>
<td>6.5</td>
</tr>
<tr>
<td>1.5</td>
<td>80</td>
<td>0.242</td>
<td>0.053</td>
<td>0.137</td>
<td>25.7</td>
<td>22.6</td>
<td>24.0</td>
<td>25.4</td>
<td>1</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Relatively high velocity was identified in the occupied zone, up to 0.35 m/s at 3 L/s/m². The results show that the lowering of the supply flow rate leads to reduction in the maximum and average values of air velocity. The temperature does not differ substantially in both conditions.

The supplied flow rate has significant impact on the draught rating index (DR). The average draught rating index for the occupied zone decreased twice when the flow rate was reduced from 3 L/s/m² to 1.5 L/s/m². DR was determined at each of the measured points within the occupied zone.

The impact of the strength of the heat load on the parameters of the thermal environment is significant and can be seen for all maximum, minimum and average values. The minimum temperature decreased slightly but the average and the maximum temperatures did not differ too much. The decrease of the temperature can be explained with the lower supply air temperature. The higher velocity and the lower temperature at 80 W/m² resulted in increase of the average draught rating.

Large number of data was obtained. In order to simplify and clarify the presentation of the results and their discussion only the maximum value of DR determined at the four measured heights (0.1, 0.6, 1.1 and 1.7 m above floor) at each location was used. The philosophy is that a person will complain of draught regardless whether he/she will experience it at one or more body parts. The results of these analyses are discussed later in this paper.

DISCUSSION

The impact of the airflow interaction on the thermal environment and occupants’ comfort was in the focus of the present study. The analyses of the results of the velocity and temperature measurements (used to calculate the Draught Rating) revealed that substantial changes of the local thermal environment at different workplaces occurred in the room when the heat load and the supply flow rate was changed. These two parameters are important factors to be taken into account for ensuring good level of thermal comfort in rooms ventilated with chilled beams. The quality of thermal comfort decreases with the increase of the heat load. It was found that higher heat load increases the risk of draught discomfort in the occupied zone. Present standards and guidelines (ASHRAE 55 2004, ISO7730 1994) define critical value of 15% for the draught rating in the occupied zone. Above that value it is considered that the quality of the thermal environment in regard of draught discomfort is low.
and uncomfortable. The calculated draught rating for two conditions with different strength of the heat loads applied to the test room showed that the average and maximum DR values increase with the increase of the heat load. Furthermore the area within the occupied zone with DR>15% increases as well. This is demonstrated by the results shown in Figure 2. Under identical other conditions the values for the calculated DR as well as the number of locations within the occupied zone increases substantially when the heat load is increased from 50 W/m² to 80 W/m².

![Figure 2. Impact of the strength of the heat loads on the DR in the occupied zone.](image)

For chilled beams the typical range for the primary (outdoor) air requirement is from 1.5L/s/m² to 3L/s/m². The working principal of the chilled beams is based on induction of room air through the heat exchanger in order to meet the cooling demands. The induction rate varies between 1:3 and 1:5 depending on the design of the devices. It is expected that with the higher demand of fresh air the induced room air will be more thus the total amount of air will become more. The results of the present study identify that under the same conditions in the room the increase of the supplied air flow had opposite effect on the airflow interaction than the effect of increased heat load. This is to say that at high flow rate the supplied from the chilled beams airflow had high momentum which counteracts better the thermal flow from the increased heat load. However the increase of the flow rate resulted in high velocities and increased draught rating in the occupied zone. This is demonstrated by the comparison of the results shown in Figure 3. The calculated values of DR increased almost twice when the flow rate was increased from 1.5 L/s/m² to 3 L/s/m². The locations in the occupied zone with DR>15% increased much more drastically.

Comparing the results in Figures 2 and 3 it could be concluded that the flow rate has the bigger impact on the occupants’ comfort in comparison with the impact of the heat loads. The results should be carefully considered since the used flow rate of 3 L/s/m² for the experiments is the highest value used for ventilation with chilled beams. The design value of 3 L/s/m² for the supply flow rate given in REHVA Chilled Beam Application Guidebook (2006) is correlated with the strength of heat loads in the ventilated rooms - the flow rate of 3 L/s/m² corresponds to 120 W/m². In the present experiments this relatively high flow rate (3 L/s/m²) was applied to remove 50W/m² which is much lower than recommended in the guidebook. Therefore further experiments with lower flow rate are recommended to be performed in order to realistically compare the impact of the heat load and the supplied flow rate on the air distribution and thermal environment in rooms with chilled beams.
CONCLUSIONS
The heat load and the supply flow rate have significant impact on the airflow distribution and the thermal comfort conditions in rooms ventilated with chilled beams.

The risk of thermal discomfort, especially draught discomfort increases when the heat load and the supplied flow rate increases.

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REFERENCES