

Experimental method for determining removal efficiency of house dust by mechanical ventilation

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Abstract

Biological contamination has recently become an important issue in the residential indoor environment. In fact, one of the leading causes of allergic diseases is the presence of mold and mites in house dust that accumulates on the floors, near the breathing zone for infants and toddlers. In this research, experimental studies were carried out in order to examine particle removal efficiency in a room with two ventilation systems: a ceiling exhaust system and a slit exhaust system. The results indicated that there was no clear relationship between removal efficiency and two different outlet locations. It was found that the use of fluorescent particles to simulate house dust was effective for determining the removal efficiency of ventilation systems.

Keywords: particle removal, airborne particles, measuring method, ventilation system

1. Introduction

Today's houses are designed to be well insulated and airtight to reduce energy use and improve thermal comfort. However, this high performance is accompanied by an increase in indoor humidity and condensation due to the lack of ventilation, and is the likely cause of microorganism pollution due to mites and mold. House dust includes mold spores as well as mite excrement and corpses. Existing studies have revealed that indoor air pollution by microorganisms could cause building-related illnesses such as asthma, allergies and atopic dermatitis [1, 2]. The number of patients exhibiting such health problems has been increasing

every year in Japan. Since house dust easily accumulates on the floors, there is a high possibility of allergic reactions in infants and toddlers whose breathing zone is near the floor surface.

Although ventilation is one of the best ways to remove house dust, the required energy consumption must be considered. Therefore, it is important to know what type of ventilation system is most effective for removing house dust.

The objective of this study was to examine how effectively house dust is removed in relation to the location and type of indoor air exhaust system. In this paper, we first describe the experimental measurement method using a box. Then, we present the measurement results for dust removal efficiency using a test house.

2. Experimental measurement method using a box

2.1 Detection equipment

For this study, IMD (instantaneous microbial detection; IMD-A 200-1, BioVigilant Systems) was used to measure the dust particles. IMD is based on optical fluorescence sensor technology and is capable of detecting the size of particles in the environmental air as well as determining whether or not each particle is biological [3]. Particle size can be detected within the range of six stages (0.5–1.0, 1.0–3.0, 3.0–5.0, 5.0–7.0, 7.0–10.0, and 10–15 μm).

2.2 Particles used for measurement

In an existing study [4] on the behavior of mite allergens, JIS-11 test particles were used as simulated particles (Figure 1a). In this case, however, existing particles in the background air might have influenced the measurement results. Therefore, riboflavin (Vitamin B2) was used as harmless biological particles that would not be present in the background air (Figure 1b).

2.3 Measurement of particles in a box

A plastic box measuring 450 mm wide, 350 mm long and 350 mm high was used for examining the measurement method. The box was set in the test house and the cover was put on the box. Then, the air in the box was sucked out and the particles in the air were measured by IMD at measurement intervals of one minute. Figure 2 shows the measurement results of the particles in the air of the box for a 24-h period. Long-term observation of the particle count for 0.5–1.0 μm showed a significant change. For example, the average existing nonbiological particle count in the first half of the measurement period was 802 particles/L for 0.5–1.0 μm and 80 particles/L for 1.0–3.0 μm . In the second half of the measurement period, the count was 1323 particles/L for 0.5–1.0 μm and 68 particles/L for 1.0–3.0 μm . On the other hand, for the biological particles, the total count in all sizes after 12 h was very small. The biological particles were useful for determining the removal efficiency of house dust by the ventilation system.

2.4 Method of supplying particles to the box

The method for supplying particles to the box was examined. A flask containing 1 g of particles at the bottom was set up in the box. As shown in Fig. 3, N₂ gas with a constant flow of 2 L/minute was injected through a tube to the particles at the bottom of the flask.

2.5 Results of measurement

1) JIS-11 test particles

Figure 4 shows the results in the case of using the JIS-11 test particles. The average particle count before supply was 1753 particles/L for 0.5–1.0 μm and 170 particles/L for 1.0–3.0 μm.

The particle count for all sizes increased rapidly just after the supply of particles and then decreased to the same level as that before the supply of particles. The decay speed of the particles in the size range 0.5–1.0 μm was slower than that of the other particle sizes. This is because particles smaller than 0.5–1.0 μm were erroneously counted as particles of that size during times of high particle density.

2) Riboflavin particles

Figure 5 shows the results in the case of using the riboflavin particles. The particle count before supply was very low compared with the count for JIS-11 test particles (Figure 4). For particles in the size range 0.5–1.0 μm, the peak count appeared immediately after the supply

of particles. As the riboflavin is biological, the existing particle count was very low. The riboflavin can be used to simulate house dust particles for the experiment.

3. Experiment on removal efficiency using a test house

3.1 Outline of test house and ventilation systems

The test room ($L \times W \times H = 5.37 \times 2.74 \times 2.25$ m) was located on the second floor of a two-storey experimental house situated at Tohoku University, Japan. Insulation boards were installed on all window surfaces to reduce the effect of cold drafts. The equivalent air leakage measured by the pressurization method was $3.17 \text{ cm}^2/\text{m}^2$.

Figure 6 shows the test room. The two mechanical ventilation systems tested in this study are shown in Figure 7. An exhaust is located on the ceiling (ceiling exhaust) in case 1 and slits (5-mm width) are set at the corners between the walls and floor (slit exhaust) in case 2. For both cases, the air inlet is located at the center of the ceiling.

3.2 Pretest for determining the measurement method

(1) Method of supplying the particles

For supplying the riboflavin particles, a flask containing riboflavin (4 g) was set up in the test room as shown in Fig. 6. The indoor air was circulated by two fans, one of which was set in

front of the flask. N₂ gas was injected into the flask for 1 h. The ventilation system was operated after the particles fell freely to the floor due to gravity force. The measurement point was located 1.0 m above the floor between the outlet and the inlet (Figure 6).

(2) Results of the pretest

Figure 8 shows the change in particle count for 90 h after the supply of particles. The particle count increased dramatically just after the supply and reached over 10,000 particles/L for those with diameter of 1.0–3.0 µm. For particles with diameter of 0.5–1.0 µm, the decay of the particle count was not constant for 12 h. It is possible that at times of high particle density some particles were detected as larger particles due to an error in simultaneous counting.

Therefore, the volume of riboflavin set in the flask was decreased from 4 g to 1 g.

Also, there was no particle generation from the floor when the ventilation system was operated.

(3) Measurement method

As a result of the pretest, the procedure for measuring removal efficiency was determined as follows:

- 1) Measurement of particles in the background for at least 12 h before the start of supply.

- 2) The riboflavin particles (1 g) are supplied to the test room by means of N₂ gas injection into the flask through a tube.
- 3) The room air is circulated by two fans while particles are supplied for 1 h.
- 4) After 1 h, the gas injection is stopped and the fans are turned off.
- 5) Operation of the ventilation system begins when the particle count decreases to 100-1000 particles/L.

3.3 Experimental conditions

Table 1 shows the experimental conditions for four cases. Two kinds of ventilation systems were tested under two different rates of air change per hour (ACH).

3.4 Results of the experiment

(1) Particle count variation in the decay period

Figures 9 and 10 show the measurement results for the slit type and ceiling type of ventilation at 2.5 ACH, respectively. There is not much difference in the decay of particle count between the two ventilation systems. Figure 11 shows the decay count using a log-scale for the y-axis for the two systems. It can be seen that there was no difference between the two systems. The

results at 0.75 ACH show almost the same tendency. There is no difference in the particle removal efficiency between the two ventilation systems from the decay period results.

Also, the measured value was divided by the value at the start of ventilation operation.

Figures 12 and 13 show the results for the two ventilation systems in the case of 2.5 and 0.75 ACH, respectively. The decay speed at 2.5 ACH was faster than that at 0.75 ACH.

(2) Particle count variation after the decay

Figures 12 and 13 show the particle count variation after the decay. In the case of the ceiling exhaust, the particle count was higher than that in the case of the slit exhaust.

Figure 14 shows that the particle count variation including the period when a person entered the room for cleaning purposes. In this period, the particle count reached a level of about 40% of the value at the start of particle supply. This clearly indicates that particles were raised from the floor by the walking motion.

4. Conclusions

1. As a result of measurement using a box, the biological riboflavin particles were useful for measuring the particle removal efficiency by ventilation because riboflavin is not present in the background air. The harmless riboflavin can be used to simulate house dust particles for the experiment.

2. Pretest results showed that particles were not generated from the floor when the ventilation system was operated.

3. The experimental results during the decay period indicate that there was no difference in particle removal efficiency between the two ventilation systems.

4. From the results after the decay, the particle count in the case of the ceiling exhaust was higher than that in the case of the slit exhaust.

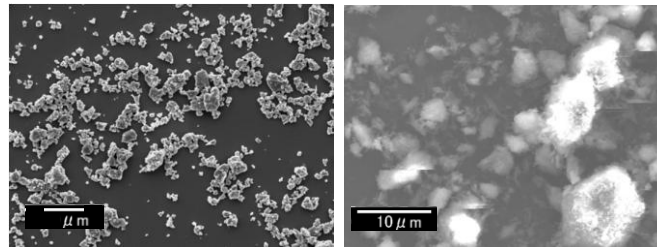
5. The particle count reached a level of about 40% of the value at the start of supply when a person entered the room for cleaning purposes. It is clear that particles were raised from the floor by the walking motion.

Acknowledgments

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a: JIS-11 test particles **b:** Riboflavin particles
Figure 1 Scanning electron micrograph of particles

Table 1 Experimental conditions

CASE	Exhaust method	Ventilation timing	Particle amount	Flow rate	Date
SE 1	Slit	settling	1.0g	2.5ach*	2009/12/26
CE 1	Ceiling	settling	1.0g	2.5ach	2009/01/08
SE 2	Slit	settling	1.0g	0.75ach**	2009/01/26
CE 2	Ceiling	settling	1.0g	0.75ach	2009/01/15

- Velocity of wind on slit : * 0.12m/s ** 0.42m/s

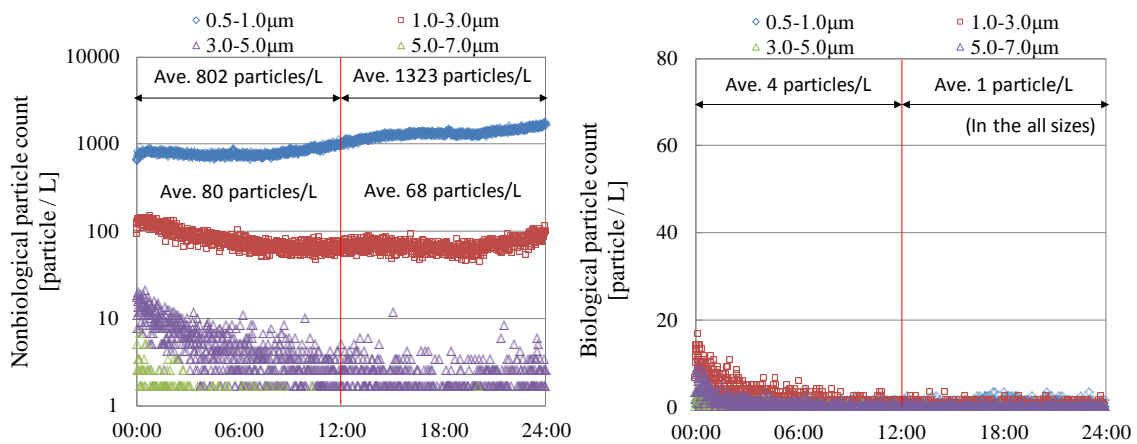


Figure 2 Change in existing particle count

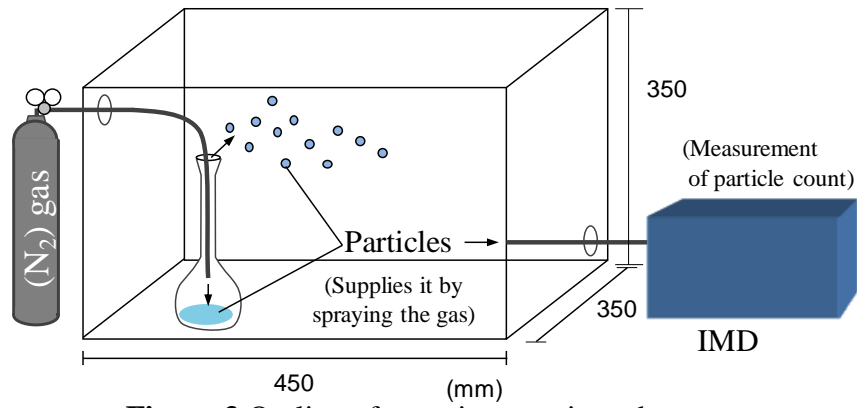


Figure 3 Outline of experiment using a box

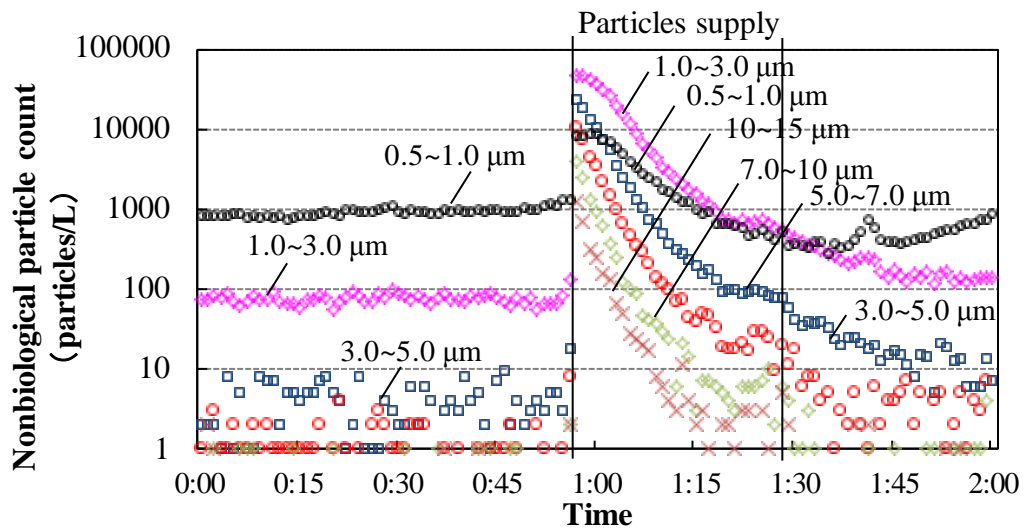


Figure 4 Change in particle count (JIS11 test particles, September 18)

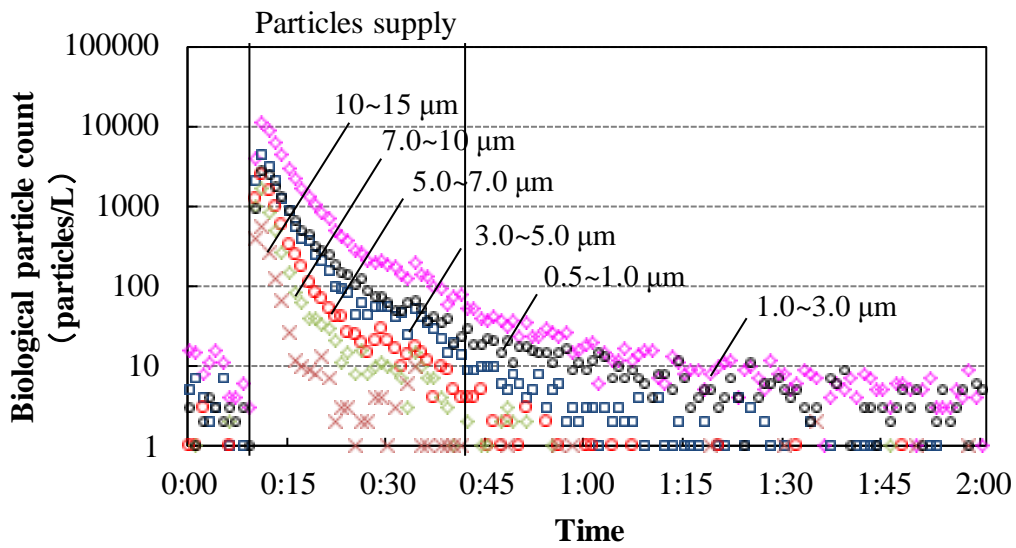


Figure 5 Change in particle count (Riboflavin particles, October 27)

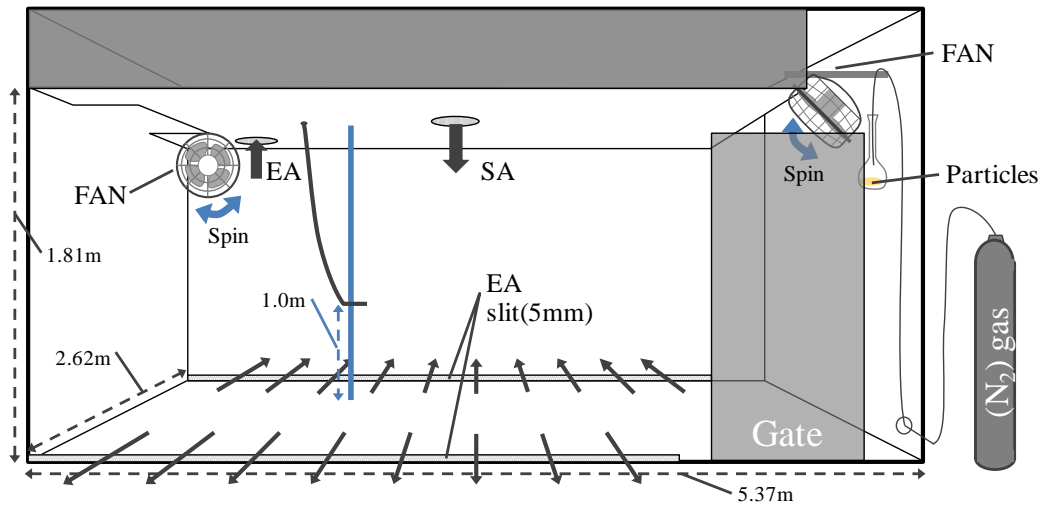


Figure 6 Outline of the test room

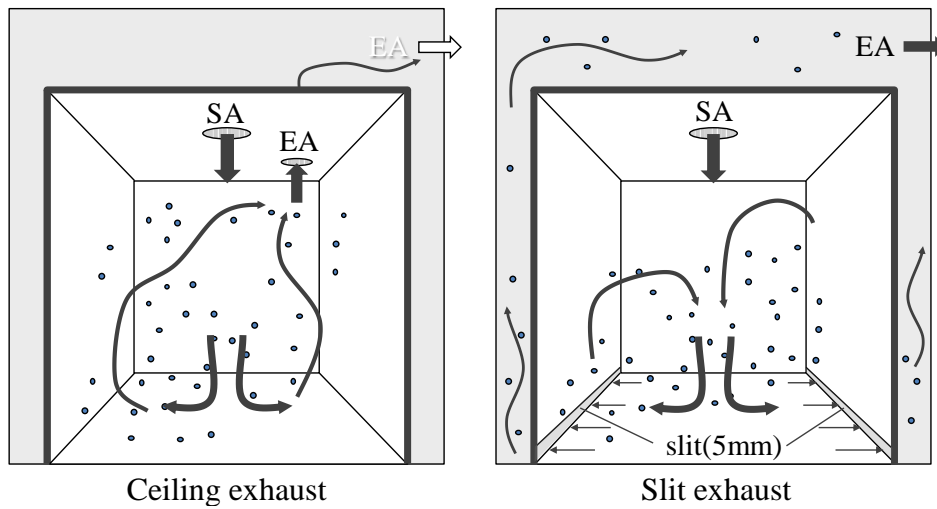


Figure 7 Exhaust methods

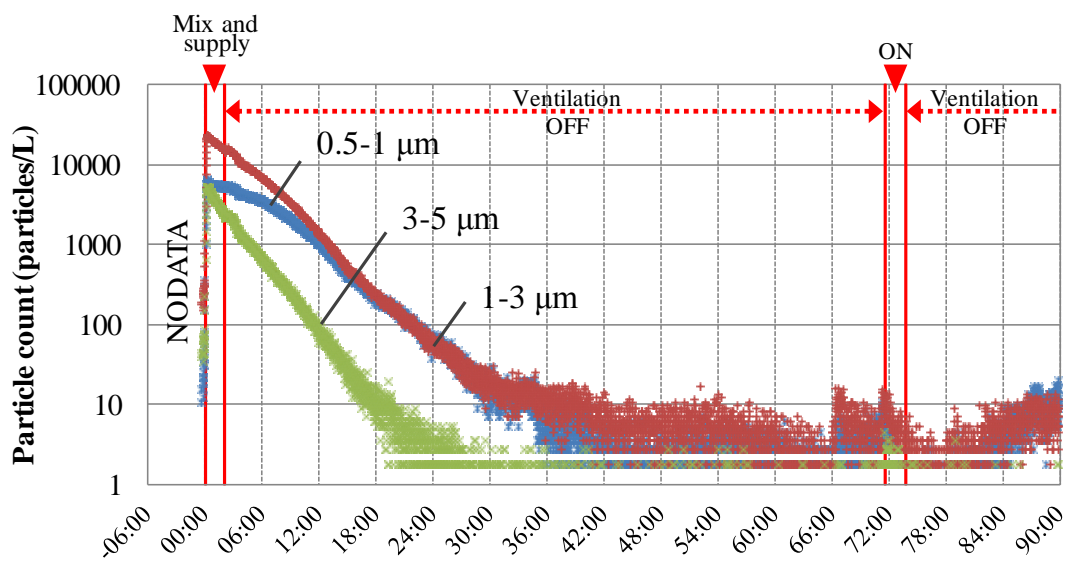
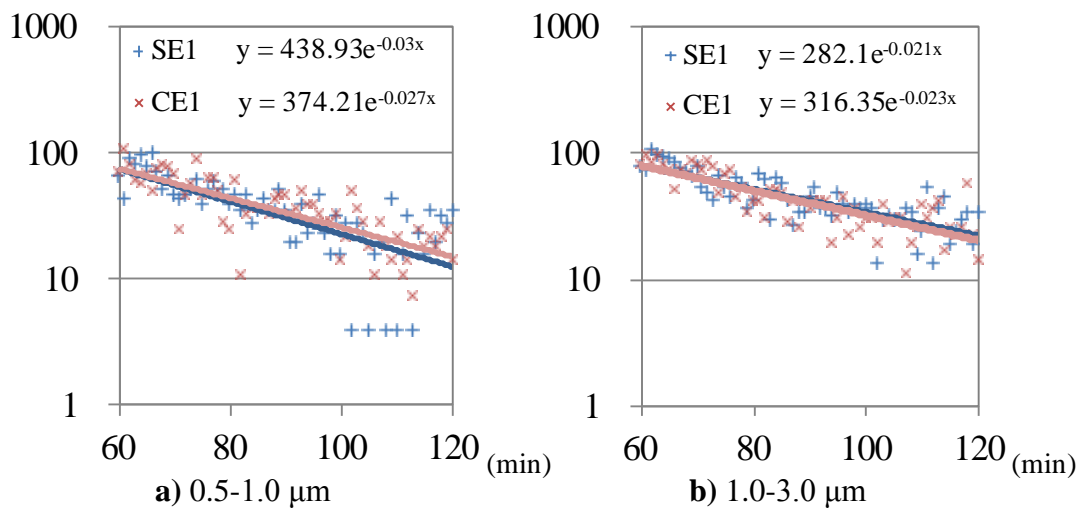
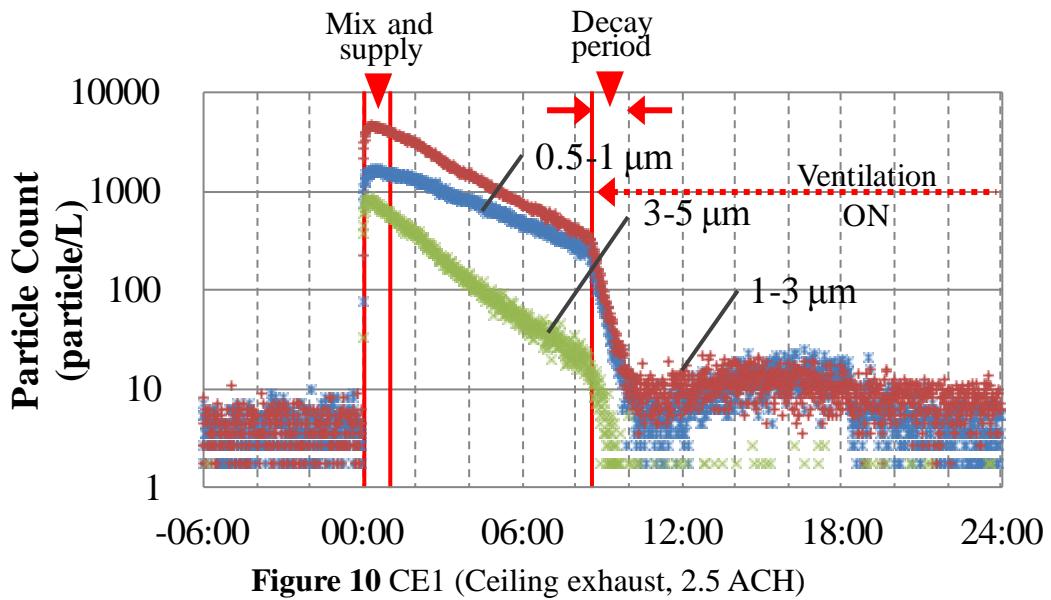
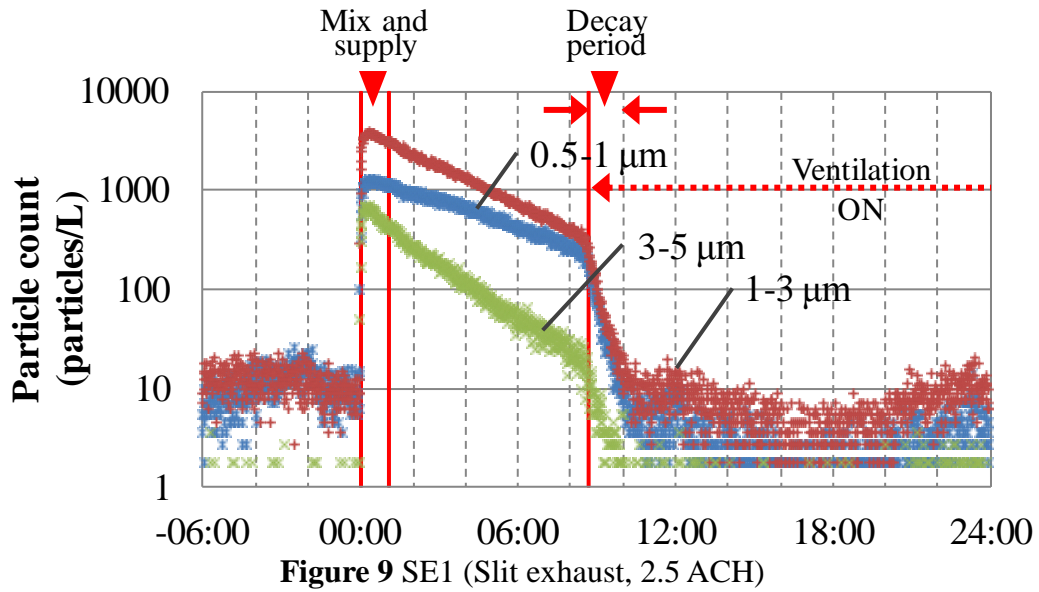


Figure 8 Change in particle count (Ceiling exhaust, 2.5 ACH)



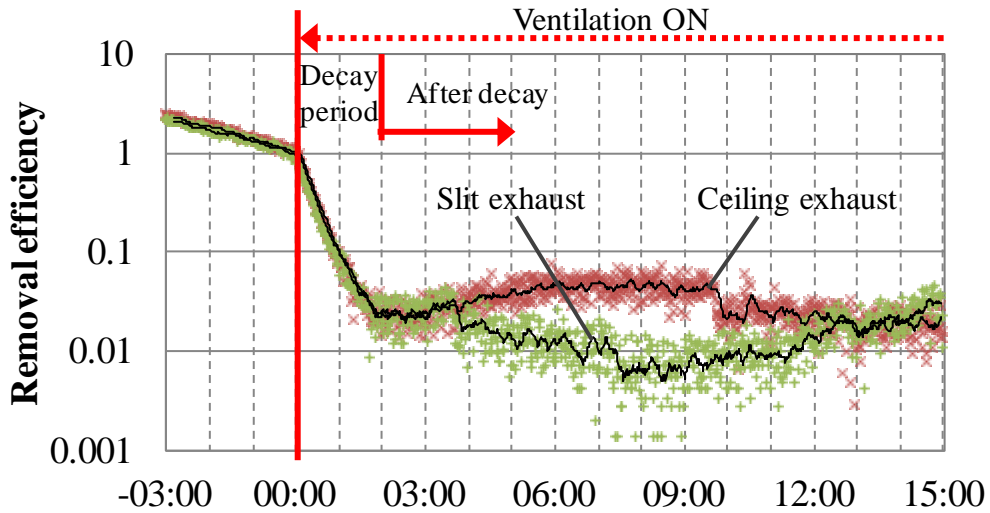


Figure 12 Air change rate 2.5 ACH (SE1, TD2: 0.5–3.0 μm)

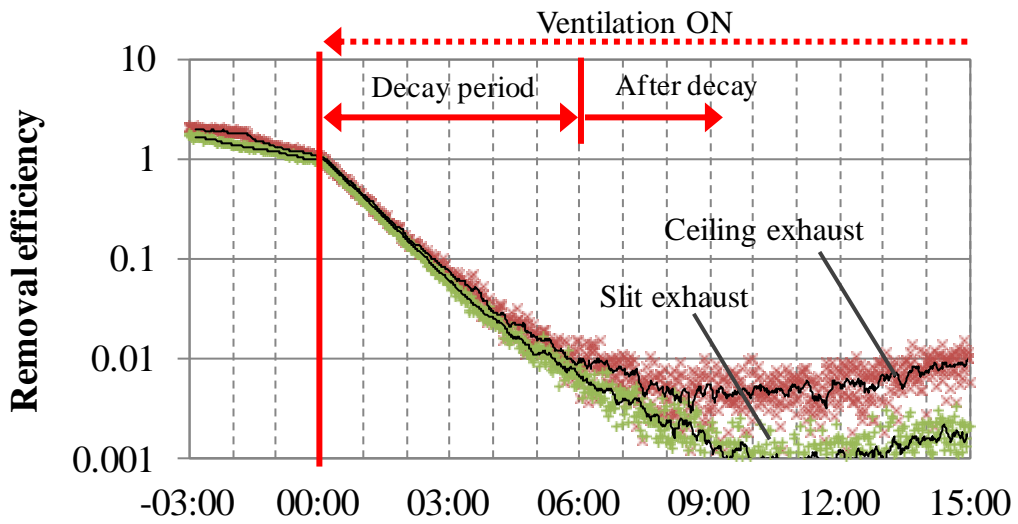


Figure 13 Air change rate 0.75 ACH (SE2, CE2: 0.5–3.0 μm)

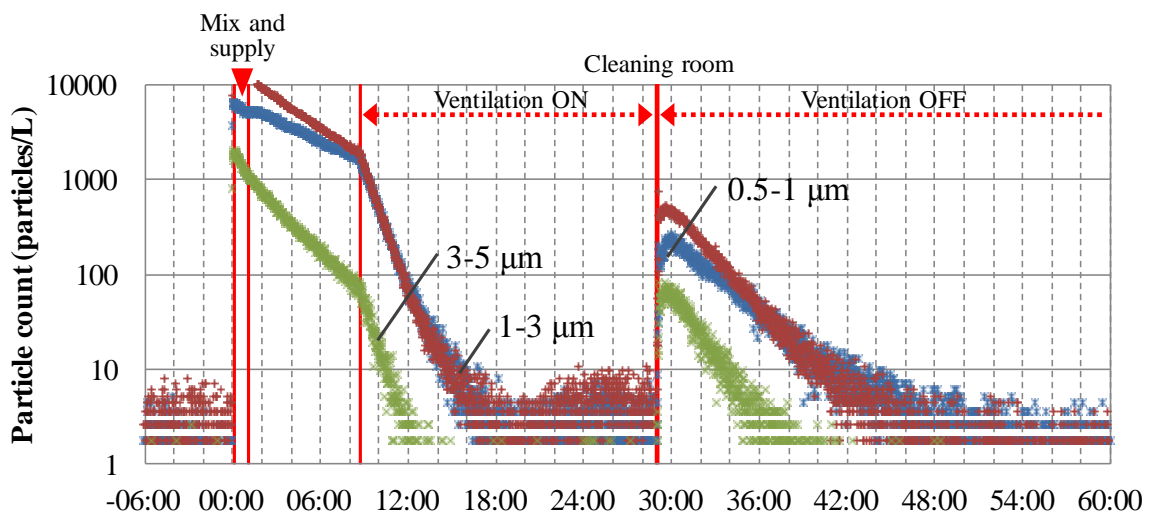


Figure 14 SE2 (Slit exhaust: 0.75 ACH)