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Temperature and Velocity Distribution for Air Slot Devices

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SYNOPSIS

Depending on the demands regarding the size and location of the occupation zone and the need for outdoor air flow rates, different ventilation systems and air supply devices have to be used in different kinds of buildings. The occupation zone in a residential building can be difficult to define, as many different activities can take place. Furthermore the furnishings of the room can change with time.

The highest air velocities and the lowest air temperatures in the occupation zone will often occur close to inlet air devices. The importance of the location and selection of inlet air devices is exemplified by studying an air slot device for mainly residential use. The slot device was placed over a window at a height of 2.0 m above floor level. Both measurements and calculations of air velocity and temperatures are presented in the paper. From a thermal comfort point of view the device tested seem to give satisfactory performance only for air flow rates less than 4 l/s. The draught problem will increase with lower inlet temperatures.

It is also shown that the internal heating in a device can be important with regard to thermal comfort. The factors that influence the relationship between outdoor and supply temperature are also discussed.

LIST OF SYMBOLS

A_o	effective area of the supply opening (m^2)
b	width of device (m)
d	characteristic length (m)
d_h	hydraulic diameter (m)
h	height of device (m)
L_i	distance to fully established velocity distribution (m)
PD	percentage dissatisfied people due to draught (%)
Re	Reynolds number
t_a	air temperature (°C)
t_{out}	outdoor temperature (°C)
T_m	minimum (or maximum) air temperature across an air jet (K)
T_o	temperature of the supply air (K)
T_r	air temperature (reference temperature) of the room (K)
Tu	turbulence intensity (%)
U	average air velocity in the device (m/s)
$\bar{u}$	mean air velocity at a point in a room (m/s)

x distance (m)
υ kinetic viscosity (m^2/s)
θ_m non-dimensional temperature decay ratio

1. INTRODUCTION

In ventilated spaces people often complain about draught. When draught problems in an apartment or an office are discussed, it often suffices just to look at the occupied zone. The area near the ceiling, for example, is usually not so important from a thermal comfort point of view. The demands regarding the size and location of the occupied zone must be strongly connected to the kind of building in question and the activities going on in the building. This means that occupation zones can be defined in many different ways.

In an office building, the occupants often have the same positions in the rooms throughout the working day. Often they sit at their desks at a predetermined place. In this case, the occupied zone is just a small part of the room. The choice of ventilation system in office buildings depends mainly on the thermal load and the thermal loads also determine the air flow rates. The conditions are completely different in residential buildings.

In residential buildings, many different activities take place. Furthermore, the furnishings of the rooms are not known before moving in and can also change with time. Thus, it is important that the whole area of the room can be used. Here the thermal loads are not the most significant factor for the choice of air flow rates, but rather the air quality.

2. DEFINITIONS OF OCCUPATION ZONE IN RESIDENTIAL BUILDINGS

The demands for thermal comfort are similar in most comfort standards [1, 2]. The standards are often based on the equations originally derived by Fanger [3]. Consequently the choice of ventilation system can depend more on how the occupied zone is defined in a particular case. In Figure 1, different occupied zones are shown. Common for all these occupied zones is a horizontal plane located above head height, approximately 1.8 m above floor level. Below this plane, the occupied zones differ as regards the positions of the vertical limitation planes.

The ANSI/ASHRAE 55-1992 Standard has general vertical limitation planes 0.6 m from walls or fixed air conditioning equipment. However this general definition is not acceptable when discussing residential buildings. If such a definition was to be acceptable, this would mean very strong restrictions on what part of a room that could be defined as the occupation zone. Moreover, only the area comprising the middle of a room could be used. When looking at offices the normal occupied zone is small and here the zone definition should be different for each room. Thus, it should also be possible to move the workplace to another part of the room.

When discussing occupied zones in residential buildings, the near zones of supply air devices, radiators and windows are the critical parts of the room, especially the near zone of supply devices. This is because the air is mainly supplied to the room through small outlet areas. A step in the right direction could be to change the position of the vertical plane limitations to 0.5 m from outdoor walls or fixed air conditioning equipment and to 0.1 m from indoor walls when defining the occupation zone for residential buildings [4].

From the point of view of apartment owners, it goes without saying that the whole room should be possible to use, as that is what they pay for.

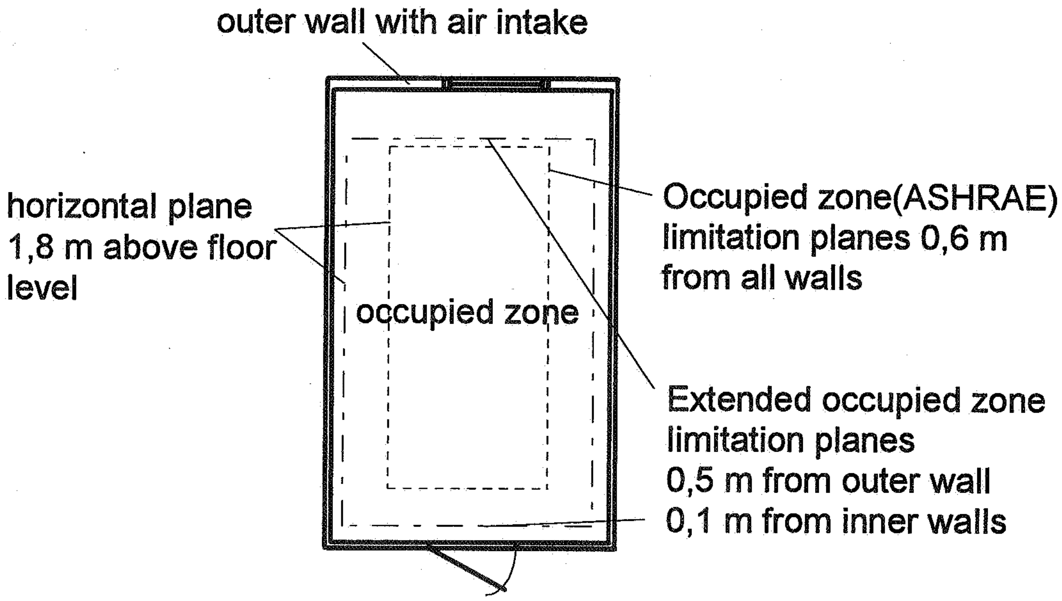

Fig 1. Room with different occupation zones.

To evalute the thermal comfort indoors due to draught risk, the PD-index (percentage people dissatisfied due to draught) can be used [5]. Draught can be defined as an unwanted cooling of the human body caused by air movements. The risk of draught depends on air velocity, turbulence intensity and air temperature according to equation (1).

$$PD = (34 - t_a)(\bar{u} - 0.05)^{0.62}(0.37\bar{u}Tu + 3.14) \quad (1)$$

If an air flow of 10 l/s with an air temperature of 21°C is to be supplied to a room, an inlet area larger than 0.07 m^2 is needed to provide a good thermal climate. In this case, assumptions have been made that the velocity is equal over the whole inlet area of the device and that the whole room volume is regarded as the occupied zone. The calculations are also based on a measured turbulence intensity of 40% for an air slot device [4]. Higher air velocity than 0.14 m/s, lower air temperature than 21°C or higher turbulence intensity will result in more than 15% being dissatisfied due to draft (see equation (1)). If the inlet area is smaller than 0.07 m^2, the PD-index will become higher. On the other hand, if the air is supplied through a device placed above head height, problems with high velocities will not necessarily exist during summer time but in the cold season the air jet will bend down in the occupation zone and cause discomfort [4].

When the outdoor air is supplied with a mechanical exhaust system, the air entering the room in the winter season is colder than the room air. This means that a larger inlet area is needed during winter to get the same thermal comfort as in the summer.

3. INTERNAL PRE-HEATING OF THE OUTDOOR AIR IN SLOT DEVICES

The thermal comfort in the near-zones of supply devices is not particularly affected by the location of the exhaust devices in mechanically ventilated buildings. The air stream from the supply devices can, on the other hand, be noticeable at large distances from the devices. Several factors influence the way the air is distributed at different distances from a supply device.

- the design and location of the supply device
- the air flow rate and supply air temperature
- the dimension of the room and air obstructions such as furnishings
- air movements in the room such as convection streams from radiators, machines, people and other warm or cold surfaces

It is important to know the inlet temperature when calculating the trajectory of the air stream in the room or the air temperature in the stream at different positions. If the device is placed above head height, an unpreheated air stream gets into the occupation zone faster, the larger the temperature difference is between the air stream and the room. The inlet temperature of a supply device depends on the outdoor temperature and the air flow rate through the device.

A common and cheap supply device for an exhaust ventilation system for residential buildings is the air slot device. Such air devices are normally placed over windows. Air slot devices for mechanical exhaust systems have been found to allow a maximum air flow rate of 4 l/s if a satisfactory thermal climate is to be maintained [4,6].

In Figure 2, the results of an investigation of the internal heating in a slot device is illustrated at an air flow rate of 4 l/s. The air slot device has an inlet area of 300 x 11 mm. The device, which is completely made of plastic, consists of five sections placed lengthways. Moreover, the device has a damper in the outlet part. The measurements were made when the device was placed in a window frame with a thickness of 60 mm.

The measurements were carried out at each lengthways position at 3 minute periods and in three different positions to get average air temperatures values. To be able to verify that all the measurements had been done under the same conditions (constant air flow rate in the device), a reference sensor was placed at the outlet of the device.

The shapes of the three air temperature curves in Figure 2 are quite similar. The air temperature increases very slowly in the first part of the device and more rapidly in the second part. In the outlet part of the device where the damper is located, the temperature increase is small. Factors that have an influence on the temperature increase are discussed below.

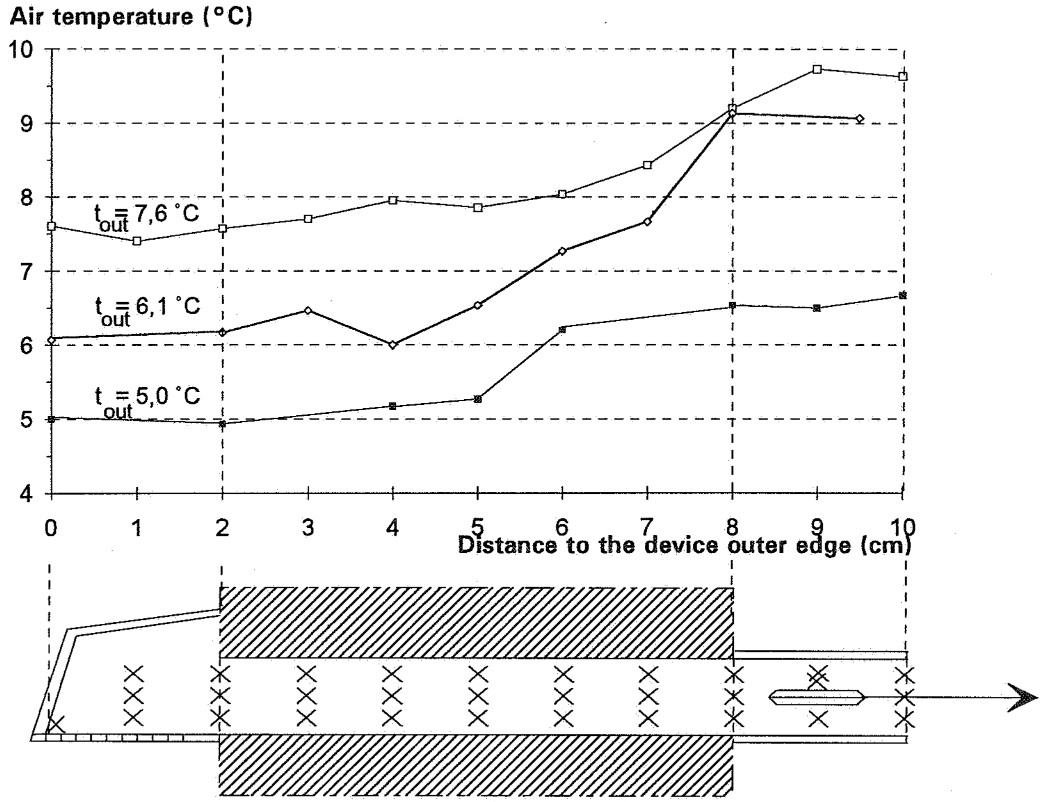

Fig 2. Temperature profile in a slot device at different outdoor temperatures, t_{out}.

- The thermal force is stronger further downstream inside the device where the temperature difference is larger between the air and the surfaces of the device that are located in the window frame. This is only partly an explanation why the temperature increase is larger at the end of the device.

- The heat transfer from the surfaces of the device to the air is affected by the heat transfer coefficient. The heat transfer coefficient is considerably higher for turbulent flows than for laminar flows. The type of flow that exists can be determined by calculation of the Reynolds number. The Reynolds number can in this case be estimated to 940 according to equation (2). In long ducts, the air flow is laminar when the Reynolds number is below 2100 [7]. However, this does not mean that the flow in the device is mainly laminar because the equation does not take into account the part of the device where the velocity profile is not completely developed.

$$Re = \left(\frac{Ud}{\upsilon}\right) \qquad (2)$$

-The velocity profile is not fully developed at the entrance of the device. Theoretically the velocity profile should have an almost rectangular shape, but in this case the air stream does not fall in perpendicular to the inlet of the device. As a rough estimate of the entrance length where the velocity profile is not completely developed, equation (3) can be used [8]. The entrance length, L_i, is defined as the distance from the inlet to the position where the centre velocity has reach 99% of the velocity that appears in a fully developed velocity profile. According to equation (3), the entrance length becomes much longer than the device. Thus, an accurate value of the heat transfer coefficient can not be determined in a simple way as the velocity and temperature profiles will affect the heat transfer considerably.

$$\frac{L_i}{d_h} = 0.0575 \cdot Re_{d_h} \qquad (3)$$

- Another explanation for the higher temperature increase at the end of the device could be that room air was ejected or leaked into the device. This possibility was examined by filling the room with tracer gas. However, no tracer gas concentration could be measured in this case inside the device.

- A possible explanation for the low temperature increase in the outer part of the device could be that an air whirl establishes there so that a part of the outdoor air escapes from the device again.

4. TEMPERATURE AND VELOCITY DISTRIBUTIONS

The discussion below is based on the assumption of a free jet, thus, limitations of room walls, backward air streams or internal heat sources will not be taken into account.

The jet from a slot device could be treated as a plane jet or as a three-dimensional jet. In practice, jets issuing from openings of aspect ratios of $1 < b/h < 40$ should be treated as three-dimensional [9]. This slot device has an aspect ratio of 27. Air jets can be classified downstreams into four different velocity or temperature decay regions, where different equations should be used to estimate the profiles. However, the extents of these regions are different. A non-dimensional jet temperature decay ratio, θ_m, can be defined by:

$$\theta_m = \left(\frac{T_m - T_r}{T_o - T_r}\right) \qquad (4)$$

Measurements of the air temperature in the air jet from the slot device [4] have been carried out at a distance, x, of 0.23 m after a slot device outlet. The lowest temperature in the air stream at this distance was 17.4°C at an outdoor temperature of 6.1°C. The air temperature at this distance has increased by approximately 8°C compared to the air temperature at the device outlet (see Figure 2). The result can be compared to the calculated decay of the maximum temperature for free jets. Figure 3 gives $\theta_m = 0.41$ for a device with an opening b/h ratio of 27 and an effective area of the supply opening, A_0 of 33 cm^2. With the measured room temperature of 22°C equation (4) gives $T_m \approx 17$°C, which is in close agreement with the measured value.

In the same way, an air velocity analysis for an air jet can be made by comparing measured and calculated air velocities. The centre velocity at different distances from the device for different openings of rectangular shapes can be estimated from [9] when the velocity in the device and the dimensions of the device are known. Estimated velocity maximum for the mentioned slot device at a distance of 0.83 m from the device is 0.32 m/s with an air flow rate of 3.5 l/s. This can be compared with the measured velocity which was 0.28 m/s at the same distance from the device [4].

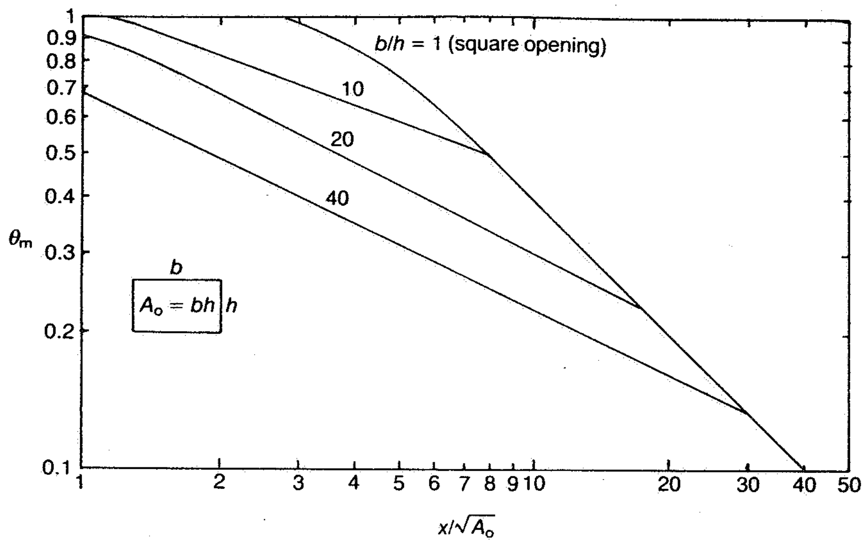

Fig 3. Decay of the maximum temperature for free jets of different aspect ratios [9].

5. DISCUSSION

The demands of outdoor air flow rates in residential buildings vary in different standards. For example ASHRAE Standard 62-1989 [10] recommends an air flow rate of at least 7.5 l/s, person.

The air velocity at different distances from the air slot device has been calculated [4, 9] for an air flow rate of 4 l/s and is shown in Figure 4. Assumptions have been made that it is a free jet that is not influenced by any air movements in the room (no air backflow or convection flows). It is obvious that the slot device system is not to be recommended for residential buildings as not even 4 l/s can be supplied without causing draught (see also [4]).

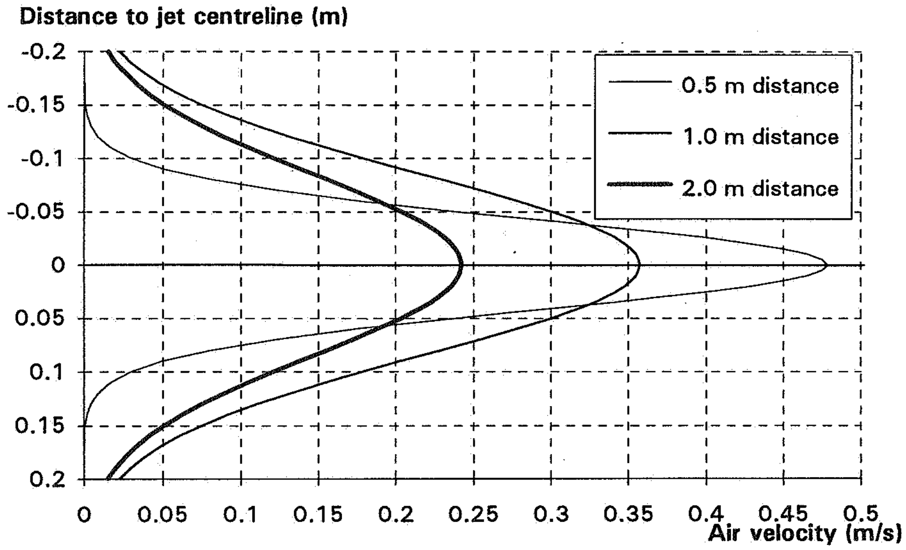

Fig 4. Velocity profiles at different distances from an air slot device for a flow rate of 4 l/s.

6. CONCLUSIONS

Air slot devices can not be recomended as inlet devices when supplying outdoor air to residential buildings. However, the demands on the size of occupation zone influence the possible selections of ventilation systems and air supply devices. It is, thus, of importance to define different occupation zones in different kinds of buildings. The following facts should be kept in mind when planning new or modifying old ventilation systems:

- Different ventilation systems have to be used depending on the demands on the size and location of occupation zone.
- The occupation zone in residential buildings should include all room-space except the near zones of fixed air conditioning equipment, radiators and windows.
- The air temperature increase in a supply device can be of importance for the thermal comfort indoors.
- Investigations of the thermal comfort in rooms with outdoor air supplied through devices with non pre-heated air should be carried out at low inlet temperatures corresponding to the lowest outdoor temperatures during the year.

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