Topic B3. Building ventilation, infiltration, and air distribution

Study of Airflow Distribution in a Simple Model Room with a Model of a Human Body and Furniture using Particle Image Velocimetry (PIV)

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SUMMARY

In planning indoor environments, it is very important to establish the ventilation and temperature distribution in the occupant zone. Particle image velocimetry (PIV) is a noncontact flow visualization method that is used to measure the airflow velocity at multiple points simultaneously. However, to perform PIV measurements, it is necessary to seed the entire measurement area with smoke. Thus, it is extremely difficult to perform indoor airflow measurements using current techniques; moreover, there are few studies on the quantitative evaluation of airflow distribution in the interior of a full-scale model room by PIV. This study uses PIV and a simple model room with a model of a human body and furniture. Airflow visualization in the room is performed using three lasers. The location of air supply ports and exhaust ports are the experiment variables. The distribution of wind speed and turbulence intensity in the room is reported.

INTRODUCTION

In planning indoor environments, it is very important to establish the ventilation and temperature distribution in the occupant zone. In a house model, these are gradually clarified by CFD analysis and visualization using a laser. Particle image velocimetry (PIV) is a noncontact flow visualization method that can measure the airflow velocity at multiple points simultaneously. In previous studies, PIV is used for the relatively small measurement area (maximum area is about 300mm square). To perform PIV for real scale rooms or office, more large measurement area is needed. However, it is necessary to seed the entire measurement area with smoke. Thus, it is extremely difficult to perform indoor airflow measurements using the current techniques; moreover, there are few studies on the quantitative evaluation of airflow distribution in the interior of a full-scale model room by PIV. This study uses PIV and a simple model room with a model of a human body and furniture to more realistically simulate indoor airflow. The aim is to create a basic document of the PIV measurement in an indoor room.

METHODS

Experimental models

The simple model room is shown in detail in Fig. 1. It is constructed of acrylic transparent boards. The acrylic transparent boards that are used to construct the simple model room are 8-mm thick. The model's size is 600 mm (width), 400 mm (height) and 400 mm (depth). The room has three air supply ports (A, B and C from the upside) and three exhaust ports (D, E and F from the upside) on opposite walls. They are sized 40 mm (width and height). A straightening vane made of honeycomb mesh is installed in an intake duct. The wind velocity is adjusted by controlling an exhaust fan with an inverter.

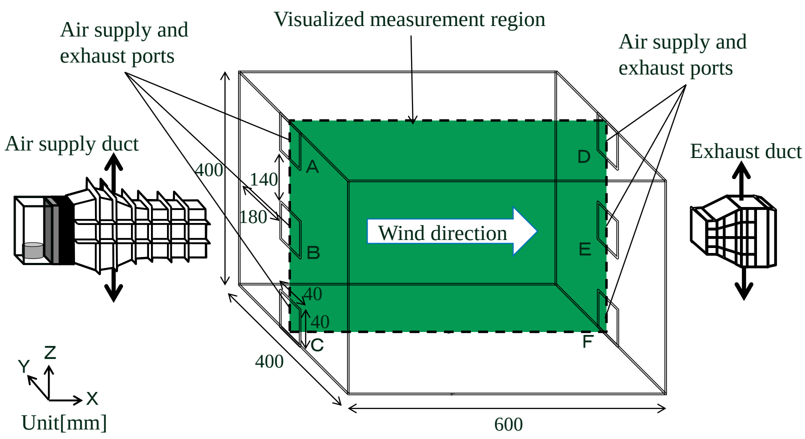


Figure 1. Simple model room.

Experiment conditions

The location of the openings is the experimental variable as indicated in Table 1. Visualization by laser sheet and photography by high-speed camera are performed to 4 cases in Experiment 1. The images used in this measurement are 8-bit grayscale images. The measurement cases in Exp. 1 are as follows: Case 1-1 sets an air supply port in B and sets an exhaust port in D, Case1-2 sets an air supply port in B and sets an exhaust port in E, Case 1-3 sets an air supply port in C and sets an exhaust port in D, Case 1-4 sets an air supply port in C and sets an exhaust port in F. In Experiment 2, one-tenth scale models of a human body assumed to be 170-cm tall, desk, and chair are located in the same sections as the openings in the room. In Exp. 2, an air supply port is set in D, and an exhaust port is set in F. Measurement cases in Exp. 2 are as follows, Case 2-1 sets the measurement area in the whole model room, Case 2-2 sets the measurement area near the model of the human body and furniture.

Table 1. Experimental conditions of measurement cases.

Experiment	Case	Air supply port	Exhaust port	Wind velocity
1	1-1	B	D	4.5 m/s
	1-2	B	E	4.5 m/s
	1-3	C	D	4.5 m/s
	1-4	C	F	4.5 m/s
2	2-1	D	F	4.5 m/s
	2-2	D	F	4.5 m/s

Experimental equipment

The experimental equipment is shown in detail in Fig. 2. Three lasers are used with the following outputs: 1W, 2W, and 3W. Three laser light sheets are adjusted on the same plane. To visualize the whole measurement range uniformly, a 3W-output laser irradiates the whole of the model, and 2W-output and 1W-output lasers are placed on opposite sides and irradiate the model.

The high-speed camera used in the experiment to take images is FASTCAM-SA3 (PHOTRON LTD.) and the images are analyzed by Flow-Expert ver. 1.25 (KATOKOKEN CO.LTD) as indicated in Table 2.

Table 2. Experimental equipment.

Camera	High-speed camera:Photoron FASTCAM SA3	
	1024 pixel×1024 pixel, 500 fps, Shutter speed:S=1/500	
Laser	DPGL-3W	LD Excitation, Nd:YAG/YVO_4 Laser
		Wavelength:532 nm, Output:3W
		Continuous light (Modulation range:0～30 kHz)
	DPGL-2W	LD Excitation, Nd:YAG/YVO_4 Laser
		Wavelength:532 nm, Output:2W
		Continuous light (Modulation range:0～30 kHz)
	G1000	LD Excitation, Nd:YAG/YVO_4 Laser
		Wavelength:532 nm, Output:1W
		Continuous light (Modulation range:0～30 kHz)
Software	Camera control	Photoron FASTCAM Viewer ver.3.3.8
	PIV analysis	Flow-Expert ver1.25

Details of Experiment and analysis conditions

The frame rate of the high-speed camera (measurement interval) is 2.0 ms (500 fps) as indicated in Table 3. Each measurement takes 16 seconds. The tracers are white powder of magnesium carbonated hydroxide. The particles are about 40 μm. The device that supplies the tracers is placed inside the air supply duct to perform the seeding. The wind velocity near the air supply port is 4.5 m/s, and it is measured by a thermistor anemometer. The PIV analysis method uses a direct cross-correlation method. In addition, the turbulence intensity is calculated in all cases as indicated in Equ. (1).

$$\mathrm{u}_{i,mrs} = \sqrt{\frac{\sum_{k=1}^{N}(\tilde{u}_{i,k} - U_i)^2}{N}} \div U_i \qquad (1)$$

i:Measurement point , k:Time, N:Number of data,

U_i:Mean wind velocity, $\tilde{u}_{i,k}$:Instantaneous wind velocity

Table 3. Parameters of PIV analysis.

Image size	615 pixel×923 pixel
Measurement range	400 mm×600 mm
Calibration value	0.65 mm/pixel
Measurement time	16 sec
Measurement interval	2.0 ms (500 fps)
Interrogation region	35 pixel×35 pixel
Search region	±15 pixel×±15 pixel

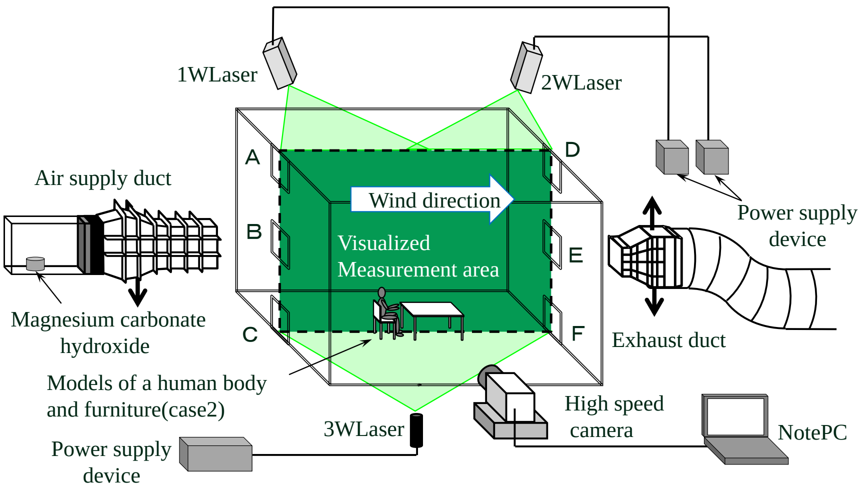
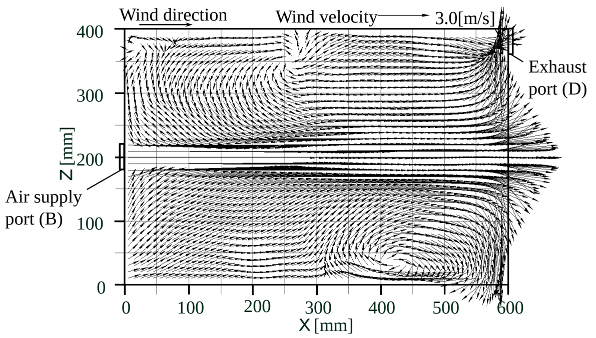


Figure 2. Experimental equipment.

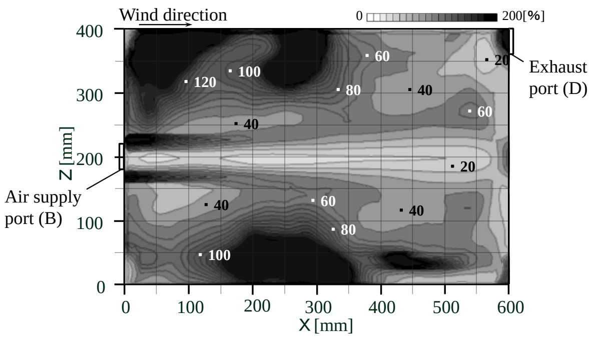
RESULTS AND DISCUSSION

PIV analysis result in Case 1-1

Airflow from an air supply port goes straight to the leeward wall as illustrated in Fig. 3 (a). Airflow that collided with the wall surface forms a vortex at a velocity from 0.1 to 0.3 m/s in X=300-600 mm and Z=0-150 mm. However, airflow does not form a vortex in X=300-600 mm and Z=250-400 mm. It is attracted to the exhaust port. When the airflow is exhausted, the wind velocity is about 1.4 m/s.
The turbulence intensity is greater than 200% in the centre of the vortex, X=150-350 mm and Z=250-400 mm, and X=0-300 mm and Z=300-400 mm as illustrated in Fig. 3 (b).



(a) Distribution of mean wind velocity vector

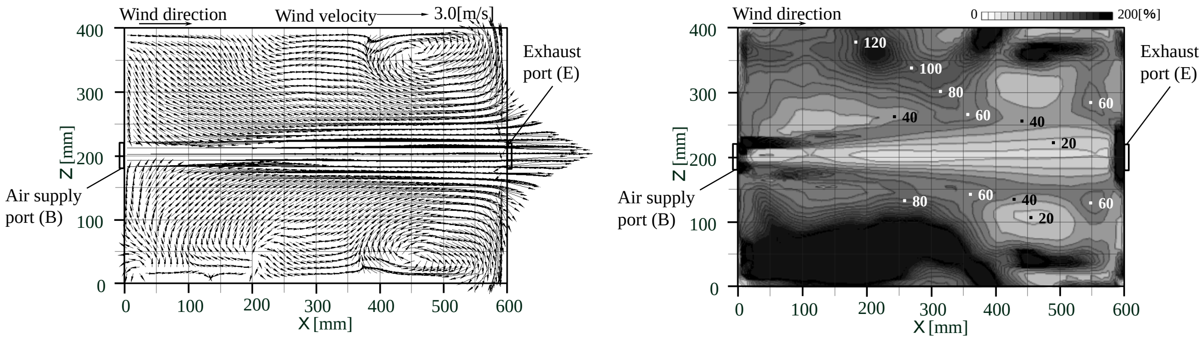


(b) Distribution of turbulence intensity contour

Figure 3. Result of PIV analysis in Case 1-1.

PIV analysis result in Case 1-2

Airflow from an air supply port goes straight to an exhaust port while diffusing as illustrated in Fig. 4 (a). When the airflow is exhausted, the velocity is about 2.3 m/s. Airflow distribution is symmetrical in the vertical direction with Z=200 mm as the axis of symmetry, and airflow forms symmetric vortexes at a velocity from 0.1 to 0.3 m/s in X=350-600 mm and Z=0-150 mm, and X=350-600 mm and Z=250-400 mm, near the corner section. However, the airflow distribution is not symmetrical in the vertical direction in X=0-250 mm near the wall.
The turbulence intensity is greater than 200% in the centre of the vortex, and X=0-400 mm and Z=0-100 mm as illustrated in Fig. 4 (b).



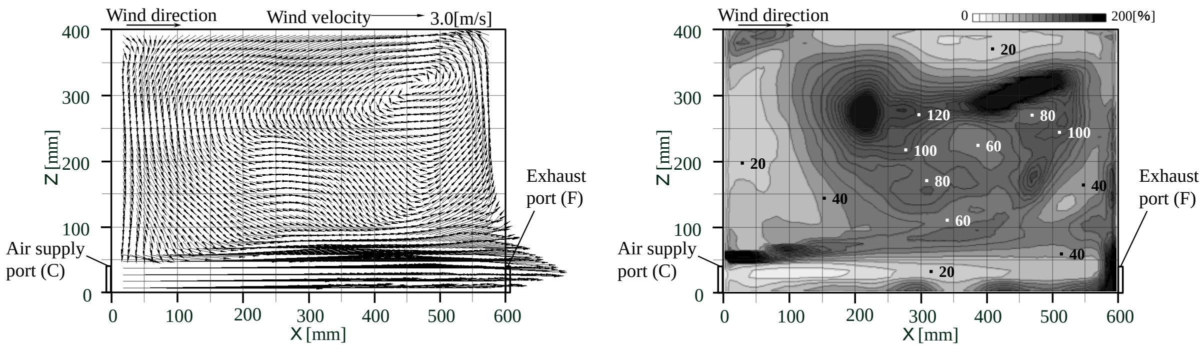
(a) Distribution of mean wind velocity vector *(b) Distribution of turbulence intensity contour*

Figure 4. Result of PIV analysis in Case 1-2.

PIV analysis result in Case 1-4

Airflow from an air supply port goes straight to an exhaust port mostly without diffusing, and is exhausted at a velocity of about 1.7 m/s as illustrated in Fig. 5 (a). In the exhaust port side, airflow that is not sucked into the exhaust port forms an updraft along the wall at a velocity of about 0.6-1.2 m/s. Airflow forms a vortex at a velocity from 0.1 to 0.5 m/s in X=350-600 mm and Z=250-400 mm.

The turbulence intensity is greater than 200% in the centre of the vortex, and X=150-250 mm and Z=250-350 mm as illustrated in Fig. 5 (b). Turbulence intensity in the centre of the model room is greater than that near the wall.



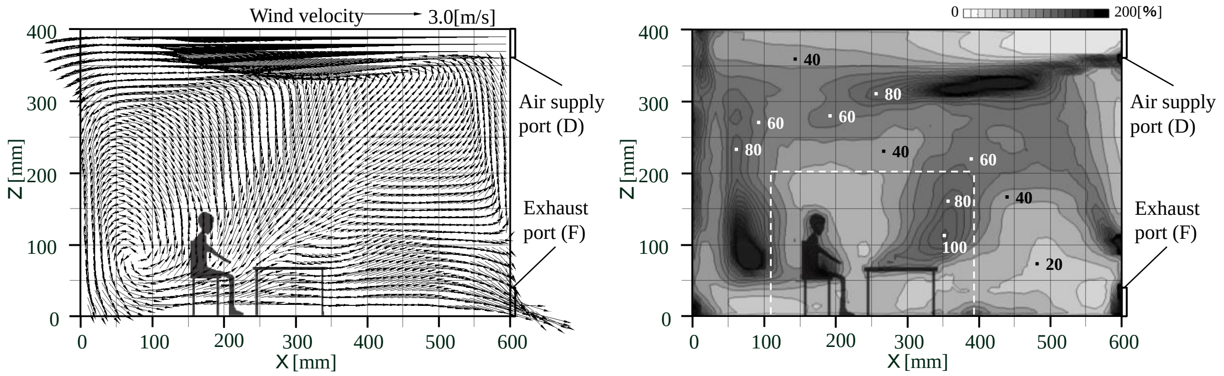
(a) Distribution of mean wind velocity vector *(b) Distribution of turbulence intensity contour*

Figure 5. Result of PIV analysis in Case 1-4.

PIV analysis result in Case 2-1

Airflow at a wind velocity of about 3.8 m/s from an air supply port goes to the opposite wall while slowing down and drops along it as illustrated in Fig. 6 (a). Airflow forms a vortex at a velocity of about 0.1 to 0.3 m/s in X=0-150 mm and Z=0-300 mm.

The turbulence intensity is greater than 200% in the centre of the vortex, and X=300-500 mm Z=300-350 mm as illustrated in Fig. 6 (b).



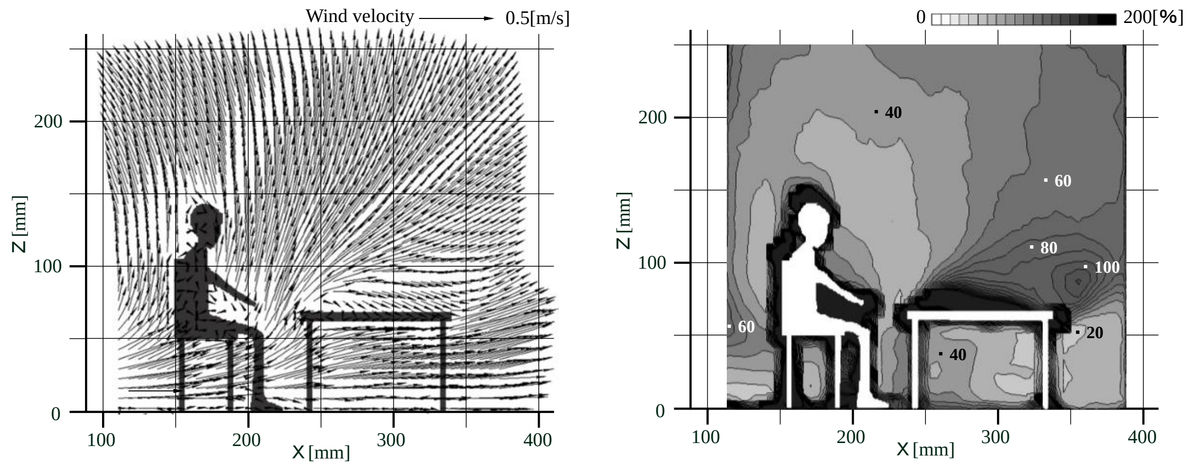
(a) Distribution of mean wind velocity vector *(b) Distribution of turbulence intensity contour*

Figure 6. Result of PIV analysis in Case 2-1.

PIV analysis result in Case 2-2

The measurement area of Case 2-2 is the range indicated by a dotted line in X=110-390 mm and Y=0-250 mm as illustrated in Fig. 6 (b). Airflow splits on the edge of the desk model in the room. One flow is an oblique up-current that passes up to the ceiling through the front of the model of the human body, the other flow proceeds to the outlet through passing under the desk as illustrated in Fig. 7 (a).

The turbulence intensity is greater than 200% near the model of the human body and furniture, and in X=240-320 mm, Z=80-90 mm near the top of the desk as illustrated in Fig. 7 (b). It is 40% at the periphery of the model of the human body. In contrast, it reaches 120% in X=330-380 mm and Z=80-110 mm.



(a) Distribution of mean wind velocity vector *(b) Distribution of turbulence intensity contour*

Figure 7. Result of PIV analysis in Case 2-2.

CONCLUSION

In this study, PIV measurement accuracy for a simple model room with a model of a human body and furniture is described. The conclusion is as below.

Experiment 1 (without human body model)

In PIV measurement, Airflow from an air supply port goes straight to the leeward wall or an exhaust port. On Case1-2, the airflow distribution is almost symmetrical. PIV technique is able to measure a unique airflow distribution of each case.

Experiment 2 (with human body model)

Using PIV technique, it is possible to measure the airflow distribution around the desk model and the human body model.

REFERENCE

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