A CFD ANALYSIS OF VENTILATION SYSTEM OF LAVATORY IN OFFICE BUILDING

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ABSTRACT

In present lavatory in Japan, the following are being tried for the purpose of further improvement in the amenity : washable seat, heated seat, deodorization with function stool. In this study, the examination was carried out on the usefulness of the local ventilation system using CFD analysis method on the assumption of the lavatory in office building. In the analysis, it is examined by changing the volumetric exhaust flow rate on ceiling ventilation, local ventilation and ceiling and local ventilation combined use. On each case, it is examined by changing air ventilation balance and outlet position. The result showed that the local ventilation could reduce the indoor pollutant quality concentration in comparison with the ceiling ventilation at little ventilation air volume. And, it was shown that diffusion range of the pollutant to the near human head was reduced.

KEYWORDS

CFD analysis, Local ventilation system, Lavatory, Air pollution, Ventilation efficiency

INTRODUCTION

In recent years, air comfort, the so-called perceived air quality, has been emphasized. Requirements for improvement of air quality have increased along with that emphasis. For example, lavatory basins with a deodorization function and individual ventilation openings, etc. have been installed in lavatories. For Japanese lavatories, many examples exist in which comprehensive ventilation is adopted as a general ventilation system: all ventilation is performed by a mechanical exhaust fan at the ceiling and by natural air supply at the lavatory entrance (SHASEJ 2001). In addition, individual ventilation systems have been installed with exhaust openings around lavatory basins. Furthermore, because air around an indoor odor source is emitted locally, it is considered that an odor can be removed using a smaller amount of ventilation.

Baba (2005) experimentally studied the relationship between the amount of ventilation and the exhaust situation of air contaminants in lavatories, in which both overall and individual ventilating openings are installed. Their results show, for example, that individual ventilation is superior to comprehensive ventilation. Because smoke is used as the air contaminant in that study, however, the distribution situation of local air contaminants in the lavatory and improvement situations around the human head, which senses odors, are not well clarified.

On the other hand, using computational fluid dynamics (CFD) analysis, changes of the exhaust opening shape and position, adjustment of the amount of ventilation and generation of air contaminants, etc., are easy (e.g. Sakai, Yamaguchi et al. 2002). Accordingly, in this study, with the intention of elucidating the feasibility of the individual ventilation system in a lavatory, CFD analysis, in which a lavatory in an office building was assumed, was performed. In this paper, results of comparison and study of concentrations of air contaminants are reported for a general area and individually ventilated areas.

OUTLINE OF SIMULATION

The system lavatory that Baba (2005) examined was used; a CFD analysis model was prepared. The analyzed area (6.0 × 2.8 × 2.5 m), sources of air contaminants, and a cut plane for result displays are shown in Figure 1. Exhaust openings were installed at the lavatory ceiling (rectangle) and on the wall at the side of a toilet stall (rectangle) and under part of a urinal (slit). The natural inflow from the entire surface of the lavatory inlet was applied to an air-supply opening.

The installation situation of exhaust openings for a toilet stall and a urinal are shown in Figure 2. Position and area of the opening are identical with the real lavatory. Exhaust only from an exhaust opening for a toilet stall and a urinal (exhaust on the wall), exhaust only from the exhaust opening at the ceiling (exhaust at the ceiling) and the combined use of exhaust openings on the wall and at the ceiling were used together with changing ventilation rates, were assumed, respectively, as case 1, case 5 and cases 2–4; analyses of every case were performed for

Table 1 Simulation cases

	Exhaust	Ventilation ratio[%]	Number of exhaust	Volumetric Exhaust flow rate [m^3/h/exhaust]			
case1	Ceiling	0	0	0	0	0	0
	Wall	100	Toilet stall : 2	45.4	68.5	90.7	136.1
			Urinal(slit) : 1	68.1	95.3	136.1	204.1
case2	Ceiling	30	1	48.6	71.3	97.2	162.0
	Wall	70	Toilet stall : 2	31.5	43.2	63.0	89.8
			Urinal(slit) : 1	47.2	64.7	94.4	134.7
case3	Ceiling	50	1	83.2	111.4	162.0	226.8
	Wall	50	Toilet stall : 2	21.6	31.7	44.5	71.3
			Urinal(slit) : 1	32.4	47.5	66.6	106.9
case4	Ceiling	70	1	108.4	146.7	194.4	291.3
	Wall	30	Toilet stall : 2	14.4	21.6	35.2	52.9
			Urinal(slit) : 1	21.6	32.4	52.8	79.3
case5	Ceiling	100	1	158.8	222.3	317.5	476.3
	Wall	0	0	0	0	0	0
Air changes per hour of lavatory: ACH [1/hour]				3.8	5.3	7.6	11.3

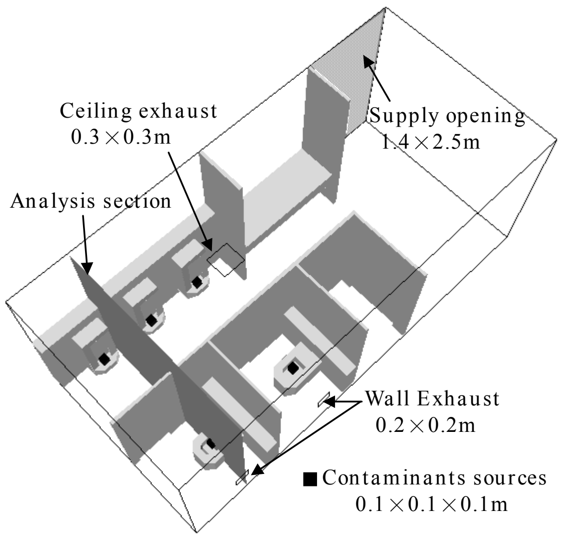


Figure 1 Analysis model of lavatory

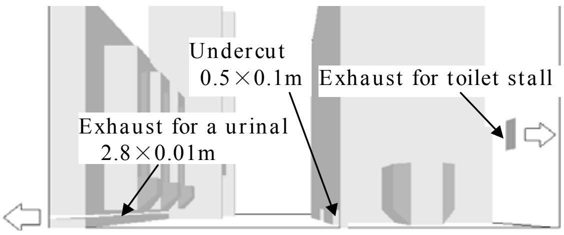


Figure 2 Exhaust openings for toilet stall and a urinal

ventilation, with air changes per hour (ACH) of 3.8, 5.3, 7.6 and 11.3 [1/hour] (ASHRAE, 2005). The study cases are shown in Table 1.

To evaluate the ventilation efficiency, the passive contaminants which did not receive the effect of a buoyancy was used instead of the pollutant (Murakami et al. 1992). The generation of air contaminants from each lavatory basin was assumed. The total amount M of generated air contaminants was specified as 0.1167 m^3/s from M=Q・(Ci-Co), considering steady concentration Ci in a lavatory as 1 [-] and the air supply concentration Co as 0, on ACH=10. This setting is because the relative comparison of the ventilation efficiency was made to be a purpose. Furthermore, as for the amount of generated air contaminant at each lavatory basin, the amounts generated per toilet stall and urinal were specified, respectively, as 0.0156 m^3/s(stall) and 0.0350 m^3/s. It was assumed the influence for human from the urinal being bigger than the stall, and the ratio was set to toilet stall and the urinal was 4 : 6.

The effect of buoyancy and human body was disregarded in order to simplify the calculation, and it was made to be the isothermal analysis. For CFD analyses, a standard k-ε model for the turbulent model, SIMPLEC method for the solution method (Doormaal et al. 1983), QUICK and PLDS for the convection term difference, and k-dependence three-layer log law for the wall surface boundary condition were used ; 80 × 48 × 33 division was applied to the mesh. Furthermore, the indoor concentration distribution was calculated using a stationary solution. In addition, CFD code for the analysis is own depelopemet (Sakai, Iwamoto et al. 2002) based on control volume method (Patanker 1980).

ANALYSIS RESULT

For these analyses, the following cases are described: case 1 (wall exhaust), case 3 (parallel use), and case 5 (ceiling exhaust) for ACH of 3.8, 7.6 and 11.3.

Air flow distribution

The air flow distribution around exhaust openings for a toilet stall and a urinal is shown in Figure 3. For the ventilation in case 1 with ACH=3.8, air near the height of 1.6 m from the floor surface flows toward the exhaust opening for a urinal.

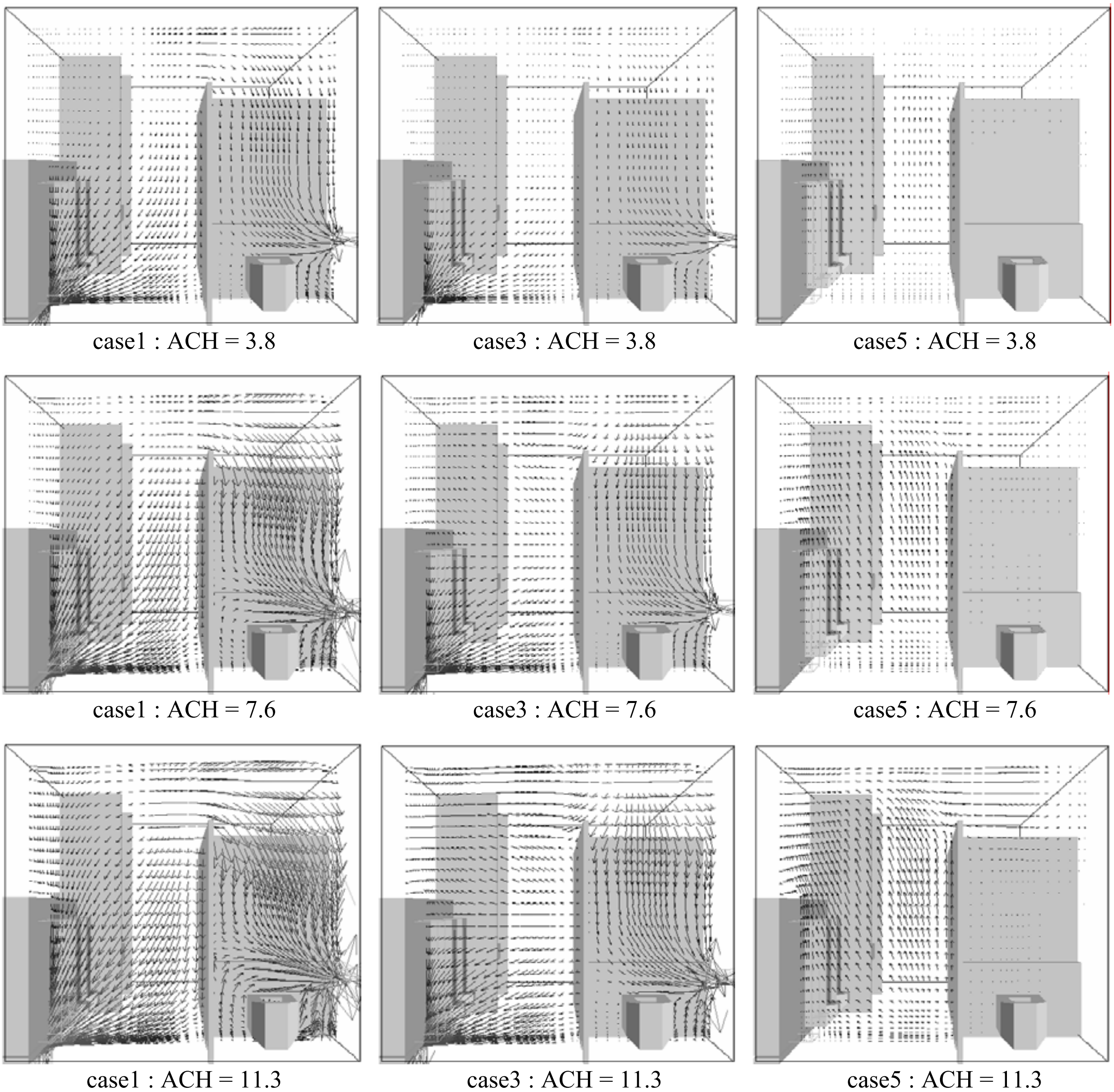


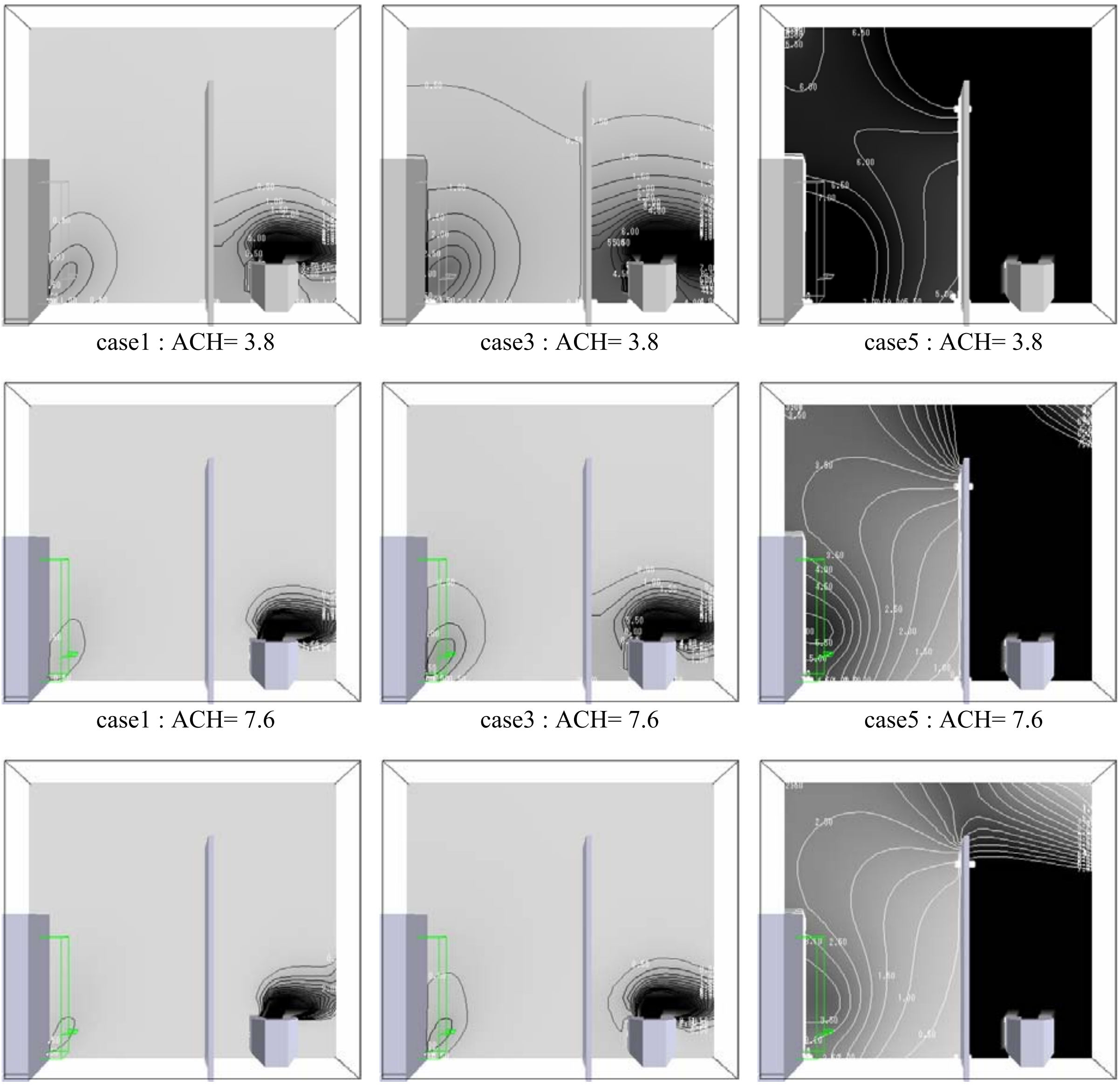
Figure 3 Air flow distribution around exhaust openings

Furthermore, the air flow, which flows toward the exhaust opening from around a toilet stall, can be confirmed. The air near the ceiling of a single room flows toward the exhaust opening for a toilet stall. For ventilation of ACH=7.6, the air current flowing toward the exhaust opening for a urinal is observed at about floor height of 2.0 m. Overall, it is confirmed that the air currents of the entire lavatory become greater than the ventilation of ACH=3.8.

The air current flowing toward the exhaust opening for a urinal with ventilation of ACH=3.8 in case 3, came to about a floor height of 1.3 m. For ventilation of ACH=7.6, the air current flowing toward the exhaust opening for a urinal is observed as about 1.7 m from the floor. The air current at the upper area of a urinal becomes greater than the ventilation of ACH=3.8.

Regarding the ventilation of ACH=3.8 in case 5, it is confirmed that the velocity of the air current at the upper area of a urinal, floor, near the ceiling and in the single room is less than in other cases, and air stagnates. For ventilation of ACH=7.6, an air current becomes large from the floor by the side of a urinal to the ceiling, but the change is observed only slightly by the air current in the single room. This tendency is similar even in ACH=11.3 in case 5.

As mentioned above, for the air flow near a lavatory basin, it was clarified that the individual exhaust of case 1 was much greater than the others. For exhaust at the ceiling of case 4, the area in which an air current stagnates is large. In cases with equivalent air exchange rate, results clarified that the air current near the lavatory basin changed by increasing the contribution percentage of an exhaust opening on the wall.



case1 : ACH= 3.8 | case3 : ACH= 3.8 | case5 : ACH= 3.8

case1 : ACH= 7.6 | case3 : ACH= 7.6 | case5 : ACH= 7.6

case1 : ACH= 11.3 | case3 : ACH= 11.3 | case5 : ACH= 11.3

Figure 4 Concentration distribution near a toilet stall and a urinal

Concentration distribution

Concentration distributions near a toilet stall and a urinal are shown in Figure 4.For ventilation of ACH=3.8 in case 1, diffusion of air contaminants from the generation source to the exhaust opening is observed for both the toilet stall and the urinal. For ventilation of ACH=7.6 and 11.3, diffusion of air contaminants is observed from the generation source to the nearby exhaust opening as well as in the ventilation of ACH=3.8, but it is confirmed that the range of diffusion becomes narrow.

The distribution situation of air contaminants in case 3 is almost equivalent to that of case 1, but the diffusion range becomes broader than case 1. Regarding ventilation of ACH=3.8, air contaminants diffuse near the floor height of 2.0 m at the side of the urinal and near the floor height of 1.6 m in the single room.

Regarding ventilation of ACH=3.8 in case 5, air contaminants fill the single room, and diffuse throughout the lavatory including the urinal side. For ventilation of ACH=7.6 and 11.3, reduction of the diffusion range of air contaminants was observed in the side of a urinal, but almost no change was apparent in the distribution of air contaminants in the single room.

The diffusion range of air contaminants tends to decrease when the air exchange rate is increased. However, the diffusion range of air contaminants differs only slightly between ventilation of ACH=3.8 in case 1 and ventilation of ACH=7.6 in case 3. In comparing in the same air exchange rate, the diffusion range of air contaminants tends to become broader with reduction of the exhaust rate on the wall.

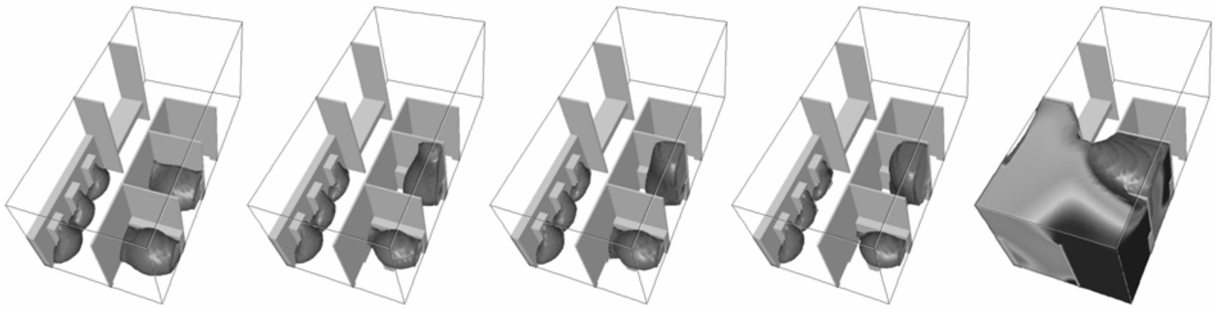


Figure 5 Concentration distribution of over full mixture concentration as 1

Table 2 Lavatory average concentration

	Lavatory average concentration [－]			
ACH＝	3.8	5.3	7.6	11.3
Case1	0.298	0.215	0.170	0.113
Case2	0.435	0.313	0.232	0.179
Case3	0.662	0.425	0.308	0.215
Case4	1.067	0.644	0.381	0.270
Case5	5.446	4.549	3.500	2.312

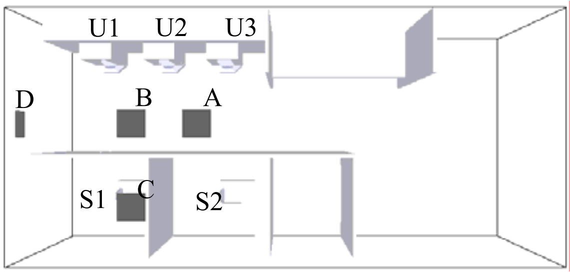


Figure 6 Study Position of ceiling exhaust

Room average concentration

The room average concentration for each case is shown in Table 2.Results show that the room average concentration tends to decrease with increased air exchange rate. For equivalent air exchange rate, the concentration is less with an increased ventilation rate on the wall. Furthermore, for ventilation of greater than ACH=5.3 in cases 1–3 and in case 4, the concentration is lower than the full mixture concentration 1 in the ventilation of ACH=10.

The concentration diffusing distribution is compared on the case of which the average concentration is almost equivalent. The results is shown in figure 5. Diffusion situation of case 1 to 4 is almost equal. Therefore, the energy saving by the ventilatory volume reduction can be expected in case 1.

Position of ceiling exhaust opening and concentration in respiratory zone

Particularly considering user comfort, for ventilation of ACH=7.6, concentrations in the respiratory zone in four kinds of ceiling exhaust-opening positions were compared and studied.

The respiratory zone was presumed as a floor height of 1.5 - 1.6 m in the case of a urinal user, and as a floor height of 0.9–1.0 m in the case of a toilet stall user, and was specified respectively as the volume of a 10 cm cube. Positions (A–D) of the ceiling exhaust openings studied and the lavatory basins, for which concentration in a respiratory zone of a user was analyzed, (toilet stalls 1–2, urinals 1–3) are shown in Figure 6.

Concentration in a respiratory zone of a lavatory basin user in each type is shown in Figure 7. On the whole, it is observed that concentration in a respiratory zone tends to increase with a reduced ventilation rate on the wall. As a tendency of concentration in a respiratory zone in each lavatory basin, urinal 3 is the lowest and the urinal 1 is the highest in the case of the urinal. In the case of toilet stalls, toilet stall 2 is high for type C and D, but toilet stall 1 is high for types A and B. Furthermore, compared with a urinal, concentration in a respiratory zone of a toilet stall becomes larger as a result.

Concentration in a respiratory zone in case 1 is lower than in other cases. In type D of cases 2–4, concentration in a respiratory zone is almost equivalent to case 1. In cases 3 and 4, differences are observed by positioning of the ceiling exhaust opening; type A is the lowest and type C is the highest in the side of a toilet stall.

In case 5, concentration in a respiratory zone is higher than in other cases, but it is confirmed that concentration reduces with type D in the side of a urinal.

As described above, the following were confirmed: in the case of the individual exhaust system, concentration in a respiratory zone can be kept low; in the case of parallel use of exhaust at the ceiling and on the wall, ventilation efficiency worsened when an exhaust opening at the ceiling was installed at the position near exhaust openings for a toilet stall and a urinal, and in the case of only the exhaust at the ceiling, concentration in a respiratory zone was higher than for others.

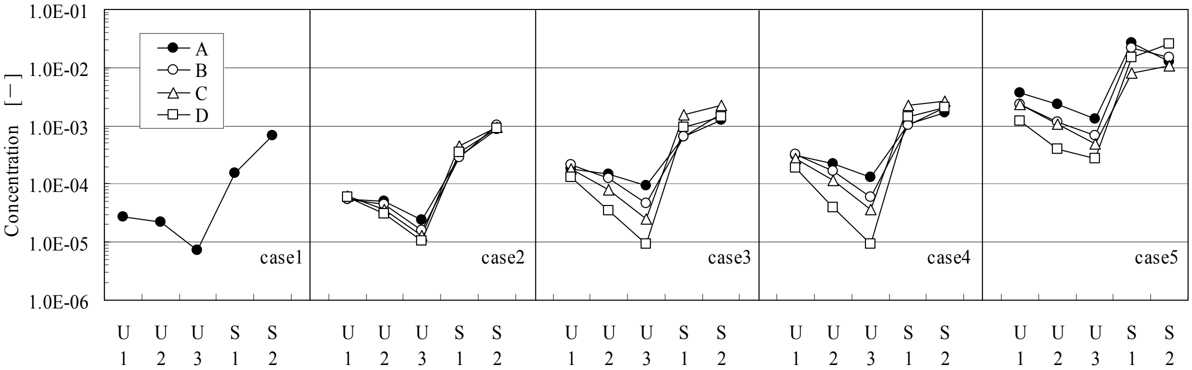


Figure 7 Concentration in a respiratory zone of a lavatory basin user in each type

CONCLUSION

Through this study, which was intended to demonstrate the availability of the individual ventilation system in a lavatory, analyses of air contaminant concentrations were performed using CFD for the overall and individual ventilation. The obtained results are summarized below.

In the individual exhaust system, in which an exhaust opening was installed near a lavatory basin, results showed that concentration of indoor air contaminants could be kept low compared with others. And it was shown that the energy saving by the ventilatory volume reduction could be expected by the adoption of this system. Furthermore, when using only ceiling exhaust, it was clarified that the indoor average concentration and the concentration in a respiratory zone were high compared to other situations.

Future studies of the influence of rising heat currents near a user and concentration properties with intermittent ventilation are scheduled.

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NOTE:

By a Building Standard Law enforcement ordinance in Japan, the air exchange rate in a hospital lavatory is specified as ACH=10 (SHASEJ 2001), but no regulation exists for ventilation of a general lavatory (Baba 2005).

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