

Ventilation strategies on indoor particles in day-care center

Junseok Park^{1*}, Sungwon Cho², and Jihyun Yoo²

¹Dept. of Architectural Engineering, Hanyang University, 04763, Seoul, South Korea

²Dept. of Architectural Engineering, Graduate School of Hanyang University, 04763, Seoul, South Korea

Abstract. In this study, a day-care center located in Seoul was monitored for one year to quantify the effects of ventilation methods, natural and mechanical, on the indoor particle levels. It is found from the field monitoring that air tightness and mechanical ventilation system with MERV 12 can be helpful to maintain indoor particles at low levels during the class hours of the day-care center. The mechanical ventilation, however, is not sufficient for lowering PM_{2.5} when the outdoor PM_{2.5} is at high levels.

1 Introduction

Exposure to indoor airborne particles has negative effects on the respiratory health of children. The level of indoor particles is strongly related to outdoor air, building properties, and ventilation system [1-3]. Infiltration and penetration through the envelope of buildings become important factors to determine indoor airborne particle concentration, especially in the urban area with high levels of the micro size particles in outdoor air. Mechanical ventilation systems are installed to remove particles from the outdoor air and the re-circulated indoor air. Mechanical ventilation systems and air cleaners are installed to remove the particles from the outdoor air and the indoor air in day-care centers. For reducing children's exposure to high levels of indoor particles, it is important to improve knowledge of the effects of ventilation and building properties on the indoor particles in day-care centers. A full-scale field measurement was carried out for one year in a day-care center located in Seoul to quantify the effects. The results of the field measurements were briefly summarized below.

2 Methods

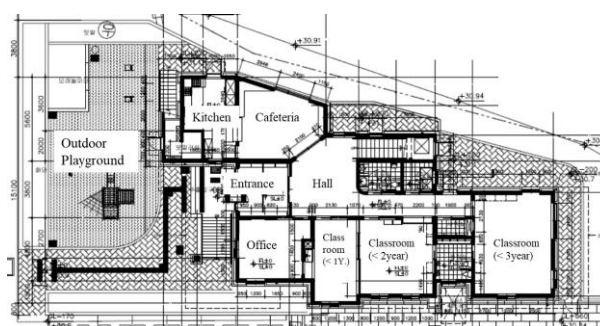
2.1 Sample building

The day-care center which is owned by a university was chosen for the monitoring buildings. The center has cared for the children of the faculties and workers of the university. They were below 5 years old. Table 1 shows the summary of the building and measured spaces. The building is a two-story single building that was constructed with reinforced concrete. The first floor consists of a cafeteria, office, and 3 classrooms for children below two years old. The second floor is an indoor playroom, office, and two classrooms for children upper three years old. The building has

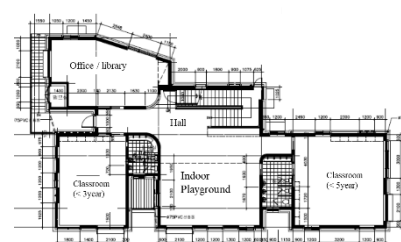
mechanical ventilation systems with a heat recovery unit, and an air cleaner is also installed in each classroom. The hydronic radiant floor heating systems using hot water are installed for heating. The classrooms have air-conditioners for cooling. Fig.1 shows the plans of the day-care center.

Table 1. Summaries of the monitored building

Structure	Reinforced concrete (2017 buit)	
Floors	Two floors	
HVAC	Radiant floor heating / Air-codnitioner / Mechanical ventilation with heat recovery	
Monitored sapce	Cafeteria	70 m ²
	Indoor playroom	42 m ²
	Classroom (2floor)	55 m ²



(a) 1st floor



(b) 2nd floor

Fig.1. Plan of the monitored day-care center

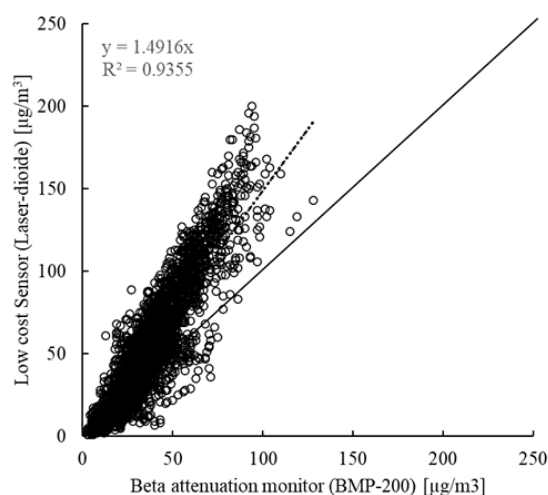
* Corresponding author: junpark@hanyang.ac.kr

2.2 Monitoring

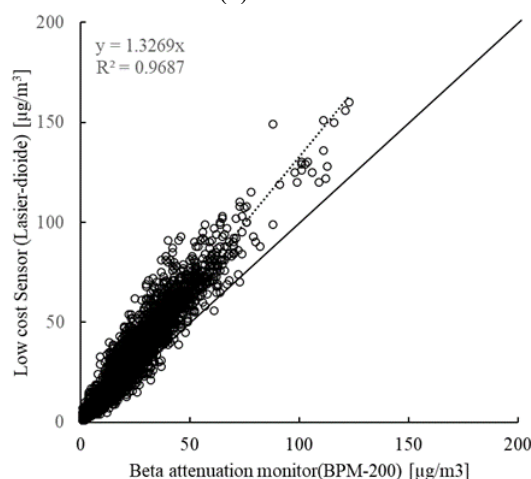
The field monitoring was conducted from 1 May, 2019 to 30 April, 2020 at the cafeteria, indoor playroom, and classroom. The indoor temperature, relative humidity, PM10, and PM2.5 were continuously monitored at 10 min interval by the low cost sensors (laser-diode) and the data were gathered by remote. The outdoor conditions were gathered from the weather station data located closely to the building. The window opening for cross ventilation was also monitored by the state data logger to check the natural ventilation of the sample spaces. And the power consumption of the mechanical ventilation and air cleaner were also continuously monitored to confirm the ventilation behaviour at each time.

Table 2. Monitoring materials and methods

Measurements	Parameters and materials
Outdoor	Temp. RH. Air velocity, Radiation, PM10, PM2.5 (Weather Station)
Indoor	Temp. RH. PM10, PM2.5 (Low cost sensors 10 min interval)
Window status	Status data logger (HOBO)
Energy consumption	Mech. Fan, air cleaner, boiler, air conditioner, (SEM3000)



(a) PM10



(b) PM2.5

Fig.2. Correlation of mass concentration between the low-cost sensor and Beta attenuation monitor

The results of the low-cost sensors for outdoor PM10 and PM2.5 were compared with those which were provided by the Korean meteorological administration. The administration has 25 stations for monitoring outdoor PM10 and PM2.5 in Seoul Metropolitan. The particle matters are monitored by using beta attenuation method (BMP-200, FPI). Fig.2 shows the relation between the low cost sensor and beta attenuation method. The low cost sensors show good linear fit with the beta attenuation method.

Even though those are slightly scattered compared with the beta attenuation method, the merits of the low-cost sensor, such as no noise and no interrupting during the classes are enough to adopt the sensors for monitoring. The concentrations reported by the low cost sensors were calibrated with those of the beta attenuation method using the regressions shown in Fig.2.

3 Results

3.1 Daily average of outdoor PM10 and PM2.5

The outdoor concentrations of PM10 and PM2.5 were fluctuated seasonally. The concentrations were higher in winter than in summer. In the one year, from October to May, PM10 and PM2.5 show the highest concentration. The concentrations of outdoor PM10 and PM2.5 were maintained at low levels from June to September. The results show the typical pattern in the metropolitans located in east Asia. The transportation, heating sources, and climate conditions significantly influence the particle matters in outdoor air. The

3.2 Infiltration factor

Infiltration factor means the equilibrium fraction of outdoor particles that penetrates indoor by infiltration [4-7]. Fig.4 show the relation the air tightness and infiltration factor. The air tightness of cafeteria, classroom, and indoor playroom is 0.18, 0.20, and 0.25, respectively. More the space is air-tight, infiltration factor is lower. The results indicate that the air tightness is an important factor to prevent incoming of outdoor particles with infiltration.

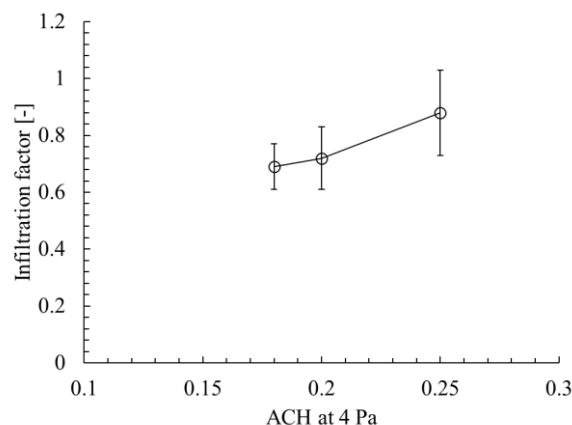


Fig. 4. Infiltration factor of PM2.5

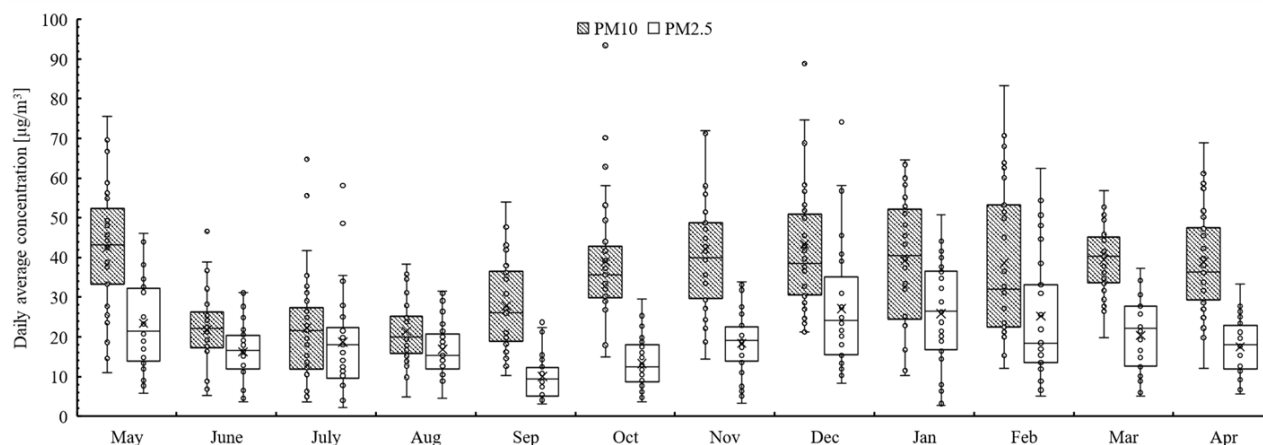


Fig.3. Outdoor PM10 and PM2.5 concentrations during the monitoring year

3.3 Daily pattern of indoor PM10 and PM2.5

Fig.5 shows the daily patterns of indoor PM10 and PM2.5 concentrations in the day-care center. The indoor PM10 and PM2.5 concentrations changed according to the activities of kindergarteners and teachers. The center is open at 8:00 AM and closed at 18:00 on usual weekdays. After closing, the indoor particle concentrations decreased to the levels of outdoor until midnight. The indoor particle concentrations show different patterns among the three spaces, classroom, indoor playground, and cafeteria, showing that the main sources of the indoor particle are outdoor and indoor activities.

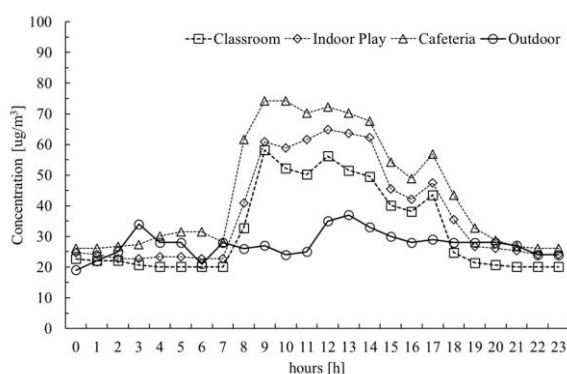


Fig. 5. Daily changes of indoor PM10 and PM2.5

3.4 Effects of ventilation method

Fig. 6 shows the operating conditions of windows, mechanical ventilation system, and air purifiers for one year. The teachers and managers of the day-care center can control and operate, the windows, mechanical ventilation system with the heat recovery unit, and air purifiers, which are installed in the indoor playground and classrooms. They also can switch on and off the heating and cooling systems. They opened the windows for cross ventilation when the outdoor air is at acceptable levels. When the levels of outdoor particles is high, they closed windows and turn on the mechanical ventilation system. The system has the filter corresponding to MERV 11.

The air purifiers were operated for winter period, because the outdoor particle level was high. During the cooling period, from July to August, the mechanical ventilation systems were not operated. The floor radiant heating system was operated from November to April.

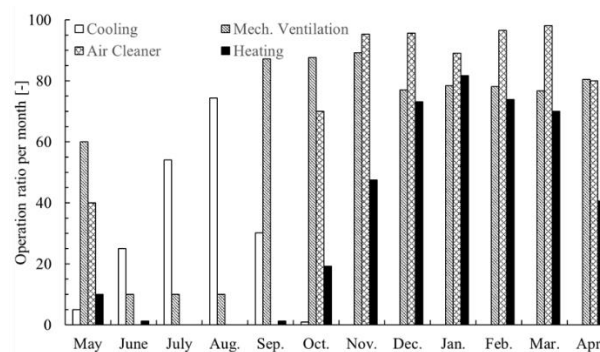


Fig. 6. Operating conditions of the mechanical ventilation systems and air purifiers in the classroom

The classroom was ventilated by three methods; one is natural ventilation with windows' opening, the second is closing with windows, and the last is to switch on the mechanical fans for ventilation. Fig.7 shows the I/O ratio of PM10 and PM2.5 at each ventilation methods for class days. The classroom was naturally ventilated when the outdoor air is moderate thermal condition and outdoor particles' concentration is low. The I/O ratio was the highest during the cooling when all windows were closed and the mechanical ventilation system was intermittently operated. The teachers did not operate the mechanical ventilation system., because of the cooling load.

The mechanical ventilation systems were operated during the heating period when the levels of outdoor PM10 and PM2.5 was high. The indoor particle concentration was maintained at the lowest level when the mechanical ventilation systems were operated. These results show that the mechanical ventilation is useful to maintain indoor particles at low levels even though the outdoor particle concentration is very high levels. Fig. 8 shows the effects of the air purifier on indoor particle concentrations. The air purifiers were operated during the heating period because the level of outdoor particles was higher than in other seasons.

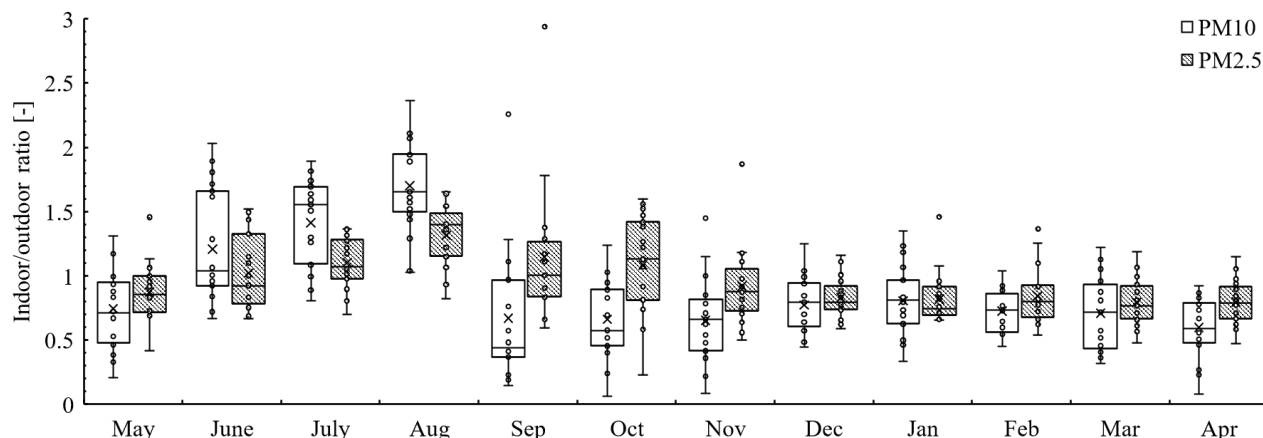


Fig.9. Daily average I/O ratio of PM10 and PM2.5 for the one-year monitoring period

The air purifier can lower the levels of submicron particles such as PM2.5. The air cleaner is helpful for the winter and spring when the outdoor PM2.5 concentration is high level.

Fig.9 shows the daily average I/O ratio of PM10 and PM2.5 on each month. Even though the outdoor PM10 and PM2.5 were high levels from October to April, the I/O ratio of PM10 and PM2.5 was maintained at close to 1.0, because of operation the mechanical ventilation systems. The I/O ratio of PM2.5 could be lower by the air purifiers between December and February when the level of outdoor PM2.5 was severe.

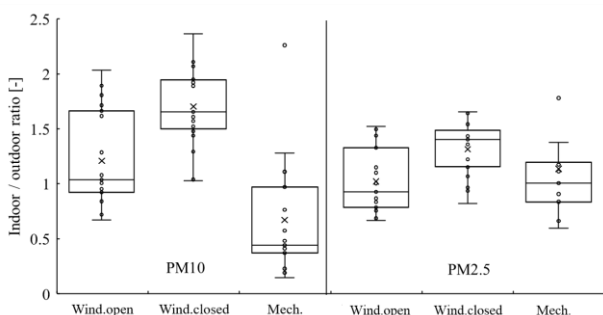


Fig. 7. Effects of the mechanical ventilation on indoor PM10 and PM2.5 concentrations

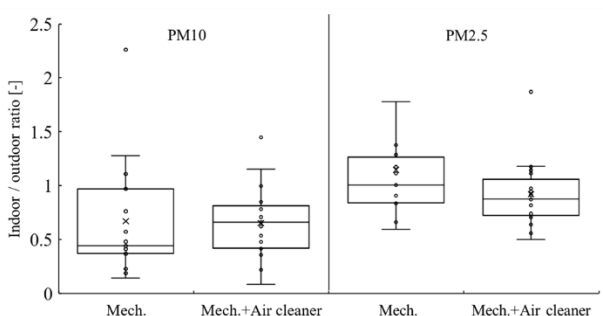


Fig. 8. Effects of the air purifier on indoor PM10 and PM2.5 concentrations

4 Conclusions

In this study, the effects of ventilation strategies on indoor particle concentrations in the day-care center were analyzed through the one-year field monitoring. From the results, it is found that air tightness and mechanical ventilation are helpful to maintain indoor PM10 and PM2.5 lower levels but the mechanical ventilation is not sufficient for lowering PM2.5 during the winter when the outdoor PM2.5 is at high levels.

Acknowledgement

This work has supported by NRF grant funded by the Korea government (MSIT) (No. 2020R1A2C2011260).

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