大学講義室内における置換換気性能に関する研究
在室者パターンが室内の熱・汚染物濃度分布に及ぼす影響
Performance of displacement ventilation in a university Lecture hall
Effect of occupation pattern on distribution of temperature and contaminant concentration

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This paper aims at evaluating the effect of occupants' seating pattern and interpersonal spacing on the air temperature and contaminants concentration in the occupied zone of a lecture hall with displacement ventilation. An analysis was carried out for 5 seating scenarios including a full room case and two different arrangements of social distancing cases.

Introduction

Displacement ventilation is considered an energy saving air conditioning system that is recommended for classrooms for providing clean air [1,2]. In displacement ventilation, warm air ascends above occupant zone carrying contaminants depending on the convection flow produced by humans and other warm objects [1]. In this paper, the effect of different occupants' arrangements on the air quality and temperature in a lecture hall is studied, addressing cases where social distancing is in effect.

１．Analysis Conditions

For the study, medium-sized lecture hall was selected. With a capacity of 120 students, the 14 m×12 m×5 m hall is totally enclosed by adjacent air-conditioned rooms.

The ventilation system is composed of inlet fans, perforated metal panel diffusers, and exhaust outlets as shown in Fig.1a. Inlet fans are located along the front and side walls at the ceiling height, blowing the 22 °C air through 20 cm wide ducts as per Fig.1b. Secondly, the diffusers are 0.9 m high positioned at the bottom of the three walls with 7.7 m and 10.7 m length at the front wall and side walls respectively. As shown in Fig.1a, the nine 0.6 m× 0.6 m exhaust openings are equally spaced in the room ceiling. The system's inflow rate is 11910 m^3/h in total, divided as 4830 m^3/h for side fans and 2850 m^3/h for the front ones.

Regarding the occupants, 120 seated students and one standing teacher are modeled as 0.2 m x0.4 m cuboids with heights of 1.2 m and 1.7 m respectively as shown in Fig.1c. Students are split into two 10-rows seating zones separated by a 1 m aisle. All occupants emit 60 W heat from the whole body surface area, and CO_2 from a 0.05 m× 0.05 m mouth surface. CO_2 concentration of exhalation is set to 1000 ppm and the emission rate to 0.25 m^3/h.

Standard k-ε turbulence model was used for the CFD simulation. Heat, radiation, and diffusion calculations were

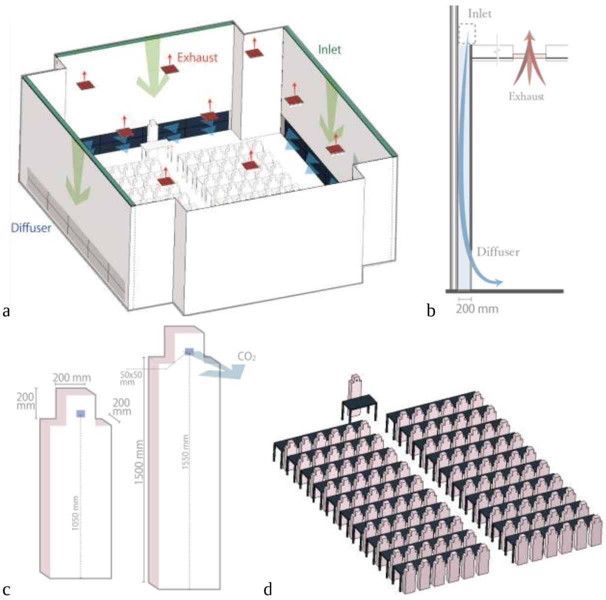


Fig.1 Lecture hall model attributes

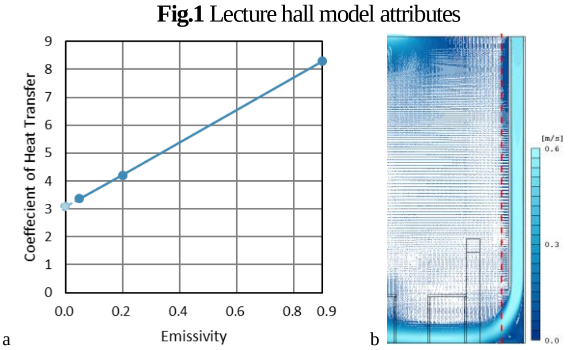


Fig.2 Analysis conditions, a. coefficient of heat transfer vs emissivity. b. Low Reynolds number simulation section

carried out. Thermal boundary conditions were set to adiabatic for ceiling, floor and external walls. 3.06 of heat transfer coefficient was deducted from ASHRAE Handbook [3] for the duct walls, Fig.2a.

Finally, the model meshing resulted in 4,856,000 meshes. The main mesh size was set to 40 mm with a geometric ratio of 1.15. However, the mesh layer adjacent to the walls was increased to 100 mm wide to include the near wall down draft based on a test with low Reynolds number simulation as shown in Fig.2b. Table.1 and Table.2 sum up the analysis and boundary conditions discussed in this section.

To compare the effect of occupational pattern, 5 cases were simulated. Table.3 is an enlistment of the cases and the changed variables. Case1 (C1) is a case testing the full room scenario with double the occupation and flow rate compared to the other cases. The arrangements of C2 and C3 are designed to test the dispersed occupants scenarios, i.e. social distancing, once aligned, C3, and another in complete scattering (C2). Finally, C4 and C5 are made to test the occupation of the front section, C4, vs the back section, C5.

Table.1 Analysis conditions

Analysis Software	Stream 20
Turbulence model	Standard k- ε model
Calculations	Heat, Radiation, Diffusion (CO_2)
Mesh count	4,841,200

Table.2 Boundary conditions

Wall Boundary	Duct wall	Heat transfer coefficient, 3.06 W/m K
	Exterior	Adiabatic
Outflow Boundary	Natural outflow	
Heat generation	60 W/ person	
CO_2 generation	0.25 m^3/h . person (Concentration: 1000 ppm)	

unoccupied one. Zone2 (Z2) and Zone4 (Z4) are the back section's occupied and unoccupied areas respectively.

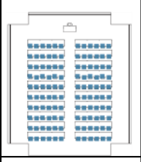
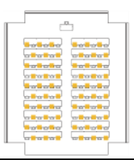
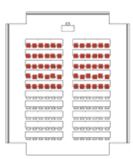
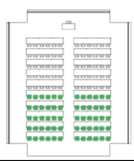
Table.4 and Table.5 show temperature and CO_2 concentration contours in one longitudinal section, two cross-sections, and two plan sections at seated and standing occupants heights. Table.6 shows the corresponding velocity contours. By comparing the velocity and temperature contours, it is clear that both contours reflect thermal plumes similarly. Thus, temperature contours are considered sufficient for exploring thermal plumes trends.

Analyzing the 5 cases' sections, it can be noted that C1 and C5 show plume interaction increasing the temperature around occupants especially in C1. In accordance, CO_2 concentrations in breathing level in C1 are higher compared to the widely spaced occupants cases, C2 and C3 where thermal plumes are separate. C4, as well, exhibits no plume interaction as occupants are seated nearer to the front diffuser providing cool fresh air. Regarding C2 and C3, only minimal differences can be noted.

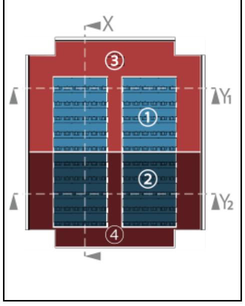
Average temperature and normalized CO_2 concentration data for each zone are plotted in Fig.3 and Fig.4 respectively. To start with, the temperature plot in Z1 shows variations between the cases, especially C4 having higher readings than the full room case, C1. On the contrary, in Z2, all cases are similar, ignoring C4 in which this zone is empty. As for the unoccupied zones, Z3, reveals lower temperature in C1 at all heights with differences reaching 1 °C at 1.7 m.

Secondly, in CO_2 concentration plots in Z1 and Z2, appears a spike in 1.1 m height in all cases. However, the spike is much milder in the dispersed occupants cases, C2 and C3, with C2 showing the least CO_2 concentration in Z1. In addition, it is worth mentioning that C1 exhibits the highest levels in both

Table.3 Occupants arrangements and room zoning

Cases		Case1	Case2	Case3	Case4	Case5
Occupants seating pattern						
Number of students		120	60			
Inflow boundary	Diffuser 1	4530 m^3/h	2265 m^3/h			
	Diffuser 2	2850 m^3/h	1425 m^3/h			
	Total	11910 m^3/h	5955 m^3/h			

Zones



2. Results

The hall plan was divided into 4 zones as shown in Table.3. Zone1 (Z1) and Zone3 (Z3) are the hall's front section, Z1 being the occupied area containing 60 seats, and Z3 is the

zones at seated occupant level. Furthermore, Z3 has less CO_2concentration in C1 and C5. Finally, in Z4, all cases experience the same trend in temperature and CO_2 concentration revealing C4 and C5 to be slightly advantageous.

Table.4 Temperature contours

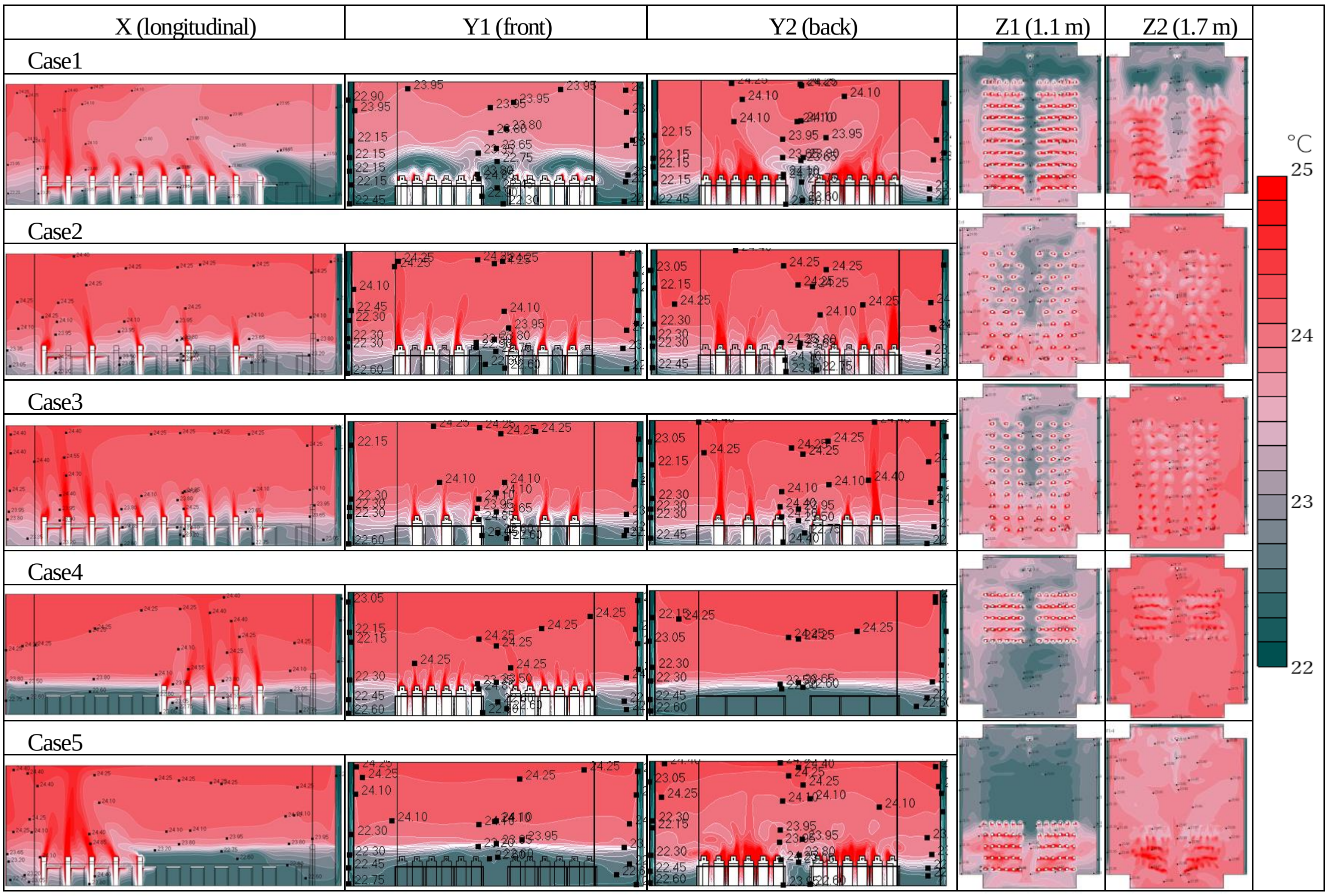


Table.5 Normalized CO_2 concentration contours

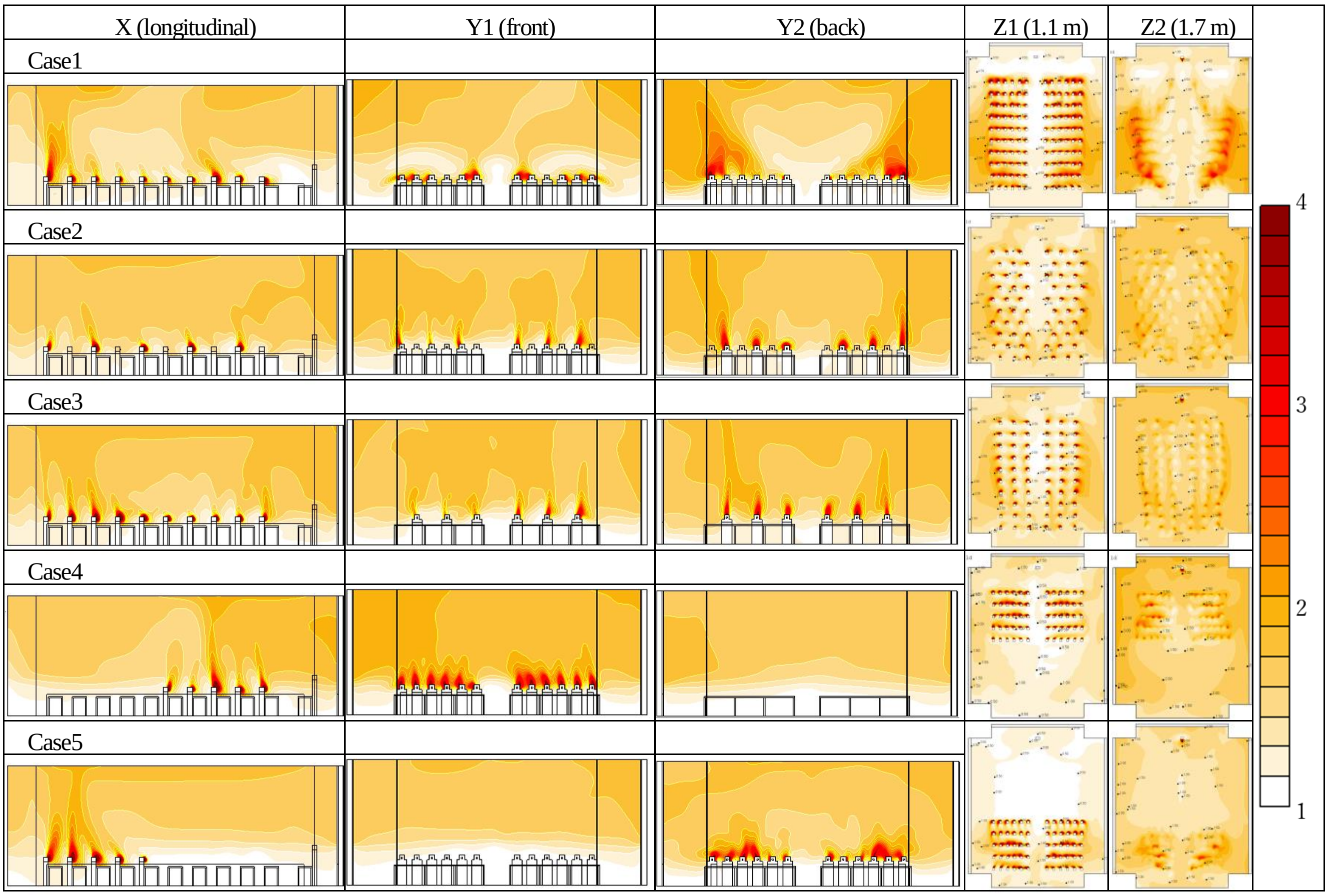
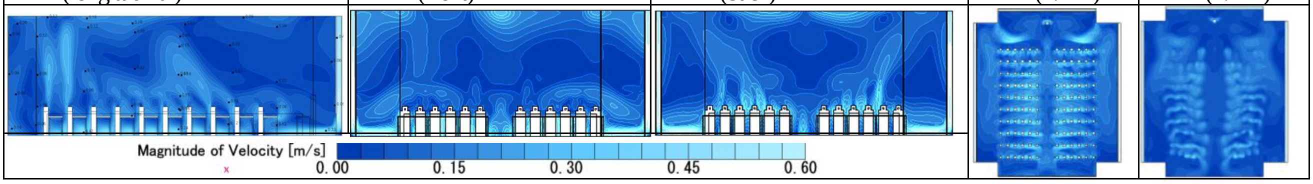


Table.6 Velocity contours for C1

X (longitudinal)	Y1 (front)	Y2 (back)	Z1 (1.1 m)	Z2 (1.7 m)



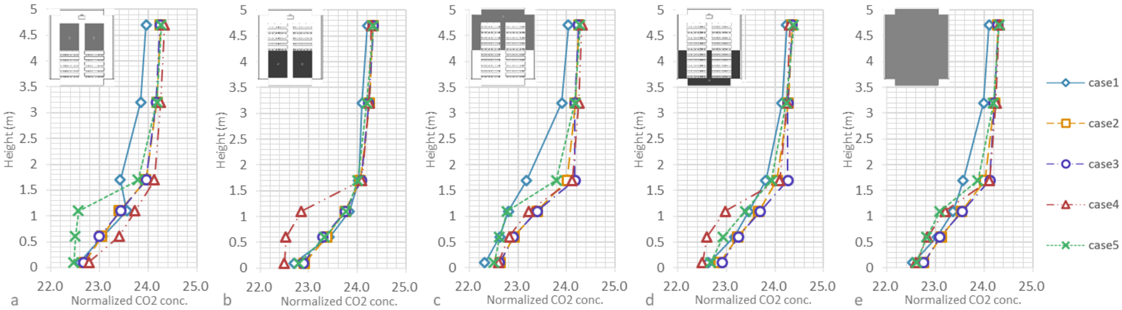


Fig.3 Zonal average temperature: a. Z1, b. Z2, c. Z3, d. Z4, e. Whole room average

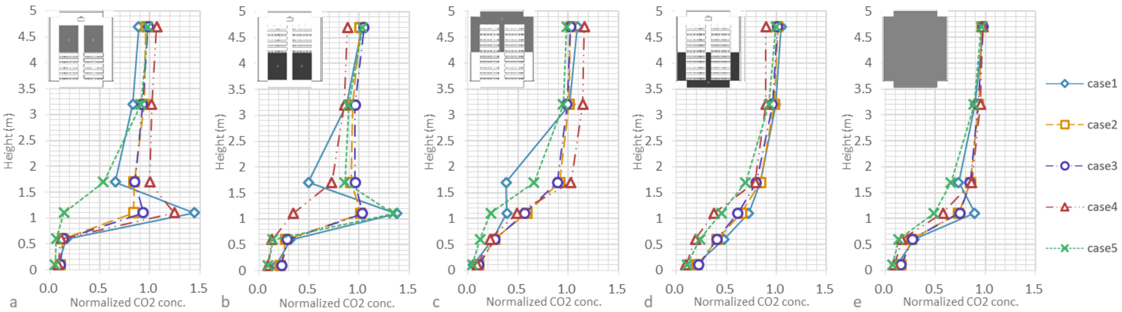


Fig.4 Zonal average normalized CO_2 concentration: a. Z1, b. Z2, c. Z3, d. Z4, e. Whole room average

To get a clearer picture of the inhaled CO_2 concentration in the different cases, Table.7 sums up the average normalized CO_2 concentration at 5 cm under occupant's mouth, and 5 cm above. The concentrations in the inhaling level are found quite high, ranging between 4 and 3 times the CO_2 concentration at exhaust. Further inspection of the velocity contours suggests the following deduction. As shown in Fig.5, the occupants were modeled with no space separating them from their desks. Such an arrangement hindered the up-flow from sweeping the contaminants up. Instead, a downward swirl was produced pushing contaminants to the breathing level fighting against side flow and buoyancy forces.

Table.7 Average normalized CO_2 concentration in breathing level

	C1	C2	C3	C4	C5
1 m	4.09	4.21	3.81	3.35	3.85
1.1 m	12.36	17.29	16.48	14.24	15.60

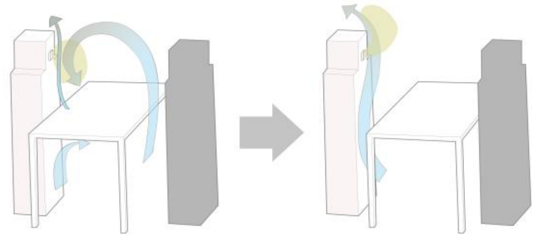


Fig.5 Effect of spacing between occupants and desks

3. Conclusion

This paper addressed the effect of occupation pattern on air temperature and contaminants concentration in a displacement ventilated lecture hall. It was deducted that position of occupants with respect to diffusers is critical to both factors. It was also noted that dispersed occupants patterns outperforms closely seated occupants cases in terms of heat and air quality.

Acknowledgement

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