11512

AN EXPERIMENTAL STUDY ON CHAIR AIR SUPPLYING

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Abstract

Displacement ventilation is acknowledged to be an efficient system for the removal of contaminants and excess heat from occupied zones of rooms, this system is aiming at supplying clean undiluted supply-air directly to the zone of occupation. Air flow rate, temperature and the design of the supply device strongly influence the parameters that determine thermal comfort.

In the paper, one kind of displacement ventilation systems — chair air supplying system is investigated. A full-scale experimental model is established, temperature field and velocity field are measured at different air flow rate, supply air temperature with four different chair air outlets. PIV (particle Image Velocimetry) technology is applied in measuring velocity field. The PD (percentage of Dissatisfied) in occupied zone is evaluated. The results show that this system has a stable temperature gradient, the vertical temperature difference between 0.1m (above floor level) and 1.1m is lower than 3 ℃ in most cases. So a comfortable thermal environment is given by this displacement ventilation system.

keywords

Displacement ventilation Full-scale experiments Air velocity Temperature gradient Thermal comfort

Introduction

Recently, the local air conditioning by chair ---- one kind of displacement ventilation systems begins to be used in high-ceiling public building in China. By displacement ventilation we mean supply air with a low-velocity diffuser located at floor level (outlets under chairs for example). The air is supplied with less temperature than the ambient and extracted at ceiling level. The aim of this ventilation principle is to create supply air conditions in the occupied zone, while the air with traditional mixing systems is to create extract-air conditions in the whole room.

In this paper, a full-scale experimental model of local air conditioning by chair is established, temperature field and velocity field are measured at different air flow rate, supply air temperature, four different chair air outlets were designed and used. The PD in occupied zone is evaluated.

Test Room

The measurements were made in a test room that measuring 4.0 × 4.0 × 3.5m^3 (L × M × H) , Fig.1 show the photography of the test room. One wall of the test room is made of 10mm thick glass. A static pressure tank measuring 2.3 × 1.5 × 0.4 m^3(L × W × H) is located in the test room, the chair is equipped on the tank, supply air is supplied into the static pressure tank, then flows into chair air outlet. One experimental unit is separated from the ambient , the area of the unit is 1.1 × 0.8m^2, the height is to the ceiling of the test room, exhaust opening is located near the ceiling.

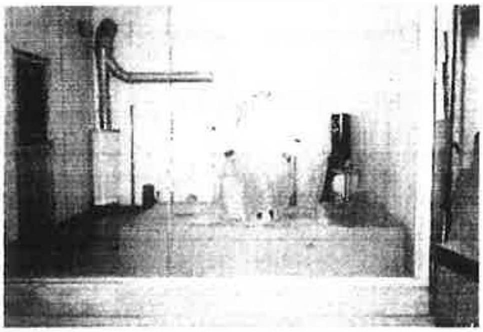

Fig.1 Photograghy of the test room

Fig.2 shows the illustration overview of the experimental unit. A thermal simulated person sits on the chair, the heat load is 80W.

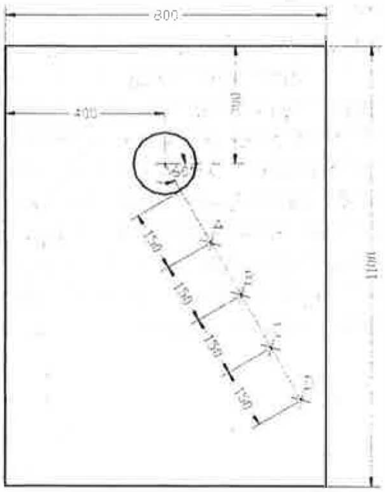

Fig.2 Overview of the experimental unit

Four different types of chair air outlets were used in this paper, the properties of them are presented in Table 1.

outlet NO.	H (mm)	R (mm)	Diameter of perforation (mm)	Promotion degree (%)
1	182	159	6	19.6
2	140	159	8	39.2
3	175	159	5	32.3
4	1/4 area in the font of NO.3 outlet is closed			

Table1 The properties of outlets

Temperature Field

The temperatures were measured at 10 points located along a vertical line, and 4 points A 、 B 、 C 、 D along a horizontal line (see Fig.2), the height lever were 0.05,0.1,0.15,0.3,0.6,1.5,1.7,1.8,2.5m.

According to the ISO7730 recommendation, the temperature between 0.1m and 1.1m above floor level must not exceed 3 ℃.

The temperature field was measured at different flow rate, supply air temperature with four different chair air outlets. Fig.3 and Fig.4 is two result of the temperature measurements. From the chart we can see the temperature varied with the height above the floor, D1 ~ D4 mean four measuring points A 、 B 、 C 、 D.

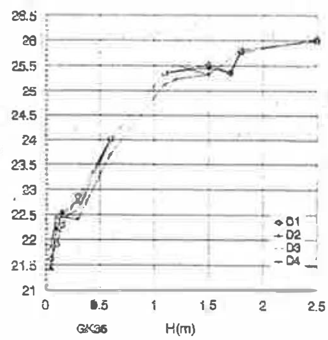

Fig.3 NO.1 Outlet t_{room}-t_s=5.5 ℃ q_s=45m^3/h

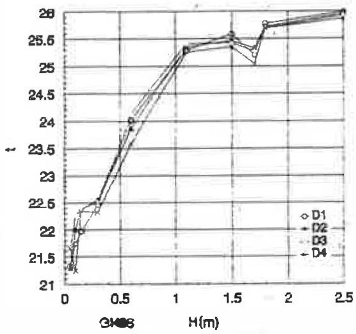

Fig.4 NO.1 Outlet t_{room}-t_s=5.6 ℃ q_s=60m^3/h

Table 2 shows the temperature difference between 0.1 and 1.1m above floor level under different conditions.

Outlet NO.	Supply air flow rate (m^3/h)	t_{room}-t_s (℃)	$t_{1.1}$-$t_{0.1}$ (℃)
1	30	5.7	3.33
	45	5.5	2.67
	60	5.6	3.01
	80	3.5	1.79
2	30	6.0	3.51
	45	5.5	3.08
	60	5.3	2.85
3	30	5.5	3.57
	45	5.5	3.36
	60	5.5	3.44
	80	3.4	1.87
4	30	6.0	3.61
	45	5.5	3.63
	60	5.3	3.66

Table 2 ($t_{1.1}$-$t_{0.1}$)under different conditions

Fig.5 and Fig.6 show two typical vertical temperature profiles recorded under two conditions using NO.2 outlet. The temperature is given as the recorded temperature minus the supply air temperature divided by the difference between the supply and extract (α). We can see that a temperature gradient comes into being.

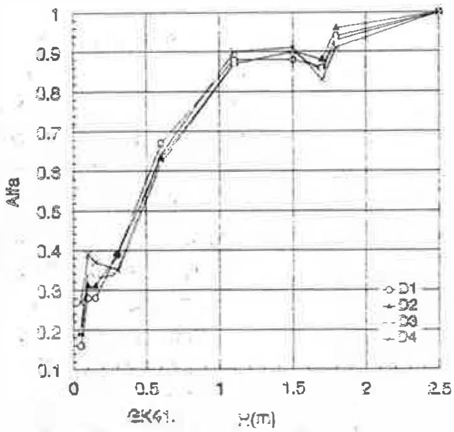

Fig.5 NO.2 outlet q_s=45m^3/h ,t_{room}-t_s=5.5 ℃

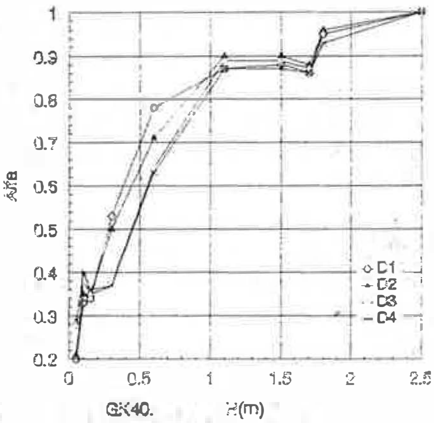

Fig.6 NO.2 outlet q_s=60 m^3/h, t_{room}-t_s=5.3 ℃

Velocity Field

The velocity in displacement ventilation system is very low, common velocity measuring apparatus can't measure precisely. In this paper, PIV (particle Image Velocimetry) was used. The technique consists of suspending zine stearate powder in the compressible medium. The particle is illuminated by an intense light flashed at a desired frequency. Photography is used to record the particle movement. With proper design of the technique, the particle paths appear in the photographys as dotted lines. From the length of the dots and the period of the light flash, flow velocities can be calculated. From the location of the plane of focus of the camera the position of the particle can also be determined.

Fig.7 show a typical PIV photograghy near chair air outlet.

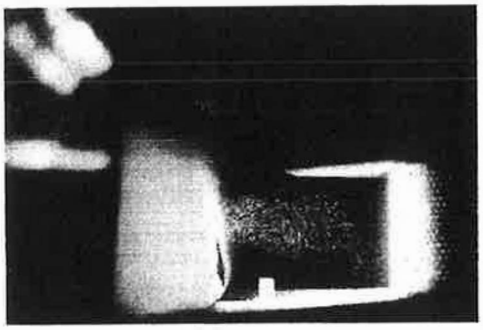

Fig.7 NO.3 outlet q_s=45m^3/h

A velocity field model near the outlet with displacement ventilation was developed by M.Sandberg (1989) :

If we make the following assumptions regarding the layer of air that is spreads out on the floor:

— density (temperature) difference between the air layer and its ambient is constant;

— the thickness of the air layer is constant;

— there are no vertical velocities.

Then the theory predicts that the velocity decay vs. distance for a three-dimensional flow becomes:

$$U_{(x)} = U_{(0)} e^{-\frac{2V_g h}{q_s} x} \qquad (1)$$

where:

$U_{(x)}$ — velocity vs. distance x, (m/s);

x — distance from the outlet, (m);

$U_{(0)}$ — mean velocity where the air hits the floor, (m/s);

V_g — gravitational spread velocity, (m/s);

h — thickness of the air layer, (m);

q_s — supply flow rate, m^3/h.

Make linear regression of $\ln V_x$ and x , V_x is the x-direction velocity measured in this paper. Fig.8 shows the regression result.

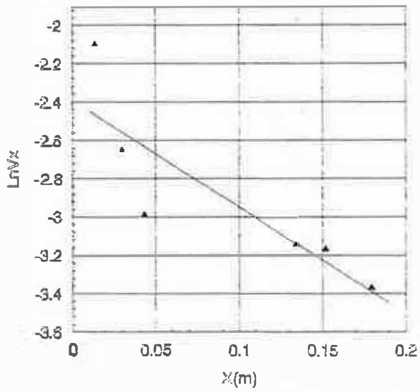

Fig.8 Linear Regression of $\ln V_x$ and X

We can get the follow equation:

$$\ln V_x = -2.392 - 5.558x \qquad (2)$$

The regression coefficient is 0.8599. Equation(2) can be conversed to:

$$V_x = 0.091 e^{-5.558x} \qquad (3)$$

So we can see V_x decay exponentially vs. distance x.

PD

A mathematical model of draft risk has been established (Fanger et al. 1988) which predicts the percentage of people dissatisfied due to draft, PD as a function of air temperature t_a (℃) , mean air velocity $\bar{V}$ (m/s) and turbulence intensity, Tu (%).

$$PD = (34 - t_a)(\bar{V} - 0.05)^{0.62}(3.14 + 0.37\bar{V}\,Tu) \qquad (4)$$

for $\bar{V}$ <0.05 m/s, insert $\bar{V}$ =0.05 m/s

for PD>100%, use PD=100%.

For x>260mm, the highest velocity is 0.0657m/s, we use it to calculate Pd_{max}.

Tu at the level 0.1m above the floor was got by using empirical equation(Nielson 1988):

$$Tu = 0.99 / \bar{V} + 9.9 \qquad (5)$$

Then we can get PD_{max} in occupied zone in this system:

$$PD_{max}=3.5\% \qquad (6)$$

According to ISO7730, the PD shouldn't exceed 15% at any point within the occupied zone.

Conclusion

1. This system has a stable temperature gradient, the vertical temperature difference between 0.1 and 1.1m above floor level is lower than 3 ℃ in most cases. To get lower $(t_{1.1}-t_{0.1})$ increased flow rate is needed.

2. The supply air velocity decay exponentially vs. distance from outlet.

3. In this system , the PD in the zone of occupation is less than 5%.

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