Odor Problems in Toilets with Reduced Ventilation Frequencies

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Abstract. Japan's toilets are generally ventilated 15 times per hour. Despite the development in toilets, the ventilation frequency in toilets has not been changed in recent times. Therefore, there is a possibility that toilets are being excessively ventilated. Reducing the ventilation frequency increases the return air to the heat exchanger and improves the efficiency of the heat exchanger. For an optimal ventilation frequency, we introduce a system that could control the exhaust air using sensors. The primary issue is the odor caused by reducing the ventilation frequency. In this study, we aim to eliminate the odor as quickly as possible by providing an exhaust port at the bottom of the wall (hereinafter referred as "baseboard deodorization"). First, we examined the relationship among the odor sensor, human's olfactory odor identification and ventilation volumes with the toilet in operation to verify the usefulness of the sensors. Next, the air environment was analyzed using computational fluid dynamics (CFD). The results of the measurements and questionnaire survey indicate a correlation between the degree of contamination in the air and the odor intensity. The CFD analyses demonstrated, even after the frequency of ventilation reduced to 5 times per hour, that the ammonia concentration obtained was equivalent to 15 times per hour. To solve the odor problem due to the ventilation reduction, it is important to evacuate air immediately after the odor is generated. Among others, it was observed that a baseboard deodorization system contributes significantly to the reduction in ammonia concentration.

1 Introduction

The Japanese regulations require 15 times/h of ventilation frequency to be designed [1] for closed spaces such as toilets. The ventilation frequency in toilets has not changed recently. Despite the synergistic effects, such as technological developments to control the generation of odor of the sanitary ware itself, the optimization of the cleaning time and methods, to be ensure that users do not get dirty, the toilets generally emit little odor. Therefore, there is a possibility that a ventilation frequency of 15 times/h is excessive.

The ventilation system of the toilets used in this study is presented in Figure 1. By reducing the ventilation frequency, it is possible to reduce both thermal energy emission and conveying power. Furthermore, when a heat exchanger is implemented for



Fig. 1. Ventilation system.

the office exhaust, more heat can be recovered by improving the efficiency of the heat exchanger. If we control the air quality by reducing the amount of CO_2 , it is expected that the fresh air and thermal load of the outdoor air can be reduced. In other words, the toilets of many office buildings are emitting conditioned air, and they are discharging air with a high energy potential.

The primary issue is the odor caused by reducing the ventilation frequency. To solve the problem, we examine the air quality in the toilet using pollution sensors and computational fluid dynamics (CFD). First, we investigated the correlation between the air pollution sensor and human's odor identification or the correlation between the ventilation volume and the sensor's measurement with the toilet in operation and verified its usefulness for toilet active ventilation control. Herein, we report the results of our experiments in toilets with a daily use. Next, we model the toilet used in the verification and verify the influence on the toilet environment by reducing the ventilation frequency based on the odor intensity of ammonia. This is because the odor intensity in toilet changes when the ventilation rate is controlled. However, it is difficult to quantify the odor emission sources and quantitatively evaluate the odor conditions in normal use condition.

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2 Verification of effectiveness of air pollution sensors

2.1 Methods of verification

A men's toilet and a women's toilet on the sixth floor of a medium-sized office building in Tokyo were used for our experiments. As this floor is dedicated to the application, it is thought that the users were related to the building. Additionally, the windows were closed at all times. Table 1 shows the diagram of the toilet, and Figure 2 shows that toilet layout and the installation position of the sensors.

An exhaust port on the bottom of the wall (hereinafter referred as "baseboard deodorization") is implemented into the actual toilet, designed to efficiently exhaust the odors generated from the floor surface. The evacuation of the exhaust inside the toilet stalls is also done from the baseboard deodorization. The whole exhaust area is built from the ceiling above the urinals and the washstand. The urinals have an automatic washing function, and the toilet bowl follow standard sanitary norms.

Table 2 shows the specification of the digital sensor that displays the state of contamination in the air with a three-level indicator, and the specification of the analog sensor that quantifies the degree of contamination. These two types of air pollution sensors and the questionnaire device were installed in the surveyed men's toilets and women's toilets.

Table 3 shows a comparison between the odor state and human's olfactory identification [2]. Users were asked to evaluate the odor on a 5-point scale, and this is presented in Table 3, along with the results of the degree of contamination measured by the digital air pollution sensor.

The toilet exhaust was schedule-operated for the men's and women's toilets. During the verification period, the ventilation air volume ratio was changed to 0%, 40%, 66%, and 100%, without notifying the toilet users.

Table 1. Diagram information of the toilet.

	Men's toilet	Women's toilet
Area[m ²]	11.4	8.1
Ceiling hight[m]	2.3	2.3
Exhaust air volume[m ³ /h]	420	280
Ventilatioin times[time/h]	16	15



: Air pollution sensor installation position
: Questionnaire device installation position
Fig. 2. Toilet layout.

Table 3. Correspondence list of the odor state and olfaction.

Odor intensity	State [ppm]	Situation in sense	
0	Any odor	Any odor	
1	Detective threshold [0.15]	Smell something	
2	Cognition threshold [0.59]	Smell a toilet	
3	Easy to perceive[2.3]	Easy to perceive	
4	Strong odor [9.2]	Strong odor	

Table 2.	Details	of	air	pollution	sensor.
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Manufacture name	New Cosmos Electric Co., Ltd.	Appearance	New Cosmos Electric Co., Ltd.	Appearance
Model number	ARU-02C		COD-203	
Detectable substances	Ammonia Methanethiol etc.		Trimethylamine etc.	
Sensitivity switching	Three levels			COSHOS
Degree indication	Three levels			
Detection principle	Hot-wire type semiconductor type		Hot-wire type semiconductor type	

0%

2.2.3 Changes in level due to changes in ventilation

In the men's toilet, the level value did not exhibit any

correlation owing to the reduction in the ventilation flow ratio. For women's toilet, most of the responses were 1

level and 2 level except when the ventilation air volume

2.2 Verification results

2.2.1 Difference between men and women

Figure 3 shows the number of indicator levels of the digital-type air pollution sensor and the ratio of the odor intensity during the whole experiment period.

In the men's and women's toilet, at level 3, the odor intensity is stronger than that at level 1. Specifically, in the men's toilet, the proportion of odor intensity 1 decreases from 46% to 14% when the level changes from 1 to 3. Meanwhile, the response in detecting smells in the women's toilet only increased by 12% when the odor intensity 1 was replaced by the odor intensity 3. That is, there was no change in the ratio of the odor intensity, similar to the men's toilet.

The 10% 0% 40% 100% 0% 66% 100% 66% 409 Male (n=229) Female (n=169) Ventilation air volume ratio [%] **Fig. 5.** Ventilation air volume ratio and steps. 3% Odor intensity 0 [%] 100% 90% 1% (Odorless) 8% 5% Odor intensity response ratio 5% 80% 11% Odor intensity 1 70% 60% (Smell something) 50% Odor intensity 2 40% (Smell a toilet) 30% 79 67 20% 46 Odor intensity 3 10% (Easy to perceive) 0% 1 step 1 step 2 steps 3 step 2 steps 3 steps Odor intensity 4 Female (n=169) Men (n=229) (Strong odor) The number of step of the air pollution sensor [%]

volume ratio

ratio was 40%.

100%

90%

80%

70% 60%

50%

40% 30%

20%

air

number of steps of the pollution sensor[%]

Fig. 3. Difference between men's and women's

2.2.2 Influence on human's olfactory identification by exhaust air volume ratio

Figure 4 shows the ratio of the number of responses of the odor intensity due to the change in ventilation volume. In the men's toilet, the more the ventilation volume is reduced, the stronger the odor intensity becomes. As the ventilation ratio decreased from 100% to 66%, 40%, and 0%, the toilet users who answered that they did not sense any smell decreased by 22%, 10%, and 2%, respectively.



Fig. 4. Olfactory and ventilation volume in the men's toilet.

2.2.4 Evaluation by multiple comparisons

Figure 6 presents the results of multiple comparisons performed at every step. For the multiple comparisons, the t-tests corrected by the Bonferroni type were conducted.

A significant difference was observed between level 1 and level 3 and between level 2 and level 3. For level 1 and level 3, the P value was 4.65×10^{-6} , and 0.00225 between level 2 and level 3.



Fig. 6. Result of multiple comparisons.

3 Investigation by CFD analysis

3.1 Analysis conditions

As the strong odor response was obtained in the men's toilet rather than in the women's one, only the men's toilet was examined in the computational fluid dynamics (CFD) analysis.

Figure 7 shows the analytical model of the surveyed toilet, and Table 4 presents the analyzed environment condition. The ventilation system used an exhaust fan in which the backflow of air did not occur from the toilet to the corridor. The occurrence of the odor was replicated using ammonia, and it was set on the floor near the urinals and the washstand [3-5].

The average measurement with the analog sensor was 0.00916 ppm from 12 PM to 1 PM, when the odor load was the longest, during the break time on weekdays with the ventilation rate ratio set to 40%. Therefore, the total amount of ammonia generated was set so that the concentration of ammonia in the washstand matched the sensor measurements. The analysis results can be predicted with an error <5%. Initially, the setting was arranged from a past research [6]. The diffusion coefficient was determined to be 2.3×10^{-5} [7].

Table 5 shows three cases of this analysis. In Case 1, we set the ventilation frequency to 16 times/h as the normal operation of the toilet. In Case 2 and Case 3, the number of ventilations was reduced. In Case 3, the exhaust ratio in this building actually investigated and the exhaust from the baseboard deodorization were increased significantly, in order to perform the odor countermeasures [8, 9].

As the odor environment was unfavorable for the men's toilet from the survey results, only the result of the men's toilet was reported. However, the influence of heat was not considered here.

The equations used for analysis are shown below. In the analysis, it was assumed that the fluid was incompressible and the diffusion coefficient was constant.

$$\frac{\partial ci}{\partial t} + \frac{\partial uci}{\partial x} + \frac{\partial vci}{\partial y} + \frac{\partial wci}{\partial z} = D \left(\frac{\partial^2 ci}{\partial x^2} + \frac{\partial^2 ci}{\partial y^2} + \frac{\partial^2 ci}{\partial z^2} \right) + di \quad (1)$$

Ci : Concentration of component i

D : Diffusion coefficient

di : Amount of component i generated

Table 4. Analysis settings.

Software		STREAM Ver 12	
Finite-difference schemes		QUICK	
Analysis method		Steady state analysis	
Analysis area		2.7 imes5.4 imes2.4 [m]	
Diffusion coefficient		$2.3 imes 10^{-5}$	
	Floor surface of urinal	2.08398 × 10 ⁻¹ [ppm/s] ⁱ)	
Odor substance	Sanitary ware body	$7.71812 imes 10^{-3} [ext{ppm/s}]^{rac{10}{3}}$	
generation amount	Toilet floor	2.05357 × 10 ⁻² [ppm/s] ⁱⁱⁱ)	
Air supply port position		Natural inflow part of toilet entrance	
Dimension of air supply port		$0.8 imes2.3~\mathrm{[m]}$ (width $ imes$ height)	
	Ceiling	$0.1 imes1.0~[{ m m}]$	
Dimension of exhaust port	Baseboard deodorization of urinal	0.25 imes 0.05 [m](width $ imes$ height)	
	Baseboard deodorization of toilet bowl	0.25 imes 0.05 [m](width $ imes$ height)	
wall function models	Speed	Logarithmic measurement	

×i) Represent the floor surface when there are three urinals

ii) Represent the dirt left at one urinal itselfiii) The analysis results can be predicted with an error of within 5%

 Table 5. Analysis pattern

		Ventilation frequency [m³/h]	Exhaust retio			
	Ventilation times [回/h]		Ceiling [%]	Baseboard deodorization of urinal [%]	Baseboard deodorization in private room [%]	
Case 1	16	350	65	17	17	
Case 2	5	110	65	17	17	
Case 3	5	110	5	90	5	



Figure 7. Analytical model

3.2 Analysis result

Figure 8 shows the ammonia concentration distribution in each case. The position of the nose of the toilet users (respiration zone) is shown as \times . In Case 1, only the urinal close to the washstand reached the detection threshold of olfactory identification. In Case 2, in which the frequency of ventilation was reduced, it also exceeded the detection threshold in the urinal closest to the washbowl and the urinal in the middle. In case 3, however, it was much lower than the detection threshold in the whole area of the toilet.

Figure 9 shows isosurfaces with ammonia concentrations of 0.15 ppm and 0.59 ppm. In Case 1, a distribution was observed around the urinal, however, in Case 3, hardly any distribution was observed around the urinal and the distribution moved around the washstand. Moreover, in case 2, we observed that the range of 0.59 spreads in the vertical direction to the floor surface.



Fig. 9. Isosurface of ammonia concentration

Figure 10 shows the vertical concentration distribution and vertical velocity distribution. The ammonia concentration did not differ significantly around the respiration zone in each case, and Case 3 presented the lowest concentration near the floor surface. From the flow velocity distribution, the floor flow speed of Case 3 was larger than that of Case 1, by approximately 2.1 times.



Fig. 8. Result of CFD analysis about concentration



Fig. 10. Vertical concentration distribution and vertical velocity distribution

4 Discussion

In the women's toilet, the answers regarding the odor intensity 0 and odor intensity 1 accounted for approximately 98% of every level. Therefore, we decided to focus on the odor issue in the men's toilets. In the assessment of the air contamination in the women's toilet, the measurements of levels 2 and 3 by the digital sensors were over 50 %. This is attributed to the sensors' response to organic substances as well as target substances such as cosmetics and perfumes. Further, as women's toilets do not contain urinals, it is possible that odors are less likely to occur.

In the men's toilet, when the sensors detected that the air quality was dirty, the olfactory identification of the odor was also made, and a certain degree of correlation was observed. From the survey where the ventilation frequency was decreased, it was confirmed that the odor increased with a decreasing ventilation volume. Even when the exhaust air flow rate ratio was 0%, 17% responded with the odor intensity 0 as the setting of 0% was used primarily at night (outside of working hours). Hence, we expect that the state of odor varies depending on the number of users.

We cannot determine unequivocally that the odor intensity can be controlled by increasing and decreasing the ventilation frequency as the odor generating conditions are different due to the daily usage of toilets. However, because the relationship between the olfactory identification and the levels was recognized, we plan to use sensors for the actual operation. Therefore, by detecting the odor levels in the men's toilet with the "air pollution sensor" and by controlling the ventilation amount based on this sensor's measurements, we expected to maintain a constant odor intensity with a minimum toilet ventilation.

As ammonia can be perceived as the odor at 0.15 ppm (Table 3), in Case 3, many toilet users did not detect any odors around the respiration area. In Case 1 and Case 2, ammonia was distributed at high concentrations compared to Case 3 in the whole toilet, indicating that the odor had diffused. The ammonia

concentration around the respiration area became almost the same as that when the ventilation took place at 15 times/h, and is considered to be due to the significant contribution of the baseboard deodorant system.

Based on the vertical velocity distribution, in Case 2 and Case 3 where the ventilation was reduced to 5 times/h, air stagnation was expected to occur near the ceiling. However, as the ammonia concentration around the respiration area was the lowest in Case 3 under the analysis condition, the odor environment is considered to be unaffected. Therefore, in Case 3, by adopting a. baseboard deodorization as a measure against odor, the odorous environment around the respiration area was the most efficient.

In Case 1, the flow velocity near the ceiling was large as the displacement from the ceiling was the largest. However, it was approximately 0.02 m/s near the floor surface. Therefore, we concluded that the odor near the floor surface was circulated to the ceiling exhaust port. Meanwhile, in Case 3, as the local ventilation was performed by the baseboard deodorization, the odor diffusion did not occur, and the concentration other than that near the floor surface did not increase. Therefore, most of the concentration in the respiration area was considered to be below the detection threshold (0.15 ppm). In Case 3, we presumed that the odor had permeated to the washbasin, and that it was important to exhaust around the urinal that is closer to the odor source. The CFD analysis indicated that many toilet users did not detect any odor in certain conditions in Case 3, when baseboard deodorization was implemented. Further, it was possible to realize an air environment with a current ventilation frequency of 15 times/h or higher. In addition, it was determined that air is quickly exhausted before the occurrence of odor affected the concentration distribution significantly. Therefore, by implementing the baseboard deodorization and adjusting the exhaust air volume, it was possible to reduce the number of ventilations to 5 times/h. Further, when the odor is strong, it is necessary to increase the ventilation volume, however, when the odor is less strong, an active ventilation control can take place.

As a future prospect, we will further examine the combination of ventilation with a suitable ventilation efficiency and the air volume ratio. We will also consider energy savings considering the fluctuations in annual heat load due to a reduction in the number of ventilation times and the air volume.

5 Conclusion

We reported the results of the examination of using air pollution sensors for the active control of ventilation volume in toilets, and the examination of the influence on the environment in toilets by reducing ventilation using CFD.

We attempted to detect the odor level in a men's toilet with an "air pollution sensor" and control the ventilation volume based on these sensors' measurements from the survey performed regarding the toilet under operation. Consequently, we assumed that constant odor intensity can be maintained with a minimum toilet ventilation volume.

The CFD analysis indicated that many participants detected no odor under constant conditions in Case 3, where a baseboard deodorization was implemented. Further, it was determined that air is quickly exhausted before the occurrence of odor affected the concentration distribution significantly. Therefore, it was possible to reduce the number of ventilations to 5 times/h by adopting a baseboard deodorization and devising the exhaust air volume.

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