EFFECTIVE VENTILATION

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Poster 2

DISPLACEMENT VENTILATION BY DIFFERENT TYPES OF DIFFUSERS

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SYNOPSIS

The paper describes measuring results of the air movement from three different types of diffusers for displacement ventilation. Two of the diffusers are low-level wall mounted diffusers, one with a low and one with a high initial entrainment. The third diffuser is of the floor mounted type.

The air flow close to the diffusers and in the rest of the room is analysed. Velocity decay in the flow from the low-level diffusers is given as a function of the Archimedes number, and the paper suggests a general equation for this part of the flow. The velocity level and velocity decay in the flow are dependent on the room geometry. The flow is not influenced by the Reynolds number for supply flow above a certain level.

Measurements of the turbulence intensity show a level in the cold flow along the floor which is rather equivalent to the level in an isothermal wall jet.

The floor mounted diffuser generates a circular jet with swirl along a vertical line in the room. The velocity decay in the flow from this jet is high compared to the decay in a conventional, free circular jet.

The ventilation efficiency based on temperatures and vertical temperature profiles are given for the diffusers for different levels of air exchange rates and thermal loads. The ventilation efficiency varies between 1.5 and 2.3 for all diffusers and it is rather unaffected by the type of diffuser.

LIST OF SYMBOLS

Ar	Archimedes number	
a_o	Diffuser supply area	m^2
H	Height of room	m
K	Constant for low-level diffuser	
K_a	Constant for diffuser	
L	Length of room	m
n	Exponent	
Q	Heat emission	W
q_o	Volumen flow	m^3/s
Re	Reynolds number	
T	Temperature	C
T_o	Supply temperature	C
T_{oc}	Mean temperature in the occupied zone	C
T_R	Return temperature	C
u	Mean velocity	m/s
$\hat{u}$	Instantaneous velocity	m/s
u'	Velocity fluctuation	m/s
u_o	Supply velocity	m/s
u_x	Maximum velocity along floor	m/s
v_o	Supply velocity	m/s
v_y	Maximum vertical velocity	m/s
W	Width of room	m
x	Coordinate	m
y	Coordinate	m
z	Coordinate	m
δ	Thickness of flow at the floor	m
ε_T	Ventilation (temperature) efficiency	

1. INTRODUCTION

Ventilation systems with vertical displacement flow have been used in industrial areas with high thermal loads for many years. Quite resently the vertical displacement flow systems have grown popular as comfort ventilation in rooms with thermal loads e.g. offices.

The air is supplied directly into the occupied zone at low velocities from wall mounted or floor mounted diffusers.

The plumes from hot surfaces, from equipment and from persons entrain air into the occupied zone and create a natural convection flow upwards in the room, see figure 1.

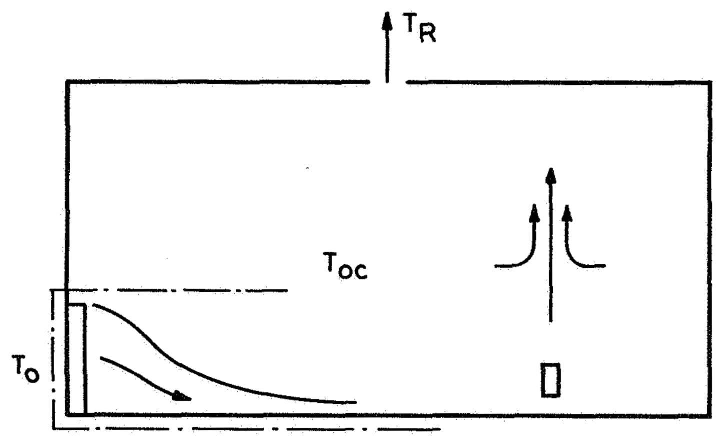


Fig. 1. Room with low-level diffuser, heat source and displacement flow.

The displacement flow systems have two advantages compared with traditional mixing systems.

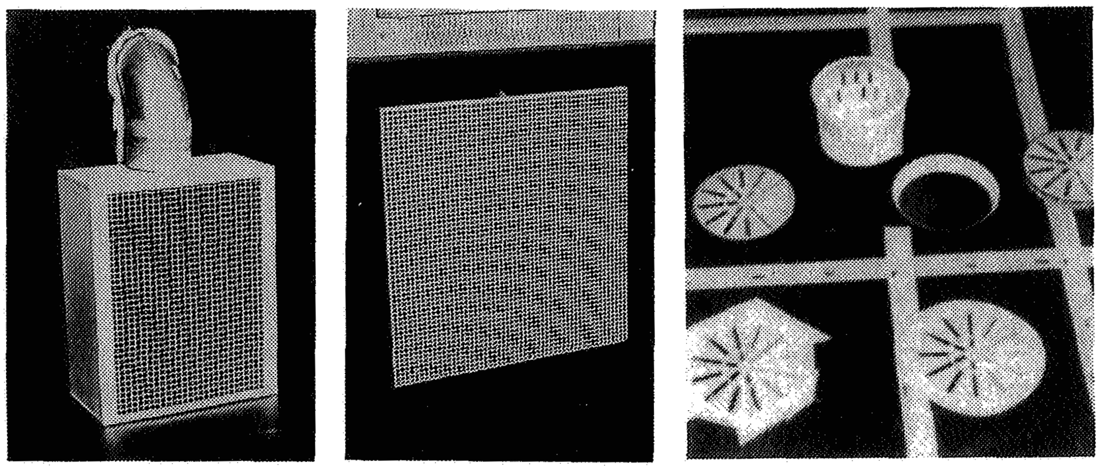
- An efficient use of energy. It is possible to remove exhaust air from the room where the temperature is several degrees above the temperature in the occupied zone which allows a higher air inlet temperature at the same load.

- An appropriate distribution of contaminant air. The vertical temperature gradient (or stratification) implies that fresh air and contaminant air are separated. The most contaminant air can be found above the occupied zone and the air flow supplied can be reduced.

A general description of the displacement ventilation system has recently been given by Skåret[1], model experiments have been shown by Sandberg and Lindström[2], and measurements in plumes have been given by Kofoed and Nielsen[3].

This paper will deal with the flow from different types of diffusers and it shows the main characteristics of the air movement which takes place in the lower part of the room (within the dotted line in fig. 1). The paper will further deal with the temperature distribution and the ventilation efficiency (temperature efficiency) obtained in the room using different types of diffusers.

2. DIFFUSERS

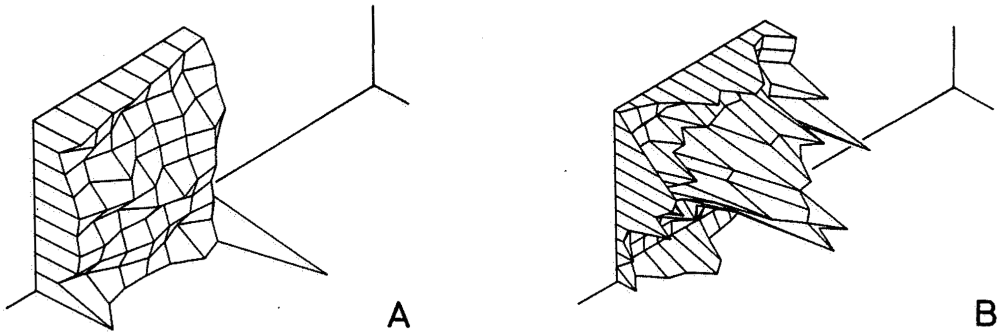


A B C

Fig. 2. Two low-level diffusers, type A and B, and a floor mounted diffuser, type C.

Figure 2 shows three different diffusers used in the experiments. The diffusers of types A and B are both low-level diffusers giving a horizontal air flow directly into the occupied zone. They both have a height of about 500 mm, but a different design. The diffuser A has a supply velocity profile which is very constant over the entire supply area, while the diffuser of type B has a supply velocity with a large variation over the supply area, see fig. 3. This variation applies to velocity level as well as to direction, and it means that the local entrainment - or diffusion - is very high close to the opening.

The third diffuser used in the experiments is a floor mounted diffuser called type C. This diffuser gives a vertical circular free jet with swirl and it is used in practice in groups of four as shown in figure 2.



A B

Fig. 3. Supply velocity profile for diffuser A and B.

The experiments take place in a test room of the dimensions L × W × H = 5.4 × 3.6 × 2.6 m. The low-level diffusers are mounted in the middle of the short end wall, while the floor mounted diffusers are located in the middle of the floor. The heat source is installed in the middle plane at a distance of 0.75 × L from the end wall. The return opening is in the middle of the ceiling.

Calculation of temperature efficiency requires measurements of the temperature distribution in the room measurements of the supply temperature T_o and the return temperature T_R. The temperature distribution in the room is measured at 24 points located at three vertical lines in the room.

3. FLOW FROM LOW-LEVEL DIFFUSERS

The flow pattern close to the openings and the local entrainment of room air influence the air movement in the room. Smoke experiments show that the flow from diffuser A spreads out within a 90° area downstream along the floor. Large temperature differences ($T_{oc} - T_o \sim 12 - 14$ K) will increase the angle and small temperature differences will decrease the angle giving a flow of a three-dimensional wall jet type for $T_{oc} - T_o \sim 0$ K.

Smoke experiments with diffuser B show that this diffuser spreads the flow over the whole floor area (180°) at all temperature differences.

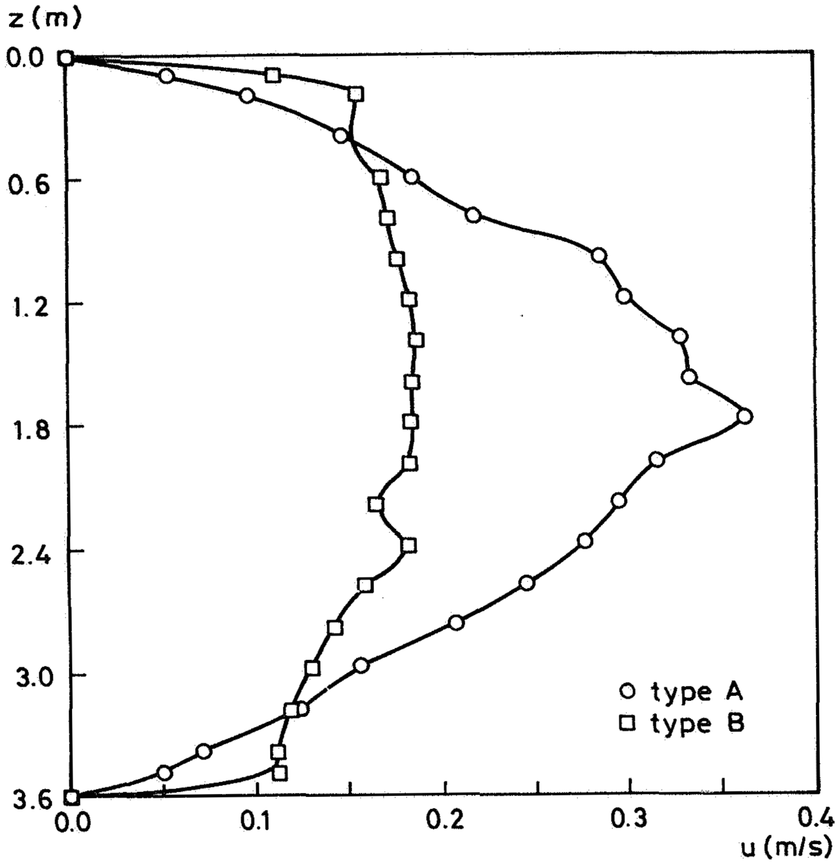


Fig. 4. Velocity distribution close to the floor in a cross-section of the room. $x = 2.4$ m, $y \sim 0.04$ m, $q_o = 0.056$ m³/s, $T_{oc} - T_o \sim 5$ K.

It is obvious that the two different low-level supply openings - with various initial diffusion - will give a different air movement in the room. Figure 4 shows the maximum velocity close to the floor (4 cm) at a distance of 2.4 m from the diffusers. Figure 4 shows that diffuser A generates a more concentrated flow in the middle plane of the room, while diffuser B spreads the flow over the whole width of the room. This implies that the velocity level will be dependent on room width in the latter case.

Figure 5 shows the velocity decay in the air movement along the floor for both supply openings. The figure indicates that the maximum velocity u_x along the floor is proportional to $1/x^n$ where the exponent n is about 1. The low diffusion in supply opening A results in a high initial acceleration of the air movement due to buoyancy effect on the cold supply air. The velocity level obtained, results in a high velocity in the whole flow along the floor.

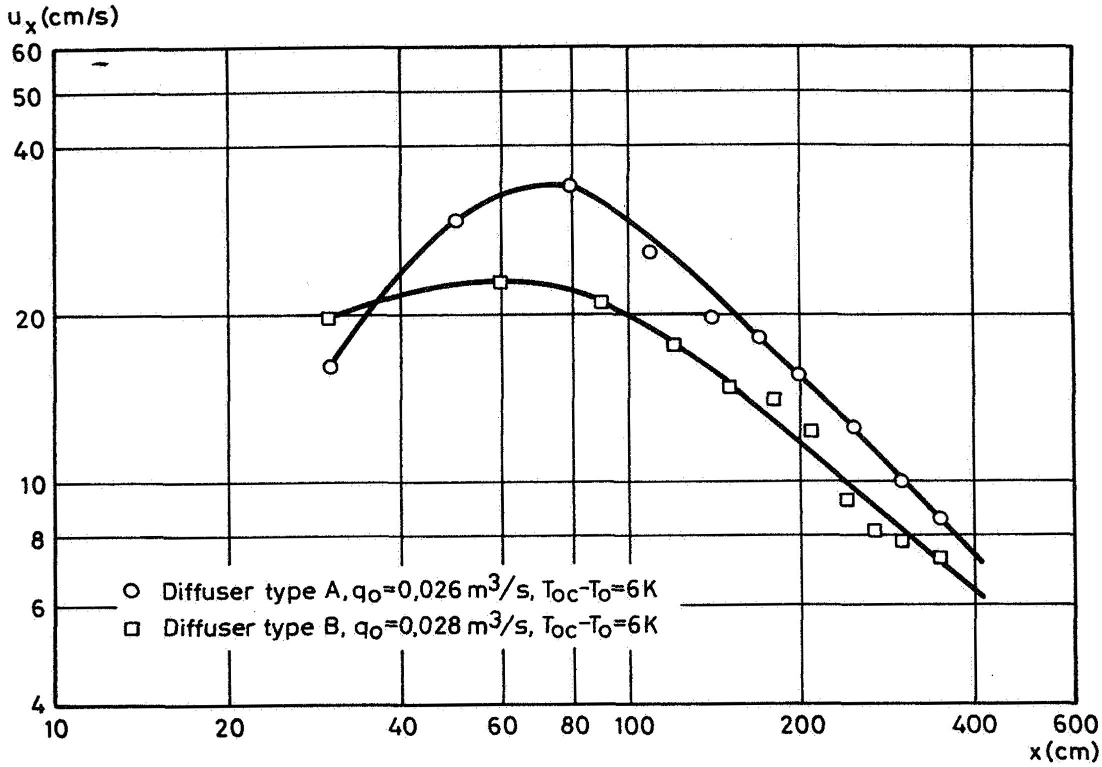


Fig. 5. Maximum velocity in flow versus distance from diffuser.

The flow from diffuser B is also dependent on buoyancy but the acceleration close to the supply opening is smaller due to the high initial entrainment of room air.

It is possible to describe the air movement along the floor by the following equation

$$\frac{u_x}{u_o} = K\left(\frac{\sqrt{a_o}}{x}\right)^n \qquad (1)$$

This description is slightly similar to the equation for velocity decay in a wall jet, but the flow is strongly affected by buoyancy expressed by a K-factor which is a function of the Archimedes number Ar.

$$K = \mathrm{func}\left(\frac{\sqrt{a_o}(T_{oc} - T_o)}{u_o^2}\right) \qquad (2)$$

The height of the flow along the floor is typical 0.2 - 0.25 m and the maximum velocity is located 0.03 - 0.04

m above the floor surface independently of distance from the diffuser.

The velocity decay in the flow from the diffuser is influenced by the location of the side wall. Figure 6 shows the velocity decay from a low-level diffuser mounted in the middle plane of the room and the velocity decay from the same diffuser mounted close to the side wall. The velocity level in the flow is higher when the diffuser is mounted close to a side wall and the exponent n is smaller.

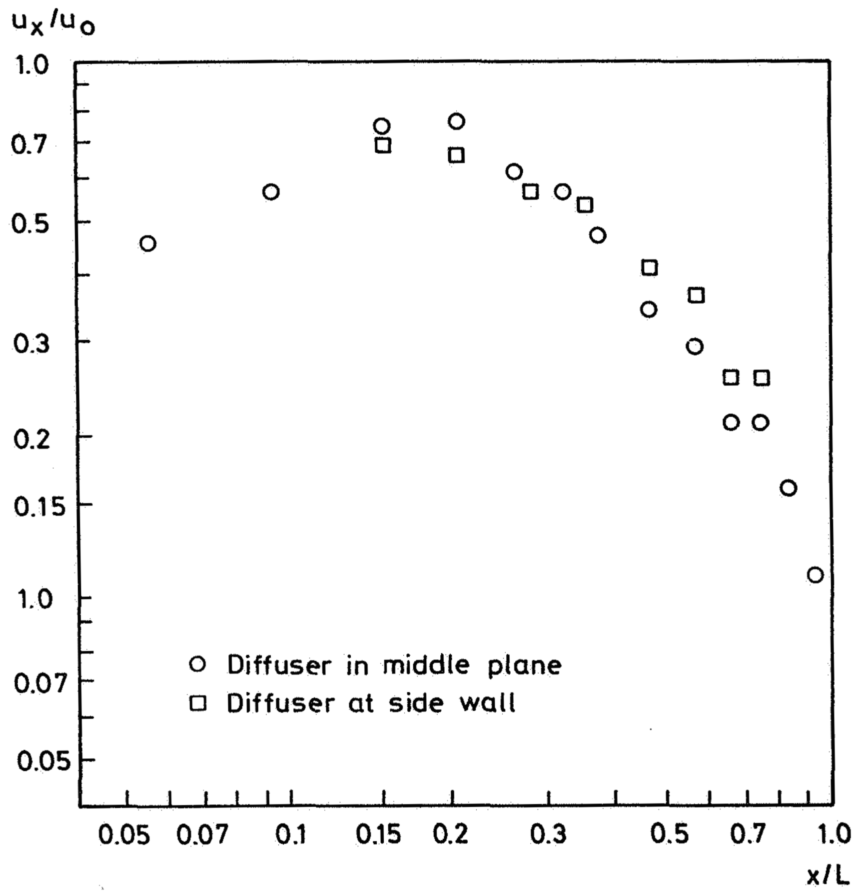


Fig. 6. Velocity decay versus distance for two locations of diffuser type A, q_o = 0.026 m³/s, $T_{oc} - T_o$ = 3.0 K.

It is generally shown by all the experiments that equation (1) is suitable for description of the velocity decay along the floor in a room. But it is also shown that both K and n are functions of diffuser type and diffuser location in the room, as well as room width, implying that-it is difficult to separate the influence of diffuser design from the influence of room geometry.

Air movement in ventilated rooms with high supply velocities will be self-similar and will be only slightly dependent on the Reynolds number Re due to the high level of turbulence in the room as shown e.g. by Nielsen[4].

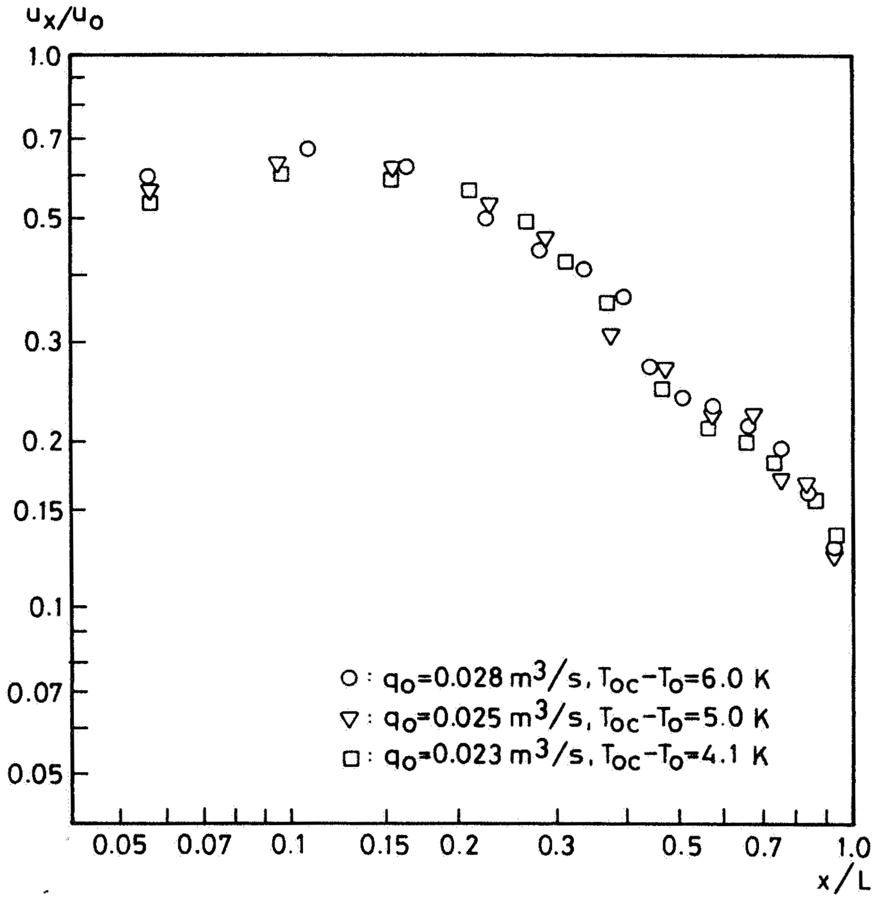


Fig. 7. Velocity decay versus distance measured for identical Archimedes number, for three different Reynolds numbers. Diffuser type B.

Figure 7 shows the results of three experiments with similar Archimedes number and different Reynolds number. The flow is self-similar and it may be concluded that the air movement has a sufficient turbulence level for $q_o > 0.023\ m^3/s$ and it is thus independent of the Reynolds number. This also means that the coefficient in equation (1) is uninfluenced by the supply velocity u_o and the Reynolds number Re for a sufficient level of the supply flow q_o.

Fanger et al.[5] have shown that the thermal comfort is influenced by mean air velocity and by turbulence. It is therefore important to study the turbulence in the room air movement. An instant velocity $\hat{u}$ can be expressed by

$$\hat{u} = u + u' \tag{3}$$

where u is the mean velocity and u' is an instantaneous deviation from the mean velocity. It is convenient to express a one-directional turbulent intensity by the following expression

$$\frac{\sqrt{\overline{u'^2}}}{u} \tag{4}$$

which is measured with a hot-wire probe in areas with sufficient mean velocity.

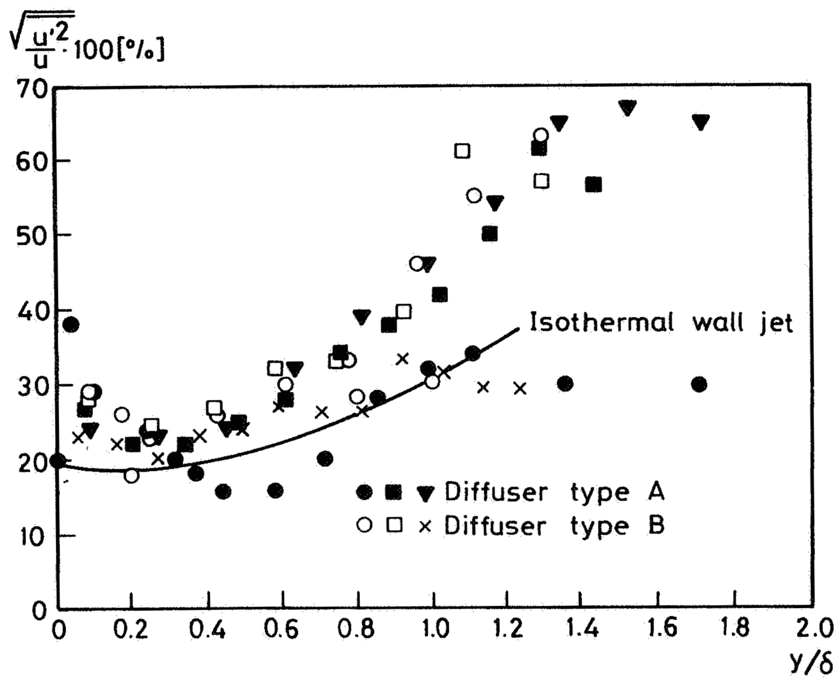


Fig. 8. Turbulence intensity in the flow close to the floor for diffuser A and B.

Figure 8 shows the distribution of turbulence intensity in the flow close to the floor (≦ 0.25 m). All measurements have been taken at a distance of 2.2 m from the diffuser at a flow of 0.056 m³/s for different temperature differences, $0.3 \leqq T_{OC} - T_O \leqq 6.2$. The thickness δ of the flow is defined as the height to half the maximum velocity $u_x/2$, and the measured turbulence intensity is compared with the level in an isothermal wall jet. It may be concluded that the turbulence intensity in the flow from a low-level diffuser is of the same level as the turbulence intensity in a room with traditionel jet ventilation (mixing system).

The measurements in figure 8 only cover a small area of the room. It is not possible to measure the intensity above the flow close to the floor with a simple hot-wire anemometer due to a low mean velocity in that area.

4. FLOOR MOUNTED DIFFUSER

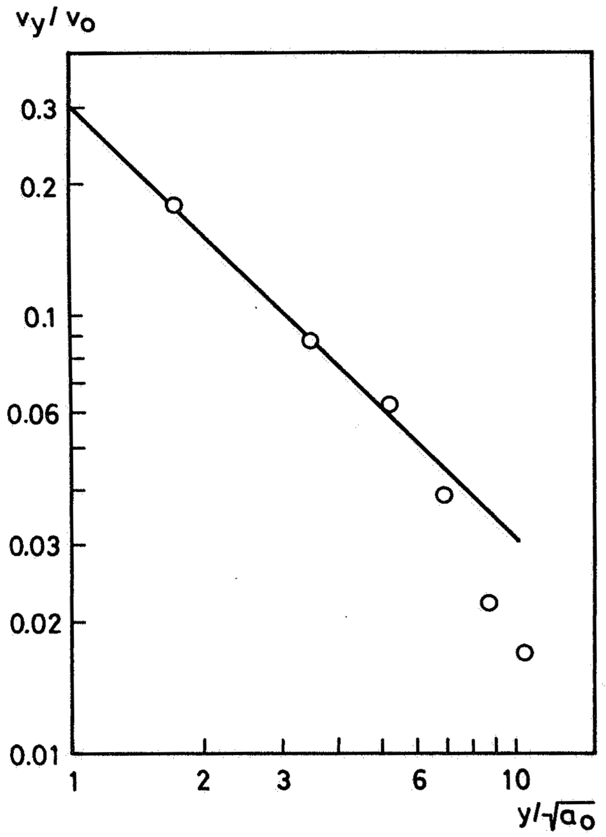


Fig. 9. Velocity decay versus vertical distance for a single floor mounted diffuser (type C).

An alternative method of locating inlet openings for displacement ventilation is floor mounted diffusers. Figure 2 shows a diffuser, called type C, which generates a vertical circular free jet with swirl. It is convenient to compare the velocity decay in this jet with the velocity decay in a conventional circular free jet given by

$$\frac{v_y}{v_o} = \frac{K_a}{\sqrt{2}} \frac{\sqrt{a_o}}{y} \tag{5}$$

The measurements in figure 9 show the velocity decay in a vertical jet with swirl. The measurements correspond to a $K_a/\sqrt{2}$ - value of 0.30 which is about ten times smaller than the same value for a conventional axesymmetric free jet. It is an important conclusion that a jet with swirl has a very fast velocity decay which has also been measured by Balandina and Lovtsov[6].

The floor mounted diffuser, type C, is often used in a group of four within an area 0.6 m × 0.6 m. In this case the measured velocity level is higher than the velocity level from a single diffuser but both of them have the same level at a height of 0.8 m.

5. VERTICAL TEMPERATURE GRADIENT AND VENTILATION EFFICIENCY

It is important that the diffuser used for displacement ventilation is able to generate good thermal conditions in the occupied zone of the room. It is also important that the ventilation system - including the diffusers - is able to generate a high ventilation efficiency, which will be discussed in this section of the paper.

It is possible to remove exhaust air from the room with a temperature several degrees above the average temperature in the occupied zone, which means an efficient use of energy in the ventilation system. The vertical temperature gradient will show this effect, especially in non-dimensional form, as given in figure 10, when all temperatures are divided by the temperature difference between return and supply.

Figure 10 shows that an increasing flow rate q_o increases the difference between the return temperature T_R and the average temperature in the occupied zone (in a non-dimensional form). This leads to an increasingly efficient use of energy for the diffuser type B at the given heat load.

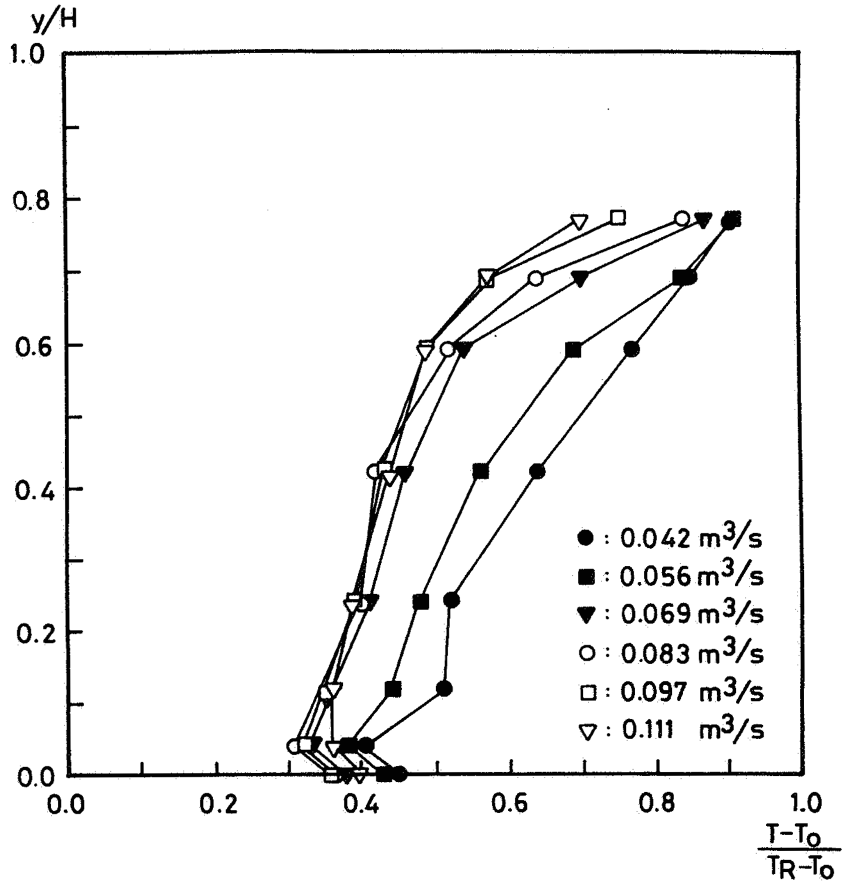


Fig. 10. Vertical temperature distribution for different air flow rates. Diffuser type B. Q = 500 W. Measurements by M. Andersen et al.[7].

The entrainment of air into the hot plume above the heat source, fig. 1, will often generate an area with recirculation of hot and contaminant air below the ceiling of the room. The height to this area will increase with the supply flow q_o, and smoke experiments show a height of ~ 1.7 m for a volumen of 0.07 m^3/s when the heat source has an emission of 500 W. This height is about the height of the occupied zone corresponding to a resonable design of a system in practice in an office.

The ventilation efficiency based on temperature is given by the equation

$$\varepsilon_T = \frac{T_R - T_o}{T_{oc} - T_o} \qquad (6)$$

where T_{oc} in this section is defined as the average temperature of the occupied zone measured at 24 points up to the height of 2.1 m. (The average temperature of the occupied zone used in section 3 is defined as the temperature at x, y, z = 3.0, 1.0, 1.8 m).

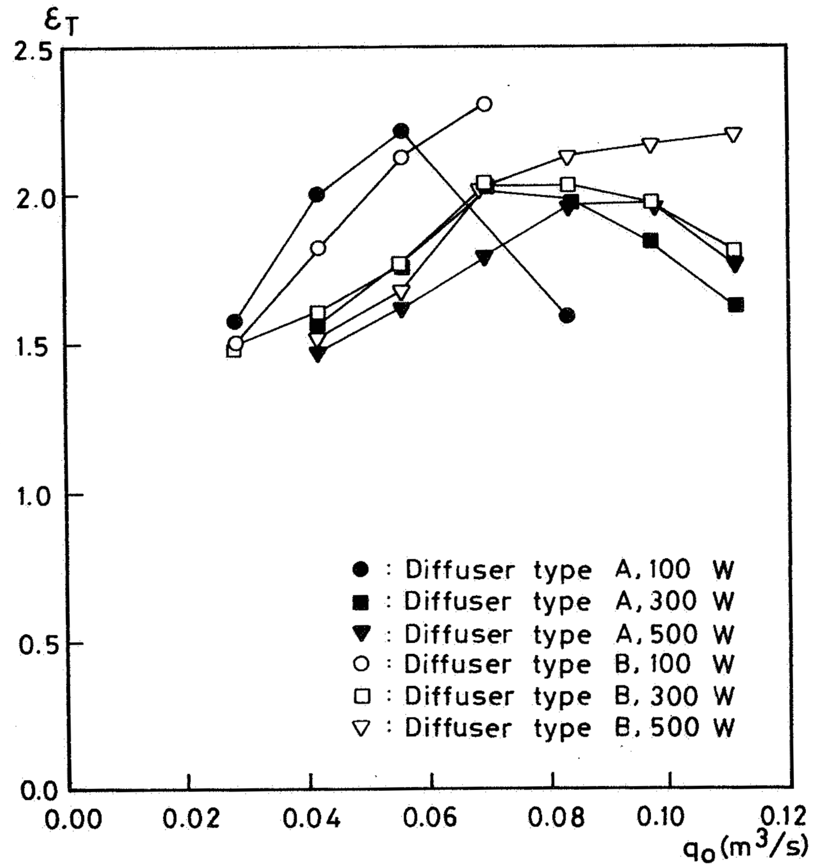


Fig. 11. Ventilation efficiency for diffusers A and B for different flow rates. Measurements by M. Andersen et al.[7].

Figure 11 shows the ventilation efficiency for diffusers A and B. The efficiency varies between 1.5 and 2.3 dependend on the flow rate, which is also the level for the floor mounted diffuser type C.

The ventilation efficiency seems to obtain the same level rather independently of the type of diffuser. Figure 4 shows a typical difference in the flow pattern from diffusers A and B. This difference will influence the local ventilation efficiency giving a slightly higher value in the middle plane of the room when a diffuser of type A is used. However, it will not have any practical influence on the average value of the room. (Correspondingly, the diffuser of type B will give a slightly highter value over the whole width of the room close to the diffuser).

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