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EXPERIMENTAL STUDY ON DISTRIBUTION OF PERCEIVED AIR POLLUTION BY ENVIRONMENTAL TOBACCO SMOKE

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ABSTRACT

The purpose of this study is to present a method to assess the distribution of perceived air pollution in a room using trained panel with reference gas of acetone. Fifty–one subjects were trained to judge perceived air quality in decipol proposed by Fanger, and sixteen judges selected from them reported the indoor air quality of tobacco smoke from smokers at three measuring points in a small chamber. Age–of–air was calculated from the history of tracer gas concentration in order to assess ventilation efficiency at points of interest in a room.

INTRODUCTION

Greater attention is being paid to indoor air quality in reference to sick building syndrome. ASHRAE issued standard 62–89 with increased ventilation requirement of 10 l/s from 2.5 l/s per person in the previous standard for ordinary offices. In this standard a concept of "ventilation efficiency" was introduced. It is considered possible to improve the indoor air quality by maintaining higher ventilation efficiency in a space without increasing ventilation rate.

In the past the air change rate, i.e., the ventilation air flow rate divided by the room volume, has been widely used as the design–parameter for assessing the air quality. The underlying assumption is that both the air and the contaminants are uniformly diluted and spread over the whole ventilated space. This assumption is, however, not always fulfilled, and a more sophisticated and comprehensive description of ventilation effects is considered necessary. The air renewal process and the contaminant removal process are generally not identical, so these two processes have to be treated separately (Skåret, 1986).

In this respect the authors conceived that it was necessary to present a method for assessing the perceived air pollution level at any point in a space and attempted to use trained panel who infer the level of the air pollution in "decipol" unit proposed by Fanger (1988). ADPI (Air Diffusion Performance Index) expresses the percentage of points in a room where there is acceptable thermal comfort, air motion being taken into consideration along with wet bulb and dry bulb temperature (ASHRAE Handbook, 1985). In analogy, a perceived air quality distribution index will be defined as the percentage of points in a room where there is acceptable air quality, which is accepted at least 80 % of the visitors (ASHRAE standard 62-89).

TRAINED PANEL

Trained panel used in this study is a group of judges who were trained to judge perceived air quality in Fanger's decipol. In the training session, a gas of acetone was used as a reference gas for quantifying perceived air pollution level instead of bioeffluents. Training procedure is comprised of a test for general olfactory discrimination and a test for evaluating acetone gas. After both tests, the best sixteen judges were selected as trained panel among fifty-one subjects and used as trained panel for the following experiments of tobacco smoke.

METHOD OF EXPERIMENT

TEST FACILITY

Fig.1 shows the plan of the air quality test chamber. The experiments were conducted in the air quality test chamber at Waseda University. The chamber is 1.8 m wide and 2.7 m long with a ceiling height of 1.8 m, its volume being 9 m^3. The judges could evaluate the air samples taken from different locations of the measuring points. Fig.1 also shows three measuring points in the chamber : point 1 with a height of 110 cm, point 2 110 cm, and point 3 50 cm.

Measurements of carbon monoxide, sulphur hexafluoride, air temperature, relative humidity were taken at regular intervals through the entire experiments.

TYPES OF EXPERIMENT

Table 1 shows the four different types of experiment : type A with the air change rate of 3 h^{-1}, type B 4.5 h^{-1}, type C 7 h^{-1}, and type D 10 h^{-1}. The air change rate was measured by tracer gas decay method at measuring point 3 in Fig.1, under the conditions of complete mixing.

EXPERIMENTAL PROCEDURE

Fig.2 shows the experimental procedure. One experiment was comprised of a smoking session (session I), and post smoking session (session II). For the purpose of generating tobacco smoke, one smoker occupied in the chamber. During the smoking session (session I), the smoker made one cigarette of tobacco (the brand of "Mild seven") burn continuously (free burning). And the tracer gas of sulphur hexafluoride (SF_6) was dosed serially in session I. In this session four stirring fans were kept running to make the air completely mixed.

Immediately after confirming the steady-state level of pollution, smoking , dosing of SF_6, and running the four fans were stopped, the butts and ashtray being removed. Then session II started. The inside wall of the chamber was cleaned after every experiment. Trained panel evaluated indoor air quality in decipol during session I and session II. The judges walked serially from the waiting room to the sniffing station, where they inhaled the air taken from different three measuring points, through the diffusers. Immediately after sniffing the air of each location, the judges were asked to report decipol values for each, using the reference gas of acetone (2, 5, 10, 20 decipol level).

RESULTS

DECAY OF SF_6 CONCENTRATION AND AGE-OF-AIR

In order to assess the difference of ventilation effect among the three measuring points, the local-mean age-of-air (Sandberg and Sjöberg, 1984) was used for data analysis. With the tracer gas (SF_6) concentration at each measuring point, the age-of-air was calculated using the following equation:

$$\tau_p = \frac{1}{C(0)} \times \int_0^{\infty} C(t)\,dt \quad \text{......(1)}$$

where τ_p :age-of-air at point p   C(0):concentration of tracer gas at t=0
t :lapse time in session II   C(t):concentration of tracer gas at time t

Table 2 shows the local mean age-of-air and the ventilation efficiency at each measuring point. The local air change rate in Table 2 is the reciprocal number of the age-of-air, and the ventilation efficiency at each measuring point was calculated according to the method by Sandberg (1983) as expressed by:

$$ADE_p = \frac{1/\tau_p}{1/\tau_n} \times 100 \quad \text{......(2)}$$

where ADE_p:ventilation efficiency (Air Diffusion Efficiency) at measuring point p [%]
τ_p:age-of-air at measuring point p
τ_n:room average age-of-air under completely mixed conditions

Sandberg and Sjöberg (1984) defined several kinds of "ventilation efficiency", and called ADE_p in equation (2) "air diffusion efficiency". In this experiment, the authors call it simply "ventilation efficiency".

As the age-of-air value at each measuring point was almost the same in type A (see Table 2) and these local air change rates were found equal to nominal air change rate. It seemed, therefore, that completely mixing level was reached under low air change rate. In type B, the age-of-air of point 3 was found greater than that of other points and completely mixing level could not be reached. This shows there might have been an upward air flow warmer than this space and the ventilation efficiency was not so high in front of the return grill, i.e., at measuring point 3, in this case. On the other hand, in type C and type D the age-of-air of point 3 showed the smallest value. There may have been a by-pass-flow from the supply air diffuser to the return air intake at high air change rate.

PERCEIVED AIR POLLUTION LEVEL

Fig.3 shows the perceived air pollution in decipol with lapse time in session II in type C. The regression lines in this figure were obtained by least square method. The perceived air pollution level decayed exponentially and considerable differences in the decay among three measuring points were found in Fig.3.

"Half-life-time of perceived air pollution" was used to assess the decay rate of perceived air pollution at each measuring point. The half-life-time at point p was calculated by the following equation using the decay constant of the regression line for a given decipol value.

$$t_{1/2,p}=\ln 2 \times k_p \qquad \cdots\cdots(3)$$

where $t_{1/2,p}$:half-life-time of perceived air pollution at measuring point p [min]
k_p :decay constant of the regression line for measuring point p [min]

The decay constant is the reciprocal of the slope of the regression line as shown in Fig.3. Table 3 shows the half-life-time of perceived air pollution at each measuring point.

DISCUSSION

Fig.4 – Fig.7 show the relationship between the age-of-air and the half-life-time of perceived air pollution. The subscripts of the plots represent the measuring point number. In type A, both the differences in the age-of-air among three measuring points and those in the half-life-time of perceived air pollution could not be found so much, and strong correlation between the age-of-air and the half-life-time was not manifested. It seems that in type A the trained panel could not distinguish the difference in the perceived air pollution and the ventilation effect at each measuring point turned out almost the same. It was found that both the age-of-air and the half-life-time of perceived air pollution at measuring point 3 were greater than that of other points in type B. Since the air temperature at point 1 and point 2 (110 cm in height) were higher than that at point 3 (50 cm), there must have been a tendency of supply air to ascend. In type B, the higher part in the chamber was ventilated more than the lower part, therefore, both the age-of-air and the half-life-time might have been greater. In type C and D, both the age-of-air and the half-life-time of perceived air pollution at point 3 showed the smallest value among three measuring points. The half-life-time of perceived air pollution had strong correlation with the age-of-air at higher air change rate. As Carlton-Foss described that cigarette smoke tends to rise toward the ceiling (1988), the difference between the results with indirect measurement (tracer gas method) and those with direct measurement for air quality could be observed. It seems important, therefore, not only to investigate ventilation efficiency but also to investigate indoor air quality directly. Moreover it may be possible to assess the ventilation efficiency based on the distribution of perceived air pollution using trained panel.

CONCLUSIONS

1) Distribution of perceived air pollution was assessed with half-life-time of perceived air pollution at three measuring points in the chamber, which was calculated by decay of decipol values voted by trained panel.
2) Ventilation effects in the chamber were assessed with age-of-air calculated by decay of tracer gas (SF_6). It seems that there was a by-pass-flow from a supply air diffuser to a return air intake with high air change rate.
3) Half-life-time of perceived air pollution had strong correlation with age-of-air except the type of low air change rate (3.0 h^{-1}), it may be possible to assess the ventilation effects based on the distribution of perceived air pollution using trained panel.

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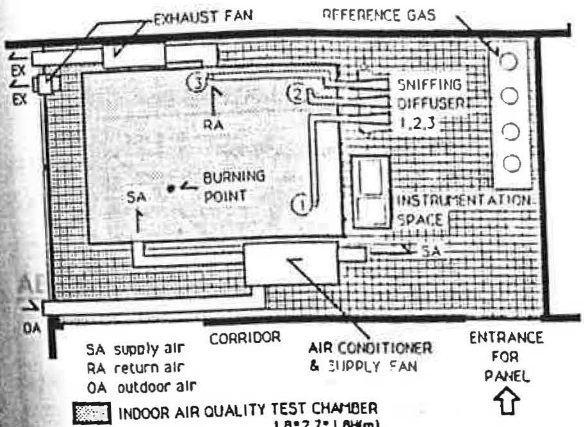
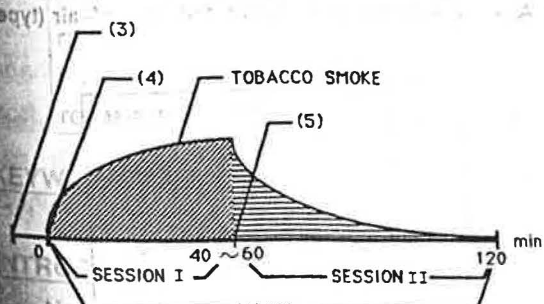


Fig.1 Floor plan of the indoor air quality test chamber

Table 1 Types of [illegible]

TYPE	AIR-CHANGE RATE (1/h)	[illegible]
A	3.0	[illegible]
B	4.5	[illegible]
C	7.0	[illegible]
D	10.0	[illegible]

* Concentration Difference above Outside Air



(1) ask perceived air quality in decipol
(2) measure air temperature, relative humidity, CO, SF_6 at 1 min. interval
(3) start SF_6 dosing, mixing fan on
(4) start tobacco burning
(5) stop SF_6 dosing, mixing fan off, and stop tobacco burning

Fig.2 Experimental procedure

Table 2 Age-of-air

Type (n*)	Point No.	Age (min)	Local air-change [illegible]	[illegible]
A	1	20.12	[illegible]	[illegible]
(3.0)	2	19.56	[illegible]	[illegible]
	3	20.30	[illegible]	[illegible]
B	1	16.07	[illegible]	[illegible]
(4.5)	2	15.41	[illegible]	[illegible]
	3	20.02	[illegible]	[illegible]
C	1	10.22	[illegible]	[illegible]
(7.0)	2	9.46	[illegible]	[illegible]
	3	8.65	[illegible]	[illegible]
D	1	6.96	[illegible]	[illegible]
(10.0)	2	7.23	[illegible]	[illegible]
	3	5.94	[illegible]	[illegible]

* Nominal air-change rate (1/h)

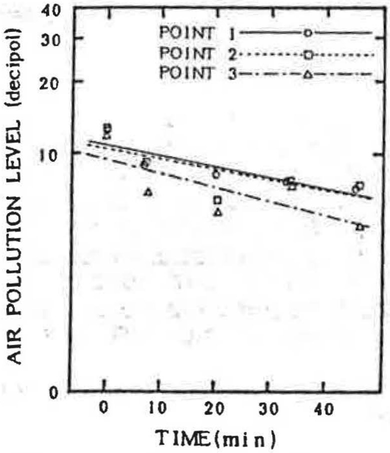


Fig.3 Perceived air pollution in decipol in the session II (type C)

Table 3 Half-life-time of perceived air pollution

TYPE	AIR-CHANGE RATE (1/h)	MEASURING POINT	HALF LIFE (min)	NORMALISED STANDARD DEVIATION
A	3.0	①	80.02	0.045
		②	77.69	
		③	73.24	
B	4.5	①	52.29	0.25
		②	44.62	
		③	71.86	
C	7.0	①	68.36	0.14
		②	70.46	
		③	53.46	
D	10.0	①	60.38	0.13
		②	60.46	
		③	47.90	

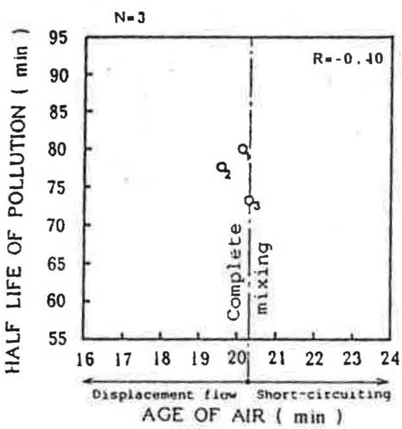


Fig.4 Relationship between half-life-time of perceived air pollution and age-of-air (type A)

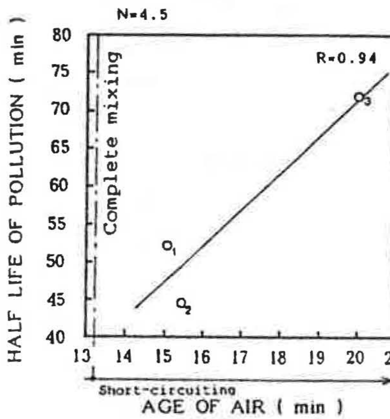


Fig.5 Relationship between half-life-time of perceived air pollution and age-of-air (type B)

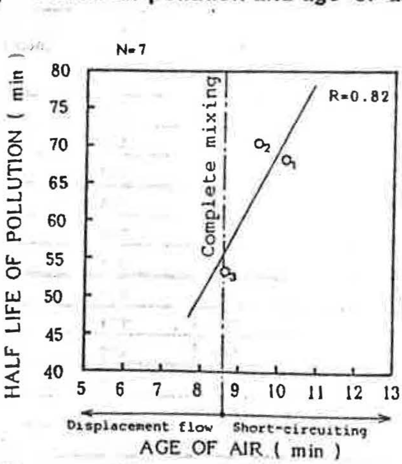


Fig.6 Relationship between half-life-time of perceived air pollution and age-of-air (type C)

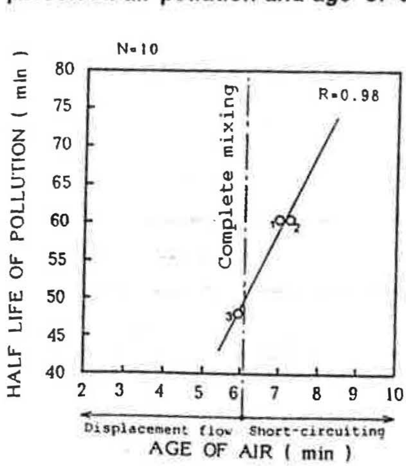


Fig.7 Relationship between half-life-time of perceived air pollution and age-of-air (type D)