EFFECT OF SUPPLY AIR CONDITION ON TEMPERATURE/CONTAMINANT DISTRIBUTION IN A ROOM WITH IMPINGING JET VENTILATION SYSTEM

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Abstract

Even though displacement ventilation system (hereinafter referred to as DV) has better ventilation effectiveness compared to mixing ventilation system (hereinafter referred to as MV), DV is not yet commonly used, due to its difficulty for heating and over cooling risks. Impinging Jet ventilation system (hereinafter referred to as IJV) was developed to overcome those difficulties without losing the high ventilation effectiveness. In order to study about the pros and cons of IJV compared to DV, some full-scale experiments were conducted at a climate chamber. Temperature and contaminant (CO_2) concentration were measured, and the relationship between supply condition and distributions of temperature and CO_2 concentration were compared in this paper. In addition, the experimental results were evaluated based on the specific Archimedes number defined in this paper, and were compared to dimensionless temperatures and contaminant removal effectiveness.

Keywords: Impinging Jet Ventilation, Displacement Ventilation, Thermal Stratification, Full-scale Experiment

1 Introduction

It is said that DV has better ventilation performance and air quality compared to MV, under cooling condition. However, DV has over cooling risks around ankle level, since it supplies the cool air directly to the occupied zone at lower level. IJV has been proposed as a new air conditioning ventilation system, which was expected to overcome the disadvantages of MV and DV. In order to study about the pros and cons of IJV compared to DV, some full-scale experiments were conducted, and the results are reported in this paper.

2 Experimental set-ups

The experiments were conducted from November, 2019 to February, 2020 at a climate chamber in Osaka university, Japan, shown in Figure 1, whose size is 5,450 (d) × 5,000(w) × 2,770 (h) [mm]. At each wall of north and south, a round duct with diameter of 150 mm was installed at the middle of the wall as the IJV supply terminals. The outlet plane of the ducts was located 600 mm above the floor. The exhaust opening was located approximately at the center of the ceiling. Twenty heating elements (50[W] x 20 =1000[W] in total) were distributed in the chamber, in order to simulate the heat generation from occupants and other interior heat generations. Four of them were chosen for simulating the emission of contaminant generated from human (15L/h for each). Additionally, DV diffuser shown in Figure 2, whose height is 600mm and the effective supply area is 0.188m^2, was installed in some cases.

As shown in Figure 1, seven poles were set vertically, and the distribution of temperature and CO_2 concentration were measured along the poles. It should be noted that the measurement points of north-south line were shifted by 200 mm from the center, so as not to disturb the development of the jet along the floor on the center line of the room. Along each of the poles, air temperature was measured at twenty points and CO_2 concentration was measured at nine points. In addition, temperature and CO_2 concentration of supply air and exhaust air were also measured.

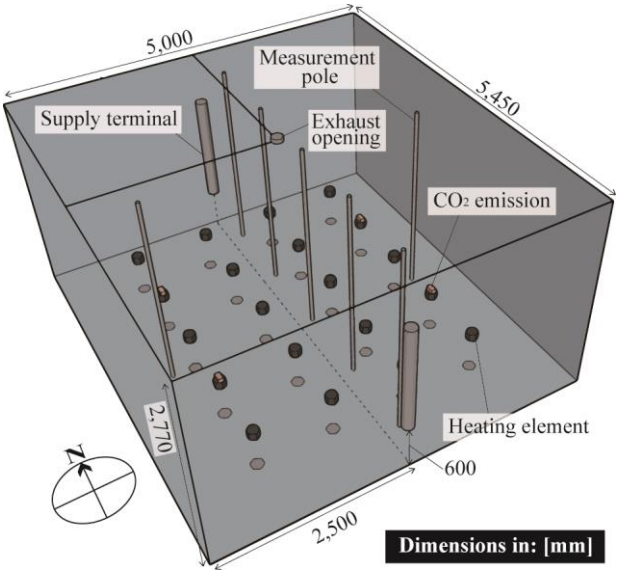

***Figure 1**. Overview of climate chamber*

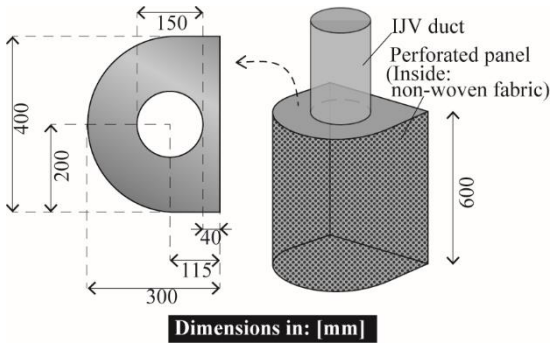

***Figure 2**. Overview of DV diffuser*

The experimental supply conditions are shown in Table 1. In order to understand the effect of correlation between supply airflow momentum and buoyancy on the indoor environment, combination of supply flow rate and temperature was varied. It has to be noted that supply temperature was set to be lower than standard temperature of IJV, in order to avoid the heat loss through the walls. The exhaust air temperature was set to be 17˚C by assuming the chamber as perfectly insulated enclosure. Additionally, the number of terminal and ventilation system (IJV and DV) were changed as parameters.

After the experiment starts, wait until the temperature gets to steady state, CO_2 was started to be emitted continuously. After CO_2 concentration gets to steady state, the state was kept for 1-3 hours, and the averaged results of last 30 minutes of the experiment was applied as the experimental results.

***Table 1**: Experimental conditions*

Case	Total supply flow rate and temperature				Supply velocity [m/s]			
	250 m³/h	300 m³/h	375 m³/h	500 m³/h	IJV		DV	
	5 ℃	7 ℃	9 ℃	11 ℃	2 terminals	1 terminal	2 terminals	1 terminal
A	X				1.96	3.93	0.18	0.37
B		X			2.36	4.72	0.22	0.44
C			X		2.95	5.89	0.28	0.55
D				x	3.93	7.86	0.37	0.74

3 Definitions of indices

Indoor environment of a room with IJV system was expected to be easily affected by supply momentum and temperature, thus, an Archimedes number is defined by:

$$\mathrm{Ar}_{\mathrm{room}} = \frac{g\beta H_c(T_e - T_s)}{{v_s}^2} \quad (1)$$

where, g is the gravity acceleration (9.8m/s^2), β is the volume expansion coefficient, H_c is the height of room (=2.77m), T_e and T_s is the temperature of exhaust and supply air, and v_s is the supply velocity. In DV and IJV system, since the cooled air supplied to occupied zone directly, there is the over cooling risks. In order to evaluate it, dimensionless temperature around ankle is defined by:

$${T_{Ak}}^* = \frac{T_{0.1} - T_s}{T_e - T_s} \quad (2)$$

where, T_h [°C] is the horizontal average temperature at the height of h [m]. Since IJV is a kind of stratified ventilation, it is the occupied zone that has to be kept comfortable. Here, occupied zone is

defined to be the zone lower than FL+1.1m when sitting (h_{oz}=1.1m) and FL+1.7m when standing (h_{oz}=1.7m), in this paper. The dimensionless temperature within occupied zone are defined by below:

$$T_{OZ-h_{oz}}{}^{*} = \frac{\frac{1}{h_{oz}}\int_0^{h_{oz}} T_h dh - T_s}{T_e - T_s} \quad (3)$$

In addition, Contaminant removal effectiveness (ε^c) is defined as below:

$$\varepsilon^c = \frac{C_e - C_s}{\frac{1}{H_c}\int_0^{Hc} C_h dh - C_s} \quad (4)$$

where, C_e, C_s and C_h[ppm] is the CO_2 concentration of the air at exhaust, supply and the height of h [m].

4 Results and discussions

4.1 Temperature and CO_2 concentration

The distributions of temperature and CO_2 concentration at cases with highest and lowest flow rate are compared in Figure 3. At IJV, distributions of temperature and CO_2 concentration did not stratify clearly at the case with large flow rate, while at DV, distributions stratified in both cases.

Some of the results of vertical distribution of temperature difference from exhaust air and normalized CO_2 concentration are shown in Figure 4 and 5. At IJV, the distribution of temperature and CO_2 concentration seems to be very close to that of mixing ventilation, when the supply velocity was large. On the other hand, the distribution was quite close to that of DV, when the supply velocity was small. In addition, by comparing the cases with same supply flow rate with different number of supply terminals, it was shown that the number of terminals have large influence on the indoor environment.

In the cases with small supply velocity, the temperature distributions of DV and IJV seems to be very close to each other, however, the CO_2 concentration distributions were different. It was assumed to be because the flow patterns in the whole room were different between DV and IJV. Further studies about velocity distribution inside the room with DV and IJV are required.

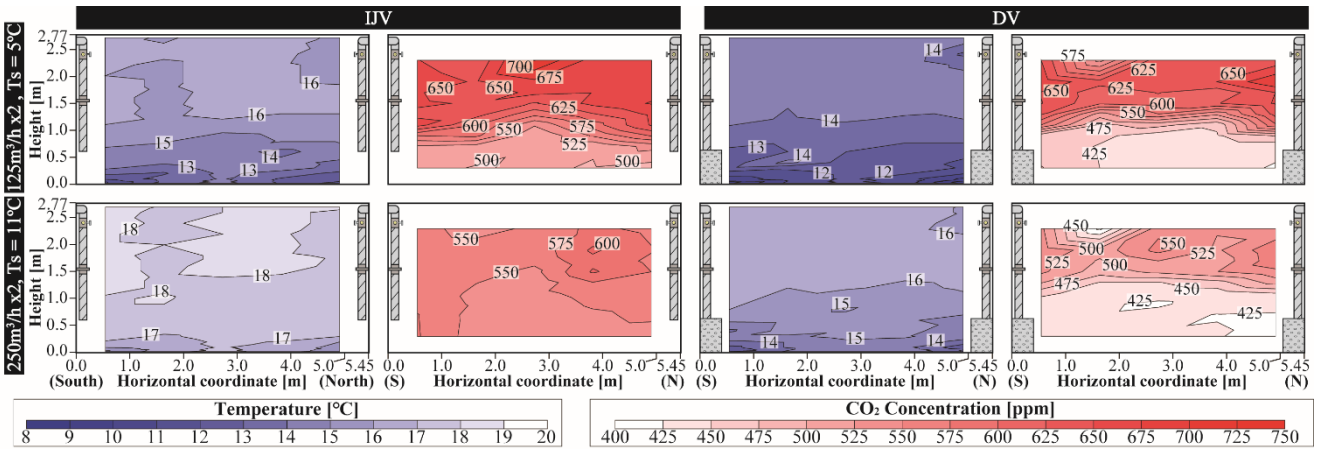

***Figure 3**. Distribution of temperature and CO_2 concentration*

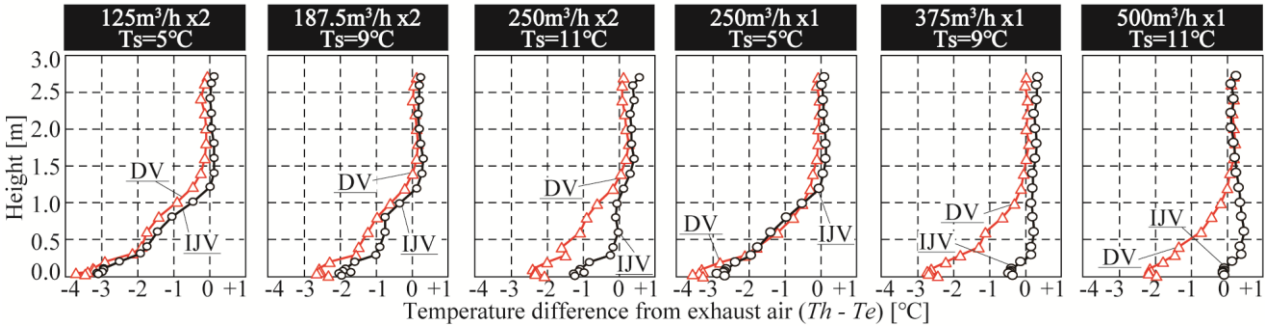

***Figure 4**. Vertical distribution of temperature difference from exhaust air*

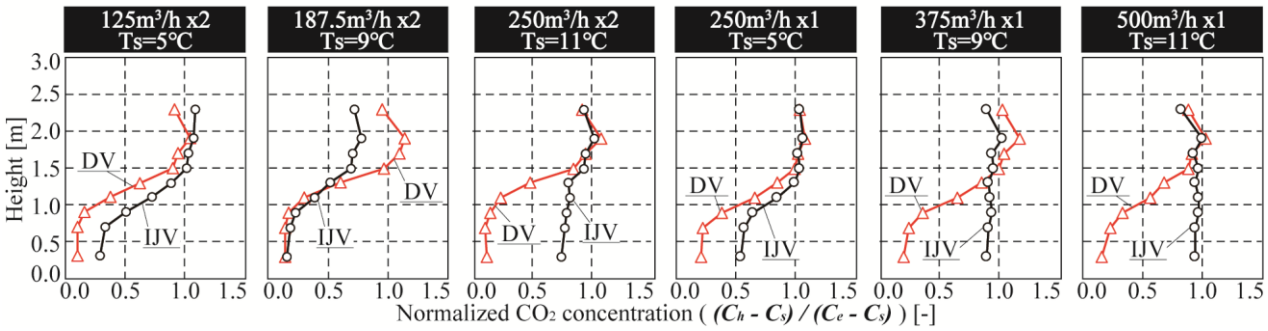

***Figure 5**. Vertical distribution of normalized CO_2 concentration*

4.2 Archimedes number and other parameters

The results of relationship between Archimedes number and indices defined at prior section are shown in Figure 6. It was shown that by increasing the Archimedes number, i.e., by decreasing the supply velocity, it is possible to accomplish the indoor environment close to that of DV, and by increasing the supply velocity, the indoor environment gets close to that of MV. It was also shown that even the supply velocity decreases, the temperature around ankle level was kept higher than that of DV.

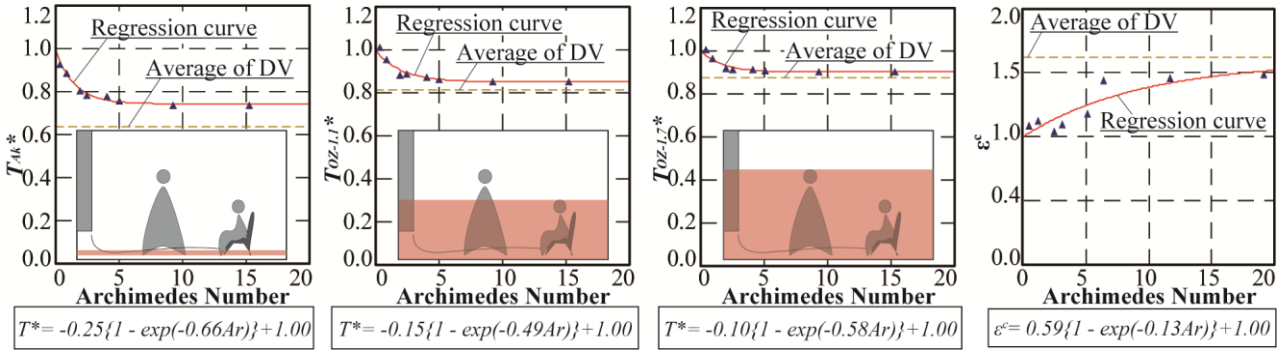

***Figure 6**. Relationship between Archimedes number and dimentionless indicies*

5 Conclusion

Full-scale experiments of DV and IJV were conducted. The findings are summarized as follows:

- Temperature distribution of IJV can be varied between MV and DV, by changing supply conditions.
- By reducing the supply velocity, contaminant removal effectiveness can be improved greatly.
- Compared to DV, IJV may be able to improve the thermal comfort around ankle.

6 References

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