The effect of student activity and outdoor conditions on particulate matter concentration in university classroom

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Abstract. The university lecture room is one of the places where the fine dust concentration can rise easily. Generally, since students move in each lecture, particulate matter formed in the outdoors is adsorbed on the clothes surface of the students and then re-suspended in the room. Also, university classrooms are often blocked for more than one hour of class, and the university's old buildings do not have a special ventilation system. In addition, when the number of students per unit area per class is large, much particulate matter can be re-suspended due to the activities of the students. The purpose of this study is to investigate the relationship between factors affecting the concentration of particulate matter in the classroom by long-term field measurements.

Particulate matter has been measured for long periods in two classrooms, hallway, and outdoor. At the same time, factors affecting the indoor particulate matter concentration such as cleaning status, window and door opening status, air conditioner operating status, and number of occupants per unit area were monitored. As a result, the increase and decrease of the outdoor particulate matter concentration had a great influence on the increase and decrease of particulate matter concentration in the classroom. At the beginning or end of the lesson, indoor and corridor particulate matter concentrations increased sharply with the movement of many students. The increased particulate matter concentration was maintained for a long time despite the window and door open condition.

Keyword. Particulate matter, Classroom, Window and door open, Occupancy density, Outdoor conditions

1. Introduction

A number of studies have reported that high particulate matter (PM) concentrations of the outdoor are highly correlated with people's adverse health effects. Especially, the mortality rate increased by 6% when the PM10 concentration increased by 10 \( \mu g / m^3 \) with some European cities \cite{1}. Therefore, Korea and other developed countries are strengthening the standard of PM concentration, and the current pm10 environmental standard is defined as below 100 \( \mu m / m^3 \) in Korea. Since 85-90\% of people spend their time indoors, it is important to analyze the factors that increase indoor PM. Even if there is no direct PM source such as cooking or candle burning in the room, if the building airtightness performance is poor, the outdoor PM can easily penetrate. Also, when building has a lot of access, people can bring in outdoor or corridor PM and movement cause resuspension effect. In addition, when outdoor PM is high in concentration and there is no PM removal system such as an air cleaning system, it is impossible to open windows and doors to introduce fresh air. In particular, the university classroom has the above three conditions and there have been many studies on the concentration of PM in university school \cite{2-4}. At first, the old university buildings have very poor airtightness performance, and high PM concentration is formed according to the outdoor even when the doors and windows are closed. Secondly, because of moving class, there is a lot of student access in university classroom. Third, in university classroom without an air cleaning system, there is no special method to remove indoor PM and its concentration can be maintained and cause health problems of students.

The purpose of this study is to investigate the causes of the increased concentration of PM in the
classroom and effect of outdoor PM condition and student activity by monitoring long-term indoor and outdoor PM and students’ activities.

2. Methods

2.1. Site description

The monitoring of PM and students’ activities are conducted in the Sungkyunkwan university. The measurement period was from October 15 to November 19, 2018. This campus is located in a city with a population of 1.17 million and is about 29km from Seoul downtown. PM was measured in two classrooms, corridors and rooftops in same building. The completion year of university building was 1994, and the ventilation system and air cleaning system were not installed in the classrooms. Table 1 shows the description of the classrooms. In order to investigate the effect of occupant’s activity on indoor PM, the classrooms where there are many occupants and the classes are frequent were selected.

| Location | Classroom 1 | Classroom 2 |
|----------|-------------|-------------|
| Floor    | 3rd         |             |
| Floor area | 70.43m²     | 72.74m²     |
| Height   | 2.6         |             |
| Windows and door number | 3 / 2       | 3 / 1       |
| Interior details | Wall: paint / Floor tile | Plastic |
| Classroom capacity | 70          |             |
| Air change rate per hour | 0.725       | 0.644       |

2.2. Instrumentation and data acquisition

Indoor PM concentration was measured at 1 minute interval using light scattering machine and AirguardK model. The outdoor PM concentration was measured at 1 hour intervals using Beta ray method, Thermo 5014i model. The PM devices were installed to a 2m-high wall to prevent interference with students' activities, and was located more than 2m away from the door and air conditioner to avoid the effects of indoor airflow. By using the monitoring system, students' movements, the doors and windows opening status, and the air conditioner operation status were monitored. Figure 1 shows the schematic installation of the PM measuring devices and the monitoring system and the measurement details are presented in Figure 2.

![Figure 1. schematic installation of the PM measuring device and the monitoring system](image)
3. Results and discussion

3.1. Indoor and outdoor particulate matter concentrations
The occupied time and the unoccupied periods were divided to investigate the difference of concentration of PM according to the presence or absence of occupants. The results are shown in Table 2 and Figure 3. During the two periods, the concentration of outdoor PM and corridor PM were similar, and in both classrooms, the concentration of PM was higher than that of unoccupied periods in occupied periods. Especially in classroom 2, the difference between unoccupied periods and occupied periods is smaller than that of classroom 1. This is because the air change rate of classroom 2 is lower than that of classroom 1, and the PM concentration, which was increased during occupied periods, was maintained.

| Location | Indoor [mg/m³] | Outdoor [mg/m³] | Corridor [mg/m³] | T[h] | Indoor [mg/m³] | Outdoor [mg/m³] | Corridor [mg/m³] | T[h] |
|----------|----------------|-----------------|-----------------|------|----------------|-----------------|-----------------|------|
| Classroom 1 | 0.050          | 0.064           | 0.047           | 156  | 0.039          | 0.061           | 0.044           | 252  |
| Classroom 2 | 0.057          | 0.064           | 0.047           |      | 0.051          | 0.061           | 0.044           |      |

Figure 4 shows the correlation between outdoor and classrooms, corridors and classrooms during unoccupied periods. Because of poor airtightness of this classroom, the correlation between indoor PM concentration and outdoor PM concentration was 0.8 during the absence of occupants. Thus, the PM concentration increased during occupied periods does not decrease even after a few hours, and high background concentration can be formed.
3.2. Indoor PM concentration in classroom according to occupant activity

The I/O ratio is the ratio of outdoor concentration to indoor concentration, which can be used to identify the influencing factors of indoor activities. Figure 5 shows the distribution of classroom PM concentration during 24 hours. During occupied periods from 9:00 to 21:00, both classroom 1 and classroom 2 show higher values than unoccupied periods. This indicates that the concentration of indoor PM has increased due to occupant activity during occupied periods. Especially, the I/O ratio of 12 ~ 16 o'clock, which was the highest activity periods, shows the largest value. The background concentration from 0:00 to 9:00 is higher in classroom 2 than in classroom 1, which means that the concentration of PM after 21:00 in classroom 2 is maintained.

3.3. Change of indoor PM concentration in classroom by resuspension effect

University students can bring high outdoor PM concentration into the classroom by moving classes. The concentration of PM is settled on the surface such as clothes during the lecture time, and after the lecture is over, the students suddenly leave the classroom and the PM on the clothes or surface are resuspended. As shown in Figure 6 (a), at the end of class at 11 o'clock, when the density decreases rapidly, the activity of the students is the biggest time, and the concentration of PM in the classroom and corridor suddenly increase because of resuspension effect. However, as shown in Figure 6 (b), at the time when the outdoor PM concentration is low, the sharp increase does not occur. This is because the amount of PM that the people bring from the outside is small, the resuspension effect does not occur.
3.4. Indoor PM concentration change according to natural ventilation conditions

Unlike air particles such as carbon dioxide, PM is deposited on the surface when a flow is not sufficient. As shown in Figure 7, in the windows and door opening conditions from 11:00 to 15:00, the concentration of carbon dioxide is immediately decreased, but the concentration of PM is not decreased but it increases according to indoor activities, which is similar to the results of previous studies [5]. This means when there is not enough airflow, the increased PM concentration is not easily removed by opening windows and door.

Figure 7. Indoor PM concentration according to natural ventilation conditions
Acknowledgments
This study is the result of cooperative research by Urban Architecture Research Project of Ministry of Land, Infrastructure and Transport (MOLIT). (19AUDP-B100343-05).

References
[1] Krzyzanowski M, Bundeshaus G, Negru M L, Salvi M C 2005 Particulate matter air pollution: how it harms health World Health Organization Fact sheet EURO/04/05 Berlin Copenhagen Rome 4 14.
[2] Ferro A R, Kopperud R J, Hildemann L M 2004 Source strengths for indoor human activities that resuspend particulate matter Environmental science & technology 38(6) 1759-1764.
[3] Alshitawi, M.S. and Awbi, H.B., 2011. Measurement and prediction of the effect of students’ activities on airborne particulate concentration in a classroom. HVAC&R Research, 17(4), pp.446-464.
[4] Braniš M, Řezáčová P, Domasová M. 2005 The effect of outdoor air and indoor human activity on mass concentrations of PM10, PM2.5, and PM1 in a classroom. Environmental research, Oct 1;99(2):143-9.
[5] Heudorf U, Neitzert V, Spark J 2009 Particulate matter and carbon dioxide in classrooms—the impact of cleaning and ventilation International Journal of Hygiene and Environmental Health 212(1) 45-55.