PERFORMANCE OF DISPLACEMENT VENTILATION IN PRACTICE

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Summary
This paper presents results of a field study in offices with displacement ventilation. It comprises detailed physical measurements of the thermal environment and collection of occupants' response at 227 workplaces. The results, both physical measurements and human response, identified draught as the major local discomfort in the rooms with displacement ventilation. Twenty three percent of the occupants were daily bothered by draught. In some buildings the maintenance personnel tried to improve occupants' thermal comfort by raising the supply air temperature or office workers themselves blocked the diffusers by rearranging the furniture. Half of the surveyed occupants were not satisfied with the indoor air quality. The main conclusion is that displacement ventilation needs careful design and room furnishing in order to ensure a comfortable environment. Occupants must understand the underlying ventilation principle. This will ensure proper and efficient operation of the system and occupants' satisfaction.

Introduction

Displacement ventilation involves supplying fresh air with low velocity to the room directly or close to the occupied zone. The air-supply diffusers are typically mounted on the wall near the floor. The supply air, with temperature 2÷4°C lower than the room average, accelerates due to the buoyancy and spreads over the floor in a relatively thin layer, 0.1-0.3m, reaching high velocity. The air rises as it is heated by heat sources (persons, lighting, computers, etc.), displaces the hot contaminated air into the upper space of the room and removes it through the exhausts, located at or close to the ceiling.

Large number of laboratory measurements indicate that in rooms with displacement ventilation occupants have potential of breathing cleaner air than in rooms with mixing ventilation (Holmberg et al, 1990, Brohms & Nielsen, 1996, etc.). However, the air reaching the breathing zone may also transport pollution from the floor covering or other passive (not heated) pollution sources. This will decrease the quality of the air inhaled by the occupants. Measurements also indicate that the relatively high velocity and low temperature near the floor in rooms with displacement ventilation may cause local thermal discomfort due to draught and vertical temperature difference, e.g. cold at the feet and warm at the head. (Melikov and Nielsen, 1989, Melikov et al, 1990).

Recently a field survey was performed in rooms with displacement ventilation. Occupants' response to the thermal environment in the surveyed rooms is discussed by Pitchurov et al. (2002). In this paper results from physical measurements and occupants' response to the indoor air quality are discussed. Observations on the interaction occupants-ventilation system are presented.

Experimental Design

Eight large office buildings in Denmark were selected for the study. Two hundred twenty-seven occupied workplaces ventilated by displacement ventilation were investigated. Ventilation systems' design utilized plane rectangular, quarter round, semi circular and curved supply air diffusers in various sizes from floor-standing and wall-mounted type.

Ninety-four male and one hundred thirty three female office workers took part in the survey. The occupants were in age between 20 and 64 years. Most of them spent about eight hours on their desk performing mainly seated office work. The occupants wore normal summer-season office clothes (0.56 clo for males and 0.58 clo for females).

Air temperature and air velocity measurements were performed at heights 0.05, 0.1, 0.3, 0.6

and 1.1 m above the floor. When occupants worked in a standing posture the measurement heights used were 0.05, 0.1, 0.3, 1.1 and 1.7 m. Data for the radiant temperature asymmetry, relative humidity and operative temperature were also collected. The collected data were used to calculate thermal comfort indices: PMV, ET*, DR, etc. The measuring instruments met specifications for instruments prescribed in the standards (ASHRAE 55, 1992; ISO 7726, 1998).

A flexible and fully portable mobile measurement system was developed in the present project (Figure 1). A sliding probe-stand allowed for measurement of the above listed parameters at different heights and with minimum influence of the measuring equipment and manipulating person on the data sampling process. All the equipment was protected to avoid damage during transportation.

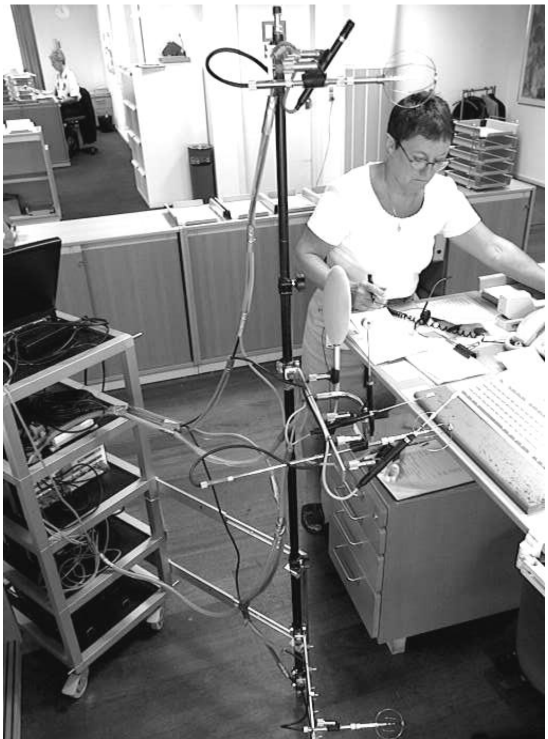

Figure 1. Mobile measurement unit

In addition to physical measurements, questionnaires for collecting human response to the thermal environment were developed. The questionnaire was split into two parts. The Online form collected data on occupants' general thermal comfort and local discomfort (draught and vertical temperature difference) and the Background one - occupants' data such as demographics, job satisfaction, air quality satisfaction, health, etc.

Two researchers collected the whole set of physical and subjective data. The procedure for each workplace started by approaching an occupant and inquiring whether he/she was willing to participate in the survey. If agreed, he/she was presented with the online questionnaire. After the occupant had completed the questionnaire he/she was asked to leave the desk and fill in the Background questionnaire. The measurement cart was moved into position and a 3-min measurement started. During this time the researchers made additional observations on the type of chair used and the arrangement of furniture, recorded the supply air temperature and made photographs. The whole procedure took between 5 and 10 minutes.

Results and Discussion

Mean velocity, turbulence intensity and air temperature were measured in total of 1135 points. The maximum measured mean velocity was 0.37 m/s. In 29% of the measured points the mean velocity was less than 0.05 m/s. This percentage was higher than in rooms with mixing ventilation (20% - Hanzawa et al, 1987) and lower than in rooms without mechanical ventilation (70 % - Melikov et al, 1988). The highest velocity and lowest turbulence intensity and air temperature were measured near the floor. The minimum mean air temperature, 20.5°C, was recorded at 0.1 m above the floor and the maximum, 26.3°C, at 1.1 m above the floor. In agreement with previous field measurements (Melikov and Nielsen, 1989; Melikov et al, 1990) the mean velocity gradually decreased and the air temperature increased with the height above the floor. As expected, the turbulence intensity decreased with the increase of the mean velocity from 60% at 0.06 m/s to 25% at 0.35 m/s and was higher in comparison with results previously reported by Melikov et al. (1990).

In 88% of the measured locations PMV index fell in the limits specified by standards, i.e. –0.5 ÷ 0.5, while in the rest of places it was in the range -1 ÷ 1. Eighty-nine percent of the workplaces met specifications for thermal environments defined by standard-addendum ASHRAE 55a (1995). An average value of 23.4°C for the operative temperature (almost equal to the air temperature) was calculated for the surveyed buildings.

Based on the physical measurements a maximum draught rate of 41% was calculated for height 0.1m above the floor. In 18 % of the locations draught rate index exceeded the 15% limit prescribed in the present indoor climate standards (ISO 7730,1994, ASHRAE 55,1992).

In the present study no workplace was found with a vertical temperature difference higher than 2.9°C (average for the sample 1.1 °C). Previous measurements in rooms with displacement ventilation (Melikov et. al, 1990, Melikov and Nielsen, 1989) reported vertical temperature difference up to 5 °C. Thus, the results of this study indicate improvement in design and performance of displacement ventilation in practice.

The maximum draught rating versus the vertical temperature difference calculated at each measurement location is shown in Figure 2. The dotted lines define the acceptable conditions for thermal comfort according to present standards. The results in the figure suggest that in rooms with displacement ventilation it should be expected more people to be bothered by discomfort due to draught than due to vertical temperature difference between the head and ankle level.

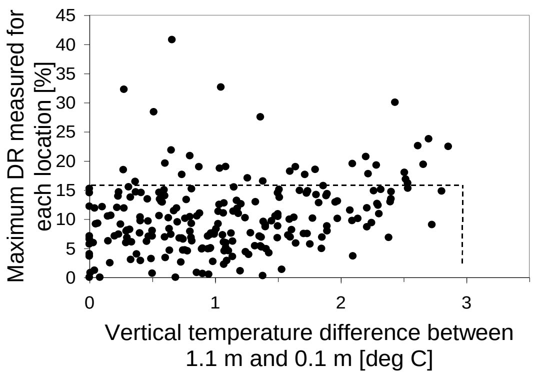

Figure 2. Maximum Draught rating versus vertical temperature difference calculated at each of the measured locations.

Nineteen percent of the surveyed occupants felt their lower leg/ankle/feet section uncomfortably cool at the moment of asking. Thirty-two percent of the occupants who voted the thermal environment unacceptable sensed air movement at their lower leg/ankle/feet body section and reported it as uncomfortably cool. Twenty-three percent of all surveyed office workers were daily bothered by draught.

Even though some office workers felt themselves slightly warm or warm they demanded less air movement. In order to diminish draught discomfort technicians in many of the visited buildings kept the supply air temperature only 1°C lower than the average room air temperature.

Forty-nine percent of the surveyed office workers were dissatisfied with the air quality (Figure 3). Lower percentage was expected since high air quality is considered as the main advantage of the displacement ventilation over the mixing one.

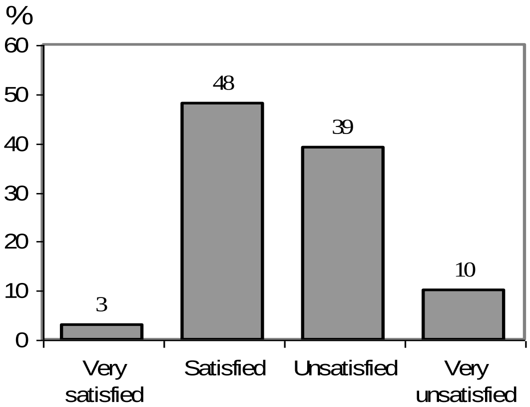

Figure 3. Air quality votes

Recent research (Fang et al, 1998) has revealed that temperature and humidity of the air inhaled by people is as important as the concentration of pollution for the perceived air quality; inhaled air is perceived bad when its temperature and humidity are high. In rooms with displacement ventilation the air inhaled by occupants is provided mainly by the free convection flow around the body. Thus the inhaled air may be clean (in case of no passive pollution sources near the floor) but it will be warmer when the temperature of the room air is high.

The analyses of the collected data revealed that the quality of the air perceived by occupants was better at lower operative temperature (p=0.01). Perceived air quality improved when head was felt cool. Fifty percent of those who were dissatisfied with the air quality demanded more air movement. In the building with lowest perceived air quality artificial walls were placed in front of the diffuser to channel the airflow and divert it away from the occupants' workplaces. This was obviously done to eliminate the draught risk.

In some office spaces the air supply devices were blocked. This disturbed the proper air distribution and the performance of the system as a whole. In some cases the blocking of diffusers was simply because occupants who lacked knowledge on the displacement ventilation principle tried to use as much as possible of the office space. Occupants also blocked air supply diffusers in order to avoid draught discomfort.

Conclusions

The displacement ventilation systems in the surveyed buildings satisfied the requirements of present indoor climate standards regarding occupants' general thermal comfort. However, draught was identified as a serious problem in the office spaces.

Twenty three percent of the occupants were daily bothered by draught and one-fifth reported draught discomfort below knee level at the moment of surveying.

In order to counteract draught discomfort occupants blocked air supply diffusers or maintenance staff increased the supply air temperature.

In many rooms the displacement ventilation systems failed to provide occupants with high air quality. Half of the occupants were not satisfied with the air quality.

Displacement ventilation requires very careful design and consideration in order to perform satisfactorily in practice. Employees should have basic knowledge on the ventilation principle and be an active part in achievement of a high quality of indoor environment in office rooms with displacement ventilation.

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