

Black Carbon and PM_{2.5} impact analysis in an urban school

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Abstract. Poor outdoor air quality increases air pollutants indoors. Indoor and outdoor air pollutants adversely affect human health, especially in children, who are particularly vulnerable. In this study, indoor and outdoor BC (Black Carbon) and PM_{2.5} were measured in an elementary school classroom located in an urban city in South Korea. Indoor and outdoor concentrations (BC and PM_{2.5}) were monitored for 7 days (140 hours) during the winter of December 2021. In addition, the classroom schedule was surveyed to identify the occupancy conditions. The reason for air pollution in the urban school was traffic. Classroom BC and PM_{2.5} concentrations were affected by outdoor and indoor factors. The primary outdoor factor was infiltration, and the impact was larger for BC than for PM_{2.5}. The primary indoor factor was occupant behavior and the impact was more significant for PM_{2.5} than for BC.

1 Introduction

Korea has accomplished rapid urbanization, and recently the scale of urban areas has been increasing. The phenomenon of urbanization worsens the atmospheric environment and is closely related to traffic [1]. Severe air pollution is emerging as a social problem: a polluted atmosphere worsens IAQ (indoor air quality) and can penetrate deeply into occupants' lungs and respiratory tracts, causing serious health effects [2]. In particular students are more vulnerable to pollutants than adults due to the greater sensitivity of their respiratory tracts [3-5]. Therefore, IAQ management is very important in schools.

Among air pollutants, BC is a carbon-based aerosol generated during the incomplete combustion and incineration of fossil fuels [6, 7]. BC is mostly found at high concentrations in the atmosphere around roads, and it has been found that this affects the concentration of BC indoors [8, 9]. BC may be generated indoors due to such activities as burning candles, combustion, or smoking [10-12]. PM_{2.5} is a fine, particulate substance with an aerodynamic diameter of less than 2.5 μm that has an adverse effect on the human body. PM_{2.5} flows indoors from outdoors through various channels such as ventilation, infiltration, and air filtration, and is generated by indoor cooking, vacuuming and occupant behavior [13-15].

For classroom IAQ management, it is important to investigate the factors affecting indoor and outdoor BC and PM_{2.5} concentrations. In this study, the surrounding atmospheric environment of schools in urban areas in winter and the classroom concentrations of BC and PM_{2.5} were measured. Through an analysis of traffic

volume on major roads around the school, the cause of air pollution affecting the room was identified. Additionally, the causes of changes in the indoor concentrations of BC and PM_{2.5} were analyzed.

2 Introduction

2.1 Data sampling and Measurements

An elementary school located in Gyeonggi-do Province, South Korea, was selected and the concentrations of BC and PM_{2.5} were measured. Data sampling was conducted for a total of 140 hours (7 days) from December 14 to 20, 2021.

Indoor and outdoor BC and PM_{2.5} concentrations were simultaneously measured. Indoor measurements were taken on a 1.5m high locker so as not to interfere with student behavior. Outside measurements were conducted at a height of 1.5m by extending sampling tubes across a classroom. BC (black carbon) was measured with an Aethalometer (model AE-51, AethLabs, USA) and PM_{2.5} was measured with an aerosol monitor DustTrak (model 8530, TSI Inc, USA). Fig 1 shows the measurement location and equipment.



(a) Classroom



(b) AE-51



(c) DustTrak 8530

Fig 1. Classroom and measurements

2.2 Data analysis

In school classrooms, indoor concentration is affected by many variables. Considering these variables, the mass balance equation (Eq. (1)) was used to analyze the change in indoor concentration. A well-mixed state and steady-state condition of the indoor particles were assumed [16].

$$\frac{dC_{in}}{dt} = aPC_{out} - aC_{in} - kC_{in} + \frac{S}{V} \quad (1)$$

Here, a is the air exchange rate (AER, h^{-1}), V is the volume (m^3) of the indoor space, and C_{in} and C_{out} are indoor and outdoor concentrations ($\mu g/m^3$), respectively. P is the particle penetration factor, k is the particle deposition rate (h^{-1}), and S is the indoor particle emission rate (h^{-1}).

The I/O ratio was calculated in order to analyze the indoor and outdoor relationship. The I/O ratio can be expressed as the following equation based on Eq. (1). F_{in} (the infiltration factor) is the ratio of outdoor particles that penetrate from the outside to indoors in a state of equilibrium and remain suspended in the room. In Eq. (1), assuming that there is no steady-state condition and S (indoor particle emission), the calculating formula can be written as follows [17].

In order to calculate F_{in} , the conditions without an indoor source were analyzed. In addition, F_{in} was calculated assuming steady-state condition. To calculate the conditions without an indoor source, the unoccupied period was analyzed through the schedule. In this study, the unoccupied period was set as the period from the end of school to the next morning before students come to school, and the occupied period was set from the time students come to school to when they leave.

3 Result

3.1 Traffic-related air pollution

Air pollution is a major factor that influences IAQ. Air pollution in urban areas is closely related to the amount of traffic. Section 3.1 reports the correlation between outdoor BC and $PM_{2.5}$ with traffic on major roads around the school. Fig 2(a) shows the average traffic volume by time zone on a road 150m away from the school. Fig 2(b) shows the outdoor BC- $PM_{2.5}$ correlation.

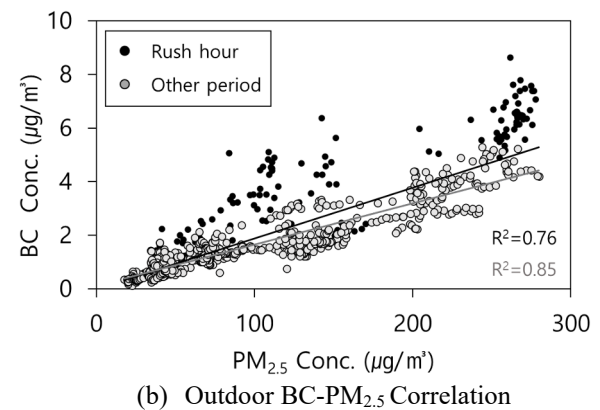
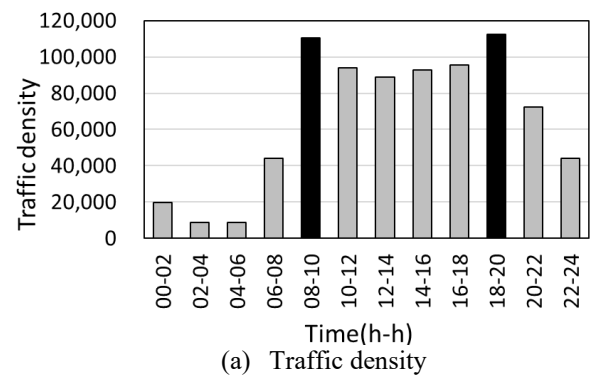


Fig 2. BC impact of increase traffic

The rush hour periods when traffic volume increased around the school were 08–10 (AM) and 18–20 (PM). The analysis results show that the atmospheric BC concentration during rush hour tended to increase significantly compared to the increase in $PM_{2.5}$. In addition, outdoor BC and $PM_{2.5}$ concentration amounts showed a significant correlation during the entire sampling period ($R^2 = 0.76$). However, there was a higher correlation in other periods besides rush hour ($R^2 = 0.85$). The results show that the concentrated traffic during rush hour generates more BC than $PM_{2.5}$. In conclusion, the atmosphere around the school located in the city center is affected by traffic volume, and the effects of traffic on BC levels were analyzed.

3.2 Infiltration

BC and $PM_{2.5}$ concentrations in classrooms are affected by many variables. As analyzed in Chapter 3.1, air pollution may enter the room, and both the generation of pollutants and occupant behavior may also influence indoors [18-22]. In order to analyze the causes of changes in indoor BC and $PM_{2.5}$, the I/O ratio was analyzed separately for the unoccupied and occupied periods.

Assuming that there is a steady state and no indoor generation in the classroom unoccupied period, the effect of BC and $PM_{2.5}$ infiltration indoors was analyzed. Fig. 3 shows the I/O ratio of BC and $PM_{2.5}$ during the unoccupied period.

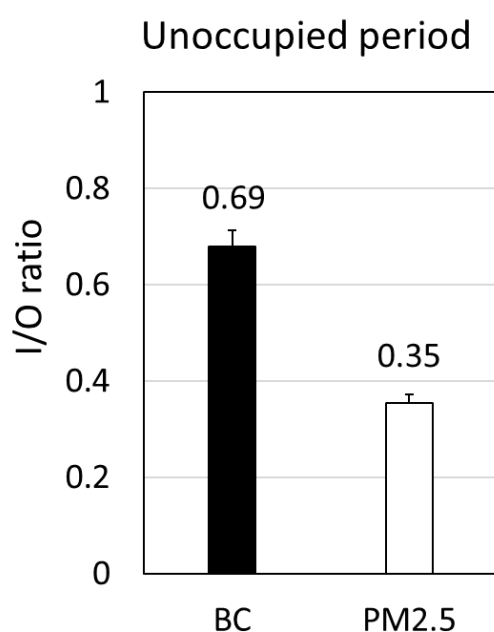


Fig 3. Unoccupied I/O ratio

The I/O ratio during the unoccupied period of the classroom was 0.69 for BC and 0.35 for $PM_{2.5}$. The fact that BC's infiltration factor is greater than $PM_{2.5}$ means that more BC flows indoors than $PM_{2.5}$. BC is a particle measured in nm (nano) units, while $PM_{2.5}$ is a μm (micro) unit particle; it was determined that because BC has a smaller particle diameter, it would more readily penetrate indoors [22]. In conclusion, it was found that the indoor infiltration effect of BC was about twice as large as that of $PM_{2.5}$. This is related to the air pollution sources analyzed in Chapter 3.1. In particular, BC, which is intensively generated during rush hour, can have a greater influence indoors.

3.3 I/O ratio analysis

The effect of occupant behavior was analyzed through a comparative analysis of the I/O ratio (Fig. 3) of the occupied period and the unoccupied period. Fig 4 shows the I/O ratio of BC and $PM_{2.5}$ during the occupied period.

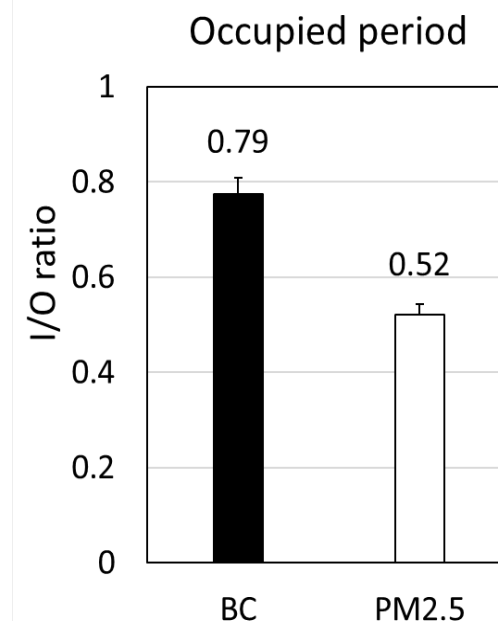


Fig 4. Occupied period I/O ratio

The I/O ratio during the occupied period is 0.79 for BC and 0.52 for $PM_{2.5}$. The I/O ratio during this time tended to increase compared to the unoccupied period (BC: 0.69, $PM_{2.5}$: 0.35). This means that the concentration of BC and $PM_{2.5}$ increased indoors because of occupant behavior. During the occupied period, the BC increased by 13% and the $PM_{2.5}$ increased by 48% compared to the unoccupied period. In conclusion, it was found that occupant behavior during the occupied period increases $PM_{2.5}$ more than BC.

4 Conclusion

In this study, the atmosphere and IAQ around a school located in the city center were monitored with BC and $PM_{2.5}$ as foci. IAQ is influenced by indoor and outdoor variables. External variables were identified through the correlation analysis between traffic volume and BC- $PM_{2.5}$. Additionally, for the internal variables, the I/O ratio was analyzed by consideration of the classroom schedule.

The outdoor factor that affects classroom IAQ is air pollution, and the increase in traffic volume during rush hour intensively generated more BC than $PM_{2.5}$. In the classroom, BC showed about twice the effect of infiltration as $PM_{2.5}$. It was found that the indoor factor changing the concentration of BC and $PM_{2.5}$ is occupant behavior, which has a greater effect on $PM_{2.5}$ than BC indoors. In conclusion, for schools that are in urban areas, the greater the traffic volume, the greater the influence of BC on indoors, and occupant behavior has a large influence on the increase of $PM_{2.5}$. Students in urban schools need to be careful of indoor and outdoor BC exposure during rush hour.

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