ACTUAL SITUATION OF VENTILATION DESIGN AND EVALUATION USING CONTAMINATION AREA RATIO OF SMOKING ROOMS

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ABSTRACT

Contamination distributions were calculated and evaluated by contamination area ratio at respiration height for actual smoking rooms. As a result, 1) Dust contamination area ratio is about 20 % for required ventilation volume by Guidelines. 2) Ventilation volume based on smell level 1 is almost as much as that based on dust criterion. 3) Contamination area ratio of smell level is more rapidly reduced than that of dust as ventilation volume is increased. 4) A desirable clean air condition is producible by increasing ventilation volume on the basis of smell level 1, but strong air current is locally created.

INTRODUCTION

Recently, smoking population has been decreasing and the buildings in which smoking is inhibited have been increasing. Adequate treatment of tobacco smoke in buildings becomes even more important to prevent passive smoking. There are mainly three standards to decide necessary volume of ventilation of smoking rooms; dust concentration, degree of smell intensity corresponded to acetaldehyde concentration and discharging air velocity at the boundary of smoking rooms. The dust criterion is 0.15 mg/m3 in Guidelines of tobacco smoke in working places. Guidelines also define discharging air velocity at the boundary of smoking rooms over 0.2 m/s to prevent smoke outflow. Standards for building equipment decide air quality of smoking rooms under smell level 1 on 6-point-scale of small sensation, 'just noticeable'.

Data of 91 smoking rooms were gathered from building equipment designers and actual situation of smoking room ventilation design was investigated in this study. Most frequent ventilation rate was between 20 and 30, and secondly between 40 and 50. Ventilation volume was determined based on smell for 44.3 %, dust for 19.6 % and air velocity and others for 18.6 %. Actual ventilation volumes were, however, much lower than that required by criterions in almost cases. Devices to increase local exhaust volume were sometimes not installed in those cases.

Asari et al., 2008 investigated highly efficient ventilation system to improve air quality in smoking room. Air inlet and outlet are placed apart and strong swirling air movement in one direction is created, though indoor air is mixed uniformly in conventional smoking rooms where both air inlet and outlet are placed in the ceiling. Sakaguchi et al., 2009 calculated tobacco smoke diffusion in a restaurant divided into smoking area and not-smoking area. They clarified that dust concentration could be decreased by decreasing number of smoked tobacco, installing filters and increasing ventilation volume. Smell level corresponding to acetaldehyde concentration could be decreased by increasing ventilation volume. Seat plan can be arranged to meet the dust concentration requirement, but it is difficult to keep smell under 'just noticeable'.

This study investigates the distribution of contaminants in actual smoking rooms. Distributions of contaminants concentration and air velocity are calculated in actual smoking rooms on the basis of their reason to decide the ventilation volume. Cases with increased ventilation volumes are also calculated and evaluated by using contaminant area ratio to keep smoking rooms air clean for smokers.

GUIDELINES AND STANDARDS OF VENTILATION FOR SMOKING ROOMS

Labour Standards Bureau of Ministry of Health, Labour and Welfare in Japan published guidelines on measures against passive smoking in workplaces in 2003. Guidelines recommend that dust concentration is kept less than 0.15 mg/m3 and CO concentration is kept less than 10 ppm, and that air velocity at the boundary of smoking area and not-smoking area is kept more than 0.2 m/s.

Many kinds of contaminant are generated by smoking, and ventilation requirement for dust is the highest. Ventilation requirement Q1 to keep dust concentration under 0.15 mg/m3 is calculated by equation (1), where 10 mg dust is generated by one cigarette and n cigarettes are smoked per hour, if dusts diffuse uniformly in the smoking room. If number of smoked cigarettes is more than 36, local exhaust is recommended before the smoke diffuse. It can be realized by smoking restricted just under ventilation fans and only in smoking corners.

$$Q_1(\mathrm{m^3/h}) = 10 \times n(\mathrm{mg/h}) \div 0.15(\mathrm{mg/m^3}) \qquad (1)$$

Required ventilation volume Q_2 to keep air velocity over 0.2 m/s at the boundary of smoking room is calculated by equation (2), where width is L and height is H and area is A of the openings of the smoking room. The velocity is needed not to flow out the contaminant from smoking rooms.

$$Q_2(\text{m}^3/\text{h}) = 60(\text{s}) \times L(\text{m}) \times H(\text{m}) \times 0.2(\text{m/s}) = 12A(\text{m}^3/\text{min}) = 720\text{A}(\text{m}^3/\text{h}) \quad (2)$$

Guidelines recommend the greater value of Q_1 and Q_2 as required ventilation volume.

Narasaki et al., 1986 inspected relation among smoke concentration, smell intensity and discomfort. CO and dust concentration were used as indices of smoke concentration. It was clarified that dust concentration was little related to CO concentration and was slightly related to smell intensity. Smell intensity was highly affected by gaseous materials in tobacco smoke. Discomfort was highly correlated to smell intensity regardless of smell test methods.

Standards for building equipments by ministry of Land, Infrastructure, Transport and Tourism decide required ventilation volume on the basis of smell intensity. Smell intensity levels are, '0: no smell','1: just noticeable', '2: weak enough to judge the kind of smell', '3: smell', '4: strong smell', '5: very strong smell'. Standards recommend smell level 1 for tobacco smoke. Ventilation volume Q3 is calculated by equation (3), where S is smoked tobacco mass to meet required smell level, 35.3 mg/m3, n is persons per area, 0.2-1.0, Af is floor area of smoking room, L is dust generated per cigarette, and N is number of cigarette per hour per person. Standards suppose that 130 m3 of ventilation volume is required per cigarette.

$$Q_3(\text{m}^3/\text{h}) = \frac{n \times Af \times L \times N}{S} \quad (3)$$

For example, when n = 1, S = 35.3, L = 700 and N=12,

$$Q_3 = \frac{1 \times Af \times 700 \times 12}{35.3} = 238Af$$

SURVEY OF ACTUAL SITUATION OF SMOKING ROOM VENTILATION DESIGN

Survey of smoking room design was carried out for building equipment designers in 2010. 40 designers in 17 organizations answered 91 smoking rooms.

Number of smoking rooms per building was not related to the building size. 41.7 % buildings had one, 22.9 % had two and 35.4 % had more than smoking

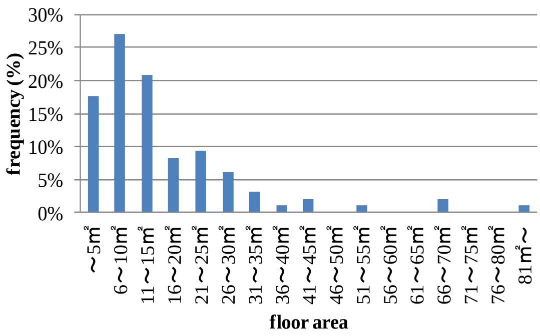

Fig.1 Area of smoking rooms

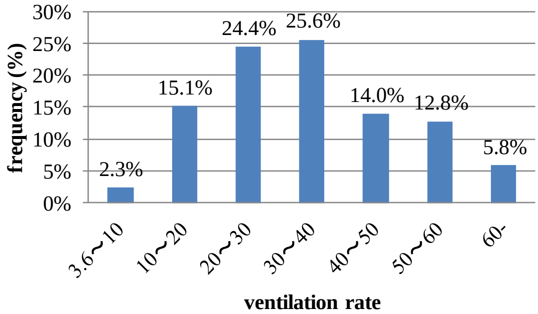

Fig.2 Ventilation rate

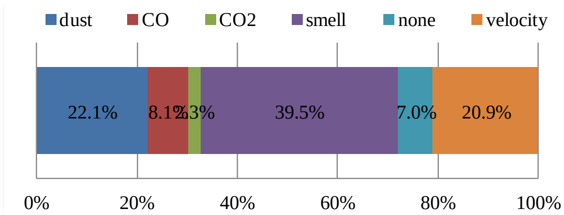

Fig.3 Reasons for ventilation volume

rooms. Only 5 % smoking buildings were built before 2002 and the others were built after 2003 when the Guidelines were published. 24.5 % smoking rooms were built when the buildings were repaired. Figure 1 shows that floor areas of 17.7 % smoking rooms were under 5 m2, 27.1 % were 6-10 m2 and 20.8 % were 11-15 m2. Mean ceiling height was 2.67 m and mean volume of smoking room was 31.5 m2. 63.5 % had hinged doors, 20.8 % had sliding doors and 9.4 % had automatic doors. Supposed number of smokers was two for 12.3 %, five for 19.3 %, six for 15.8 % and ten for 14.0 %. The median was six. 15.1 % were adopted duct systems, 5.4 % fan coil unit systems, 43.0 % by cassette package air conditioners, 9.7 % by concealed package air conditioners, and 26.9 % were without air-conditioning systems. 84.4 % were installed with exhausting electric fans, 34.6 % with air cleaners and 45.6 % with smoking tables.

57.1 % exhausted by electric fans and 26.5 % supplied outdoor air by air-conditioners and exhausted by electric fans. 68.0 % ventilation system were all time operated, 16.5 % automatically and 13.4 % operated by occupants. 64.3 % ventilation inlets were placed at the ceilings, 21.4 % at the door slits. 81.6 % ventilation outlets were placed at the ceilings.

Figure 2 shows the frequency distribution of ventilation rate. Ventilation rate ranged 3.6- 85, most frequent at 20-30, half were 20-40 and mean was 30.9. Designed ventilation volume when fully operated was under 500 CMH for 19.4 %, 500-1000 CMH for25.8 %, 100-1500 CMH for 21.5 % and averaged value was 1496CMH and median was 1000CMH. Mean ventilation volume calculated by ventilation rate and room volume was 1323 CMH and median was 900 CMH. Figure 3 shows the reasons used at decision of designed ventilation volume. 44.3 % rooms used smell, 19.6 % dust and 18.8 % air velocity or others.

Supposed number of smokes was 5 for 9.8 %, 6 for 13.7 %. 12.7 % did not suppose occupant number. Smoking time per person was three min for 18.6 %, five min for 8.8 and 14.7 % did not suppose smoking time.

CALCULATION RESULTS AND DISCUSSION

Comparison between actual and required ventilation volume

Figure 4 shows comparison between actual and required ventilation volume for eight smoking rooms designed on the basis of dust concentration. Required ventilation volume was calculated according to equation (1). Actual ventilation volume is the product of answered ventilation rate by room volume. Answered disposal volumes are also shown. Required volumes are much larger than actual volumes except for two cases. It is because numbers of cigarettes smoked per hour were too large. Ventilation volumes were sometimes not sufficient even if a general smoking table of 600-1000 CMH was installed.

Figure 5 shows comparison about smell levels. Required ventilation volume depends on not only floor area but also population density supposed 1.0 in Standards. Modified required volumes are also shown in the figure when population density was adjusted by supposed number of smokers and actual floor area. Required volume based on smell depends on floor area. Actual volumes were much lower than required especially for large smoking rooms. The difference was as much as 3500 CMH in the case without smoking tables. Ventilation was not sufficient even if three general smoking tables were installed.

Investigation of smoking rooms ventilation by CFD analyses

Three rooms each were selected from answered samples which floor area and room volume are similar and ventilation volume per person are

Table 1 Calculation conditions

Calculation code	General purpose structured mesh thermal-fluid analysis system Ver.9
Analysis summary	Uncompressed、Turbulence、Stationary analysis
Initial condition	Room temperature 30℃、Outside temperature 30℃ Individual temperature 20℃
Turbulence model	Standard k-ε model
Boundary condition	i)Heat boundary : Heat transfer is ignored ii)Wall boundary : Smooth wall
Flow rate condition	i)Air conditioning : Supply : Wind speed 6.0m/s、Four inclinations of 45 ° to the ceiling $0.019m^2/s^2$、ε=$0.0005m^2/s^3$ Suction : Quantity of flow 24.0m/s
Flow rate condition	i) A wall ventilation fan : Internal radius : 30cm Amount of ventilation, Ventilation rate are on Table. 3
Diffusion of taining material	Buoyancy and molecular diffusion are ignored. Calculation of advective or turbulence diffusion.
Generation of dust	15 mg /one tabacco × 8 tabacco /h=120 mg/h= 0.033 mg/s
Human model	Body surface area : 1.7 ㎡、Fixed temperature : 37℃ Smoking at the height of 1.4m.

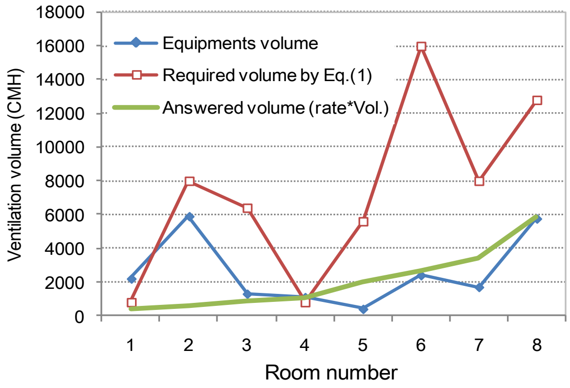

Figure 4 Actual and required ventilation volume (for dust)

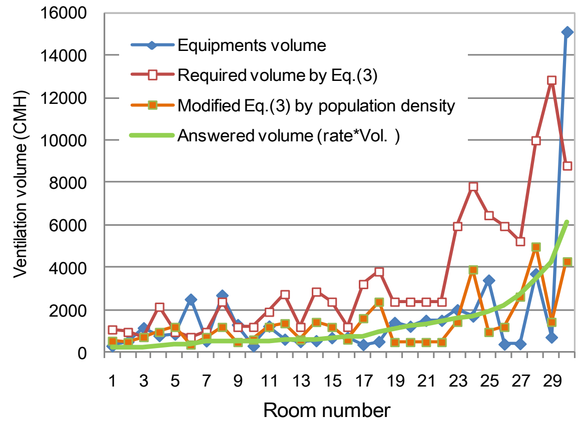

Figure5 Actual and required ventilation volume (for smell)

Table.2 Smoking rooms

	Dust 1	Dust 2	Dust 3	Smell 1	Smell 2	Smell 3	Wind 1	Wind 2	Wind 3
Size	10	12	15	12	11	10	8	13	10
Volume	27	30	37.5	31.2	28.6	27	20	35.1	25
Capacity	10	8	7	10	6	2	4	8	5
Ventilation rate	20	30	40	25	30	40	5	30	40
Amount of ventilation	540	900	1500	780	858	1080	100	1053	1000
Ventilation per capita	54	112.5	200	78	143	540	25	131.625	200
Ventilation of the dust criterion	8000	6400	6000	8000	4800	1600	3200	6400	4000
Ventilation of the smell criterion	2380	1904	1785	2380	1428	476	952	1904	1190

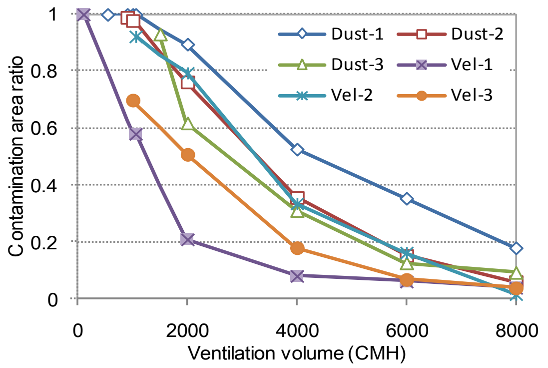

Figure 6-1 Ventilation volume and contaminant area ratio of the dust concentration more than 0.15 mg/m3

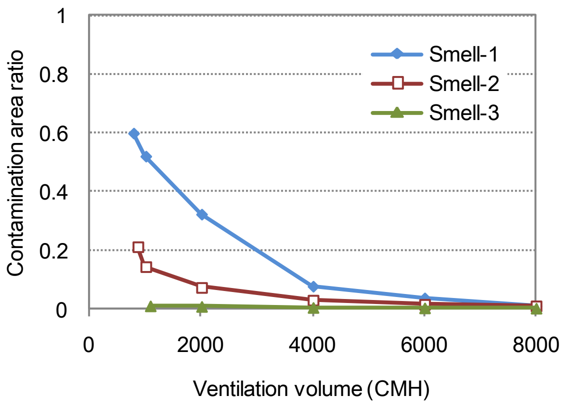

Figure 6-2 Ventilation volume and contaminant area ratio of smell level-2

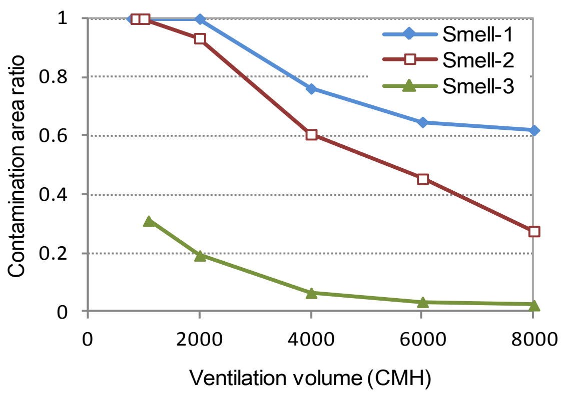

Figure 6-3 Ventilation volume and contamination area ratio of smell level 1

different for reasons of dust, smell and air velocity. Contaminant distributions were calculated for actual and increased ventilation volumes 1000, 2000, 4000, 6000 and 8000 CMH. Table 1 shows the calculation conditions. Air-conditioning and fan type, air velocity and direction at the outlet, and flow rate at the inlet were decided according to the survey.

Criterion of dust concentration is set as 15 mg/m3 and smell level is set as level 1, 'just noticeable' for 'good' air quality in this study. Concentration of acetaldehyde was converted to smell level 1-6. Standard air velocity at the border of smoking area and not-smoking area was over 0.2 m/s. velocity also under 1.5 m/s corresponding class 1 in Beaufort velocity classification. Table 2 shows nine selected smoking rooms for simulation. Cases are evaluated by the ratio of the area more than standard to the area of smoking room at the respiration height level of standing smokers. We call the ratio contaminant area ratio. Relations between ventilation volume and contaminant area ratio are shown in Figure 6 for different reasons of dust, smell and air velocity.

Figure 7 and 8 show dust distributions of Case Dust-1 at 1.0 m and 1.4 m. little area meets the standard of dust. Dust concentration exceeds 0.5 mg/m3 for almost the area at 1.4 m. It is because ten smokers occupy the room with ventilation volume of 540 CMH. Air flows strongly towards the exhausting fan and dust concentration is especially high around smokers near the fan. Contaminant area ratio of dust is about 70 % at both 1.0 m and 1.4 m. It is still high at 1000 CMH, but decrease to 50 % at 4000 CMH and 20 % at 8000 CMH.

Figure9 and 10 show air velocity distributions of Case Dust-1 at 6000 CMH at 1.0 m and 1.4 m. Ventilation volume of 6000 CMH is required for air quality but air velocity locally exceeds 1.5 m/s.

In Case Dust-2, room size is similar to Case Dust-1, number of smokers is eight and ventilation volume is 1.7 times larger than Case Dust-1. Ventilation volume requirement is 6400 CMH and dust concentration is lower. Contaminant area ratio is lower than 20 % at 6000 CMH and changes similarly to Case Dust-1 as ventilation volume increases.

Ventilation volume is larger in Case Dust-3, but contaminant area ratio is similar to Case Dust-2. It is still 61.8 % at 1.4 m at 2000 CMH. Area of high contaminant is limited to mouths of smokers at 4000 CMH and contaminant area ratio decreases to 20 %

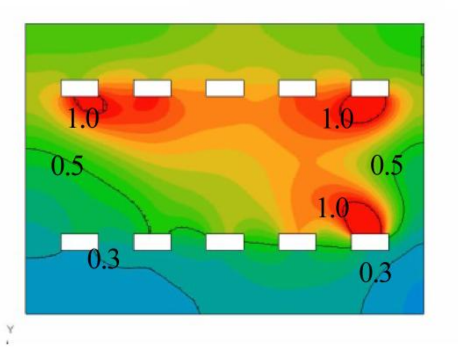

Fig.7 Dust concentration
(Case Dust-1, 540CMH, h= 1.0 m)

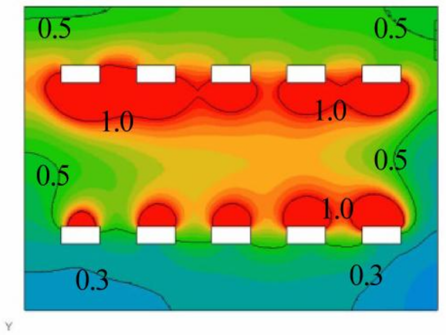

Fig.8 Dust concentration
(Case Dust-1, 540CMH, h= 1.4 m)

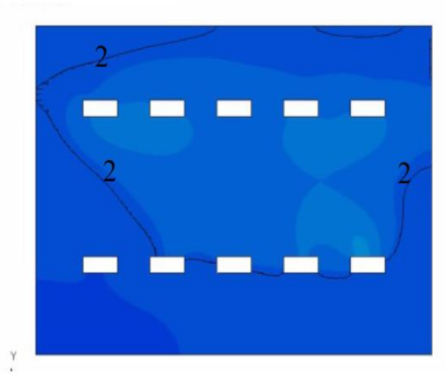

Fig.11 Smell level distribution
(Case Smell-1, 780CMH, h= 1.0m)

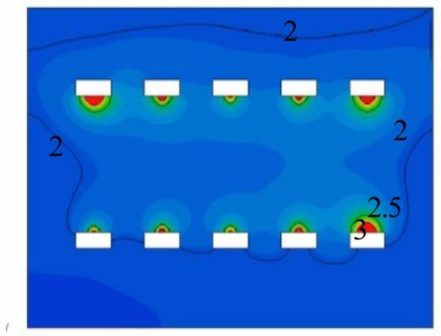

Fig.12 Smell level distribution
(Case Smell-1, 780CMH, h= 1.4m)

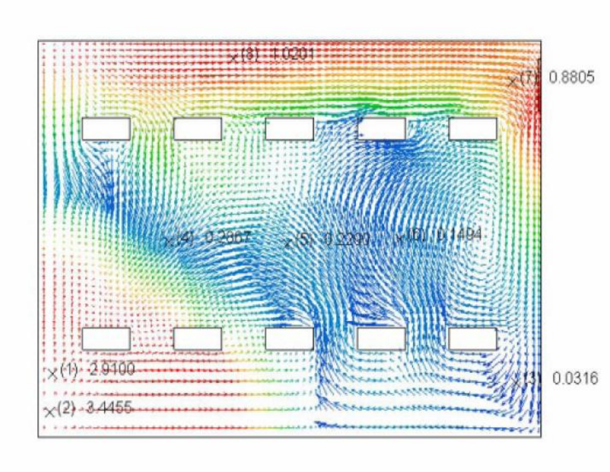

Fig.9 Air velocity distribution
(Case Dust-1, 6000CMH, h= 1.0 m)

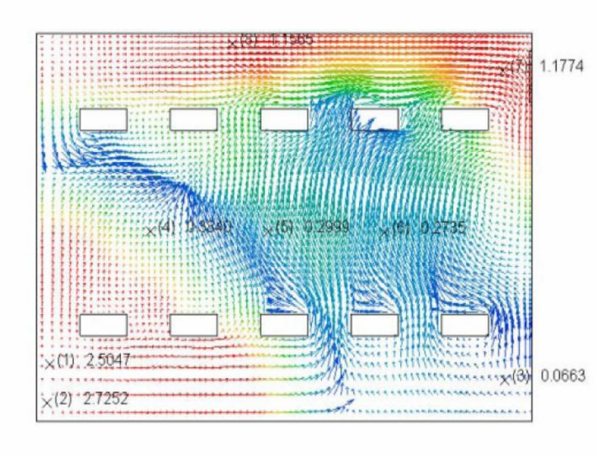

Fig.10 Air velocity distribution
(Case Dust-1, 6000CMH, h= 1.4 m)

at 5000 CMH. It is 12.6 % at 6000CMH, required ventilation volume.

Figure11 and 12 show that almost area exceeds smell level 2 of acetaldehyde in Cases Smell-1. Contaminant area ratio of smell level 2 at 1.4 m is 60 % at actual ventilation air volume. But it decreases to 32.3 % at 2000CMH and 7.7 % at 4000 CMH. 8000 CMH is needed to meet the requirement on the basis of dust, but smaller ventilation volume can meet if smell requirement is adopted.

In Case Smell-2, area of smell level 2 distributes only around smokers. It does not distribute backward of smokers and corners. Contaminant area ratio of smell level 2 is 21.2 % at actual volume of 858 CMH and 14.4 % at 1000 CMH. Required ventilation volume is 1428 CMH and air quality is acceptable at 1000 CMH, but larger volume is needed to increase smell level 1 area. Contaminant area ratio of smell level 1 is more than 60 % at 8000 CMH.

In Case Smell-3, smokers is two and ventilation volume per person is 540 CMH. Contaminant area ratio of smell level 1 is 68.8 %, but ratio of smell level 2 is 1.0 % at actual ventilation volume of 1080 CMH.

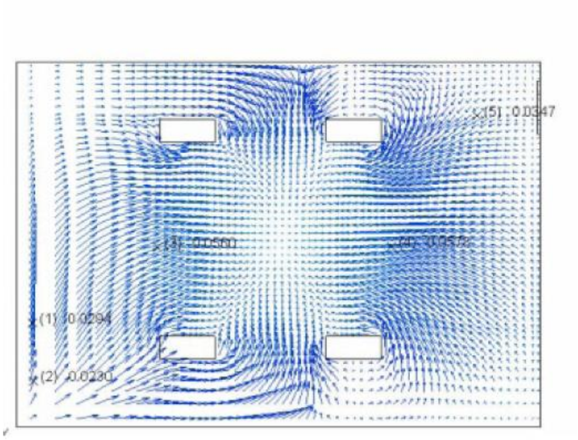

Fig.13 Air velocity distribution
(Case Velocity-1, 100CMH, h= 1.0m)

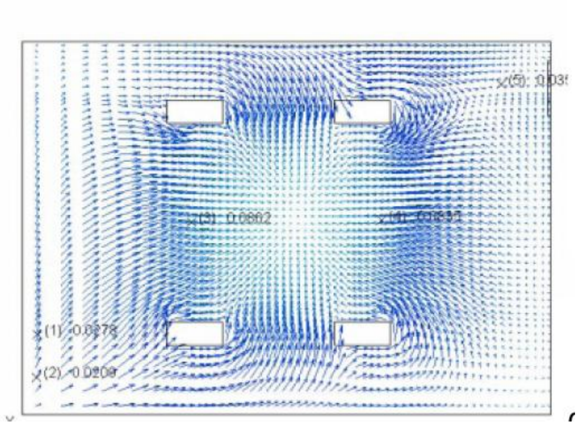

Fig.14 Air velocity distribution
(Case Velocity-1, 100CMH, h= 1.4m)

Air velocity at the entrance door is 0.02 m/s in Case Velocity-1 as shown in Figure 13 and 14. It is much lower than the guideline. Dust contaminant area ratio decreases quickly till 2000 CMH and slowly after 2000 CMH. Contaminant area ratio is small despite of ventilation rate of five. It is because number of smokers is only four.

Air velocity at the door in Case Velocity-2 is greater than 0.2 m/s. Change of contaminant area ratio according to ventilation volume is similar to Case Dust-2. Required ventilation volume 6400 CMH is also similar to Case Dust-2. Contaminant area ratio of dust is 13.6 %.

Air velocity at the door is 0.27 m/s at 1.4 m and 0.15 m/s at 1.0 m in case Velocity-3. Contaminant area ratio of dust is 30.1 % at actual ventilation volume of 1000 CMH. It is 50.8 % at 2000 CMH and 17.9 % at 4000 CMH.

CONCLUSIONS

Smoking rooms contaminant distributions are calculated by CFD for actual and increased ventilation volumes. Air quality is evaluated by an index of ‘contaminant area ratio’ at respiratory height of the room. Results show that 1) contamination area ratio for smoking rooms of required ventilation volume determined by Guidelines of dust criterion is about 20 %. 2) When standard for smell level 2 is used, almost the same ventilation volume is needed as the volume determined by dust criterion. 3) Contamination area ratio of smell level can be more rapidly reduced than that of dust as ventilation volume increased. 4) A desirable clean air condition in smoking rooms is producible by increasing ventilation volume on the basis of smell level 1, but strong air currents more than 1.5 m/s is locally created.

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