Generation Rate of Suspended Particulate Matter from Occupants in Different ~~Rooms~~ Types of Rooms

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By
Masaya Narasaki
(Department of Architectural Engineering)

Abstract

The degree of indoor particulate concentration depends upon the activity level of occupants and the ventilation rate supplied.We need to quantify the pollution from occupants so that it can be diluted to an acceptable level.The generation rate of particulate matter from occupants will depend upon the use of the room.We therefore need to identify the rate from the occupants in different types of room.

This paper describes the investigation to estimate the generation rate of particulate matter from the the activity of occupants in a sales area of a supermarket,a keypunching room,and three office spaces.

1. Introduction

Suspended particulate matter will be generated in a room according to the activity condition of occupants. For the purpose of designing indoor air cleaning, it will be required to estimate the generation rate of particulate matter from occupants in different types of room.

One approach would be to model the particulates generated from each occupant. This would require estimates of all parameters of the model for each occupant; a complex task. Therefore the approach used here is ~~that~~ one by evaluating the total rate of particulates genarated in a whole room. This would be taken estimates of the mean generation rate of particulates per occupant without distinction of various activities of occupants in a room. And this must be taken account of the rate of particulates matter sinking on the floor, and must be distinguished between the particulates generated by activity of occupants and the particulates generated by smoking.

2. One-Compartment Model on Mass Balance for Pollutant Flow

The mass balance for particulate matter flow into and out of an indoor volume, including recycling and interior sources and sinks, is described in Fig.1 and expressed by

Air mass balance: $q_{mA}^{*-} + q_{rA}^{*-} = q_{mA} + q_{mA}$, (1)

Particulate mass balance:

$$V_A \frac{dD_A}{dt} = (q_{mA} D_A + q_{mA} D_A + G) - ((q_{mA}^{*-} + q_{rA}^{*-}) D_A + S) \quad (2)$$

Where,

q_A, q_{mA}, q_{mA}^{*-}: flow rate for make-up air, supply air and exhaust respectively in forced ventilation system (m^3/hr),

q_{mi}, q_{mo}: flow rate for infiltration and exfiltration (m^3/hr),
D_A: indoor concentration at time t (mg/m^3),
D_o: outdoor concentration at time t (mg/m^3),
D_s: supply air concentration at time t (mg/m^3),
G, S: indoor source generation rate and indoor sink removal rate (mg/hr),
V_A: room volume (m^3).

Let

$$F(t)=\{q_{mi}D_o+q_{mi}D_s+G\}=1 \text{ at } t\geq 0 \tag{3}$$

and

$$D_A=D_o=0 \text{ at } t<0 \tag{4}$$

The solution of Eq. (1) and (2) for the change in D_A with t; $A(t)$ is then

$$A(t)=\frac{1}{q_{mi}+q_{mo}+V_s(V_f/H)}\left[1-\exp\left\{-\left(\frac{q_{mi}+q_{mo}}{V_A}+\frac{V_s}{H}\right)t\right\}\right] . \tag{5}$$

Where, V_s is a proportionality constant for the particulates which is called the settling velocity of suspended particulates (m/hr), such that $S=V_s(V_f/H)D_A$.

This is the integral function of unit impulse response function; $h(t)$, which is the indoor particulate concentration when a unit mass of particulate matter is supplied in a moment at $t=0$.

Therefore

$$h(t)=\frac{dA(t)}{dt}=\frac{1}{V_A}\exp\left\{-\left(\frac{q_{mi}+q_{mo}}{V_f}+\frac{V_s}{H}\right)t\right\} . \tag{6}$$

Hence we obtain the indoor particulate concentration D_s when the generation rate of particulates in a room is G at $t\geq 0$.

$$D_{A1}(t)=\int_0^t h(\tau)\,G(t-\tau)\,d\tau \quad . \tag{7}$$

If it is assumed that supply air particulate concentration is D_{A2}, then the particulate rate supplied into the room is regarded as $q_{in}D_{A2}$. Therefore the solution of indoor particulate concentration D_{A2} with t is

$$D_{A2}(t)=\int_0^t h(\tau)\,q_{in}D_{A2}(t-\tau)\,d\tau \quad . \tag{8}$$

We can also deal with D_{A3} in the same manner,

$$D_{A3}(t)=\int_0^t h(\tau)\,q_{re}D_{A3}(t-\tau)\,d\tau \quad . \tag{9}$$

Equation(6) can be regarded as a decay-type equation for the case of D_r with t such that $D_A=1/V_A$ at $t=0$. Therefore the indoor particulate concentration D'_{A4} with t such that $D'_{A4}=D_{re}$ at $t=0$, is

$$D'_{A4}=h(t)D_{re}V_A \quad . \tag{10}$$

Thus the generalized equation of indoor particulate concentration D_A with t may be added the value obtained from Eq.(7),(8), (9)and(10) and written in the following form,

$$D_A(t)=D_{A1}(t)+D_{A2}(t)+D_{A3}(t)+D'_{A4}(t) \quad . \tag{11}$$

Now, assuming that D_{A2}, D_{A3} and G are holding constant and ~~boundary~~ initial value is $D_A=D_{re}$ at $t=0$, the solution will have the form,

$$D_A=\frac{q_{in}D_{A2}+q_{re}D_{A3}+G}{(n+V_A/H)V_A}\left[1+\exp\left(-\left(n+\frac{V_A}{H}\right)t\right)+D_{re}\exp\left(-\left(n+\frac{V_A}{H}\right)t\right)\right], \tag{12}$$

where, n is air change rate(1/hr) and is equivalent to (q_A+q_{in}).

Therefore if D_A, D_λ, D_λ and $(q_{mA}+q_{nA})$ are measured successively, the indoor source generation rate G will be obtained by substituting them one by one into Eq.(11) or (12). It is also possible to estimate the mean values of settling velocity V_A from Eq.(12) at $G=0$.

3. Method of Survey

We took a sales area for clothing and notions of supermarket and a keypunching room in an office as no smoking model, and three general office spaces as smoking permitted model. The outline of their rooms surveyed are described in Table 1.

Supply fan are equipped into every room for ventilation, and so the indoor air may be pressurized. Therefore, it is considered that q_{mA} may be nearly equivalent to the air change rate, n, in the room. q_{mA} of each room were measured in turn by means of gathering q_{mA} emitted from each outlet of supply duct into a big polyethylene bag for a given time. The values of D_λ and D_A are possible to estimate by measuring with a light-scattering dust-analyzer at intervals of 10 minutes at the outlet of supply duct and the exhaust grille, separately. At the same time, the number of occupants P and the number of people smoking at one time P_λ, in the room are counted at intervals of 5 minutes.

4. Results and Discussion

Figures 3 and 4 show some examples on the values of P, D_A, and D_λ with t for a sales area and a keypunching room as "no smoking". The generation rate of particulates in a whole room G(mg/hr) and the rate per one occupant g(mg/hr·person) are derived by substituting them into Eq.(11). They are also shown in Fig.3 and Fig.4. Fig. 5 and 6 show the relationship between the number of occupants,

P, and G in each room. Where, Fig.6 shows the generation rate over the periods of small traffic into or out of a room, (10-12 a.m.) and (1-5 p.m.) with a circle sign, and (5-6 p.m.) with a triangle sign. The observation in Figs.5 and 6 indicates that G depends on P and the activity level of occupants.

Next, Fig.7 and 8 show some examples on the measured values of P, P_S, D_A, and D_S with t in the general office spaces A, B and C as "smoking permitted".

The suspended particulate matter in the room is mixing with the one generated by smoking and by the activity of occupants. So, it is assumed that the rate of particulates generated continuously by smoking cigarettes one by one for an hour g_S is 250mg/hr and that the settling velocity for the particulates of cigarette smoke is about 2.0m/hr in the office space. Therefore it is possible to decide the generation rate of particulates by smoking in the room G_A from the product of the number of people smoking P_S and the rate of particulates generated continuously per one smoker over an hour g_S. And the values of particulate concentration in a whole room increased by smoking D_{PS} can be derived by substituting them into Eq.(7).

Then it is assumed that the particulate concentration increased by the activity of occupants D_A is the difference between the measured values of $(D_A - D_S)$ and the predicted values of D_{PS}. And we are possible to derive G by substituting D_A into Eq.(11). D_A and G are also shown in Fig.7 and 8.

From Fig.7 and 8, it would be revealed that the indoor particulate concentration remarkably depends upon the particulate matter concentration increased by smoking. Figure 9 and 10 show the relationship between the number of occupants P and the generation rate of particulates from occupants G. But their dependence is

less obviously indicated than the results obtained at the room for "no smoking"(Fig.5 and 6). The main reason would be considered that we took the generation rate of particulates per one smoker over an hour as constant.

But it seems to be quite all right to consider that the suspended particulate concentration by occupants depend upon the number of occupants and their activity level.

Futher,Table 2 show the mean values of G and g obtained over each traffic period. ~~It seems that they are afforded as~~ The values seem to be considered appropriate.Of course, g is remarkably dependent upon the activity level of occupants,the kind of activity,the cleaning level of room and so on.

Therefoere we will need to investigate the values of g over a long period of time.

5. Conclusion

It would be surmarized that:

1. The indoor particulate concentration is seriously dependent upon the generation rate of particulate matter by smoking.

2. The generation rate of particulate matter from the activity of occupants ~~except that the one~~ (except the particulate matter) from smoking depends upon the use of the room and traffic level through a room.

3. The mean values of the generation rate of particulate matter per one occupant can be estimated at approximately 2.0 mg/hr·person in a keypunching room,13.0 in a sales area for clothing and notions of supermarket,and 4.0~18.0 in a genaral office area.

References

1) M.Narasaki,Annual Report AIJ(1961)101~104(in Japanese).

2) M.Narasaki,Annual Report AIJ in Kinki District(1972)65~68(in

Japanese).

3) M.Narasaki,Annual Report AIJ in Kinki District(1973)41-44(in Japanese).

4) M.Narasaki and T.Kusumi,Annual Report SHASE in Kinki District (1978)91-94(in Japanese).

Table 1 Outline of the Condition of investigated Rooms

Type of room		A sales area of supermarket	A keypunching room	genaral office			
				A	B	C	
Date		Aug.24th (Sat.) 26th (Mon.)	July 10th (Wed.) 11th (Thu.)	July 4th (Thu.) 5th (Fri.)	July 8th (Mon.) 9th (Tue.)	Feb.17th (Mon.) 21th (Fri.)	July 28th (Mon.) Aug. 1st (Fri.)
Time		9p.m- 7p.m.	8a.m- 6p.m.	8a.m.- 6p.m.	8a.m.- 6p.m.	8a.m.- 7p.m.	7a.m.- 7p.m.
Volume of room V_R (m^3)		2920	205	221	329	1040	
Height of ceiling H (m)		3.0	2.7	3.0	2.7	2.5	
Air change rate n (1/hr)		3.4	2.3	5.1	4.9	3.7	7.1
Settling velocity V_g (m/hr)	Particulates generated from activity of occupants	2.4	1.0	7.7	7.4	1.9	3.6
	Particulates generated from smoking	——	——	2.0	1.9	0.6	1.1

Table 2 The Mean Generation Rate of Particulate Matter from a Occupants for an Hour $\underline{g}$ (mg/hr·person)

Type of room		date	Time		Average
			Periods of small traffics	Periods of large traffics	
sales area of supermarket		Aug.24th.	——	——	13.1
		Aug.26th	——	——	12.6
		Average	——	——	12.9
keypunching room		July 10th	1.5	2.9	1.8
		July 11th	2.2	2.4	2.3
		Average	1.8	2.6	2.0
general office	an office A	July 4th	6.0	21.2	10.2
		July 5th	4.8	13.8	7.3
		Average	5.4	17.1	8.9
	an office B	July 8th	8.8	46.4	17.6
		July 9th	1.5	9.8	3.5
		Average	5.1	28.1	10.5
	an office C	Feb 17~21	——	——	4.0
		July 28th~ Aug. 1st	——	——	18.5
		Average	——	——	11.8

Figure Captions

Fig.1. Diagram of a model for ventialtion system and pollutant flow.

Fig.2. The variation of number of occupants P, particulate concentration of indoor air D_A, the concentration of supply air D_S, generation rate of particulate from occupants G and the one per occupant g throughout the day of Aug.26th in a sales area of super market.

Fig.3. The variation of P, D_A, D_S, G and g throughout the day of July 10th in a keypunching room.

Fig.4. The relationship between number of occupants P and generation rate of particulate from occupants G in a sales area of supermarket.

Fig.5. The relationship between P and G in a keypunching room.

Fig.6. The variation of P, P_S, D_A, D_S, D_{TS}, G and g throughout the day of July 5th in an office A. Here, D_{TS} is the estimated values of particulate concentration increased by smoking and P_S is number of smoking people.

Fig.7. The variation of P, P_S, D_A, D_S, D_{TS}, G and g throughout the day of Aug.1st in an office C.

Fig.8. The relationship between P and G in an office B.

Fig.9. The relationship between P and G in an office C.

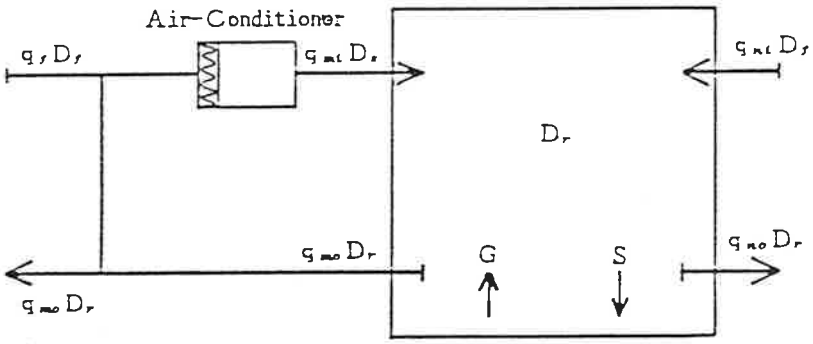

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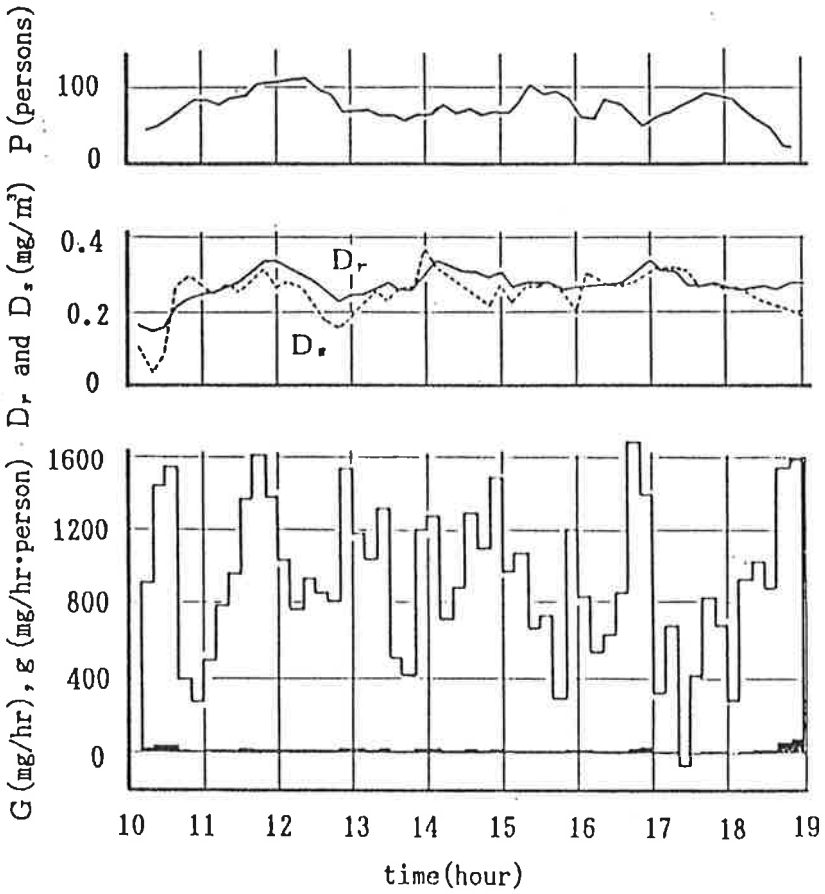
Fig. 1 M. NARACHI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0
Dr and Ds (mg/m³)
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0.2
0
Dr
Ds
G (mg/hr), g (mg/hr·person)
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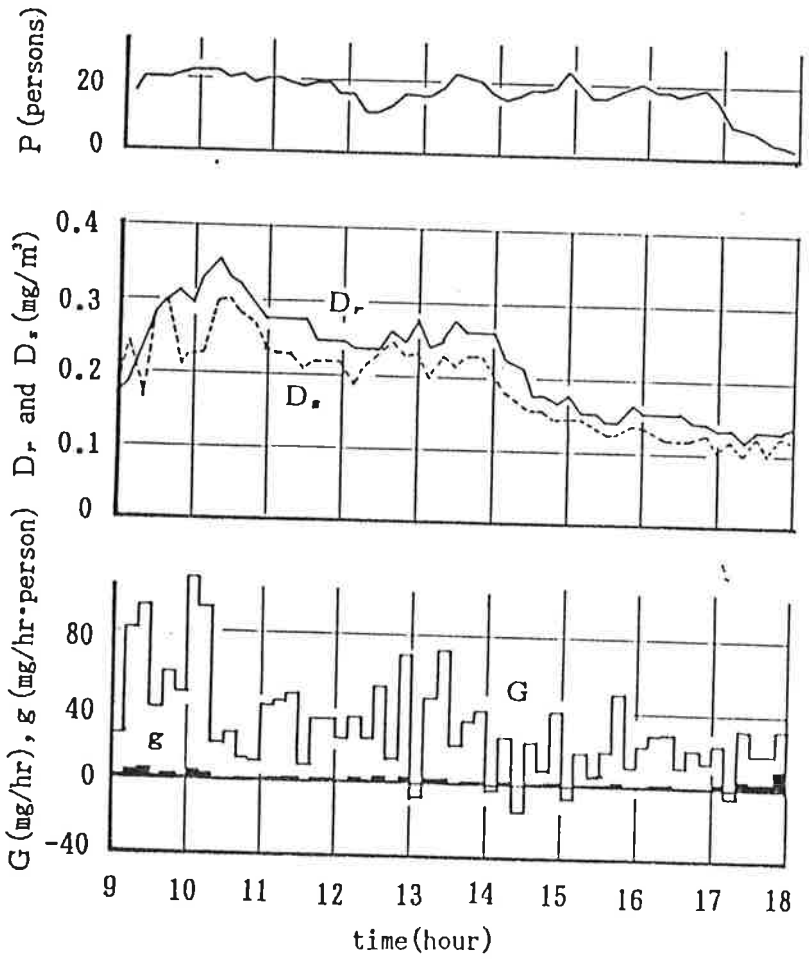
1200
800
400
0
10
11
12
13
14
15
16
17
18
19
time (hour)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0.3
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D,
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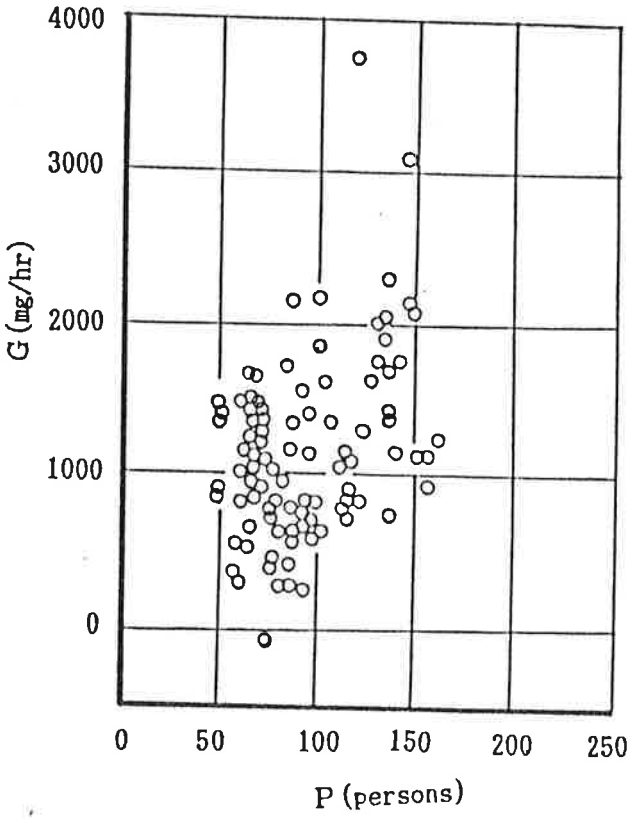
40
0
-40
G (mg/hr), g (mg/hr·person)
G
g
9
10
11
12
13
14
15
16
17
18
time (hour)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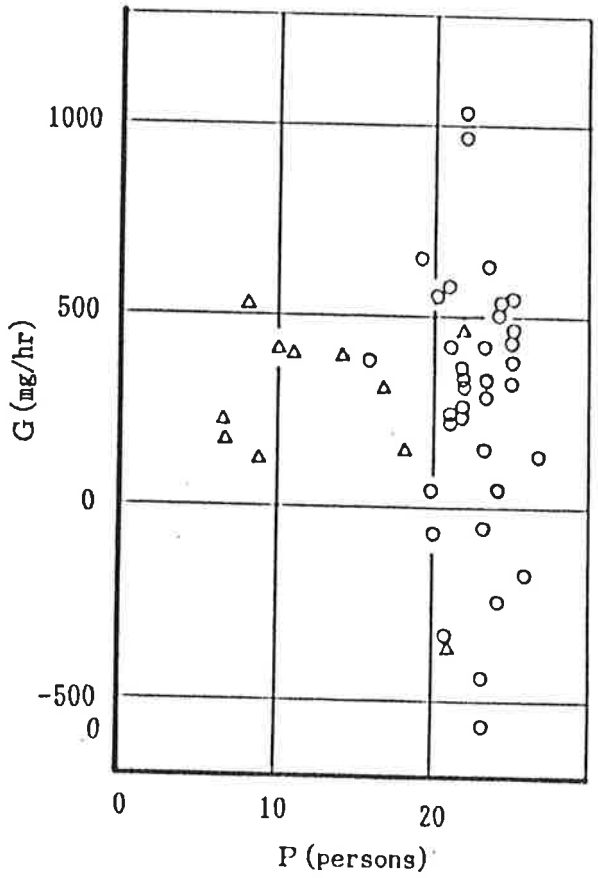
P (persons)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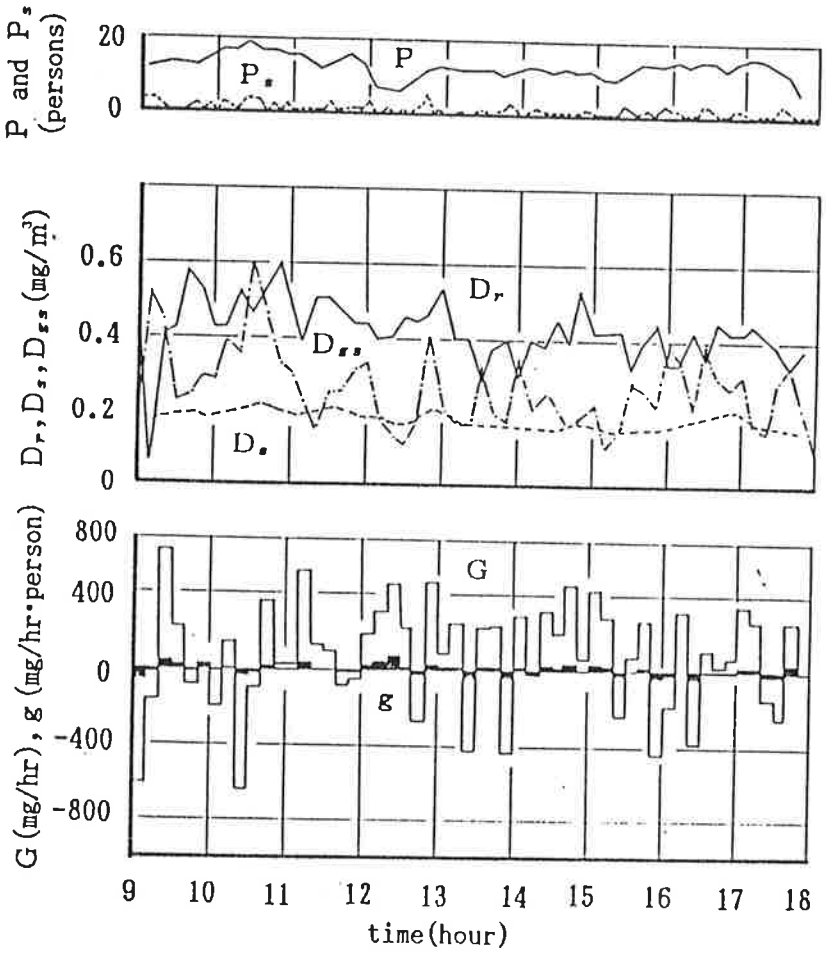
P (persons)


P and Ps (persons)
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0
P
Ps
Dr, Ds, Dss (mg/m³)
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0.4
0.2
0
Dr
Dss
Ds
G (mg/hr), g (mg/hr·person)
800
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18
time (hour)

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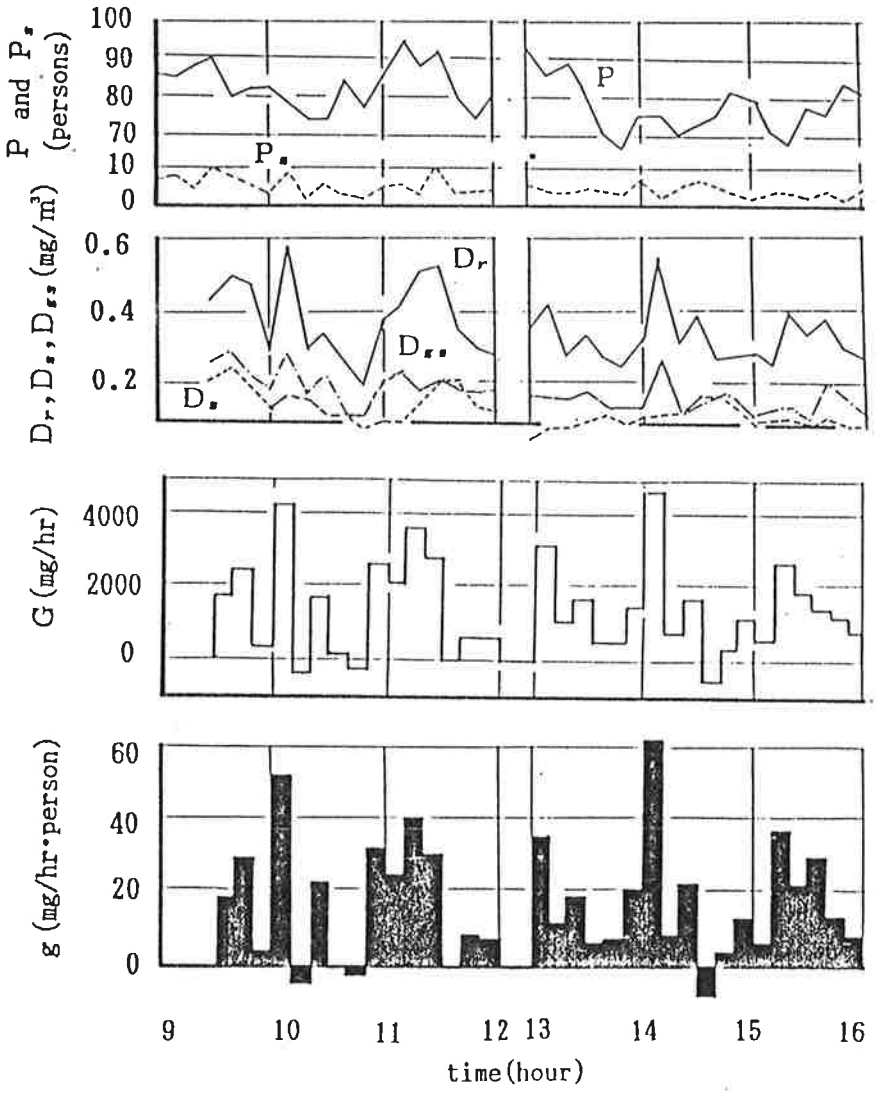
10

18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90
80
70
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P
P.
Dr, D., D.. (mg/m³)
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0.4
0.2
Dr
D..
D.
G (mg/hr)
4000
2000
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g (mg/hr·person)
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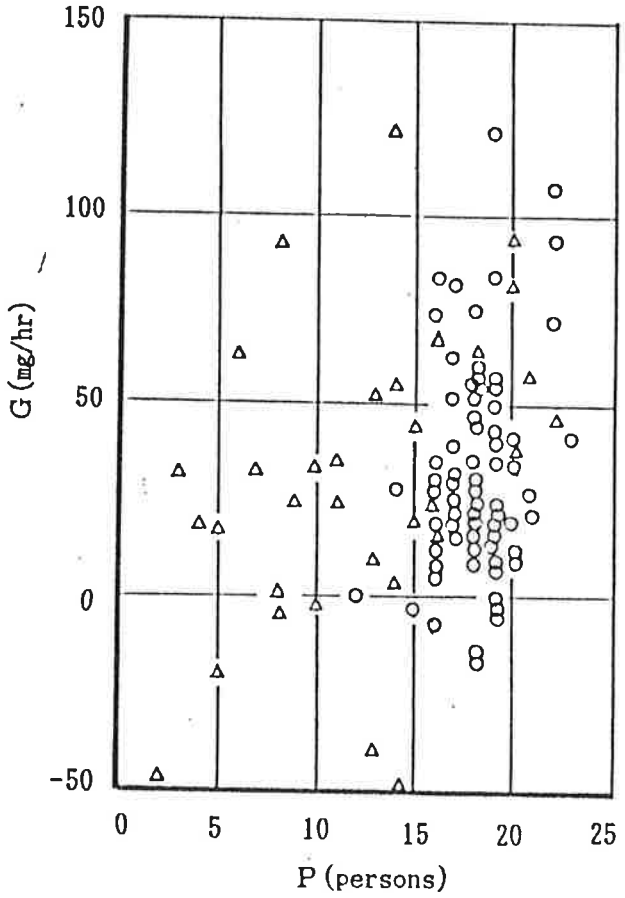
time (hour)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20
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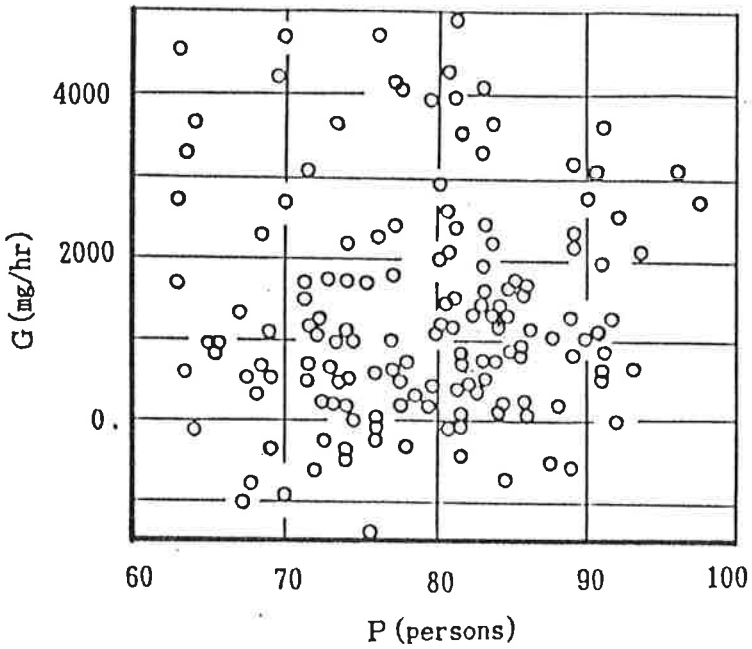
P (persons)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G (mg/hr)
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P (persons)