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An experimental study of the influence of a walking occupant on three air distribution methods

Weiqin Wu [a], Zhang Lin [b,*]

[a] Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong, China
[b] Division of Building Science and Technology, City University of Hong Kong, Hong Kong, China

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ABSTRACT

Most indoor air studies have not considered the influence of walking occupants. However, the occupants of many air conditioned rooms are a mixture of sedentary and walking occupants, such as in an opening plain office. In this paper, a series of tests are conducted under three air distribution methods (stratum ventilation, displacement ventilation and mixing ventilation) with a real walking occupant. The occupant walks at a speed of 1.5 m/s along two different walking routes. Velocity, temperature and CO_2 concentration are measured to find the influence on air distribution. The results show that a short walk does not change the temperature or CO_2 concentration profiles. When the walk lasts for a long time (30 min in this study), the walking occupant causes mixing effect. The influence under mixing ventilation is the smallest. The influence under stratum ventilation is smaller than that under displacement ventilation. The ventilation efficiency of stratum ventilation is still higher than that of mixing ventilation. Stratum ventilation and mixing ventilation recover from the influence more quickly than displacement ventilation. The results show the application potential of stratum ventilation with frequently walking occupants.

1. Introduction

Stratum ventilation is a technically feasible air distribution method to accommodate higher room temperature in a small or medium room. The fresh air is directly sent to the occupants' breathing zone. Lin et al. (2009) [1] found that stratum ventilation could provide better thermal comfort and air quality in the breathing zone with proper design. Its potential in saving energy was also proved by Lin et al. (2011) [2] using TRNSYS. The higher design supply air temperature of stratum ventilation allowed higher chilled water temperatures which contributed to the improvements of the coefficient of performance (COP) of the refrigerating plant and offer a significant energy saving. It was found that the year-round energy saving could reach 25% and 44% at least when compared with displacement ventilation and mixing ventilation. Tian et al. (2010) [3] studied the diffusion of gaseous contaminant under stratum ventilation and under displacement ventilation. Different positions and types of contaminant sources are considered. The results showed that under stratum ventilation, the contaminant concentration in the breathing zone is lower in most conditions. Tian et al. (2011) [4] also studied the local mean age of air and thermal comfort in a stratum ventilated office. It was found that stratum ventilation is able to provide satisfactory inhaled air quality and thermal comfort with relatively higher room and supply air temperatures. Lin et al. (2012) [5] studied the anti-airborne infection performance of stratum ventilation and compared it with that of displacement ventilation. It was found that the droplet concentration in the breathing zone under stratum ventilation was significantly less than that under displacement ventilation.

Although the studies show the potential of stratum ventilation, the influence of walking occupants has not been dealt with. However, the influence of movement has been found in a ventilated room. Mattsson et al. (1996) [6] presented the first results of room air velocity measurements, carrying out the study in a full-scale test room with a cylinder shaped manikin doing single and back-and-forth movements across the room. Most of the studies were taken under conditions without mechanical ventilation and heat sources while some results were acquired under displacement ventilation. The results showed that a single motion caused laminar horizontal air movements and continuous periodical movements caused a complex turbulent flow field. The results obtained without mechanical ventilation were similar to those under displacement

* Corresponding author. Tel.: +852 34429805; fax: +852 34429716.
E-mail address: bsjzl@cityu.edu.hk (Z. Lin).

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Nomenclature

Abbreviations

CP	computer
D-*p*	in *p* condition under displacement ventilation
EA	exhaust air
FA	fresh air
L	line
M-*p*	in *p* condition under mixing ventilation
S-*p*	in *p* condition under stratum ventilation
s	steady condition
w	walking condition
r	recovery condition

Letters

C_r	concentration of return air (ppm)
C^*	dimensionless concentration
C^*_{i-j}	dimensionless concentration of point at *j* m height along L*i*
C^{*sd}	standard deviation of concentration
C^{*sd}_{max}	maximum standard deviation of concentration
C_{i-j}	concentration of point at *j* m height along L*i* (ppm)
C_t	concentration at time point *t* (ppm)
$\overline{C}$	average concentration (ppm)
N	total number of time points
Q	cooling load (W)
T_{sa}	temperature of the supply air (°C)
T^*	dimensionless temperature
T^*_{i-j}	dimensionless temperature of point at *j* m height along L*i*
T^{*sd}	standard deviation of dimensionless temperature
T^{*sd}_{max}	maximum standard deviation of dimensionless temperature
T_{i-j}	temperature of point at *j* m height along L*i* (°C)
T_t	temperature at time point *t* (°C)
$\overline{T}$	average temperature
V	supply airflow rate (m^3/h)
v	velocity (m/s)
v_{i-j}	velocity of point at *j* m height along L*i* (m/s)
v^{sd}	standard deviation of velocity (m/s)
v_t	velocity at time point *t* (m/s)
$\overline{v}$	average velocity (m/s)

ventilation, which illustrated that the influence on air velocity field caused by occupant's movements was irrelevant to the temperature stratification in a room. And then Mattsson et al. (1997) [7] did another experiment with a cylinder shaped manikin and a detailed person simulator under displacement ventilation. It was found that there were some differences in measured air quality between using these two moving objects, but the qualitative results were the same. And the action of turning trended to mix the air more. Han et al. (2014) [8] studied the dynamic airflow of human movement with a life-size manikin in a full-scale cabin without ventilation. Five moving speed, 0.5, 0.75, 1.0, 1.25 and 1.5 m/s, was used. Both experiment and numerical simulation were conducted. The results showed that moving could significantly influence the airflow motion in enclosed environments and enhance the contaminant transmission risk. Matsumoto et al. (2004) [9] studied the effect of a moving object on the performance evaluation of displacement ventilation in a full-scale experiment with a heated and movable manikin. It was found that when the moving speed was 0.4 m/s, the vertical temperature gradient was larger than the case of the manikin standing still while it was smaller than the case with the moving speed of 0.8 m/s. The higher the moving speed, the smaller the local air exchange index was in the occupied zone. Brohus et al. (2008) [10] defined five typical movements to determine the influence of different kinds of movement compared with the case of no movement under mixing ventilation and displacement ventilation respectively. It was found that movements could cause significant effect on the local concentration distribution under displacement ventilation, though on average displacement ventilation was more effective than mixing ventilation. Bjørn et al. (1997) [11] combined the influence of movements and human breathing in their study to find the effect on the vertical contaminant distribution and the occupant's exposure. Tracer gas was added in three ways. It was found that the movements had significant effect on the vertical contaminant distribution and higher speed meant less stratification.

In reality, the occupants in many air conditioned rooms are a mixture of sedentary and walking occupants. From time to time, occupants move around, especially in spaces like waiting rooms or open plan offices. The walking persons may make the air distributions in these rooms different from the design which is done for the steady condition. Therefore, this paper studies the influence of a walking person on three air distribution methods, namely stratum ventilation, displacement ventilation, and mixing ventilation, to determine whether stratum ventilation is sensitive to the walking occupants and whether the advantages of stratum ventilation could be kept when there is continuous walking. This study should be able to find how a walking person influences the airflows under different air distribution methods.

2. Methodology

The test is carried out in the environmental chamber (5.1 m × 8.8 m × 2.4 m) at the City University of Hong Kong. The configuration of the test room is shown in Fig. 1. The condition in a small classroom or waiting room is imitated. There are six sedentary occupants in the room with five simulated persons and one real person. The simulated person is a cardboard box (0.4 m × 0.3 m × 0.76 m) and heated by a 100 W bulb inside. The real person seats at Position 4. At Positions 7–9, there is a cardboard box (0.4 m × 0.3 m × 0.76 m) without heat source on each chair as a block respectively. Three computers (CP1, CP2 and CP3) are used to record the measurement and a researcher is in the room to conduct the test. Table 1 shows the information on internal heat sources in the chamber. The CO_2 sources are the three real occupants in the room.

The room temperature is expected at 26 °C. The conditions of these three air distribution methods are shown in Table 2. In order to observe significant change in CO_2 concentration, the airflow rate is set to be small at 4 air change per hour (ACH). For easy comparison, the airflow rates for the three air distribution methods are identical.

There are two walking routes, Routes A and B, as shown in Fig. 1. For Route A, it is vertical to the air supply direction under stratum ventilation or displacement ventilation, which means along Route A, the walking occupant blocks and disturbs the supply air. For Route B, it is parallel to the air supply direction which means the walking occupant does not disturb the supply air much. These two routes are selected also because they are common walking