Effect of outlet location on indoor air quality for stratum ventilation under heating mode

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Abstract. Warm air supply is widely used to condition indoor environment in winter. It has been proved that stratum ventilation (SV), as a novel air distribution, has potentials to be applied for heating. The outlet location may affect indoor air quality (IAQ) due to interaction between thermal plumes from heat sources and room airflows. In this study, the effect of outlet location on IAQ for SV was investigated for 9 cases under heating mode. The outlets were located at the heights of 0.4 m on the same side wall as the inlet, 0.4, and 1.3 m on the opposite side wall, respectively. The concentration of carbon dioxide was measured in an experimental chamber with dimensions of 5850 mm(L) × 5057 mm(W) × 2554 mm(H). The average concentration of carbon dioxide and carbon dioxide removal efficiency (ε_{CRE}) were used as the evaluation indexes. The results showed that the concentration of carbon dioxide in the breathing zone with the outlet located on the same wall as the inlet was lower than those with the outlets located on the opposite side wall. At this scenario, ε_{CRE} was greater than one, showing a good ventilation performance.

1 Introduction

Existing studies on stratum ventilation focused on cooling applications [1]. Some studies on the effect of outlet location for SV under cooling mode have been carried out. Lin [2] found that SV could meet the need of people for thermal comfort and had a good IAQ. Yao et al. [3] analysed the IAQ for SV with different outlet locations in summer by both experiment and numerical simulation. When the supply airflow rate was 10 air changes per hour (ACH) a layout with the outlets located at the same wall as the supply inlets performs better, achieving good thermal comfort and indoor air quality. Yin et al. [4] had a study on the effect of outlet locations on indoor pollutant distribution for SV. The results showed that ε_{CRE} was efficient and IAQ in the breathing zone is better when the outlet was located on the ceiling.

Current works on the effect of outlet location on IAQ for SV under heating mode were limited as compared with that under cooling mode. In this study, the effect of outlet location on IAQ including the average concentration of carbon dioxide (CO_2) and ε_{CRE} under heating mode were experimentally investigated in a stratum-ventilated environmental chamber. This study helps to obtain the outlet location with better IAQ for SV in winter. The outlet locations in summer and winter for SV are unified to make a further application of SV. The data obtained in this study can also provide a reference for the design and optimization of SV under heating mode.

2 Methods

2.1 Experimental chamber

The experiments were carried out in an environmental chamber located in Chongqing University. This chamber resembled an office with dimensions of 5850 mm(L) × 5057 mm(W) × 2554 mm(H), as shown in Fig. 1 (a). It had two windows with dimensions of 2853 mm(L) × 1496 mm(W) and 2229 mm(L) × 945 mm(W), respectively. All the walls and windows were interior.

A rectangular box with dimensions of 400 mm(L) × 250 mm(W) × 1200 mm(H) was used to represent an occupant. It has been experimentally verified that the rectangular thermal manikin was adequate to simulate the effect of a human body on the global air distribution of SV [5]. A light bulb of 100 W was placed inside dummy to simulate human body heat [6]. The plastic tube connected to the carbon dioxide cylinder was inserted into the round hole of dummy at 1.1 m to simulate human breathing. Six ceiling lamps with the heat load of 23 W each were installed on the ceiling. The outlets were located at the height of 0.4 m at the same side wall as the inlet (i.e., sa-0.4), 0.4 and 1.3 m at the opposite side wall (i.e., op-0.4, op-1.3), respectively. The locations of inlet and outlets with dimensions of 0.18 m × 0.18 m each were shown in Fig. 1 (b).

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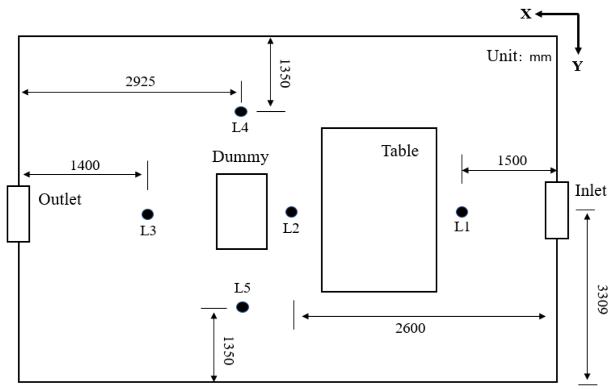
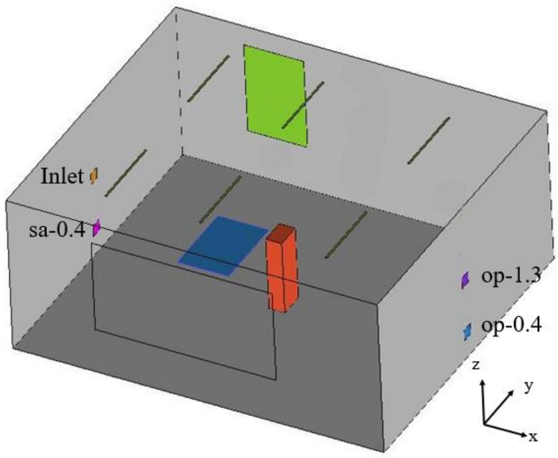


(a)



(b)

Fig. 1. (a) Layout of the measuring lines (Sampling Lines L1-L5), and (b) Locations of the inlet and outlet.

In this study, the vane angle of supply air was set as 30° downwards to counteract the effect of positive thermal buoyancy. We tested nine different cases. The boundary conditions of these cases were summarized in Table 1.

Table 1. Information on cases.

Case	Supply air velocity (m/s)	Supply air temperature (℃)	Supply air angle (°)	Outlet location
1	1.22	26.9	30	sa-0.4
2	1.22	27.0		op-0.4
3	1.22	27.0		op-1.3
4	1.68	26.1		sa-0.4
5	1.68	26.1		op-0.4
6	1.68	25.9		op-1.3
7	2.07	25.0		sa-0.4
8	2.07	25.0		op-0.4
9	2.07	24.9		op-1.3

2.2 Measurement instrument

The concentration of carbon dioxide was measured using PSENSE Ⅱ portable carbon dioxide detector. The instrument had been calibrated prior to the experiments. The details of measurement instrument were summarized in Table 2.

Table 2. Information on measurement instrument.

Type of instrument	parameter	Measuring accuracy	Measuring range
PSENSE II portable carbon dioxide detector	concentration of carbon dioxide	$\pm 30ppm \pm$ 5% of readings	0-9999ppm

2.3 Measurement procedure

The air-conditioning system and the exhalation system of occupant should be firstly opened for approximately one hour to ensure that the indoor environment reached a steady state before recording data. Electric heater should be opened at the same time for heating air. When the concentration of carbon dioxide reached statistically steady, a steady state was assumed to be achieved. For Sampling Lines L1-L5 (see Fig. 1 (a)), the concentration of carbon dioxide was measured at the heights of 0.1, 0.6, 1.1, 1.7, and 2.2 m above floor by attaching the measurement instruments to a vertical bar. These heights represented the ankle level, the abdomen level, the breathing zone for sedentary, the breathing zone for standing, and the upper zone of the room, respectively. Due to the limited instruments, five portable carbon dioxide detectors were employed to conduct the measurements one Sample Line by one Sample Line. For two adjacent Sample Lines, at least 15 min was kept to ensure that the flow fields reached statistically steady again after moving. For each Sample Line, the measuring duration was 10 min.

3 Results and discussion

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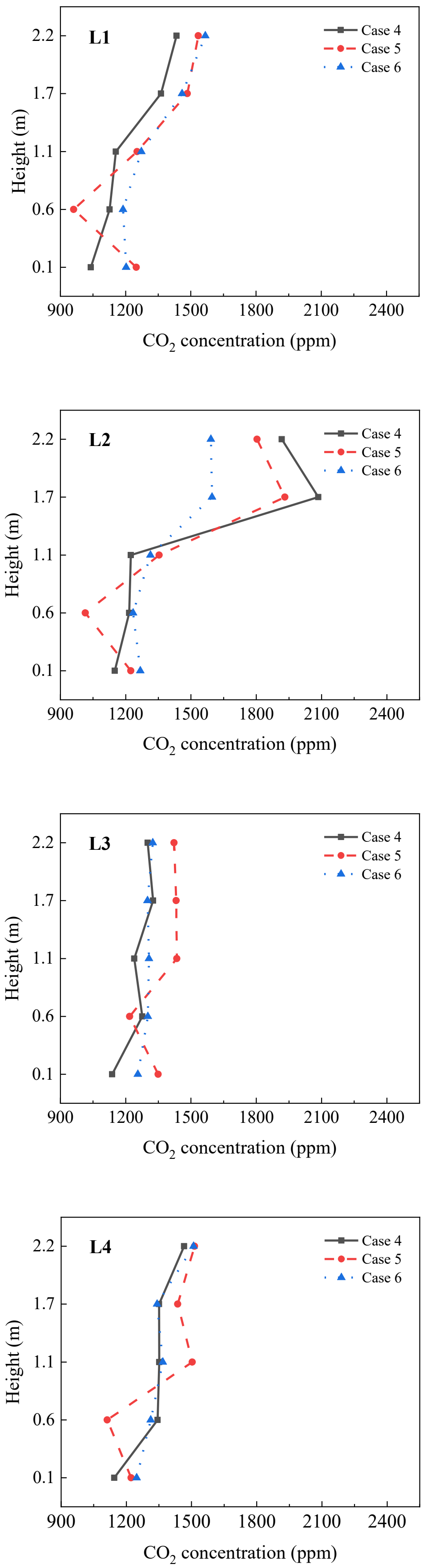
3.1 CO_2 concentration distribution



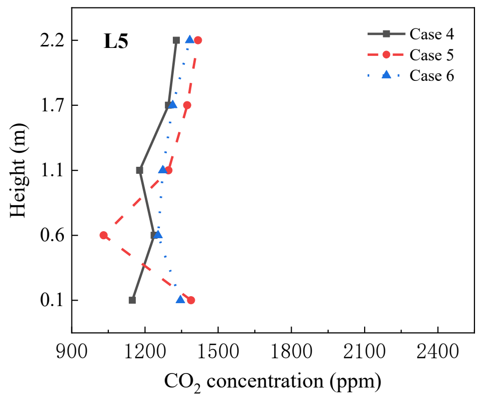


Fig. 2. CO_2 concentration distribution (ppm) of Case 4, Case 5, Case 6.

Fig. 2 shows the distributions of carbon dioxide concentration along Sampling Lines L1-L5 for Case 4, Case 5, and Case 6. Cases 4-6 with suitable supply air velocity and air temperature were thus selected to represent the typical distribution of carbon dioxide concentration. As can be seen from a comparison in Fig. 2, the concentration of carbon dioxide of Cases 4-6 globally increased with the height. This was because air entrainment during warm airflow rising caused the pollutants gathering at the top of room. The concentration of carbon dioxide in the breathing zone with the outlet located on the same wall as the inlet was lower than that with the outlet located on the opposite side wall. As illustrated by the figure, with the height of 0.6 and 1.1 m, the concentration of carbon dioxide in supply air jet zone (L1-L3) was lower than other zone as air supply was sent directly to the breathing zone. The distributions of carbon dioxide concentration of Cases 1-9 along L2 are shown in Fig. 3.

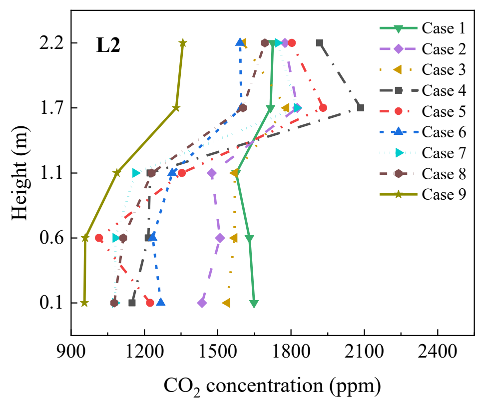


Fig. 3. CO_2 concentration distribution (ppm) of Cases 1-9 along Sampling Line L2.

3.2 Carbon dioxide removal efficiency

The index, ε_{CRE}, is widely used to evaluate indoor air quality [7,8]. A larger ε_{CRE} indicated better indoor air quality and ventilation performance [9]. The calculation formula is as follows.

$$\varepsilon_{CRE} = \frac{C_e - C_s}{C_i - C_s} \tag{1}$$

Where C_e is the concentration of carbon dioxide in the outlet, ppm; C_s is the concentration of carbon dioxide in the inlet, ppm; C_i is the average concentration of carbon dioxide in occupied zone, ppm.

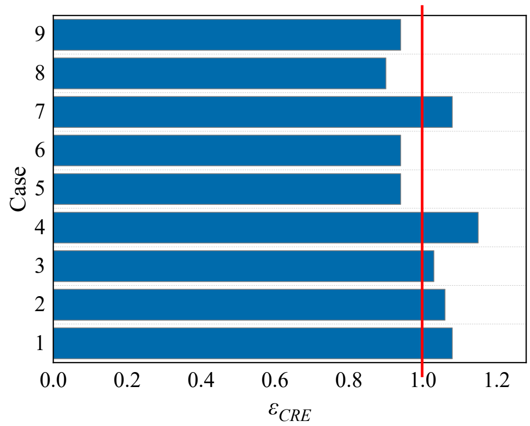


Fig. 4. CO_2 removal efficiency under nine cases.

Fig. 4 shows the values of ε_{CRE} for nine cases. When the outlet was located below the inlet at the height of 0.4 m (Cases 1, 4, 7), ε_{CRE} was greater than one. This was because the outlet and inlet were located at the same wall, some fresh air reached the opposite wall and then recirculated. However, ε_{CRE} was similar for the two scenarios (op-0.4 and op-1.3) with the outlet located at the opposite side wall. ε_{CRE} of Cases 5 and 6 were about 0.94. ε_{CRE} of Case 7 was 20% higher than that of Case 8. The outlet location can have a significant effect on indoor air quality. The layout with outlet located at the same side wall as the inlet has a better ventilation performance than that located at the opposite side wall. The study of Yao et al. [3] also showed that the layout with the outlets located at the same wall as the supplies performs better, achieving good indoor air quality.

4 Conclusions

In this study, the effect of outlet location on indoor air quality for stratum ventilation under heating mode was experimentally studied. The concentration of carbon dioxide and carbon dioxide removal efficiency for different outlet locations were investigated. The outlet location can have a significant effect on indoor air quality for stratum ventilation under heating mode.

From the results of concentration of carbon dioxide in nine cases, the concentration of carbon dioxide in the upper zone of the room was higher than that in the lower zone of the room globally. Based on the experimental results, it can be concluded that there are significant differences in carbon dioxide concentration among different cases. The concentration of carbon dioxide is lowest with the outlet located at the height of 0.4 m below the inlet in Cases 4-6.

ε_{CRE} could be greater than one in Cases 1-4 and 7 and up to 1.15 at most, showing a better pollutant removal efficiency with the outlet located below the inlet at the height of 0.4 m (Cases 1,4, and 7). With this layout, fresh airflows reach the opposite wall and then recirculated. Besides, ε_{CRE} was similar for the two scenarios (op-0.4 and op-1.3) with the outlet located at the opposite side wall.

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