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Measurements of the three-dimensional wall jet from different types of air diffusers

by

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"Clima 2000" world congress on heating, ventilation
and air conditioning.
Copenhagen 1985.

$$\frac{\delta_y}{\sqrt{a_o}} = D_{ay} \frac{x + x_{oy}}{\sqrt{a_o}} \qquad (1)$$

$$\frac{U_x}{U_o} = K_a \frac{\sqrt{a_o}}{x + x_o} \qquad (2)$$

where δ_y is wall jet thickness perpendicular to the surface defined to the velocity $U_x/2$, where U_x is the local maximum velocity. x is the length from the opening and a_o the area of the supply opening. x_{oy} and x_o are virtual origins of the wall jet growth and velocity decay respectively, while D_{ay} and K_a are constants and U_o is the supply velocity.

x_{oy} and x_o are small compared to the distance x in the wall jet, and equation (1) shows that the growth of the wall jet thickness is in practice proportional to the distance from the opening with the growth rate D_{ay}. Equation (2) shows that the velocity ratio U_x/U_o is proportional to 1/x, which is typical of a three-dimensional wall jet.

The theory behind the wall jet assumes that the flow has a fully developed turbulent level, which also means that the normalized flow (velocity, turbulence) is rather independent of the Reynolds number. The general turbulent flow in ventilated rooms is often fully developed, see Hanel and Scholz (5), but the following measurements on diffusers will explore this problem in more detail.

Measurements

Isothermal wall jet

All the measurements are made in a big full scale room according to the Swedish regulation SP VVS 17 1973. Two different GTH diffusers with the dimensions 30 x 10 cm and 40 x 15 cm are used. The vanes in the GTH diffusers are adjusted to a high horizontal spread, and a 20^{o} upward direction of the jet in all measurements. Fig. 2 shows the level of K_a assuming x_o = 0 in equation (2), and it is obvious that there is a slight influence from the Reynolds number at low supply velocities. A closer examination of the measurements for the GTH-40-15 shows some uncharacteristic velocity profiles and growth rates at low supply velocity (low Reynolds number), but equation (2) is still valid as a description of maximum velocity U_x in the flow.

Two parallel jets are established from the GTH diffuser due to the high horizontal spread. The jets merge downstream in the flow, and this may be the reason for the velocity decay in the first part of the flow which is less than 1/x and somewhat between the velocity decay in a two-dimensional jet and a three-dimensional jet.

The growth rate D_{ay} is of the level 0.08 for the GTH-40-15 at higher Reynolds numbers.

Fig. 2. K_a versus Re for the GTH and the PVD diffuser. The Reynolds number is equal to $U_o\sqrt{a_o}/\nu$ where ν is the kinematic viscosity. $x_o = 0$.

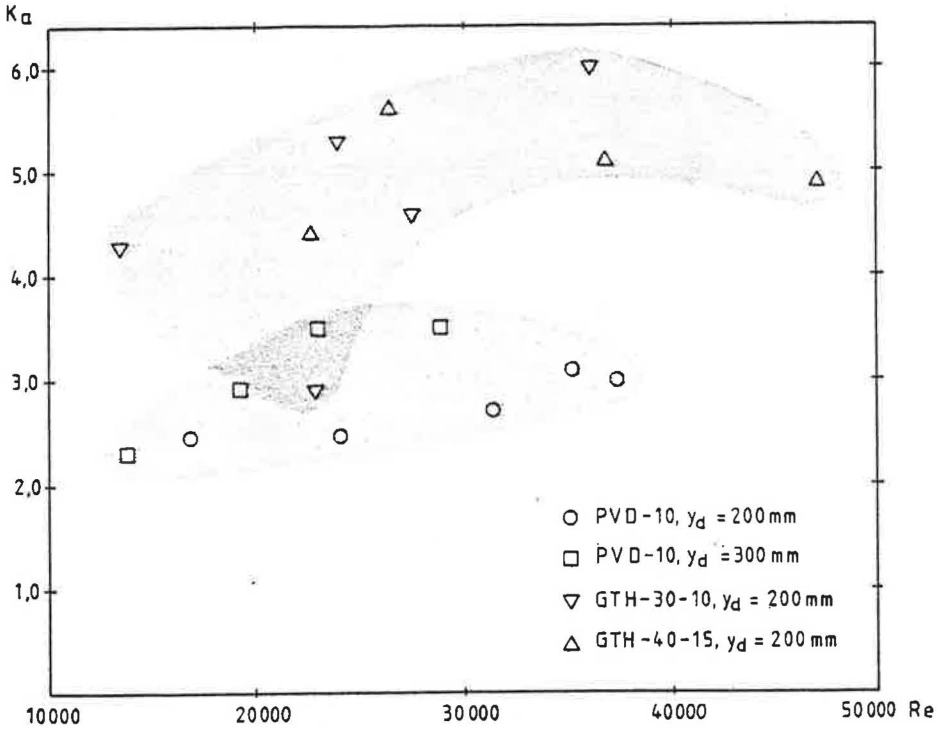


Fig. 2 shows a K_a factor of 3.0 for the PVD-10 diffuser. This is a low value; it means that a high amount of air may be supplied by the diffuser at a low velocity U_x and thus at a low velocity in the occupied zone. The upward-directed flow from the diffuser and the deflection at the ceiling resulting in a semi-radial flow at the ceiling coupled with a high diffusion around the opening geometry, may explain the low K_a factor. The flow is only slightly dependent on the Reynolds number.

The growth rate D_{ay} is of the level 0.06 for the PVD-10 diffuser at higher Reynolds numbers.

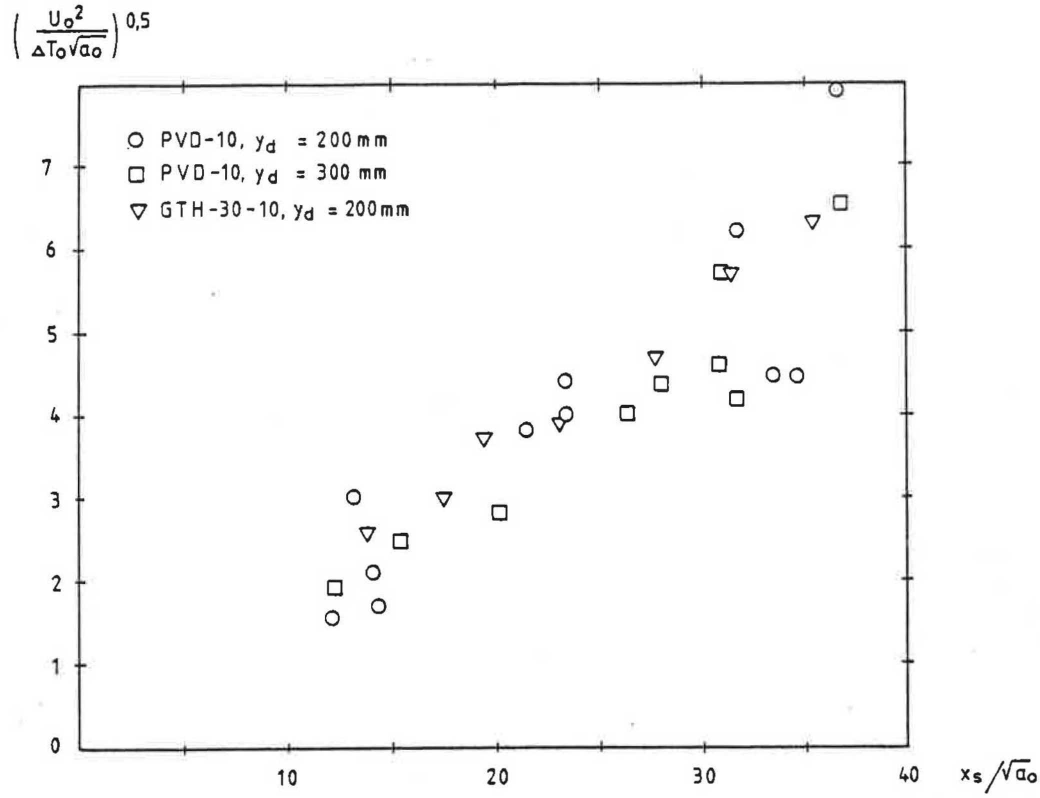
Penetration depth

An undisturbed wall jet will penetrate the ventilated room in the case of isothermal flow and entrains air from the occupied zone to induce recirculating air movement in the room. This picture will change when a thermal load is supplied to the room. The supply temperature will be reduced and the load may reach a level such that the wall jet will separate from the ceiling at a distance x_s from the diffuser and flow down into the occupied zone. Situations with a short penetration depth are undesirable, because the jet may have a high velocity and a low temperature when it flows into the occupied zone, and a calculation of the penetration depth is thus a part of the dimensioning procedure of the air distribution system.

Grimitlin (6) and Schwenke (7) have shown that the penetration depth for a cold three-dimensional wall jet is proportional to $1/\sqrt{Ar}$, where Ar is the Archimedes number, and it is expressed by the following equation:

$$\frac{x_s}{\sqrt{a_o}} \sim \left(\frac{U_o^2}{\Delta T_o \sqrt{a_o}} \right)^{0.5} \tag{3}$$

Fig. 3. The figure shows the normalized penetration depth $x_s/\sqrt{a_o}$ versus $1/\sqrt{Ar}$. y_d is the distance between ceiling and diffuser.



The measurements in fig. 3 show the linear relation between $x_s/\sqrt{a_o}$ and $1/\sqrt{Ar}$. It has not been possible to show any influence from the K_a factor as demonstrated in (6) and (7), but there is a difference in the jet flow after separation, where the jet enters the occupied zone more steeply in the PVD tests than in the GTH tests.

The experiments in fig. 3 are somewhat influenced by room geometry and the location of heat load.

Conclusions

Side-wall-mounted diffusers placed close to the ceiling will often generate a three-dimensional wall jet along the ceiling with a velocity decay inversely proportional to the distance from the opening.

The velocity decay is strongly dependent on details in the diffuser geometry, and the effect can be expressed by a single coefficient, K_a. The flow is only slightly dependent on the Reynolds number.

Measurements show that the penetration depth of a cold jet is proportional to $1/\sqrt{Ar}$, where Ar is the Archimedes number for the flow. The penetration depth is given for two different types of diffusers.

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SUMMARY

P.V. Nielsen and Å.T.A. Möller: Measurements of the three-dimensional wall jet from different types of diffusers. Parts of the flow in air-conditioned rooms takes place as three-dimensional wall jets. A detailed description of the wall jet may therefore give a good understanding of the whole air flow. Expressions based on the theory of three-dimensional wall jets are derived, and measurements on two different diffusers show velocity decay in jet, jet growth rate, and the influence of the Reynolds number. The paper concludes with measurements on penetration depth of a jet at different non-isothermal conditions.

RESUME

P.V. Nielsen et Å.T.A. Möller: Mesures de jets muraux tridimensionnels de différentes bouches de distribution d'air. Une partie de l'écoulement dans un local à air conditionné se produit sous forme de jets muraux tridimensionnels. Pour cette raison une description détaillée d'un jet mural peut être utilisée pour décrire l'écoulement total. Il est présenté des formules pour le jet mural tridimensionnel et des mesuses sur deux différentes bouches de distribution déterminent la perte de vitesse dans le jet, la croissance en largueur du jet, ainsi que l'influence du nombre de Reynolds.Enfin il est présenté des résultats de mesures portant sur la profondeur de pénétration d'un jet d'air sous différentes températures.

KURZFASSUNG

P.V. Nielsen und Å.T.A. Möller: Messungen an dreidimensionalen Wandstrahlen aus verschiedenen Arten von Zuluftdurchlässen. Teile der Strömung in einem klimatisierten Raum verlaufen als dreidimensionale Wandstrahlen. Eine detaillierte Beschreibung eines Wandstrahls bildet deshalb eine gute Grundlage für die Beschreibung der ganzen Strömung. Es werden Formeln für den dreidimensionalen Wandstrahl aufgestellt, und Messungen an zwei verschiedenen Zuluftdurchlässen bestimmen den Geschwindigkeitsabfall im Strahl, die Strahlverbreiterung, sowie den Einfluss der Reynoldschen Zahl. Zum Schluss sind Messergebnisse für die Eindringtiefe eines Luftstrahls bei verschiedenen Temperaturverhältnissen aufgestellt.