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ROOM AIRFLOWS WITH LOW REYNOLDS NUMBER EFFECTS

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ABSTRACT

The behaviour of room airflows under fully turbulent conditions is well known both in terms of experiments and numerical calculations by computational fluid dynamics (CFD). For room airflows where turbulence is not fully developed though, i.e. flows at low Reynolds numbers, the existing knowledge is limited.

It has been the objective to investigate the behaviour of a plane isothermal wall jet in a full-scale ventilated room at low Reynolds numbers, i.e. when the flow is not fully turbulent. The results are significantly different from known theory for fully turbulent flows. It was found that the jet constants are a strong function of the Reynolds number up to a level of $Re_h \approx 500$.

KEYWORDS

Room airflow, low Reynolds number effects, full-scale experiments, plane isothermal wall jet

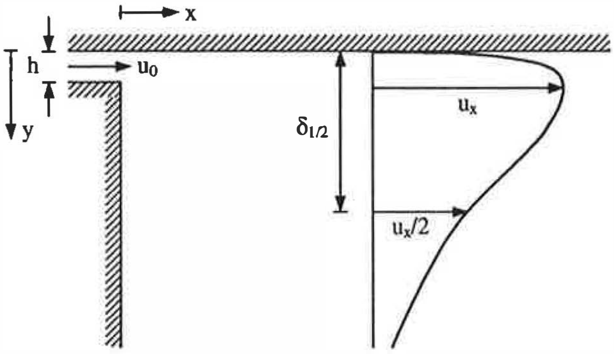
INTRODUCTION

Supply flow rates for ventilation is often reduced due to more efficient ventilation or to reduce the energy consumption in mechanical ventilation. In natural ventilation where buoyancy and wind pressure are the driving forces there will be some periods during the year when the supply airflow rate is moderate.

Air for ventilation is often supplied as a jet above the occupied zone to achieve mixing with room air. When designing ventilation systems the jet and the entire room airflow is traditionally treated as turbulent flow although the airflow in some regions of a ventilated room is laminar or not fully turbulent.

The behaviour of turbulent jets is well known (Rajaratnam (1976) and Launder & Rodi (1983)) while little effort has been spend to investigate the behaviour of jets at low Reynolds numbers. It has been the objective of this work to investigate the behaviour of a plane isothermal wall jet in a full-scale ventilated room at low Reynolds numbers, i.e. when the flow is not fully turbulent.

As the wall jet enters an open space a boundary layer builds up along the wall. In the boundary layer the velocity changes from zero at wall to its maximum value, u_x, at some distance from the wall, see Figure 1.



h: Height of inlet slot
u_0: Inlet velocity
x: Co-ordinate along the wall
y: Co-ordinate perpendicular to the wall
u_x: Maximum velocity at a given x-station
$\delta_{1/2}$: Distance from the wall where $u=u_x/2$

Figure 1: Outline of a typical velocity profile for a plane wall jet.

The velocity profile is generally represented by the maximum velocity, u_x, and the distance from the wall, $\delta_{1/2}$, at which the velocity has dropped to $u_x/2$.

For a plane fully turbulent wall jet the decay of the maximum velocity and the growth rate of the jet along the wall are given by

$$\frac{u_x}{u_0} = K_p \sqrt{\frac{h}{x + x_0}} \tag{1}$$

$$\delta_{1/2} = D_p (x + x_0) \tag{2}$$

where K_p is the velocity decay constant, D_p is the growth rate of the jet per unit distance from the inlet and x_0 is the virtual origin of the jet. K_p and D_p are both characteristic parameters for the diffuser.

At high Reynolds numbers (fully turbulent flow) K_p and D_p are constants and Eqn. 1 and 2 are valid. It has been chosen in the present work to apply Eqn. 1 and 2 to jets at low Reynolds numbers too, assuming D_p and K_p to be functions of the Reynolds number.

METHODS

A series of isothermal experiments were performed in a full-scale test room as shown in Figure 2 (left), corresponding to the room used in the IEA Annex 20 project but with full width slots (height h=0.02 m) as supply and exhaust openings. The supply opening was located at the top of the left end wall and thus generates a plane wall jet along the ceiling while the exhaust opening was located either at the top of the right end wall or at the foot of the left end wall, see Figure 2 (right).

The wall jet generated by the supply opening was considered plane due to the full width slot and velocity profiles were thus measured in the centreline of the jet. From smoke experiments similar recirculating airflow patterns were observed for the two ventilation set-ups indicating no influence of exhaust location.

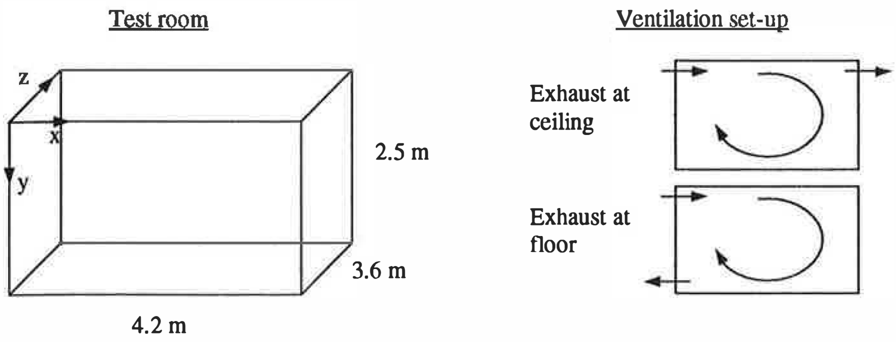


Figure 2: Outline of the full-scale test room (left) and the location of the full width supply and exhaust openings (right).

Velocity profiles were measured with hot-sphere probes in the centreline of the jet at different air change rates in the range from 0.4 h^{-1} to 4.0 h^{-1}, corresponding to supply Reynolds numbers, Re_h, ranging from 79 to 770.

RESULTS

In the following the Reynolds number refers to the diffuser and is based on the contracted slot height, h_0. The Reynolds number is thus given by

$$Re_h = \frac{u_0 h_0}{\nu} \qquad (3)$$

where ν is the kinematic viscosity.

Velocity Profiles

For a plane wall jet the velocity profiles at different x-stations and different Reynolds numbers are expected to express similarity when plotted in terms of u/u_x and $y/\delta_{1/2}$. The measured profiles are shown in Figure 3. Also included in the figure are the empirical relation by Verhoff (1963) for a fully turbulent wall jet and a laminar relation established from experiments by Quintana et al. (1997).

It is seen from the figure that the profiles express similarity to some extend as a high degree of similarity is found for the highest Reynolds numbers, i.e. $Re_h \geq 477$ while for $Re_h < 477$ there is no obvious similarity within the jet.

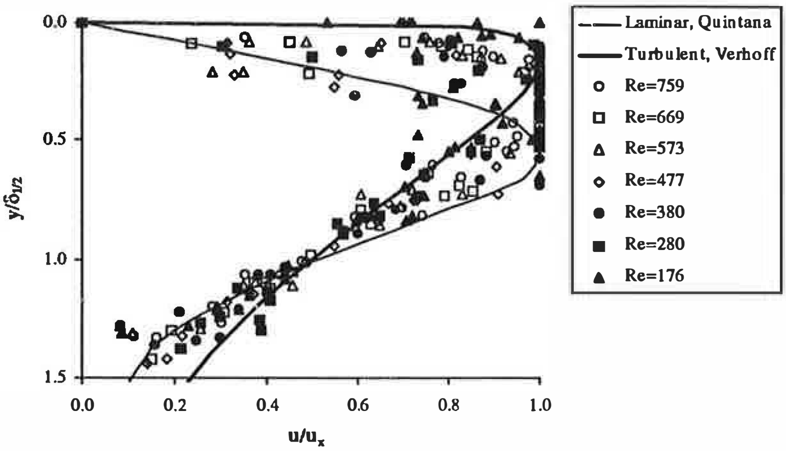


Figure 3: Velocity profiles in the wall jet plotted in non-dimensional co-ordinates.

From the figure it should further be noticed that the profiles neither fit the turbulent or the laminar relation but lies somewhere in between indicating that the jet is transitional.

Characteristic Parameters, D_p and K_p

The jet growth rate along the ceiling, D_p, has been established from a best fit of the experimental data to the relation of $\delta_{1/2}$ and x given by Eqn. 2. Figure 4 shows D_p versus Re_h for both ventilation set-ups. Results obtained by Nielsen, Filholm, Topp & Davidson (2000) from model experiments are included for comparison.

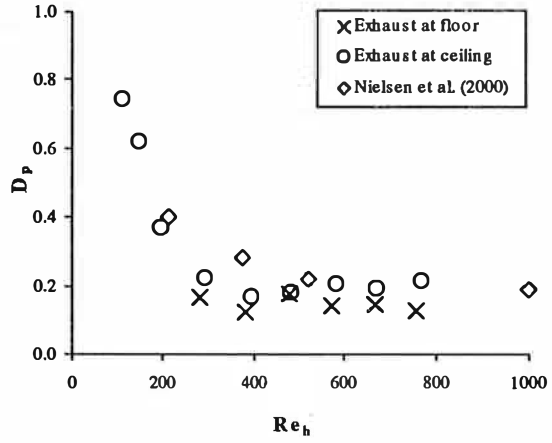


Figure 4: The growth rate of the jet per unit distance from the inlet, D_p, as a function of Reynolds number, Re_h. Results from model scale experiments by Nielsen, Filholm, Topp & Davidson (2000) are included for comparison.

It is seen that the jet growth rate is a strong function of Reynolds number. As Re_h increases D_p dr rapidly and seems to reach a constant level at $Re_h \approx 400$. It should be observed that there is significant difference in D_p between the two ventilation set-ups. In addition, the results agree with the model scale experiments.

The velocity decay constant, K_p, has been established from a best fit of the experimental data to relation of the maximum velocity, u_x, and the horizontal distance, x, given by Eqn. 1 with $h=h_0$ contracted slot height). Figure 5 shows K_p versus Re_h for both ventilation set-ups. Results obtaine Nielsen, Filholm, Topp & Davidson (2000) from model experiments are included in the figure.

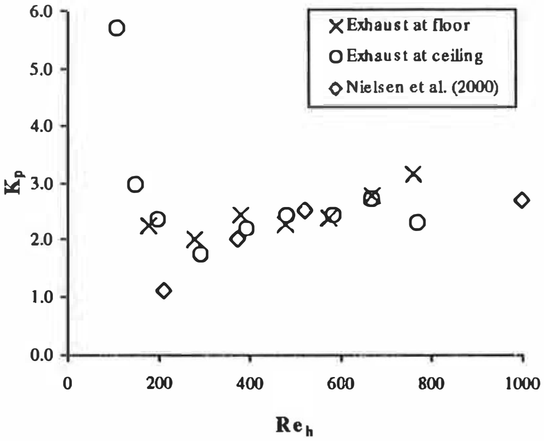


Figure 5: The velocity decay constant, K_p, as a function of Reynolds number, Re_h. Results from model scale experiments by Nielsen, Filholm, Topp & Davidson (2000) are included for comparison.

In similar to the jet growth rate the results show that K_p is a strong function of Re_h as K_p drops with increasing Re_h up to $Re_h \approx 400$ where K_p reaches a minimum. For $Re_h > 400$ K_p takes on increase. Again, it should be observed that there is no substantial difference between t ventilation set-ups. The results agree well with the model scale experiments except for at $Re_h \approx$

DISCUSSION

A series of full-scale experiments were performed to investigate the behaviour of a plane is wall jet at low Reynolds numbers, i.e. when the flow is not fully turbulent.

Designers of jets for ventilation purposes traditionally use turbulent relations that are indepe Reynolds number, Re_h. Care should be taken though, as the present work shows the jet significant function of Re_h when the flow is laminar or transitional. The measured velocity express similarity for $Re_h > 400$ while the characteristic jet parameters D_p and K_p are strong of Re_h up to a critical Reynolds number of approximately 500.

Two different locations of the exhaust opening were investigated and no substantial differer observed indicating that the exhaust has no significant influence on the jet.

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