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Displacement ventilation – Airflow in the near zone

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DISPLACEMENT VENTILATION - AIRFLOW IN THE NEAR ZONE

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Introduction

Displacement ventilation is becoming popular for spaces occupied by people with sedentary activity, such as offices, conference rooms, computer rooms, etc. Several recent laboratory studies (1,2,3,4,5) have been reported recently on the air velocity and air temperature distribution with this type of ventilation. Investigations have been performed in test rooms at different conditions: type, location and height of the outlet; exhaust and supply air temperature difference; airflow rate; with and without additional heating in the room; with a local distribution of solar heat load; etc. Measurements of mean velocity, standard deviation of the velocity fluctuations and turbulence intensity (the standard deviation of the velocity divided by the mean velocity) have been published (1,2,4). In some of these studies (1) the thermal comfort conditions in the test room were evaluated as well.

In rooms with displacement ventilation the outlets are located near the floor. The supply air with a temperature 2-4 °C below room air temperature spreads near the floor in a relatively thin layer. This gives rather high velocities in the zone near to the outlets and substantial nonuniformity of velocity and temperature distribution in the occupied zone on a horizontal plane. The velocity distribution depends on many factors: type of the supply device (initial velocity profile, shape, etc.) room and supply air temperature difference, geometry in the room, etc.).

This paper presents results from field measurements of airflow characteristics in the zone near the outlets in rooms with displacement ventilation. The results include measurements of mean velocity, turbulence intensity, and energy spectra. The impact of the initial conditions (mean velocity and turbulence intensity distribution at the outlet) on the airflow field is analysed.

Experimental conditions

The measurements were performed in twelve rooms with displacement ventilation used by people with sedentary activity. Floor area of the rooms ranged from 7 to 69 m^2. The spaces were selected to cover typical locations and types of outlets with different shapes (Fig. 1) encountered in Scandinavian ventilating practice. The spaces were furnished and the measurements were performed during normal operating conditions. At least two persons, those taking the measurements, were in the room. For larger spaces, the normal number of occupants was simulated by heated laminated cylinders.

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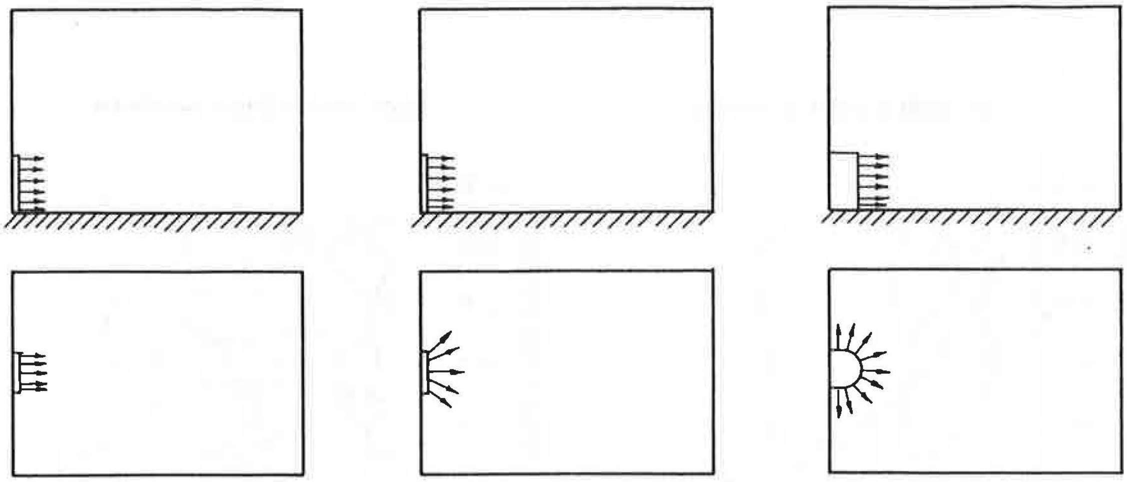

Fig. 1. Different ways of introducing supply air into the occupied zone. The upper row shows cross sections and the lower one shows plan views of the rooms.

In each space comprehensive measurements of mean velocity, standard deviation of the velocity, and air temperature were performed in front of the outlets and in their vicinity and also within the occupied zone at six heights: 0.033, 0.1, 0.3, 0.6, 1.1 and 1.7 m above floor level. Energy spectra of the velocity, standard deviation of the velocity and air temperature were measured by DANTEC Multichannel Flow Analyser - type 54N10 and Brüel & Kjaer Indoor Climate Analyser - type 1213. Instantaneous velocity was recorded on a tape recorder (Brüel & Kjaer - type 7005) and later analysed by a signal analyser (Brüel & Kjaer - type 3032).

The characteristics of the investigated spaces and the experimental conditions are described in detail by Melikov et al. (6).

Airflow characteristics at the outlets

Melikov et al. (6) have analysed, discussed and compared the results from the measurements in the occupied zone with measurements in rooms with mixed ventilation and heated rooms without mechanical ventilation. In the following only results from measurements in the vicinity of the outlets and near the outlet zone are included.

The low velocity outlets used for displacement ventilation can be divided into two groups according to their initial velocity profile. The first type of outlets, known as "low induction" (LI) outlets produce flow with relatively uniform initial velocity profile while the second type of outlets, known as "high induction" (HI) outlets produce flow with large variations of the initial velocity over the entire supply area. Figure 2 shows initial profiles of mean velocity, turbulence intensity and air temperature for several outlets of the two types. As expected the variations for the mean velocity and the turbulence intensity are larger for the HI outlets than for the LI outlets. It can be seen from Figure 2 that the initial velocity was not uniform for some of the LI outlets. Histograms of the mean velocity and the turbulence intensity for low and high induction outlets are shown in Figure 3. Measurements for twelve low-velocity outlets are pooled in the figure. Figures 2 and 3 show that LI outlets have lower initial turbulence intensity than HI outlets. Both types of outlets give almost equal uniform temperature profiles.

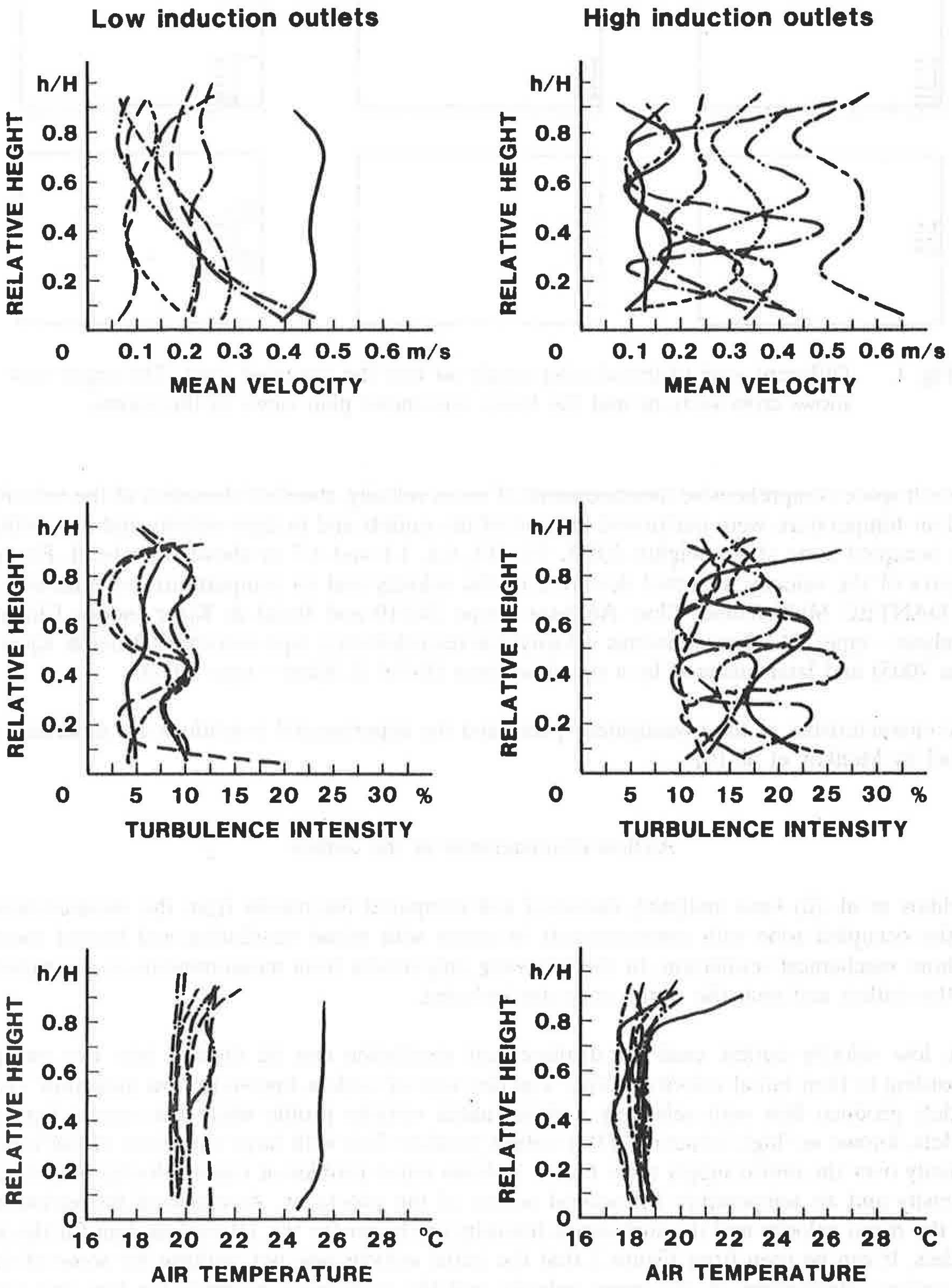

Fig. 2. Mean velocity, turbulence intensity and air temperature profiles in front of the outlets.

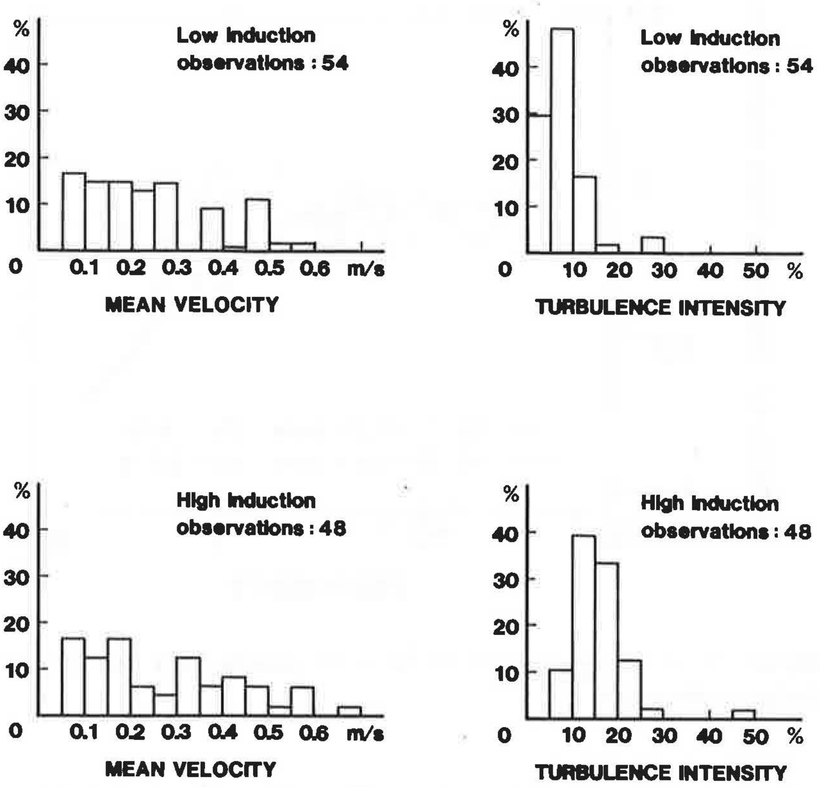

Fig. 3. Mean velocity and turbulence intensity histograms in front of the outlets.

The turbulent energy distribution in the frequency spectra depends on the mean velocity and the turbulence intensity. Typically for HI outlets, supply air flows out from holes or nozzles, thus forming systems of jets close to the outlet. Mean velocity and turbulence intensity profiles are not uniform, e.g. with rater high and low values (Fig.2). Because of this, the turbulent energy distribution in the spectra depends on where in the cross flow profile it was measured. In areas with low turbulence intensity the spectral distribution function remains in average with constant value for a wide range of frequencies. This is the case also for the spectra measured in front of LI outlets. In the areas in front of HI outlets with high turbulence intensity, the spectral distribution function decreases when the frequency increases. This is shown in Figure 4 which compares spectra with the same mean velocity and different turbulence intensity measured in front of the outlets. In the case of low turbulence intensity (LI outlet) the spectral distribution function remains in average with constant value almost up to 5 Hz, while in the case of high turbulence intensity (HI outlet) it gradually decreases after 0,4 Hz.

Airflow near to the outlets

Figures 5 and 6 present the airflow field on a vertical plane in front of low and high induction outlets. Lines with constant mean velocity and turbulence intensity are shown in the figures. The figures show clearly how in front of the outlets the airflow moves down to the floor. At some distance from the outlet (depending on the temperature difference of room and supply air and the initial conditions at the outlet) the supply air reaches the floor and spreads into the occupied zone. But the flows on the two figures are some how different. The flow on Figure 5 is more like wall type jet flow. In the core of the initial region mean velocity is high and

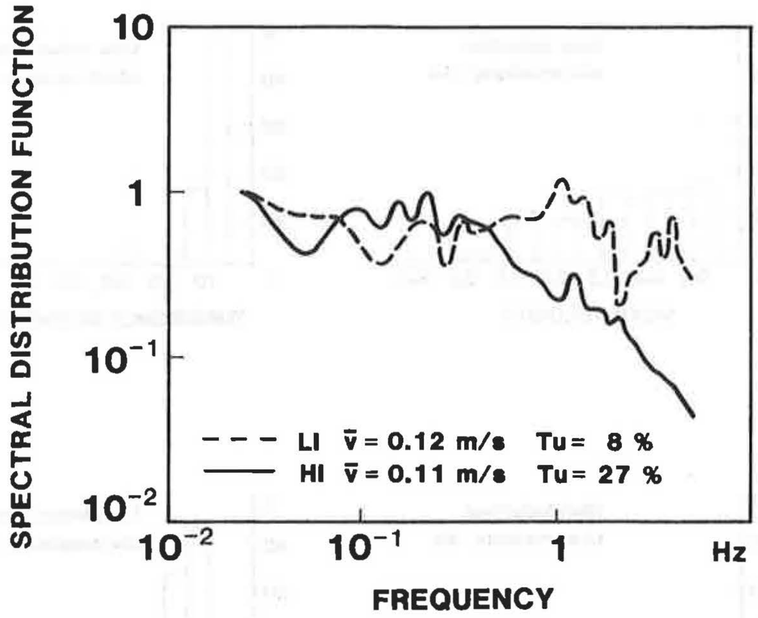

Fig. 4. Comparison of energy spectra in front of outlets with low (LI) and high (HI) turbulence intensity.

turbulence intensity low. With the distance from the outlet velocity decreases and turbulence intensity increases. Gradually, at long distance the flow becomes a fully developed turbulent flow. On the one side of the flow, near the floor, there is a boundary layer and on the other side, to the occupied zone, a free shear layer. In these areas of the flow mean velocity decreases and turbulence intensity increases out of the core. The flow in Figure 6 has the core with high mean velocity but not the core with low turbulence intensity. Turbulence intensity was measured to increase gradually from the floor. Areas with high mean velocity do not correspond to areas with low turbulence intensity. In the outer part of the flow there is a closed area with high turbulence intensity (30%) but it does not correspond to the area with maximum gradient of the mean velocity in the cross section profiles of the flow. This type of flow was identified in several rooms.

Smoke experiments by Nielsen et al. (2) showed that temperature difference between room and supply air was an important factor for the flow distribution after low velocity outlets. The larger the temperature difference, the more different the flow from wall type jet becomes. This temperature difference was 1.9 °C for the flow in Figure 5 and 5.1 °C for the flow in Figure 6. The small temperature difference makes the flow in Figure 5 closer to wall type jet. A large temperature difference will "push" the air to reach the floor closer to the outlet than small temperature difference. It was estimated that although the flow in Figure 6 had higher initial velocity than the flow in Figure 5, it reached the floor after approximately a distance corresponding to 1 height of the outlet, while the flow in Figure 5 after 1.5 heights of the outlet. The height for maximum velocity in the cross section of the flow varied in the investigated rooms (because of different conditions) but it was always measured below 0.15 m. The results show that the maximum velocity remains almost at the same height above the floor independently of the distance from the outlet, which corresponds with Nielsen et al. (2).

The energy spectra at different distance from the outlet are compared in Figure 7. The spectra in the figure were measured in points near the floor in the area of the maximum velocity. Near

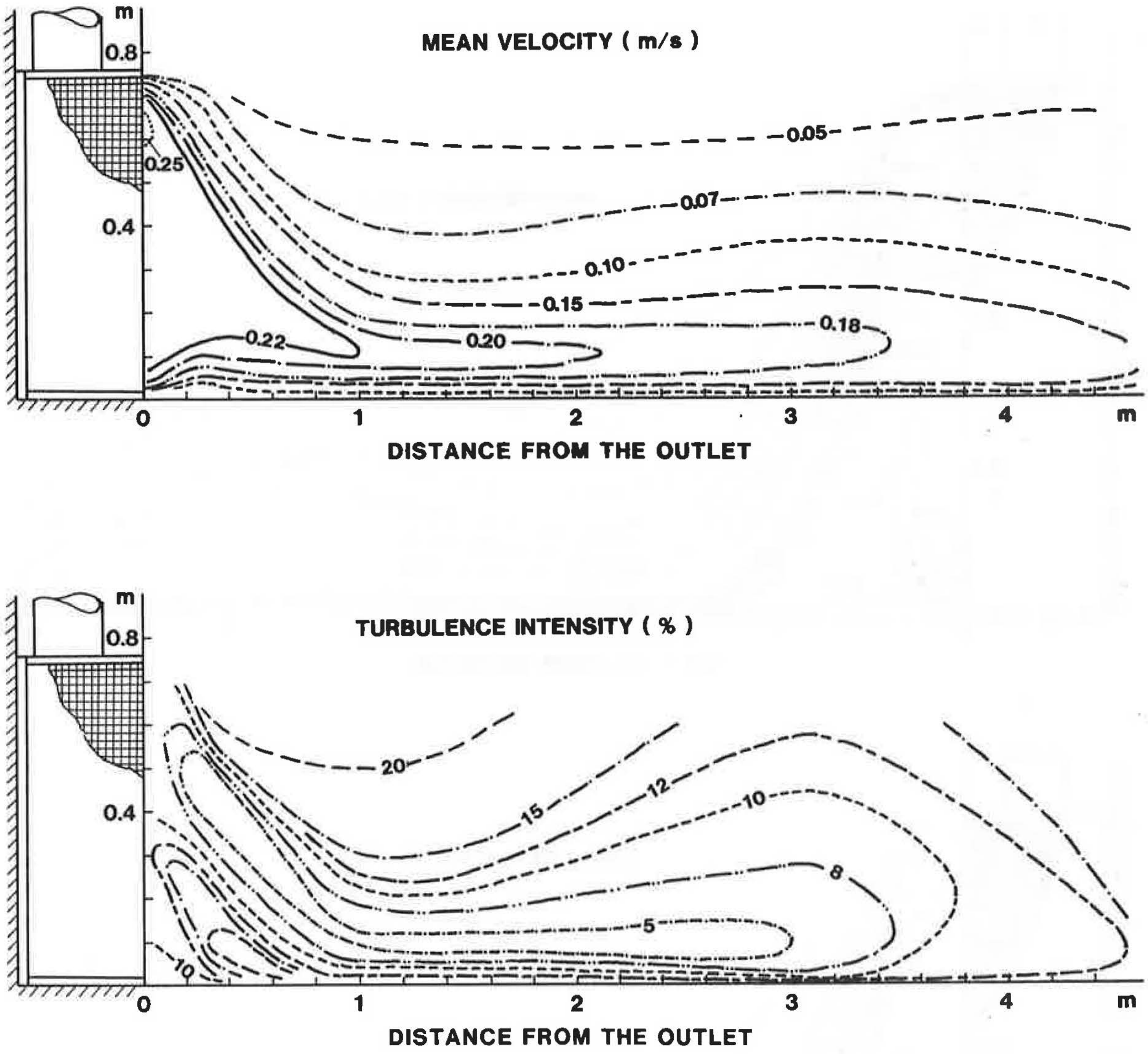

Fig. 5. Lines of constant mean velocity and turbulence intensity of airflow near low induction outlet.

the outlet turbulent energy is almost equally distributed in a wide range of frequencies. At some distance from the outlet the turbulent energy starts to concentrate in a narrow range of frequencies, forming a peak and finally, at a distance further from the outlet, the peak disappears. The energy distribution becomes similar to that in a fully developed turbulent flow with most of the energy concentrated at the low frequencies (6,7). The peak was identified more clearly when the difference between room and supply temperature was small. For large temperature differences the peak was observed but not so clearly because it was masked by high turbulence intensity in the areas with high mean velocity. It is believed that the peak is related to coherent structures, formed in the free shear-layer in the initial region of the flow. Well organised at the beginning as vortices, they move in the flow direction. They interact between themselves and inject air from the outer regions. In this way, promoting mixing of the supply air with the room air these vortices become more turbulent and transform into large-scale structures, eddies. The flow becomes fully turbulent. Depending on the initial and the room

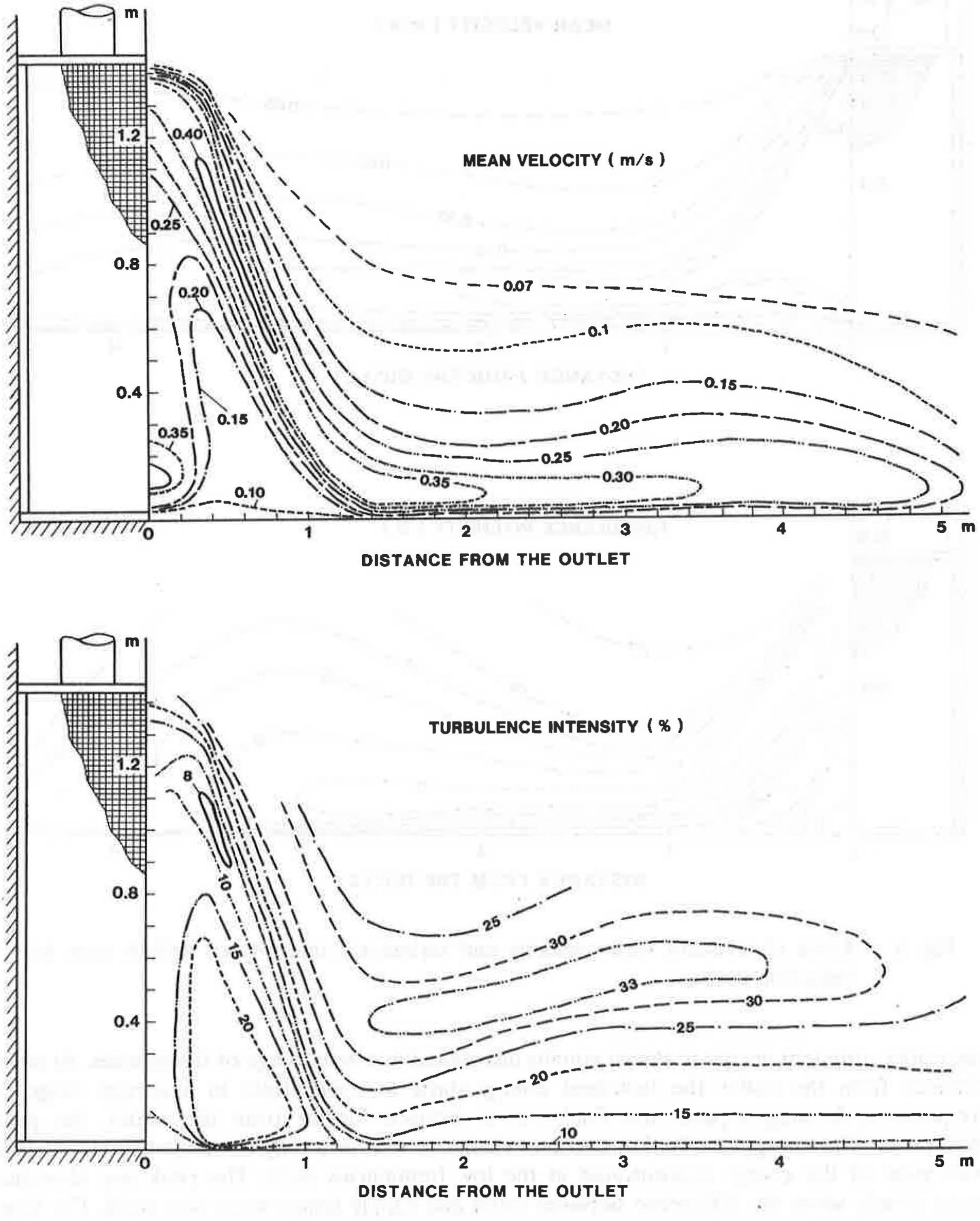

Fig. 6. Lines of constant mean velocity and turbulent intensity of air flow near high induction outlet.

conditions and the development of the flow, the peak was measured at different distances, up to 3.3 m from the outlet. Figure 8 presents energy spectra measured at different height above the floor at a distance of 0.6 m from the outlet. The corresponding mean velocity and

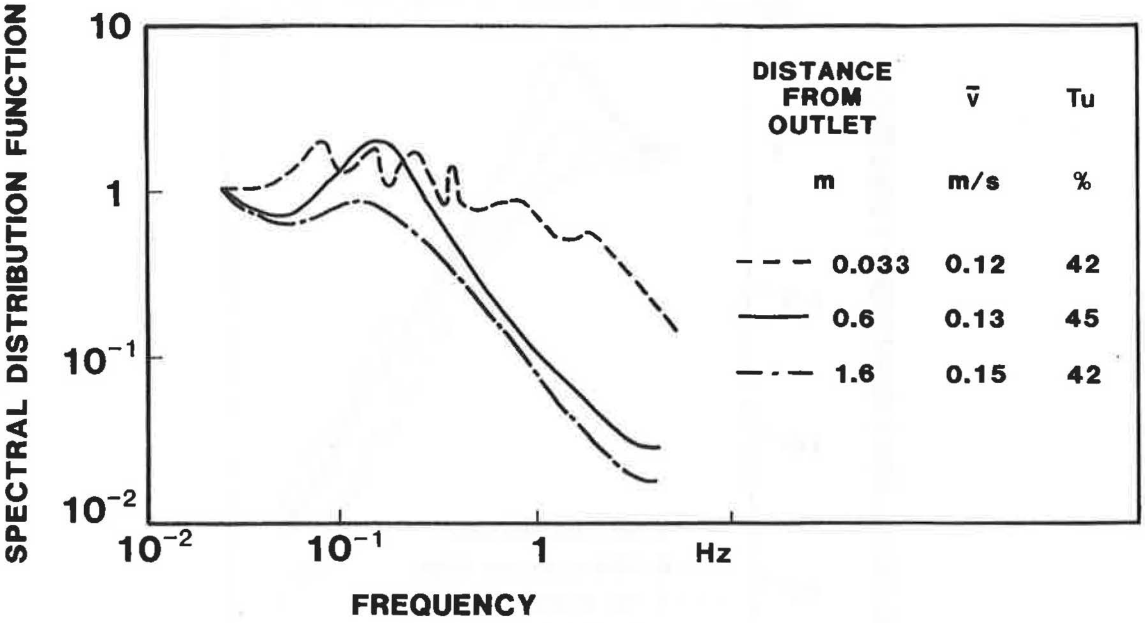

Fig. 7. Energy spectra at different distance from the outlet.

turbulence intensity profiles for the location where the spectra were measured are shown in Figure 9. The peak appears in the spectra curves for the points near the floor in the region with high mean velocity and low turbulence intensity. For some of the spectra measured, turbulent energy in the peak was calculated to be 68% of the total turbulent energy. This energy concentration is combined with a random turbulent field.

The near zone

In the literature, the zone near the air supply devices known as "near zone", is defined most often as the zone around the outlet within which the mean velocity is higher than 0.2 m/s (8). In some cases the near zone is restricted only for height 0.1 m above the floor level. The field measurements (6) identified higher velocities nearer to the floor than at 0.1 m height. Subjective studies by Fanger et al. (9) show that local discomfort due to draft depends on the mean velocity, the air temperature and the turbulence intensity. A model of draft risk was developed (9) which predicted the percentage of dissatisfied people due to draft (PD) as a function of mean velocity, $\bar{v}$ (m/s), turbulence intensity, Tu (%) and air temperature, t (°C):

$$PD = ((34 - t)\cdot(\bar{v} - 0.05)^{0.62}\cdot(3.14 + 0.37\cdot\bar{v}\cdot Tu)$$

for $\bar{v} < 0.05$ m/s insert $\bar{v} = 0.05$ m/s

for PD > 100% use PD = 100%.

The data from the present measurements were analysed by the model of draft risk. Figure 10 shows lines with constant PD for one of the low velocity supply devices. The lines of 10 and 15% dissatisfied are shown in the figure. For comparison the zone after the outlet with mean

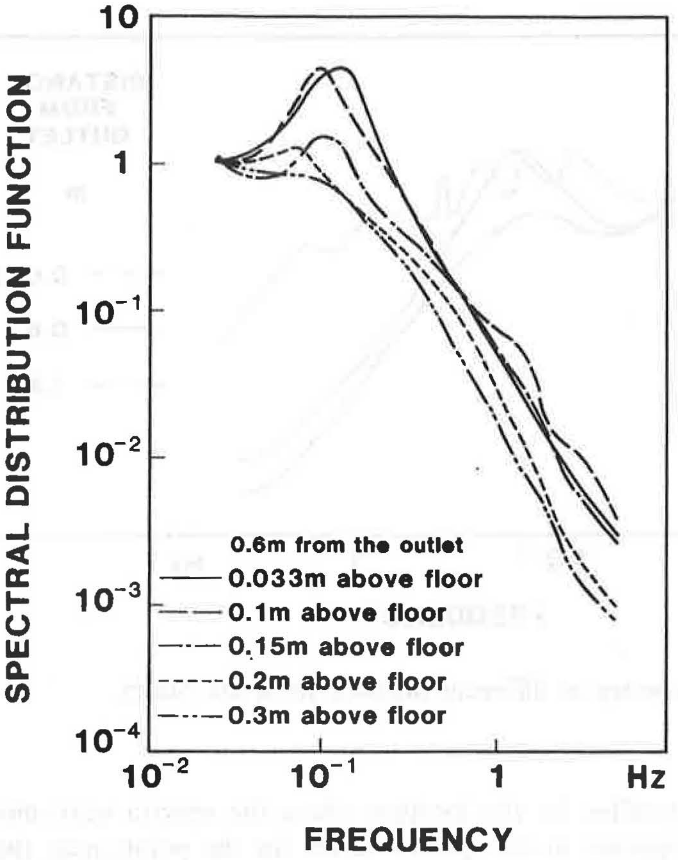

Fig. 8. Energy spectra measured 0.6 m from the outlet at different hights. The vertical axis represents the spectral distribution function divided by the spectral distribution function at 0.025 Hz.

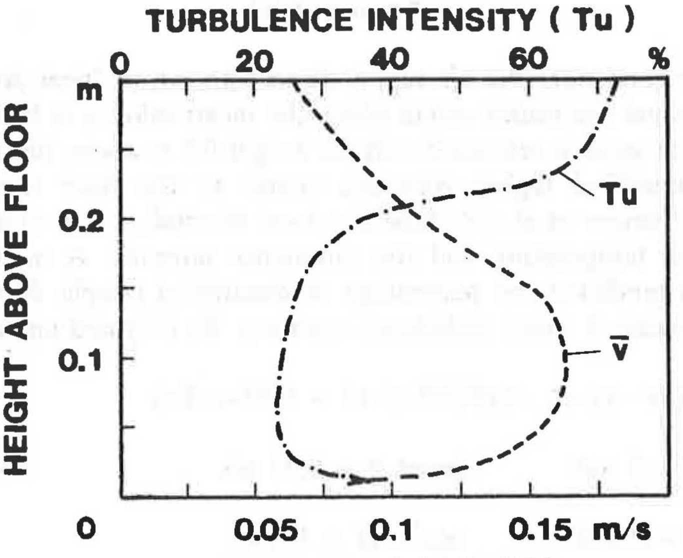

Fig. 9. Vertical profiles of mean velocity (v̄) and turbulence intensity (Tu) measured 0.6 m from the outlets.

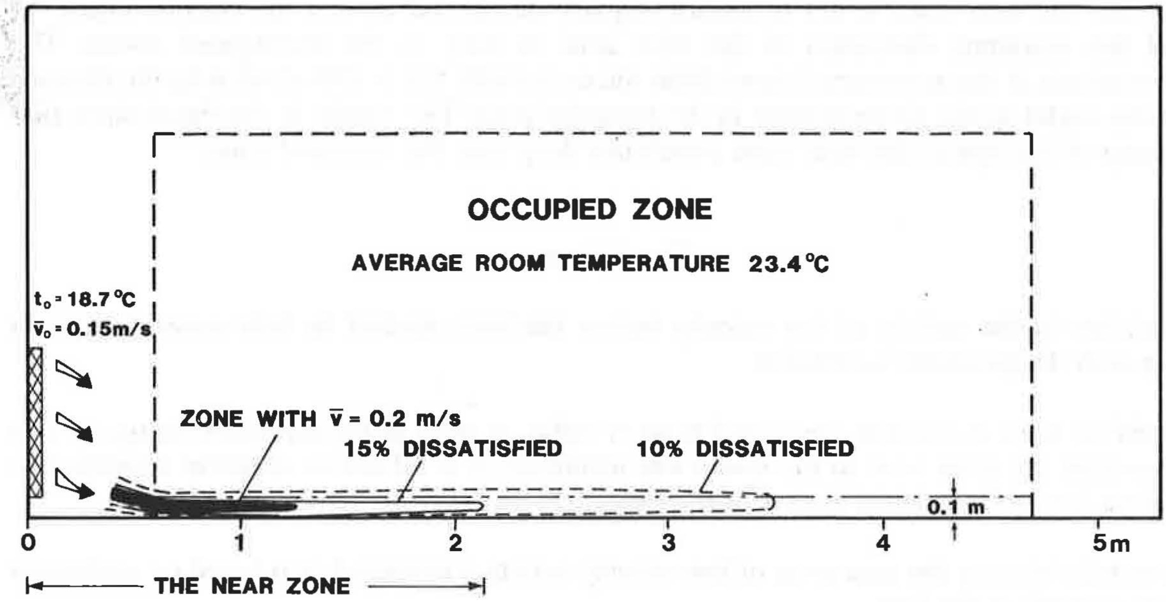

Fig. 10. Lines with constant Percentage of Dissatisfied due to draft after low velocity outlets. The calculations are based on the model by Fanger et al. (9).

velocity equal to or higher than 0.2 m/s is shown as well. It can be seen that in the occupied zone the velocities higher than 0.2 m/s are located below the height of 0.1 m. The limit of 15% dissatisfied due to draft was proposed by Fanger et al. (9) as the most realistic to be achieved in practice. Compared with the zone defined by the mean velocity of 0.2 m/s the zone for 15% dissatisfied penetrates almost twice as deep into the room. Therefore, as proposed by Melikov et al. (6), it is more reasonable to define the near zone as the zone around the outlet where PD is larger than 15%. Because of the location of outlets, arrangement of the furniture in the

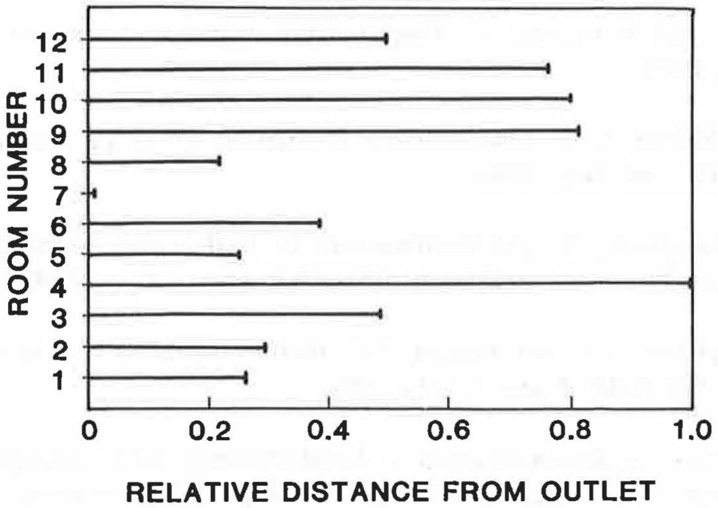

Fig. 11. Near zone in the investigated rooms. The relative distance is the maximum distance from the outlets where Percentage of Dissatisfied due to draft is higher than 15%, divided by the depth of the room.

room, etc. the near zone is not necessarily equally distributed around the outlets. Figure 11 shows the maximum dimension of the near zone in each of the investigated rooms. The horizontal axis is the maximum distance from the outlet with PD > 15% divided by the distance from the outlet to the farthest point in the occupied zone. The results in the figure show that for many of the spaces the near zone penetrates deep into the occupied zone.

Conclusions

The airflow in the vicinity of low velocity outlets has been studied by field measurements in rooms with displacement ventilation.

The airflow after the outlets was found to be complex. A peak in the turbulent energy spectra measured in the zone near to the outlet was identified. It is related to coherent structures in the shear layer of the initial region of the flow.

A new definition for the near zone of low velocity outlets is proposed. It is based on evaluation of risk of draft at the feet.

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