Field Measurement for Indoor Gas Dispersion to Discuss the Sensitivity Corresponding to Indoor-Outdoor Temperature Difference

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Abstract

From the standpoint of health risk management for the occupants of a building, it is important to analyze the ventilation efficiency in room; if the ventilation system efficiently exhausts any air pollutant that can occur in the building. We carried out the measurements using tracer gas method to analyze the ventilation efficiency. The measurements were carried out twice; in summer and in winter, under the same experimental conditions, except that the pattern of temperature difference between the inside and outside of the building. Using the measurement results, we analyze the sensitivity on the results caused by season.

Key words: Field Measurement, Tracer gas method, Season, Dispersion

Introduction

From the standpoint of health risk management for the occupants of a building, it is important to confirm at the stage of ventilation system design that the ventilation system efficiently exhausts any air pollutant that can occur in the building. The mass transfer and dispersion phenomenon generally tends to assume a three-dimensional aspect. This tendency is especially conspicuous in large space. Because of this, in studies of ventilation systems at the design stage, three-dimensional CFD analysis has come to be increasingly employed (Kondo et al 2009, Chen et al 2009).
When three-dimensional CFD analysis is applied, the code that is used in the analysis must be sufficiently reliable. Therefore, it is common practice to verify the reliability of a given analytical code by first selecting a representative example of the phenomenon to be analyzed and then comparing the results of calculations performed by using that code with the results of measurements made under the same conditions as used for the calculations. In any numerical analysis in which the boundary conditions are precisely defined, the same output from input of the same boundary conditions is reproducible. However it is often difficult to represent the physical phenomenon under consideration by a single measurement. The measured values that serve as data for verification are obtained under conditions involving various factors which can hardly be reflected in the boundary conditions of the numerical analysis.
In the present study, concerning the mass transfer and dispersion phenomenon, we carried out an experiment on the dispersion of tracer gas in summer and winter, respectively, under the same experimental conditions, except that the pattern of temperature difference between the inside and outside of the building. The temperature difference in summer is reverse to that in winter. And we examined the influences of the temperature difference between the inside and outside of the building, *etc.* on the measurement results.

1. Object of Measurement

The building in which the measurements were made is a medium-rise office building with 14 stories above and one under the ground (total floor area: about 20,000 m^2) in Chiyoda Ward, Tokyo. The basement is of SRC construction and the 14 stories above the ground are of S construction.
The experiment using tracer gas, reported in this paper, was carried out in the entrance space on the first floor and in the lobby space on the second floor. The two spaces are made continuous by the well that rises from the entrance space on the first floor.

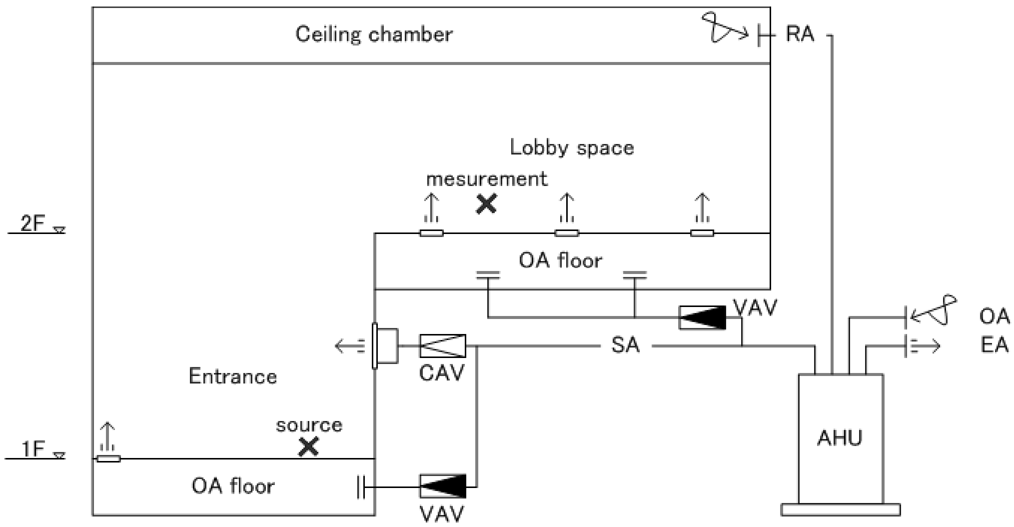

Figure 1. Scheme of air-conditioning system

They are isolated from the other spaces by fire doors and automatic doors. Since the two spaces are ventilated by a single air handling unit (AHU), when the tracer gas is generated in either of the two spaces, it is transferred to the other space through the well and air conditioner. The AHU is equipped with VAV units for controlling the flow rate of air and CO2 sensors for controlling the amount of air let in from the outside. The air-conditioning system is schematically shown in Fig. 1.

2. Outline of Measurement

The experiment using tracer gas was carried out in summer (August 4-7, 2008) and in winter (February 13-17, 2009). The pattern of temperature difference between the inside and outside of the building in summer is reverse to that in winter. As the tracer gas, perfluorocarbon (PFC) was used (SHASE 2004, Kumagai et al 2008). The experiment was done for a total of two cases. In Case 1, the tracer gas was generated at a specific point for a relatively short time and the time series change in gas concentration at a point in the adjoining space was measured (Fig. 2). In Case 2, the amount of outside air let in by the air conditioner during the measurement was measured.

2.1 Case 1

(1) Method of tracer gas generation

In both summer and winter, tracer gas was generated for 30 minutes from a gas source (doser) installed in the entrance space on the first floor. As the doser, a 1 ml measuring flask filled with perfluorocarbon (liquid) was used. In order to maintain a constant rate of gas generation, the perfluorocarbon was kept at a constant temperature

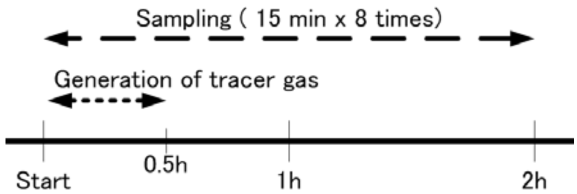

Figure 2. Time series in Case 1

in a thermostat bath (EHB of TAITEC). In addition, the wind speed at the position of the doser was kept constant by covering the doser with a casing provided with a 12V DC PC fan. As the perfluorocarbon, perfluoro methyl cyclohexane (PMCH, C7F14, molecular weight 350) was used. The thermostat bath was set at 40ºC.

(2) Method of tracer gas sampling

A measuring point was set in the lobby space on the second floor and the temporal sequence in tracer gas concentration in two hours after generation of the gas was measured. The time series of tracer gas generation and sampling are shown in Fig. 2. A sampling pump was used for active sampling of the tracer gas. During the sampling, the tracer gas concentration was measured by letting the tracer gas be adsorbed by a two-layer adsorption tube connected to the sampling pump, one layer being 100 mg carbon molecular sieve (Carboxen 1000) and the other layer being 100 mg graphite carbon (Carbotrap B). The sampling interval was adjusted by replacing the adsorption tube. In Case 1, the time series change in tracer gas concentration was measured every 15 minutes (eight times in two hours). Assuming that people would sit and talk in the lobby, the gas sampling point was decided to be 110 cm above the floor, the point being the normal level at which people in their sitting position breathe.

Table 1 Analytical conditions

Analyzer	Desorption by heating - gas chromatograph - mass spectrometer TDS(Gestel)-GC/MS (Agilent6890-5973N k-002)
Desorption conditions	In summer:20°C (3min)-(60-°C/min)-250°C (10min) In winter:20°C (3min)-(60-°C /min)-350°C (10min)
Mode	TDS without split, CIS with split 1/100
CIS liner	Glass Tube
CIS trap temperature	-150°C
CIS trap conditions	In summer:-150°C -(12°C /min)-280°C (5min), In winter:-150°C -(12°C /min)-350℃(5min)
TDS-CIS transfer temperature	In summer:280°C In winter:350°C
Columns	DB-624, 0.25mmI.D.×60m, 0.5μm
Oven temperature	In summer: 50°C (3min)-(10°C /min)-250°C (10min) In winter: 40°C (5min)-(3°C /min)-100°C -(10°C /min)-250°C (5min)
Detector	MS(SCAN)
Carrier gas	He 1ml/min

Table 2 Conditions for tracer gas generation

	Date of measurement	PFC	Time of gas generation	Total amount of gas generated [mg]	Amount of gas generated per hour [mg/h]
Case1-1	2008/8/7	PMCH	13:00~13:30	173	346
Case1-2	2009/2/16	PMCH	13:30~14:00	162	324
Case2-1	2008/8/7	PDCH	10:25~15:15	196	40.6
Case2-3	2009/2/16	PDCH	10:21~15:33	110	21

2.2 Case 2 (amount of outside air let in by air conditioner)

During the present experiment, perfluorocarbon was also used as the tracer gas to measure the amount of outside air let into the air conditioner for ventilating the space under consideration. As the tracer gas, perfluoro dimethyl cyclohexane (PDCH, C8F16, molecular weight 400) was used. It was generated at the inlet of outside air (OA louver), and the amount of outside air was calculated by substituting the measured concentration in the OA duct in the following Seidel equation (1).

$$p - p_0 = \frac{k}{Q} \qquad (1)$$

p: Measured concentration [g/m^3]
p_0: Outside air background concentration [g/m^3] (=0)
k: Amount of tracer gas generated [g/h]
Q: Amount of outside air let in air conditioner [m^3/h]

For the measurement of average concentration, active sampling by a sampling pump was used. In order to put the concentration substituted in the Seidel equation into equilibrium, generation of tracer gas (PDCH) was started about three hours before the gas sampling. A thermostat bath was not used during the generation of perfluorocarbon. The purpose of measurement in Case 2 was to determine the amount of outside air (fresh air) that works effectively to thin the tracer gas flowing into the building. Therefore, the background concentration of outside air in Equation 1 was assumed to be 0.

2.3 Pressure difference between spaces

In order to study the route and intensity of air transfer along the vertical flow line generated by differential temperature ventilation, the difference in pressure between the entrance space and the staircase space connected to the entrance space via a fire door was measured. In the measurement, a micro differential pressure converter (Type 670BD21 of MKS, measurement accuracy: 0.12%) and a data logger (NR-2000 of Keyence) were used. The measuring interval was 5 Hz.

2.4 Method of analysis

The gas samples collected by the absorption tubes were analyzed by GC/MS after desorption by heating. The conditions of analysis by GC/MS are shown in Table 1. In the present analysis, the minimum limit of determination was 21ng in terms of absolute value and the minimum limit of detection was 3/10 of the minimum limit of determination.

3. Measurement Results

The conditions for tracer gas generation are shown in Table 2, and the conditions for measurement of the individual adsorption tubes and the sampling air concentrations calculated from the detection results

Table 6 Room temperatures and outside air temperatures during measurement

Date	Time	1F room temperature [°C]	2F room temperature [°C]	Air-conditioned air temperature [°C]	Outside air temperature [°C]	Difference in temperature between inside and outside of building *1 [°C]
2008/8/6	14:00	24.8	26.6	12	34	8.3
2008/8/7	14:00	25	26.7	11.9	32.9	7.05
2009/2/13	14:00	19.2	20.6	35	12.2	-7.7
2009/2/16	14:00	21	21.9	32.9	14	-7.45

*1: "Difference in temperature between inside and outside of building" is outside air temperature minus (1F room temperature + 2F room temperature)/2.

are shown in Table 3. In Table 3, the sign "<" indicates that the measured concentration was lower than the minimum limit of determination (i.e., the minimum value of determination of the target substance that is considered reliable with the present method of analysis). The difference in pressure between the entrance space and the staircase space is shown in Table 4. In this table, the sign "+" indicates that the pressure in the staircase space was positive and that the sign "-" indicates that the pressure in the staircase space was negative. Table 5 shows the amounts of outside air let in by the air conditioner during the measurement. It is considered that the amount of outside air let in changed day by day as a result of the control of the amount of outside air by the CO2 sensor. Table 6 shows the room temperatures at the first and second floors and air-conditioned air temperatures that were recorded by the building management system, together with the open-air temperatures in Tokyo (latitude 35' 41.4", longitude 139' 45.6", altitude 6.1 m) announced by the Meteorological Agency, on the days of measurement. Needless to say, the outside air temperature is higher than the inside air temperature in summer, whereas the inside air temperature is higher in winter. On the other hand, the pressure in the staircase space is negative in summer and winter (Table 4). This suggests that the air transfer route along the vertical flow line through starecase does not change much even when there is a marked difference in temperature between the inside and outside of the building. It is considered from this phenomenon that the air flow in the staircase space is determined not by the force of ventilation produced by the temperature difference between the inside and outside of the building, but by the balance between air supply and air exhaust by the air conditioner at each floor.

Fig. 3 shows the time series of value $p*$ (Equation 2), which is the measured concentration in Case 1 divided by the amount of tracer gas generation.

$$p* = \frac{p}{k'} \qquad (2)$$

k': Amount of tracer gas generated [g]

Table 3 Sampling conditions and measured concentrations

	Date of measurement	Sampling time	Concentration [μg/m^3]
Case1-1	2008/8/7	13:00~13:15	17
		13:15~13:30	31
		13:30~13:45	41
		13:45~14:00	42
		14:00~14:15	31
		14:15~14:30	21
		14:30~14:45	15
		14:45~15:00	14
Case1-2	2009/2/16	13:35~13:45	<
		13:45~14:00	28
		14:00~14:15	37
		14:15~14:30	23
		14:30~14:45	14
		14:45~15:00	9
		15:00~15:15	<
		15:15~15:30	<
Case2-1	2008/8/7	13:00~15:00	10.5
Case2-2	2008/2/16	13:30~14:30	14

Table 4 Difference in pressure between entrance space and staircase space

Date	Measuring time	Average value [Pa]
2008/8/6	15:30~16:30	-0.20
2008/8/7	13:00~15:00	-0.31
2009/2/13	14:00~15:00	-0.26
2009/2/16	No data	

Table 5 Amount of outside air let in by the air conditioner

Date	Time	Amount of air [m^3/h]
2008/8/6	15:30~16:30	4900
2009/2/13	14:00~15:00	4500

There is a tendency that in the measurement results obtained in summer, the peak appears later than that in winter and the peak concentration is higher than that in winter.

Next, the local ventilation time at the measuring point in summer and winter was obtained. Here, the ventilation time is defined by Expression (3) and is calculated by using Expression (4) derived by modifying Expression (3) and the method of least squares using the measured concentration. In the calculation of ventilation time, only the data following the data in which a peak was observed is used on the assumption that the concentration will decrease at a common ratio from the data following the data in which a peak was observed.

$$\frac{p}{p_1} = e^{-\frac{t}{\tau}} \qquad (3)$$

$$\log_e p = \log_e p_1 - \frac{1}{\tau} t \qquad (4)$$

τ : Ventilation time (time constant) [h]
t : Elapsed time [h]
p_1: Initial concentration [g/m^3]

The calculated ventilation time was 0.9 h in summer and 0.5 h in winter, indicating that the concentration is diluted faster in winter than in summer. Since the volume of the space under consideration is about 3,000 m^3, the ventilation time calculated by using the amount of outside air let in by the air conditioner shown in Table 5 is 0.8 h in summer and 2 h in winter. From this, it is considered that in winter the natural ventilation that is effective to dilute tracer gas at the measuring point was working. It is also considered that as a result of the natural ventilation, the amount of outside air let in by the air conditioner on February 16, shown in Table 5, was kept smaller.

4. Conclusions

1) Concerning the mass transfer phenomenon, we carried out an experiment on the dispersion of tracer gas in summer and winter under the same conditions, except that the pattern of temperature difference between the inside and outside of the building.
2) In the experiment, we also measured the amount of outside air let in by the air conditioner and the difference in pressure between the entrance space and the staircase space.
3) There was a tendency in summer that the peak concentration of tracer gas appeared later and was higher than in winter.
4) The study results of the ventilation time at the measuring point in summer and winter suggest that in winter the natural ventilation that influences the decrease in gas concentration was working.

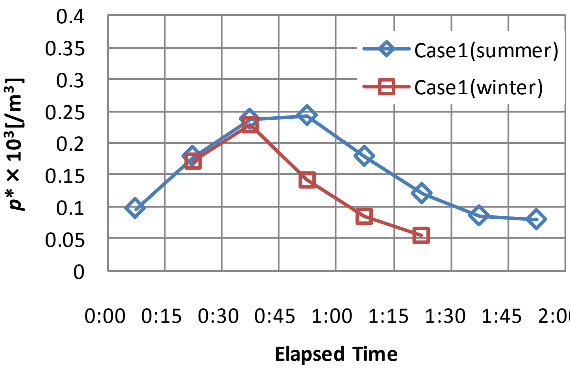

Figure 3. Time-serial change of measured concentration

Acknowledgments

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