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The Effect of Human Walking on Distribution Characteristics of Indoor Particulate Matter

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ABSTRACT
In modern society, house dust particulate matters pollution had become serious. Ventilation is an important method for removing house dust particulate matters and it is very important to explore the removal efficiency of house dust particulate matters under different ventilation modes. This study analyses the removal effect of house dust particulate matters under the two typical ventilation modes called ceiling exhaust and slit exhaust strategy through experiments and date analysis. In the process of experiments, riboflavin particles were used as the house dust particulate matters, instantaneous microbial detection (IMD) was used to measure the house dust particulate matters. Walking test was carried on after the ventilation system running for some time, which aimed to explore the influence of human behaviour on the house dust particulate matters distribution under two different ventilation modes. It is concluded that larger size particles had larger sedimentation velocity and sedimentation velocity of particles would be faster significantly after the ventilation system working. After walking experiment, particles concentration returned to background concentrations due to the effect of the ventilation system. Particles concentration in slit exhaust strategy was lower than ceiling exhaust so that the effect of slit exhaust strategy is superior to the ceiling exhaust.

KEYWORDS
Ventilation strategy; House dust particulate matters; Experiment; Concentration distribution; Walking test

INTRODUCTION

In modern society, people spend 80% of the time in indoor environment (Peggy et al., 1992; Robinson and Nelson, 1995), thus indoor air quality is particularly important. With the worsening of atmosphere particle pollution, indoor particle pollution has become increasingly severe due to the infiltration by building exterior and other reasons. US Environmental Protection Agency had conducted an investigation for 5 years, which found that indoor pollution was serious in residential and public building (Zhu, 2002). Due to the limitations of various factors in China, indoor air environment can't build a more comprehensive monitoring network, resulting to indoor air quality is even more worrying.

Epidemiological studies showed that short or long-term exposure to dust particle would lead to widespread adverse effects on human multiple systems. "Global Environment Outlook" published UNEP pointed out that nearly 2 million premature deaths were related with particulate matter pollution. There was a positive correlation between the particle mass concentration with human mortality and morbidity, even the concentration lower than the national limits standards (Yang, 2014). Dockery (1993) conducted a prospective study in six cities, and it found that particle pollution was related with cardiovascular diseases. With the increase of the annual average concentration of particulate matter, all-cause mortality, cardiovascular mortality and lung cancer mortality was significantly increased after controlling confounding factors (Pope et al., 2002). Under the same concentration, house dust particulate matters pollution was more harmful to the human body (Dockery et al., 1993; Pope et al., 2002; Guo et al., 2010; Tinker and Roberts, 1999). House dust particulate matters can enter the lungs to made greater harm to human body (Wang et al., 2013; Wang et al., 2007; Nikasinovic et al., 2006; Neas et al., 1994; Delfino et al., 2006; Zhu et al., 2015).

A growing number of epidemiological studies had shown that population incidence and mortality were associated with the particle mass concentration, especially significantly the indoor particulate matter concentrations (Yang, 2014; Dockery et al., 1993; Pope et al., 2002; Guo et al., 2010; Tinker and Roberts, 1999; Wang et al., 2013; Wang et al., 2007). Thus, the distribution characteristics of indoor particles and the health risks have been common concern in environmental science and engineering. Zhang and Chen (2006) studied particle transportation and distribution in ventilation chamber using experimental and numerical methods, who found that different ventilation forms had a great impact on indoor particle concentration distribution. Munat (2001) investigated and analysed the influence of different airflow forms on particle suspension, and the results showed that displacement ventilation system had small resuspension harm. Zhao B (2004) compared the diffusion characteristics of indoor particulate matter in displacement ventilation and mixing ventilation using numerical simulation method.

Many indoor air environment-related research study have been carried out, but it’s not clear how indoor human behaviour affects indoor particle distribution under different ventilation. To solve this problem, the study made a research to figure out the effect of indoor human behaviours’ influence to house dust particle distribution under different airflow. It will improve the prevention and control level of indoor air pollution and provide scientific basis of human health.

METHODS

Selection of particles

In the experimental study of house dust particulate matters, Japan used JIS-11 as experimental particles (Liu et al., 1996). JIS-11 test powder is non-biological particles produced by volcanic ash. The concentration of non-biological particles was high in the air, and its impact on the health is not clear, so in this study, riboflavin particles were used as the test particles because it is harmless for biological particles (Kurihara et al., 2010). Riboflavin is a special kind of biological particles which can emit fluoresce when it is exposed to light sources with certain specific wavelength. And it can be detected by particle detector (IMD) based on optical sensors and fluorescence detection techniques as biological particles. Studies have shown that value of riboflavin powder is low in the air, so it doesn’t affect experimental results (Kurihara et al., 2010).

Ventilation systems and experiment process

Figure 1 shows experimental room (L×W×H=5.37m×2.74m×2.25m) and ventilation systems. The window is sheltered by aluminum foil corrugated board to prevent solar radiation, and the walls are insulated by expanded polystyrene board. This study analyses the effect of the human walk activity on indoor particles distribution under two typical ventilation modes including ceiling exhaust and slit exhaust. Ceiling exhaust is the traditional ventilation way. For the slit exhaust strategy, delivery outlet was located in the center of the ceiling (In this study, delivery outlet of two ventilation system was same), the exhaust port is located at the junction of walls and floors. Delivery outlet size of two ventilation systems were 0.05m × 0.10m. The exhaust port size in ceiling exhaust was 0.05m × 0.10m. As for the slit exhaust system, exhaust port size in the east was 4.2m×0.005m, 4.53m×0.005m in the west. Figure 2 shows ceiling exhaust and slit exhaust system. Ventilation time was 0.75 times/h during the experiment

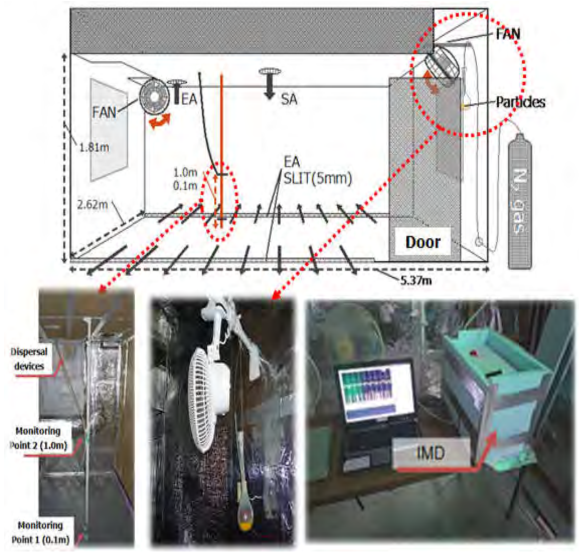


Figure 1. Experimental room and ventilation systems.

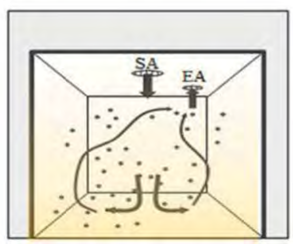
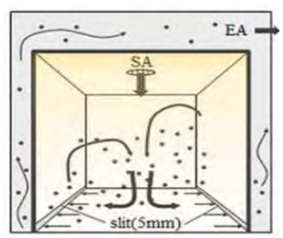
a)  b) 

Figure 2. Two ventilation system. a) ceiling exhaust, b) slit exhaust

Indoor particles distribution was shown in Figure 1. The house dust particles were put in a measuring flask, which was fixed at the corner near the ceiling of the room. Nitrogen gas was blown into the measuring flask to disperse the house dust particles. Nitrogen gas flow rate was set as 10 L/min. To make the distribution of house dust particles as evenly as possible in the room, the house dust particles were mixed by an electric fan which was fixed close to the flask. Taking into the account of the height of the child, the position of the monitoring point was set at 0.1m and 1.0m. IMD (instantaneous microbial detection; IMD-A 200-1, BioVigilant Systems) was used to measure the particles, which is based on optical fluorescence sensor technology and is capable of detecting the size of biological or non-biological particles in the environmental air. Particle sizes were classified as the following six levels: 0.5-1.0 μm, 1.0-3.0 μm, 3.0-5.0 μm, 5.0-7.0 μm, 7.0-10.0 μm, and 10.0-15.0 μm.
Experimental procedure (total 42 hours): the first hour - indoor particles spreading; 2 to 9 hours – indoor particles free settling; 10 to 42 hours - the ventilation system running. Indoor people started walking test from 27th hours. The purpose of the walking test was to explore the impact of walking behaviour to indoor particle concentration distribution under two different ventilation modes. Research was determined according to Liu Yu's experimental

methods from Japan's National Public Health Institute (Lu et al., 1982). In the study, male experimenter entered to room doing walk test, and walked in the room for 10min according to designated route (60 steps/ minute, 60 cm/step, a total of 600 steps). Figure 3 shows the walk test details.

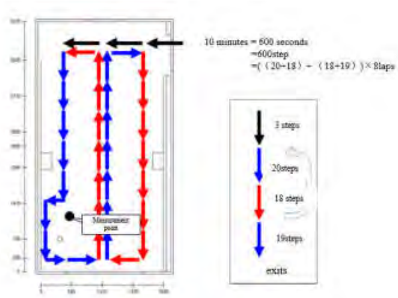
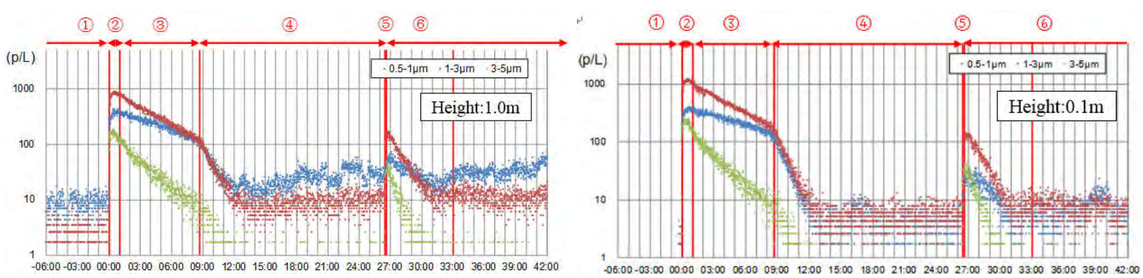


Figure 3. The walk test details

RESULTS AND DISCUSSIONS

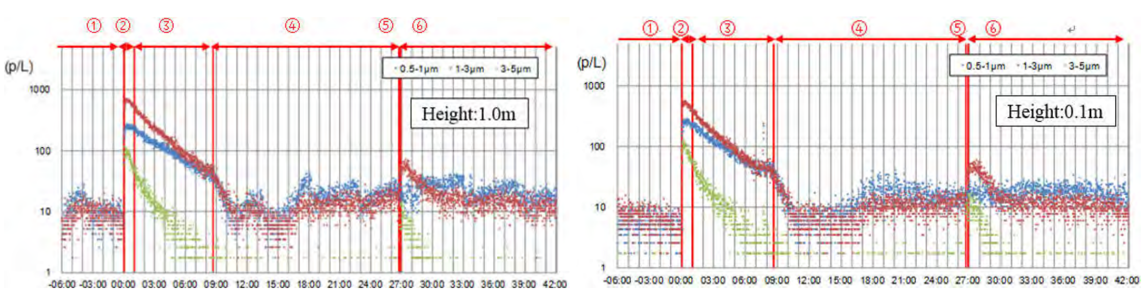
The results in the ceiling exhaust strategy

Figure 4 shows the variation of particles concentration(0.5-1.0 μm, 1.0-3.0 μm, 3.0-5.0 μm) in two different measuring points (from the ground 0.1 meters and 1.0 meters)in the ceiling exhaust strategy. It shows that: ①Before spreading powder (-6-0h), all size particles' background concentration was low in air (about 10P/L). ②When powders walked for 1 hour (0-1h), indoor particles concentration increased rapidly; After 8hours(1-9h), different size particles (0.5-1.0 μm, 1.0-3.0 μm, 3.0-5.0 μm) exhibited different settlement curve because of gravity; The larger particle size, the faster fall velocity. ③After running the ventilation system (9h ~), all size particles accelerated subsidence(settlement curve sudden steep in figure 6); When did walk test(27h-) , particles concentration increased significantly, which may be due to suspended caused by disturbance of human walking; After the walk test, particles concentration returned to background concentration under the action of the ventilation system running continuously. Two measuring points showed above trend.



Remarks: ①background values;②powder spreading;③free settling;④ventilation;⑤walk test;⑥ventilation

Figure 4. Variation of particle concentration inthe ceiling exhaust strategy



Remarks: ①background values;②powder spreading;③free settling;④ventilation;⑤walk test;⑥ventilation

Figure 5. Variation of particle concentration in the slit exhaust strategy

The results in the slit exhaust strategy

Figure 5 shows the particles concentration variation of two different measuring points (from the ground 0.1 m and 1.0 m) in the slit exhaust strategy. The variation trend of particles concentration in two measurement point was basically same with Figure 4, but there were some differences in concentration distribution.

Comparison of indoor particles concentration distribution in both ventilation systems

Figure 6 shows the different size particles concentration after ventilation system running (9h-) under two ventilation modes. Figure 6a shows the results in the height of 1.0m, and Figure 6b shows the results in the height of 0.1m. The results indicate that particles concentration in slit exhaust was lower than that of ceiling exhaust in the two measurement points. The lower the height, the more obvious of the effect for slit exhaust. The exhaust outlet was located at the junction of walls and floors for the slit exhaust, thus indoor particle gathered in the corner and excluded.

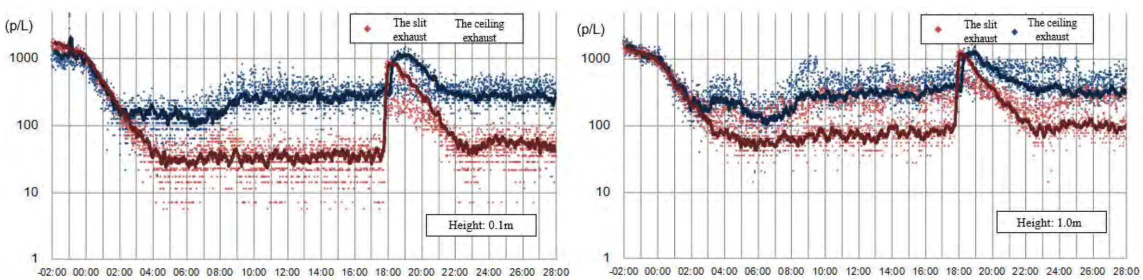


Figure 6. Particles concentration after ventilation system running in two ventilation systems.

CONCLUSIONS

This paper clarifies the effect of human walk behaviours on house dust particle distribution under different ventilation modes (including ceiling exhaust and slit exhaust). The following conclusions have been drawn:

1) Riboflavin was used to indoor house dust particles and IMD was used to measure the riboflavin particles concentration.

2) Larger size particles had larger sedimentation velocity and sedimentation velocity of particles accelerated significantly after the ventilation system working. Comparison of the number of particle in experimental monitoring point shows that the number of house dust particles in the ceiling exhaust was higher than that of the slit exhaust after house dust particles decreased as same level as background.

3) At the beginning of walking test, particles concentration increased significantly. After the walking test, particles concentration returned to background concentration under the action of the ventilation system running continuously.

4) Particles concentration in slit exhaust strategy was lower than that of the ceiling exhaust, thus the effect of slit exhaust is superior to the ceiling exhaust.

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