Effect of air-diffuser’ offset ratio on draught comfort in a slot-ventilated room

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Abstract—Slot-ventilated rooms are widely used in comfort type HVAC (stands for Heating, Ventilation, Air Conditioning) systems. Location of the slot air-diffuser is an important designing parameter of room air distribution in ventilation systems. Offset ratio (OR) of the slot-diffuser is the non-dimensional horizontal distance between the wall and the air inlet. This OR value can influence room airflow characteristics including draught comfort. In this article effect of various offset ratios was investigated on room’s draught comfort. The investigations included air velocity and temperature measurements and the measured data were evaluated using statistical methods.

I. INTRODUCTION AND THEORETICAL BACKGROUND

People spend most of their life in closed spaces so it is important to provide acceptable air microclimate parameters. Air velocity, turbulence intensity and air temperature – like the most important microclimate parameters – effect the draught comfort in rooms [1]. Slot-ventilated rooms like e.g. offices are widely used in HVAC designing practice. In these ventilated spaces usually a linear slot diffuser is commonly used as air inlet. This diffuser is usually located next to a wall surface as shown in Fig. 1. The main advantage of such slot diffuser placement is that supply air is injected outside of the occupied zone of the room. As a result the draught risk can be decreased in the space [2], [3].

On Fig. 1 it can be seen that supply air flows out from the slot diffuser and a negatively pressurized recirculation zone appears between the supplied air jet and the wall. Then the Coanda-effect appears and the injected air jet bends towards the wall and adheres to the surface at the attachment point. After this, the injected air jet flows along the wall surface and then ventilates the room. The vertical distance between air inlet and the attachment point is the attachment distance (yₐ) which can influence room airflow [4], [5].

The horizontal distance between the slot diffuser and the wall surface is h, so the offset ratio (OR) of the diffuser is:

\[ \text{OR} = \frac{h}{s_0}, \text{m/m} \]  \hspace{1cm} (1)

Fig. 2 shows a simple sketch of the slot ventilated room. The injected air jet, which is the primary airflow induces secondary airflows in the room. These primary and secondary airflows make an air distribution system in the room [2].

The inlet (or slot) Reynolds-number can be calculated using the inlet air velocity magnitude (v₀), slot width (s₀) and the kinematic viscosity of the injected air (ν₀ = 1.5*10⁻⁵ m²/s on 20 °C):

\[ \text{Re}_0 = \frac{(v_0 s_0)}{\nu_0} \] \hspace{1cm} (2)

The previously defined OR and \text{Re}_0 are important inlet parameters of room air distribution design. These
parameters effect air velocity and temperature distribution in ventilated rooms. It is a well-known fact that air velocity is a time-dependent quantity which has an average \( (v_{\text{mean}}) \) and a fluctuating value \( (v_{\text{RMS}}) \), where RMS stands for Root Mean Square) around the average. Using the average and RMS velocity components, turbulence intensity of the airflow can be calculated [6]:

\[
Tu = (\frac{v_{\text{RMS}}}{v_{\text{mean}}}) \times 100 \%,
\]

Average air velocity, turbulence intensity and temperature \( (t_{\text{mean}}) \) are the main features of draught comfort in rooms. The most common and internationally accepted model to predict draught comfort in rooms in Europe is Fanger’s draught model – or DR model. This model is based on a calculated DR (Draught Rate) number, which is a semi-empirical formula and describes draught comfort in the room [6].

\[
DR = (34-t_{\text{mean}})(0.37 \times Tu \times v_{\text{mean}})^{0.62} (0.05) \times 100 \%.
\]

Note that equation (4) can be valid for one point in the room, or it can be used for the whole room. According to standard CR 1752:2000 [s1] the occupied zone of the ventilated room can be categorized from the aspect of draught comfort. Category A is the best (DR ≤ 15 %) and it is followed by category B (15 < DR ≤ 20 %) and finally category C (20 < DR ≤ 25 %).

Considering the previous statements, it is important to predict air velocity, turbulence intensity and DR in the room to describe draught comfort. Several researchers have investigated draught comfort in the past decades. The most accepted and well-known researches of draught comfort in closed spaces come from Fanger et al [1], [6], [7]. They have investigated the main parameters of draught comfort like air velocity, turbulence intensity and air temperature in whole rooms. The investigation were based on experimental methods including measurements in rooms. They have only made the difference between displacement and mixing ventilation systems. T. Magyar, R. Goda et al. [2], [3], [8], [9], [10] took experimental and numerical investigations on slot-ventilated rooms to describe draught comfort. Cao [11], Rohdin and Moshfegh [12] used experimental method and numerical simulation to model room airflow. Moureh and Flick [13], [14] also took experimental and numerical researches in slot-ventilated rooms. All of the previously introduced authors investigated room airflow in the occupied zone of the ventilated space. In most of these investigations inlet Reynolds-number was the changing parameter.

Some researchers like Nozaki et al. [4], [15], Nasr and Lai [5], Rathore and Das [16] only investigated injected air jets and their attachment process near the air inlet and did not consider the airflow inside the room. In these researches inlet aspect ratio, offset ratio and Reynolds-number were the changing parameters.

Based on recent literature review it is obvious that most of the researchers investigated air inlet and room airflow separately and did not consider the effect of air diffuser’ offset ratio on room airflow and draught comfort;
IV. EFFECT OF OFFSET RATIO (OR) ON AIR VELOCITY

Average air velocity could be calculated in each measurement height, using the measured values in 29 points:

\[ v_{\text{mean}} = \frac{1}{n} \sum_{i=1}^{29} v_{\text{mean},i} \]  

(5)

Based on equation (5), there are four average air velocities at the four heights at each offset ratio. Changing of average air velocity is plotted on Fig. 3 as a function of inlet offset ratio (OR). Average air velocity was found to be constant at ankle level based on the Abbe and general regression tests at probability level 95%. Expected value of the average air velocity at ankle level is 0.230 m/s and confidence intervals on different probability levels are:

\[ P(0.222 \leq v_{\text{mean}, \text{m/s}} \leq 0.238) = 0.90 \]  

(6)

\[ P(0.221 \leq v_{\text{mean}, \text{m/s}} \leq 0.239) = 0.95 \]  

(7)

\[ P(0.218 \leq v_{\text{mean}, \text{m/s}} \leq 0.242) = 0.99 \]  

(8)

At the other three measurement heights, above ankle level, average air velocity was increasing linearly as OR was higher. Correlation square between the measured data is above 0.90, which means an acceptable linear connection [17].

Average air velocities in the four relevant heights at a certain offset ratio are plotted on Fig. 4. It is obvious that at ankle level are higher air velocities than in the other three levels. Main reason of this tendency is the airflow characteristic of the slot-ventilated room. Due to Fig. 2 primary air flows on the floor while in the middle of the room are secondary airflows, induced by the primary airflow. In the primary airflow there are always higher air velocities than in the secondary flow. Average air velocity range is about two times higher at knee, sitting and standing person’s head levels than at knee level. This range is between 0.20 and 0.25 m/s at ankle level and between 0.10 and 0.18 at the other three levels, considering the measurement uncertainty, which is 5% according to the applied probes.

V. EFFECT OF OFFSET RATIO (OR) ON TURBULENCE INTENSITY

Average turbulence intensity was calculated in each measurement height, using the measured values in 29 points:

\[ T_{\text{u, mean}} = \frac{1}{n} \sum_{i=1}^{29} T_{\text{u},i} \]  

(9)

This average Tu was determined at all measurement heights and was found to be constant at ankle level at p=95% with an expected value \( T_{\text{u}} = 27 \% \). Confidence intervals on different probability levels are:

\[ P(26.7 \leq T_{\text{u, m/s}} \leq 27.3) = 0.90 \]  

(10)

\[ P(26.6 \leq T_{\text{u, m/s}} \leq 27.4) = 0.95 \]  

(11)

\[ P(26.5 \leq T_{\text{u, m/s}} \leq 27.5) = 0.99 \]  

(12)

At the other levels the turbulence intensity is increasing as OR becomes higher. Main reason of this increasing is that there are bigger recirculation zones between the wall and the injected air jet if the slot diffuser is further away from the wall (OR is higher). In bigger recirculation zones turbulence intensity is also higher [1], [5], [6].

Average turbulence intensity intervals at the four levels are in Table I. At ankle level is the lowest average turbulence intensity, which is constant. At the other three heights, size of the average turbulence intensity range is almost the same in the range of OR = 5÷30.

<p>| TABLE I. AVERAGE TURBULENCE INTENSITIES AT THE FOUR HEIGHTS, IN THE RANGE OF OR = 5÷30 |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Ankle level (0.1 m from floor)</th>
<th>Knee level (0.6 m from floor)</th>
<th>Head level of sitting person (1.1 m from floor)</th>
<th>Head level of standing person (1.7 m from floor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 % constant</td>
<td>33±41 %</td>
<td>34±41 %</td>
<td>34±37 %</td>
</tr>
</tbody>
</table>

Fig. 5 contains the relative frequency of the measured turbulence intensity in the whole occupied zone at different offset ratios. According to relevant standards, \( T_{\text{u}} = 40 \% \) average turbulence intensity is used for draught comfort design calculations in mixing ventilation. It is obvious that most of the measured turbulence intensities—in 116 measurement points—are less, than 40% at all offset ratios. E. g. at OR = 5.83, 82% of the measured turbulence intensities are less, then 40%, while 18% of the measured turbulence intensities are higher, than 40%.
VI. EFFECT OF OFFSET RATIO (OR) ON DRAUGHT COMFORT

DR (Draught Rate) number is a widely used and accepted value in Europe to describe draught comfort in ventilated rooms. According to equation (4), DR number was calculated at each measurement point. These values were averaged at ankle, sitting, standing person’s head levels and in the whole occupied zone. Changing of the average DR can be seen on Fig. 6 at different offset ratios.

At sitting, standing person’s head levels and in the whole occupied zone DR was increasing linearly as a function of OR. Average DR numbers resulted comfort categories A and B above ankle level and C at the ankle level of the investigated model room.

VII. CONCLUSIONS AND SUMMARY

In this article a slot-ventilated model room’s draught comfort was investigated experimentally, considering the effect of air diffuser’s offset ratio. Air velocity and temperature measurements were taken in the room and measured data were evaluated with statistical methods. Based on the measured values, turbulence intensity of the airflow and DR (Draught Rate) number were calculated, so draught comfort of the room could be described.

Average air velocity was found to be constant at ankle level, however, at the other three measurement heights, average air velocity was increasing linearly as OR was higher. At ankle level were higher air velocities than in the other three heights according to the airflow characteristic of the slot-ventilated room. Average air velocity range was about two times higher at knee, sitting and standing person’s head levels than at knee level.

Average Tu was found to be constant at ankle level, while at the other levels the turbulence intensity was increasing as OR became higher. At ankle level was the lowest average turbulence intensity, which was constant. At the other three heights, size of the average turbulence intensity range was almost the same in the range of OR = 5–30. Most of the measured turbulence intensities – in 116 measurement points – were less, than 40 % (suggested by relevant standards) at all offset ratios.

DR was found to be constant at ankle level, but at sitting, standing person’s head levels and in the whole occupied zone DR was increasing linearly as a function of OR. Average DR numbers resulted comfort categories A and B above ankle level and C at the ankle level of the investigated model room.

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**RELEVANT STANDARDS**


