TURBULENCE INTENSITIES AND BUOYANCY EFFECTS IN A DISPLACEMENT VENTILATED ROOM MEASURED WITH LDA

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SUMMARY

The objective of this paper is to examine the air flow patterns and air turbulence behaviour in a displacement ventilated room. LDA (Laser-Doppler-Anemometry) technique produces data, not only on the average velocities and their fluctuations, but also on the direction of air flow. Three individual counter-flowing horizontal strata were observed. The mean vertical air velocities, outside of the buoyant plumes arising from the heat sources, were minimal. However, the presence of turbulence creates a different form of behaviour. High turbulence values were apparent throughout the whole room. This was a result of the unstable turbulent situation near the floor, where a negative temperature gradient increased the vertical turbulence, or the exchange of air pockets. Cooling of the floor surface temperature resulted in the reduction of this temperature gradient and the elimination of turbulence at this point. This may result in an improvement of the comfort conditions.

INTRODUCTION

It is commonly believed that turbulence levels in a displacement ventilated room are lower than those in a room with a mixing ventilation system. This is based primarily on the fact that lower supply air velocities are used. It is possible that this relationship is actually more complex than at first envisaged.

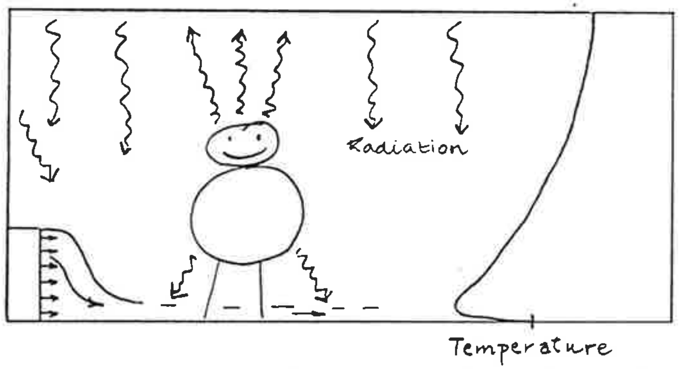

Fig.1. A typical situation representing displacement ventilation. The vertical temperature gradient is shown to the right of the diagram. The floor temperature is higher than that of the air which flows just above it. This is caused by radiation from heat sources, the ceiling and walls.

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Just above the floor level, the vertical temperature gradient is negative, while throughout the rest of the room it is positive. This negative temperature gradient could have an effect on the turbulence throughout the room. Refer to Fig. 2.

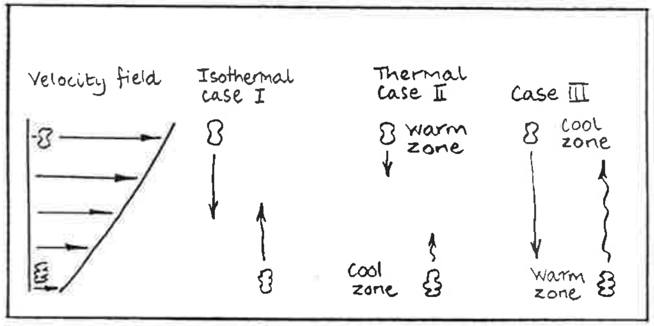

Fig. 2. A simple explanation of the turbulent behaviour. Small pockets of air with differing velocities in the main airstream exchange position under different thermal conditions. The thermal conditions can either dampen or amplify this process, indicated in cases II and III, respectively.

Case III has clearly the greatest turbulence relationship. The buoyancy effect assists air pockets with different velocities in the main airstream to interchange. In a displacement ventilation system such conditions exist immediately above the floor level.

TEST PROCEDURE

The experiments were carried out in a full scale test room at the Sulzer Infra laboratory, refer to Fig. 3. The room, with dimensions of 6.70 m x 4.40 m x 2.65 m (LxWxH), had a floor area of about 30 m^2 and a volume of about 80 m^3. The walls, floor and ceiling could be either heated or cooled. Five air changes per hour were provided via a displacement ventilation diffuser built into the middle of the wall construction. Exhaust air was removed via air handling luminaires. The heat output of occupants was simulated using eight hollow vertical internally heated cylinders. The total heat gain of about 800 W (27 W/m^2) was offset by either the supply air or a combination of the supply air and floor cooling, maintaining the room in equilibrium.

Air velocities were measured by means of a Laser-Doppler-Anemometer (LDA). The LDA provides a virtually disturbance-free measurement of turbulent airflow. By making measurements at two different angles it was possible to determine the vector components of the mean velocity and the turbulence level. An optical probe with a focal length of 300 mm was used. A remote control device enabled the probe to be moved without the necessity to enter the room. Refer to Fig. 4.

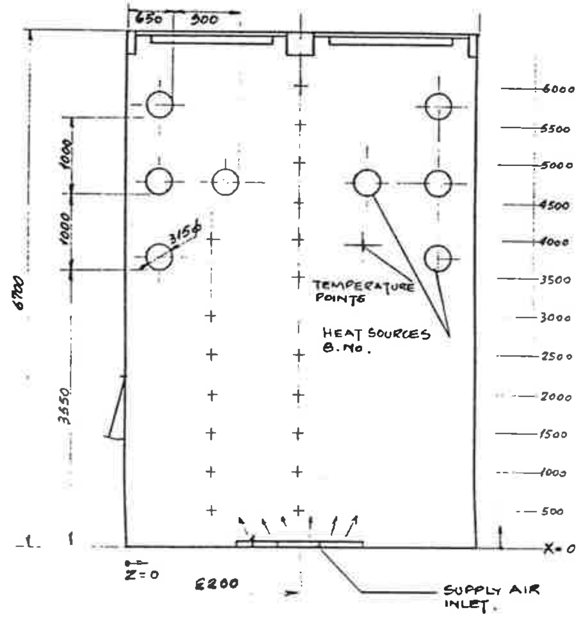

Fig. 3. Room set-up showing the position of the diffuser and the heat sources. The measurement positions are also indicated.

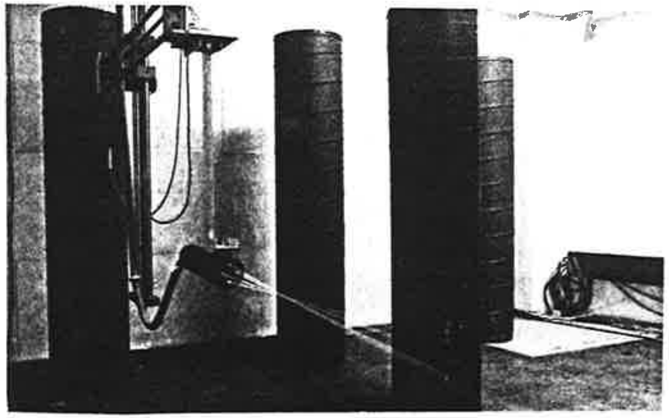

Fig. 4. Velocity measurement using LDA in a ventilated room. The probe is mounted on a traversing mechanism. The point where the laser beams are seen to cross is the point of measurement.

MEASUREMENT RESULTS

The results of two experiments with the same air quantity (400 m^3/h) and heat load (27 W/m^2), but with different floor surface temperatures, namely 23.2°C and 19.5°C, are presented. In the latter case, the floor was cooled.

Air Flow Pattern

The supply air from the wall diffuser travels horizontally along the floor surface until it meets the opposite wall, where it reverses direction and forms a higher level air stream travelling in a direction opposite to that of the one below. In the room, three separate horizontal layers are formed. The ascertained velocity profiles at three positions are presented in Fig. 5.

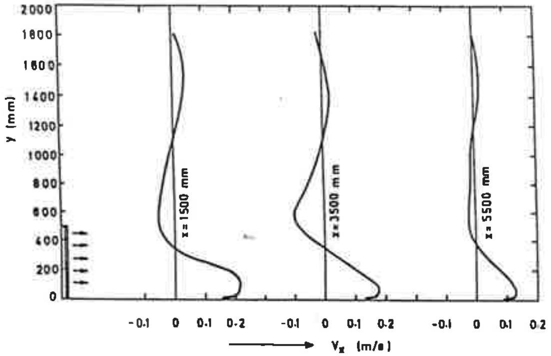

Fig. 5. Vertical velocity distribution profiles (x-component) along the centre-line of the room.

Temperature and Turbulence

The measured temperatures and vertical RMS velocities are portrayed in Figs. 6 and 7.

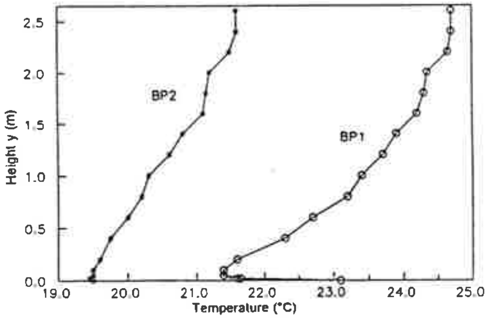

Fig. 6. Vertical temperature distribution in the room with and without floor cooling. Operating points BP2 and BP1, respectively.

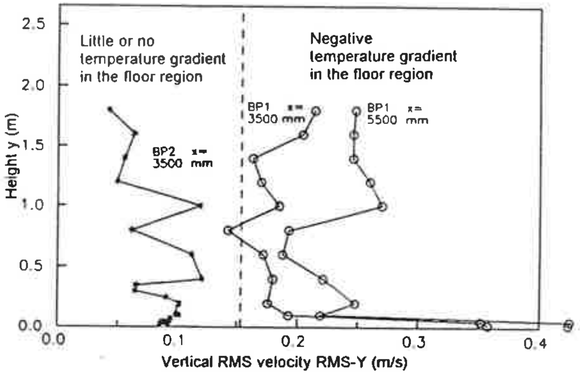

Fig. 7. Vertical RMS velocities (y-component) with and without a negative temperature gradient at the floor. Operating points BP2 and BP1, respectively.

The air flow in the zone just above the floor is unstable. This is because of structural turbulence phenomena. In addition, there exist vertical instability or exchanges of air in the vertical axis throughout the whole room. The relationship can be described in the following way:

- The temperature of the floor has a significant effect on the turbulence process in the room. Negative temperature gradients cause large RMS velocities within 50 mm above the floor level, as seen to the right in Fig. 7. This situation propagates itself throughout the whole room in a vertical direction.
- The two horizontal RMS velocities and the vertical RMS velocity have the same order of magnitude. The slightly higher vertical values grow down stream. This is particularly clear with the negative temperature gradient.
- With little or no temperature gradient at the floor, resulting from floor (or ceiling) cooling, a more uniform flow exists with little turbulence. In particular, the vertical RMS velocities were lower; refer to Fig. 7 on the left-hand side. In the region 50 mm above the floor they are one fourth and in the remaining area above, one half of the magnitude shown before.

CONCLUSIONS

A typical air flow pattern characteristic of a displacement ventilation system was observed. The cooler supply air from the wall diffuser spread itself out in the floor region due to the greater density of the air. The development of three layers of flow, each one situated above the other, was observed. The layer next to the floor level and the top layer flowed in the same direction, while the in-between layer flowed in the opposite direction, back towards the air outlet wall.

High turbulence levels existed throughout the entire room. This was a result of the unstable turbulent events in the floor region, where a negative temperature gradient above the floor amplified the vertical turbulence.

A reduction in the floor surface temperature, by means of a cooled floor, contributed towards better comfort conditions. The temperature gradient was made smaller and the turbulence eliminated.

The Laser-Doppler-Anemometry (LDA) measuring technique enabled these phenomena to be studied. The results would not have been feasible using traditional hot-wire anemometry.

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