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Prediction of Air Quality in a Hallway of an Apartment where a Gas Water Heater is installed

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Abstract

Exhaust gas emissions caused by the combustion of gas water heaters worsens hallway air quality because the exhaust outlets of the gas water heaters are typically installed in the hallway of apartment buildings in Japan. To mitigate this problem, adequate natural ventilation planning is required considering various factors such as characteristic of exhaust gas, width of the hallway, and opening size. The purpose of this study is to predict the air quality in the hallway where gas water heaters are installed.

First, we construct a model of a general hallway where gas water heaters were installed in Japan. We measure the CO_2 concentration in the model with the gas water heater to verify the jet characteristics of exhaust gas. From these results, we reproduced the actual phenomenon in Computational Fluid Dynamics (CFD). We evaluate the CO_2 concentration in the model with various factors, such as the characteristics of exhaust gas, width of the hallway, and opening size by CFD. Finally, we define new installation standards of the hallway where gas water heaters are installed in Japan.

The CFD results show good agreement of air quality in a hallway of an apartment building where gas water heaters were installed. The standard indoor CO_2 concentration is less than 1000 ppm by the Building Sanitation Management Standards, Japan. The measured results showed that the CO_2 concentration in the model was measured less than 1000 ppm. From CFD results, we note that when the opening size of the hallway is large, its air quality is unaffected by the characteristics of exhaust gas and width of the hallway.

We constructed the general hallway's model in Japan. The CFD results show good agreement of air quality in a hallway of an apartment building where gas water heaters were installed. It was confirmed that air quality in a hallway satisfy Japan standard if hallway opening size is taken into consideration based on the CFD.

1. Introduction

Gas water heaters are typically installed in the hallway of apartment buildings in Japan. When exhaust gas stagnates in the hallway, it always leaks into the living room via the air supply opening for ventilation. Consequently, there exists a possibility of harm to a resident's health. To understand this problem, an experiment was carried out using a full-scale hallway model and analyzed using CFD.

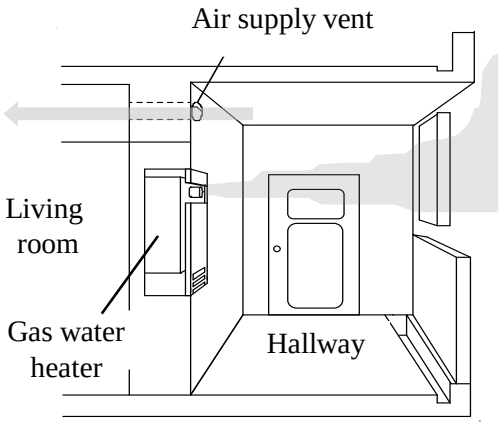


Fig. 1. Hallway of apartment buildings in Japan

2. Methods

2.1 Experiment

First, the model (figure 2) of a general hallway where gas water heaters are installed in Japan was constructed. This full-scale hallway model was reproduced, and a gas water heater was installed in it. The peak hour of hot water usage, 19:30–20:30, which includes concurrent use in a kitchen from a filling bathtub with hot water, was reproduced by considering the hot-water supply mode under the assumption of the hot water operating condition (figure 3) of a standard apartment. The CO_2 (exhaust gas) concentration of the hallway air flowing into a room was measured by installing an air supply opening for ventilation in the full-scale hallway model, and attracting air supply opening circumference air through a duct. In figure 2, U and T denote the air supply openings installed in the wall and ceiling, respectively, and the numerals next to these letters denote the distance (unit: m) from the gas water heater.

Experiments were conducted in cases as shown in Table 1. Opening area (=5.4 m^2) is the same in all cases.

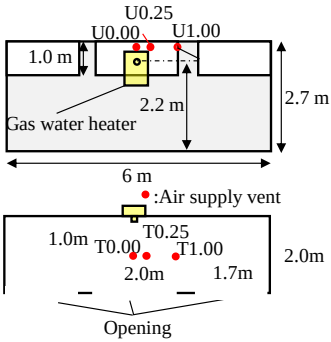


Fig. 2. Full-scale hallway model

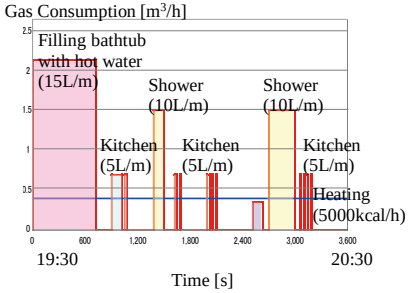
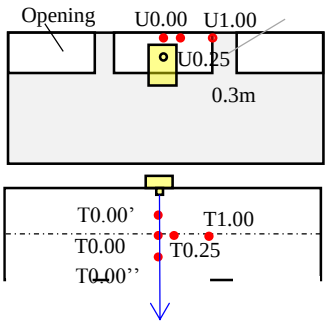
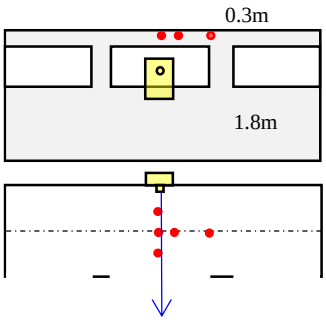
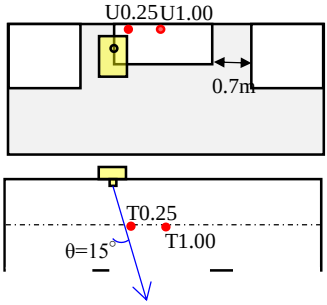
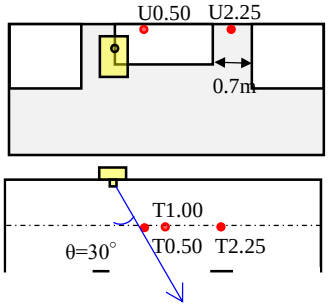


Fig. 3. Gas consumption

Table 1. Case of experiments

CASE 1	CASE 2
	
CASE 3	**CASE 4**
	

2.2 Simulation

A CFD analysis model was developed, as shown in figures 4 and 5. The hallway in the apartment building, the gas apparatus, and the air supply vent that were used in the experiment were reproduced as figure 4. Results of the survey that is characteristic of exhaust gas and flux of air supply (Table 2) were used as the analysis conditions. The exhaust wind velocity of the gas water heater was set as the conditions at the time of 15 L/min tapping with the longest time by the operation pattern in hot water supply mode. With the aim of simple prediction the hallway of air quality, we were examined to predict the hallway of air quality to low end CFD software (FlowDesigner) not only high end CFD software (Star-CCM).

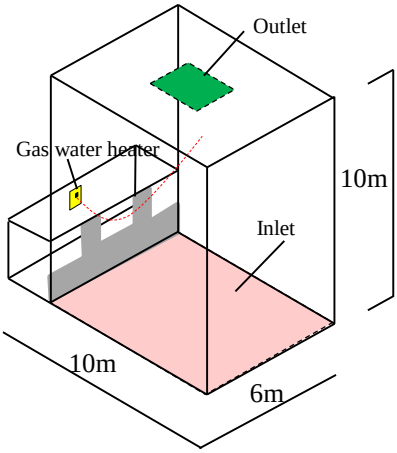


Fig. 4. CFD simulation model

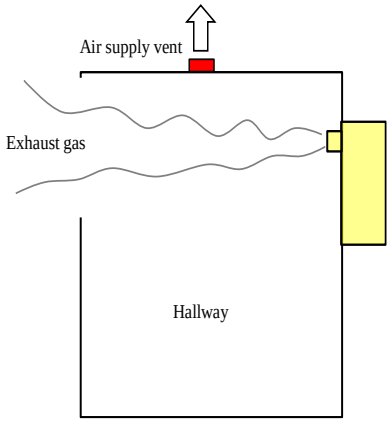


Fig. 5. Hallway analysis model

Table 2. Analysis conditions

Velocity of exhaust flow [m/s]	6.3
Concentration of exhaust gas [%]	4.8
Temperature of exhaust gas [°C]	60.0
Flux of air supply [m^3/h]	90.0
Concentration of inlet [%]	0.4
Temperature of inlet [°C]	18.0

3. Results

3.1 Experiment results

Experimental measure of the CO_2 concentration in the air supply vent shown for Case 1 and Case 2 is shown in figure 6. From results, CO_2 concentration is less than the recommended standard of 1000 ppm. When the gas water heater is a front exhaust and hallway's form meets the requirement that we constructed, it is possible to install the gas water heater wherever air supply ventilation is installed. For Case 3 and Case 4, experimental measure of the CO_2 concentration in the air supply vent shown is shown in figure 7. The CO_2 concentration was higher in Case 4 (the exhaust gas injected at 30°) than in Case 3 (the exhaust gas injected at 15°). This is believed to be due to increasing the exhaust gas angle. It seem to overestimate influence of diffusion of exhaust gas.Having obtained these experimental results, investigation by CFD was carried out to ascertain the cause.

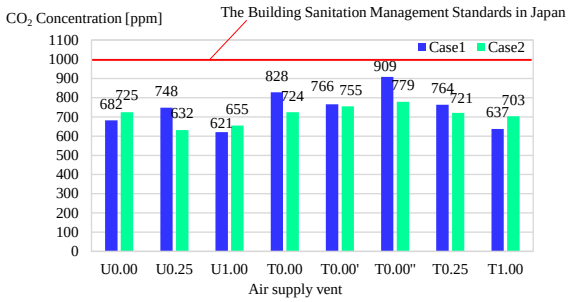


Fig. 6. Cases1 and 2 experimental results of CO_2 concentration

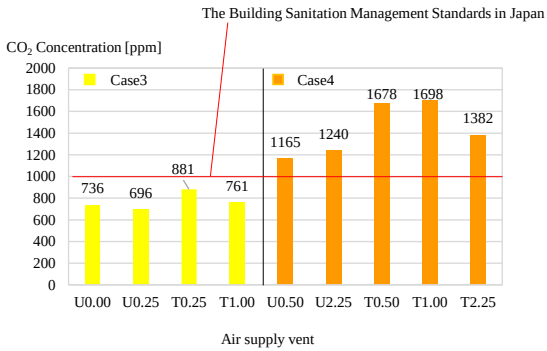


Fig. 7. Cases 3 and 4 experimental results of CO_2 concentration

3.2 Simulation results

As shown in figure 8, the CO_2 concentration of the exhaust gas decreases for both experimental study and simulations with the two types of CFD software. The result indicates that reproduction of exhaust gas success by two types of CFD software. Figure 9 presents experimental and CFD results of the CO_2 concentration in T0.00 air supply vent. The difference in CO_2 concentrations at T0.00 between the experiment and CFD was 100 ppm or less, which implies that the prediction results of CFD are highly reliable. It was noted that it is possible to predict, easily, the hallway of air quality in the case of injecting the exhaust gas forwardly.

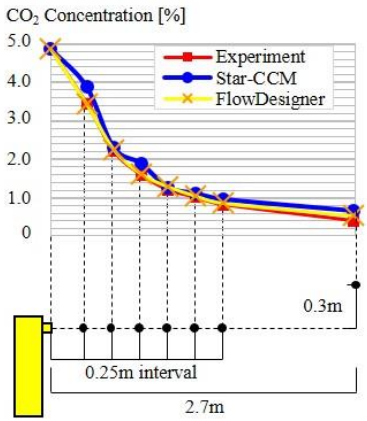


Fig. 8. CO_2 concentration decrease in exhaust gas

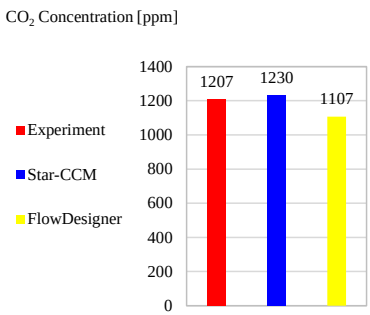


Fig. 9. Comparison between CO_2 concentrations measured by experiment and CFD

Next, the cases of the injection exhaust gas at 15°and 30° were analyzed by CFD to investigate the residual cause of exhaust gas. As shown in figure 10, in the case of the injection exhaust gas at 15°, the main jet was passed through the opening. However, the injection exhaust gas at 30°of main jet touched the wall. The orbit of the exhaust gas seemed to spread more than was predicted. Therefore, we examined the position of the gas water heater for the injection exhaust gas at 30°. As shown in figures 11 and Fig. 12, CO_2 concentration, in the cases of shifting the gas water heater 0.25 m and 0.50 m, is decreased but the CO_2 concentration was increased when shifting 0.75 m due to touch the wall. From these results and Table 3, CO_2 concentration decreased slightly as the orbit of the exhaust gas passed through the gas water heater side as compared to the middle in the central of the opening.

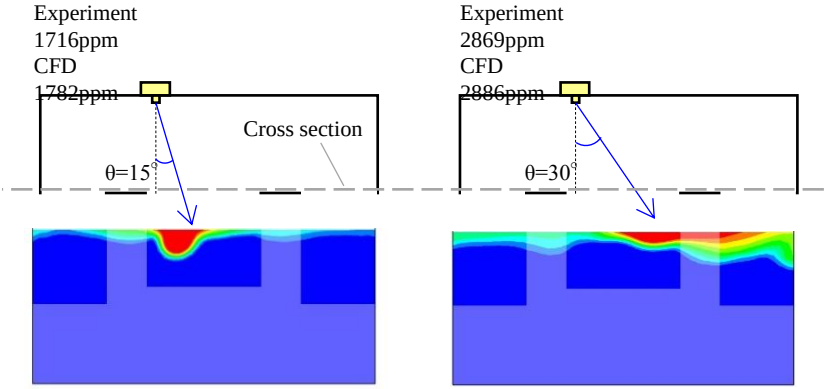


Fig. 10. Comparison of concentration distributions for angle of the exhaust gas

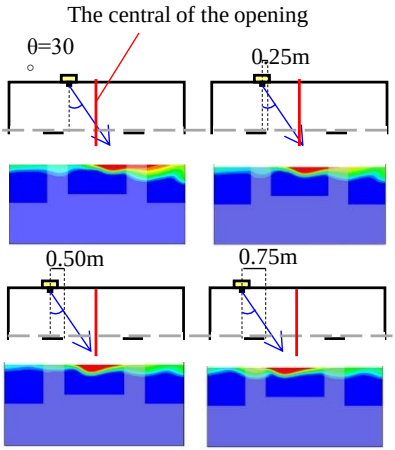


Fig. 11. Comparison of concentration distributions for positions of the gas water heater

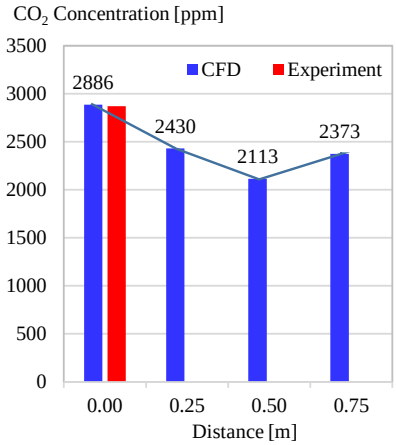


Fig. 12. CFD results of CO_2 concentration

Table 3. Relation between the CO_2 concentration and the position of the gas water heater

Angle of exhaust gas(°)	The moving distance of the gas water heater(m)	Distance* from the central of the opening(m)	CO_2 Concentration of air supply vent by CFD (ppm)
30	0	-0.15	2886
	0.25	0.10	2430
	0.50	0.35	2113
	0.75	0.60	2373

* The gas water heater side is a positive value

4. Conclusions

The general hallway's model in Japan was constructed. The CFD results showed good agreement of air quality in a hallway of an apartment building where gas water heaters were installed. General CFD software in Japan (FlowDesigner) confirmed that it is possible to predict, easily, the hallway of air quality in the case of injecting the exhaust gas forwardly. When exhaust gas is injected obliquely, it was found that hallway of air quality worse if orbit of the exhaust gas touches the wall. The position of the gas water heater was subsequently examined, and we proposed improvement measures.

References

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