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Investigation of average air velocity and turbulence intensity in a slot ventilated space

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RESEARCH ARTICLE

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Abstract

In HVAC practice in slot ventilated spaces tangential air distribution systems are generally used. The determination of average air velocity and turbulence intensity is most important from the point of view of draught comfort, of effective and economical ventilation.

In this paper the changing of the average air velocity, turbulence intensity and the relative average air velocity at different measurement heights were investigated considering the connection between these quantities in a slot ventilated space. Both the average air velocity and turbulence intensity determine the draught rate (DR), which affects draught comfort in ventilated spaces.

Using the experimental investigation method we found that the changing of the average air velocity and turbulence intensity at the relevant heights may depend on the tangential air distribution system.

Keywords

turbulence intensity · average air velocity · slot ventilated · tangential air distribution system

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1 Introduction and theoretical background

In the slot ventilated spaces usually tangential air distribution system are frequently used. As far as we know, primary air introduced to the ventilated space makes indoor air move in a sensible and characteristic way. As a result, the primary airflow induces secondary flows in the ventilated space. These primary- and secondary flows make an air distribution system (ADS) [1]. In HVAC practice tangential air distribution systems using slot diffuser(s) are frequently used not only in comfort places but also in industrial spaces [2]. At this ADS supply air is usually injected at the edge of the occupied zone, generally along the wall, window, and floor or ceiling surface. This tangential air introduction makes higher air velocity injection possible into the ventilated spaces under 3 [m] height, so there may be draught [1].

Draught can be defined as a local discomfort factor, which can cause local overcooling of human body or zones of human body by airflow. This problem can be seen in residential buildings, on vehicles (e.g. cars, trains, airplanes, and so on). Consequently, draught is well known as one of the most disturbing discomfort factors in ventilated spaces. As a result, people usually require higher indoor air temperature, so the percentage of people dissatisfied with draft decreases, but the building's energy consumption (and also operation costs) increase [3, 4, 5].

The draught comfort can be described e.g. with the help of Fanger's draught model [6], which is a function of average air temperature (t_m), average air velocity (v_m) and turbulence-intensity (Tu):

$$\begin{aligned} \text{DR } (Draught\ Rate) &= (34-t_m)\cdot(v_m-0,05)^{0,62} \\ &\cdot(0,37\cdot Tu\cdot v_m+3,14)[\%] \end{aligned}$$

It should be considered that boundary conditions of this formula are: $20 < t_m$ [°C] < 26; $0,05 < v_m$ [m/s] $< 0,5$ and $0 <$ Tu [%] < 70.

$$\text{Tu} = v_{RMS}/v_m\cdot 100[\%]$$

The ratio between average air velocity and velocity fluctuation (v_{RMS}) is called as turbulence intensity [5, 6].

As it is known, velocity as a function of time can be written as the sum of the average airvelocity and velocity fluctuation, which depends on time [7]:

$$v(\tau) = v_m + v_{RMS}$$

The average air velocity is written:

$$v_m = 1/T \cdot \int_0^T v(\tau) \cdot d\tau \left[\frac{m}{s}\right]$$

The velocity fluctuation is:

$$v_{RMS} = \sqrt{1/T \cdot \int_0^T (v - v_m)^2 \cdot d\tau \left[\frac{m}{s}\right]}$$

The calculation of draught rate and turbulence intensity are very important from the point of view of designing ventilation systems.

When calculating turbulence intensity or draught rate we assuming that airflow is turbulent [4]. Researchers at different comfort type ventilated spaces showed that turbulence intensity commonly varies from 0 to 80 [%] [8, 9]. Fanger and Christensen discovered that the higher the turbulence intensity in the occupied zone the higher the draught perception [4]. The main physical principles of this are the followings [7, 10]. Each body dived into liquid or gas is rounded by a boundary layer, which behaves as a thermal insulation. Heat transport through this boundary layer depends on the main characteristics of it, e.g. thickness, laminar or turbulent flow, density, material, etc. If the turbulence intensity around the body is high, it can support increased heat transfer through the boundary layer. By the decreasing of the insulating laminar boundary layer the high turbulence intensity supports heat transfer and increases the heat transfer factor by forming dominant turbulent boundary layer.

The specific heat transfer for the laminar boundary layer can be calculated by using Fourier's experimental formula:

$$\dot{q}_{lam} = -\lambda \cdot \text{grad}(t) \left[W/m^2\right]$$

The specific heat transfer for the turbulent boundary layer can be calculated as:

$$\dot{q}_{turb} = c \cdot \rho \cdot \left(\overline{v_{RMS} \cdot t_{RMS}}\right) \left[W/m^2\right]$$

where t_{RMS} is the fluctuating air temperature, c is the average specific heat capacity ρ is the average air density and λ is the average heat conducting factor.

At that parts of the body, where $\dot{q}_{lam} < \dot{q}_{turb}$ inequality exists may be local overcooling, or in other words draft, because the local heat transport is increased.

2 General aims and investigation method

Considering the previous principles the general aims of our investigations are the following:

- Average air velocity and turbulence intensity measurements in the occupied zone of a slot ventilated test room
- Using the measurement results investigation of the changing of the average air velocity in the occupied zone
- Investigation of the changing of turbulence intensity in the occupied zone at different measurement heights.

To realize the previous investigation aims, the measurement investigation method was applied. All of the investigations were conducted in case of applying vertical air inlet, isothermal condition and stationary state. In the test room a tangential air distribution systems was used with one line slot diffuser.

3 Experimental method

The measurement investigations were conducted in a test room at the Ventilation Laboratory of BUTE. Basic area of the test room is 3x3 [m] and the interior height is nearly 3 [m]. The supply air was circulated by a CRAC (*C*omputer *R*oom *A*ir *C*onditioning), which is actually a compact air handling unit. In the ventilation system an air-filter was applied in order to filter the supply air. The airflow rate to the room was measured and controlled by a flow control valve by measuring the pressure difference at an orifice plate (Δp) in Pascal. The airflow rate can be calculated by the measured dynamic pressure and position (K) of the flow control valve, which is proportional with the free cross section of the airflow [11]:

$$\dot{V}_0 = 3,6 \cdot K \cdot \sqrt{\Delta p} \left[\frac{m^2}{h}\right]$$

Air velocity, temperature and turbulence intensity measurements were carried out according to standards *EN ISO 5167-1:2003*, *EN 24006:2002* and *ISO 7726*. These quantities in the occupied zone were measured by an omni-directional hot sphere, calibrated anemometer.

In the occupied zone the measurements were conducted at four relevant heights in accordance with standard *ISO 7726*. These heights are the following: y = 0.1; 0.6; 1.1 and 1.7 [m]. In these measurement heights 116 points were took up at each series of measurement. Altogether seven series of measurements were taken up by changing the airflow rate to the room. The applied range of airflow rate to the room (V_0) went from 60 to 140 [m³/h].

Fig. 1 shows a short sketch about the measured ventilation system. The position of the measurement points can be seen in Fig. 2 seen from above, while Fig. 3 contains these points from front-view.

In Fig. 1: CRAC = *C*omputer *R*oom *A*ir *C*onditioning; F* – airflow damper and orifice plate; F – airflow damper; SZ – air filter; PC – personal computer; Δp – measured pressure difference on the orifice plate.

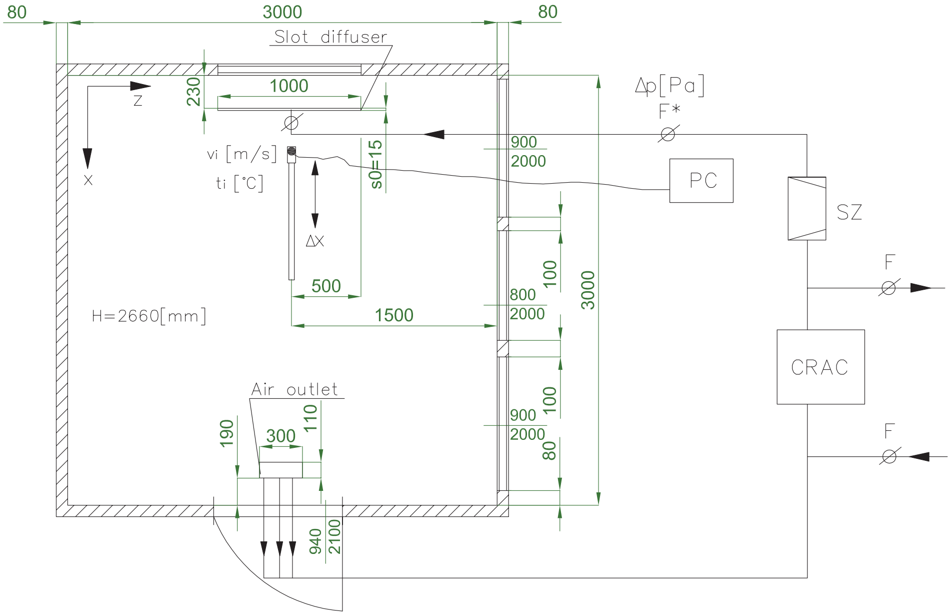

Fig. 1. Sketch of the ventilation system

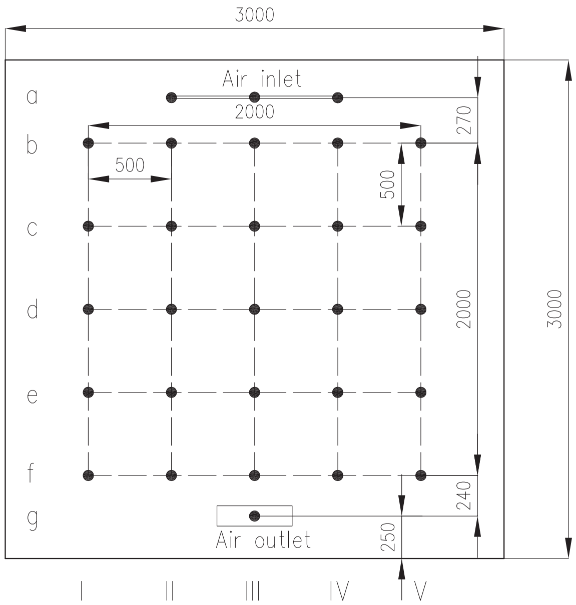

Fig. 2. Position of the measurement points seen from above

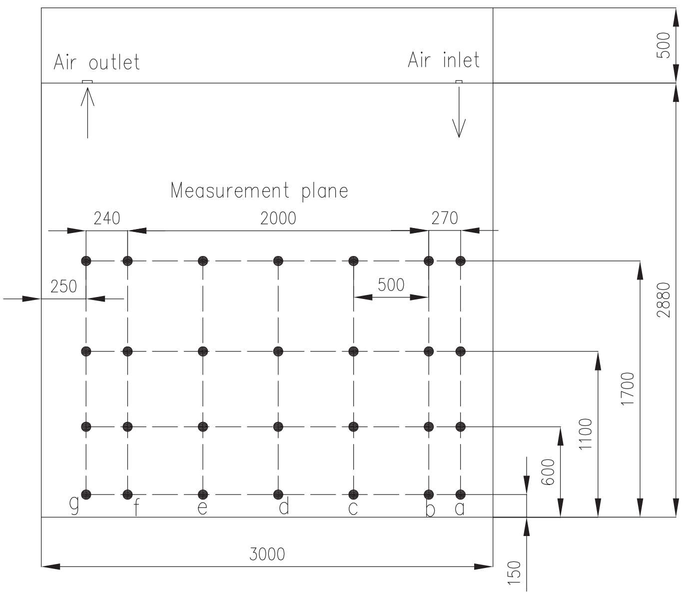

Fig. 3. Position of the measurement points seen from front-view

4 Results and discussion

4.1 Changing of the average air velocity in the occupied zone

Using the measured values at the relevant points - according to the previous section - the changing of the average air velocity can be investigated. Fig. 4 shows the changing of this velocity component at four relevant heights on a constant (maximum measured) airflow rate. It is clear that near the floor (at y = 0.1 m height) the average air velocity is almost constant on the whole measurement plane. Under the air inlet (position "a") this velocity component is a little bit higher than in the whole occupied zone. Of course, this phenomenon contains the measurement error of the velocity measurements; therefore it has not got any importance from the point of view of our results.

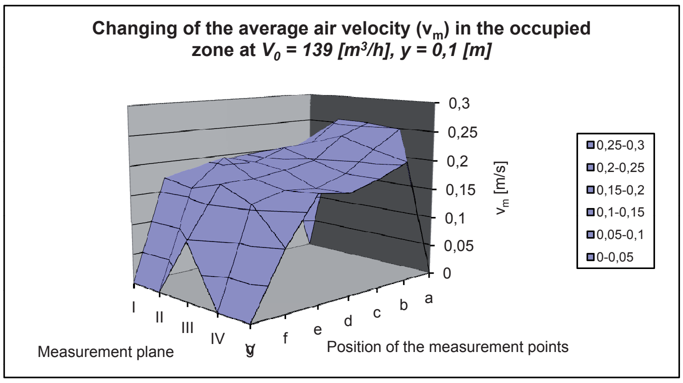

Fig. 4. Changing of the average air velocity at y = 0.1 [m]

When increasing the measurements height, at y = 0.6 [m] (Fig. 5) the previously mentioned tendency cannot be observed. At this height the average air velocity is higher under the air inlet (position "a") than in the occupied zone (position "b"-"f"). The explanation of this tendency is the following: The one-line slot diffuser was located next to the wall surface (next to position "a") so the primary air jet was supplied along the wall surface. As a result, the average air velocity should be higher under the air inlet and next to the wall, than in the other places of the occupied zone. Under the air inlet (position "g") the average air velocity starts to increase because of the presence of the wall and the outflow.

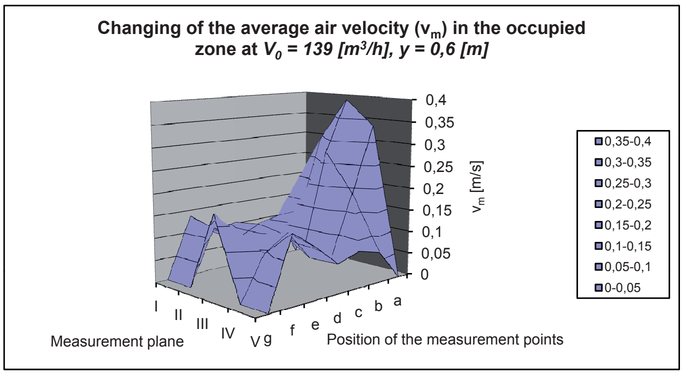

Fig. 5. Changing of the average air velocity at y = 0.6 [m]

In Fig. 6 can be seen a similar tendency to the previous heights. The only difference is in the maximum value of the measured average air velocity. Getting closer to the air inlet (Fig. 7) by increasing the measurement heights, the maximum air velocity will be higher; however the tendency is the same.

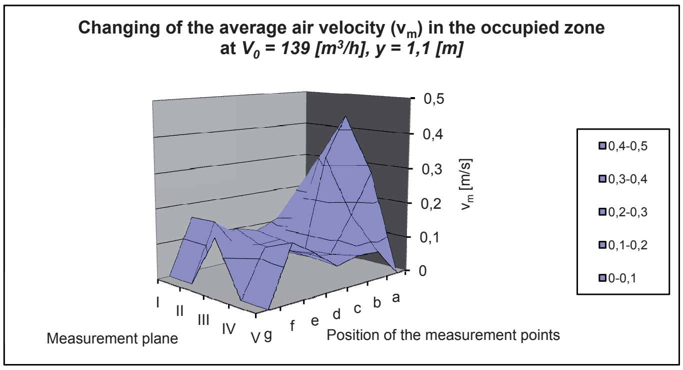

Fig. 6. Changing of the average air velocity at y = 1.1 [m]

Naturally all these tendencies can be observed at each series of measurements and relate to the characteristic of tangential air distribution.

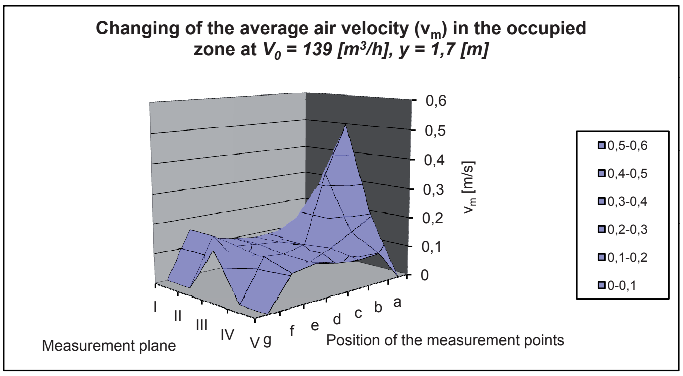

Fig. 7. Changing of the average air velocity at y = 1.7 [m]

4.2 Investigation of the relative average air velocities at different measurement heights

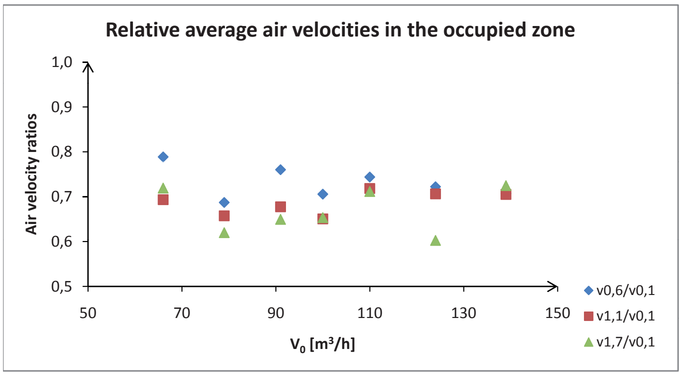

Fig. 8. Relative average air velocities

The ankle level is a relevant height from the point of view of designing draught comfort [12]; therefore the average air velocity was related to this height. In the whole occupied zone at the four heights the average of the measured average air velocities was made in each series of measurements. This average value at y = 0.1 [m] was marked with v0.1, at y = 0.6 [m] with $v_{0.6}$ and so on. Results can be observed in Fig. 8. It is obvious that the changing of the relative average air velocities shows similar tendency considering the measurement error which may cause some jutting points in this diagram. At smaller airflow rates the measured points have higher deviation than at bigger airflow rates.

4.3 Changing of turbulence intensity in the occupied zone at different measurement heights

Using the measurement results we have found that the changing of the average turbulence intensities at each height (y = 0.1; 0.6; 1.1 and 1.7 m) as a function of the airflow rate to the room decreases up to half of the room. The length of the test room is measured from the air inlet (0) to the air outlet (3000 mm).

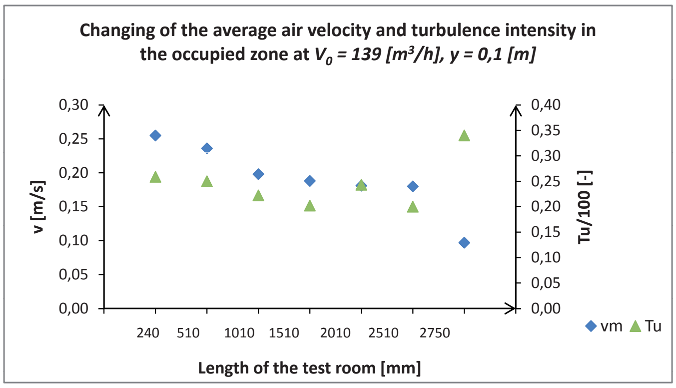

Fig. 9. Changing of the average air velocity and turbulence intensity along the room length

From the half of the room the turbulence intensity increases, especially under the air outlet because of the presence of the wall surface. The least measured turbulence intensities can be found near the floor (y = 0.1 m), then they increase as the height increases.

Seeing the changing of the average air velocity we found that from the air inlet to the air outlet it decreases along the test room's length. These previously mentioned tendencies can be seen at all series of measurements.

5 Summary

In this paper a tangential air distribution system was investigated in a slot ventilated test room experimentally. The investigations included average air velocity and turbulence intensity measurements at four relevant heights in the occupied zone of the test room. Results showed that near the floor the average air velocity is almost constant in the whole measurement plane. At higher measurement heights (closer to the air inlet) under the air inlet this velocity component is higher than in the other parts of the occupied zone. This tendency refers to the tangential air distribution. The previously mentioned tendencies can be observed at all series of measurements.

By making the relative average air velocities related to the significant y = 0.1 m measurement height (ankle level) it was clear that the changing of the relative average air velocities shows similar tendency considering the measurement error which may cause some jutting points in this diagram. At smaller airflow rates the measured points have higher deviation than at bigger airflow rates.

Using the measurement results we have found that the changing of the average turbulence intensities at each height (y = 0.1; 0.6; 1.1 and 1.7 m) as a function of the airflow rate to the room decreases up to half of the room. Seeing the changing of the average air velocity we found that from the air inlet to the air outlet it decreases along the test room's length.

References

1 **Magyar T.,** *A helyiségek levegő átöblítése*. Magyar Épületgépészet, 39 (5-6), pp. 189-194, (1990).

2 **Moureh J., Flick D.,** *Airflow characteristics within a slot-ventilated enclosure*. International Journal of Heat and Fluid Flow, 26 (1), pp. 12–24, (2005).
DOI: 10.1016/j.ijheatfluidflow.2004.05.018

3 *ASHRAE Handbook 2005: Fundamentals*. Thermal comfort (2005).

4 **Fanger P. O., Christensen N. K.,** *Perception of draught in ventilated spaces*. Ergonomics, 29 (2), pp. 215-235, (1986).
DOI: 10.1080/00140138608968261

5 **Fanger P. O., Melikov A. K., Hanzawa H., Ring J.,** *Air turbulence and sensation of draught*. Energy and Buildings, 12 (1), pp. 21-39, (1988).
DOI: 10.1016/0378-7788(88)90053-9

6 **Fanger P. O., Melikov A. K., Hanzawa H., Ring J.,** *Turbulence and draft.* ASHRAE Journal 31 (4), pp. 18-25, (1989).

7 **Magyar T.,** *Laboratóriumi kísérletek a huzathatás mérésének továbbfejlesztésére*. Magyar Épületgépészet, 57 (5), pp. 3-7, (2008).

8 **Hanzawa H., Melikow A. K., Fanger P. O.,** Airflow characteristics in the occupied zone of ventilated spaces. ASHRAE Trans. 93, pp. 524–539, (1987).

9 **Kovanen K., Seppänen O., Sirén K., Majanen A.,** *Turbulent air flow measurements in ventilated spaces*. Environment International, 15 (1-6), pp. 621-626, (1989).
DOI: 10.1016/0160-4120(89)90084-6

10 **Magyar T.,** *Qualification of the occupied zones of different types of air supply systems on the basis of measurements*. Periodica Polytechnica Mechanical Engineering, 44 (2), pp. 217-226, (2000).

11 Lindab airflow damper technical guide.
http://itsolution.lindab.com/lindabwebproductsdoc/pdf/documentation/ads/cz/technical/diru.pdf (Last viewing: 12. 01. 2014.)

12 *ASHRAE Handbook 2005: Fundamentals*. Thermal comfort (2005).