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# Operation method for the air purifier and ventilation systems of old school classrooms considering noise

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**Abstract.** Old schools with low airtightness performance are vulnerable to outdoor fine dust. Air purifier and ventilation systems are typically used to improve indoor air quality. However, due to the noise that these systems generate, some classrooms do not operate these mechanical facilities despite the deterioration of indoor air quality. This study aimed to propose a ventilation operation method for appropriate improvement of indoor air quality through CONTAMW simulation while minimizing students' disturbance from noise from air purifier and ventilation systems. By controlling the volume of air in the air purifier and ventilation system, it is possible to minimize this disturbance in an old school and effectively improve indoor air quality.

## 1 Introduction

Recently, in Korea, the number of days with poor air quality each year is increasing as the concentration of fine dust in the air increases. In the case of Seoul, South Korea, the number of days each year with poor air quality, with the daily average $PM_{2.5}$ concentration exceeding 75 μg/m$^3$, is continuously increasing [1]. As the outdoor $PM_{2.5}$ concentration increases, it flows indoors, deteriorating air quality [2].

$PM_{2.5}$ is considered one of the most harmful pollutants by the World Health Organization (WHO). According to previous studies, prolonged exposure to $PM_{2.5}$ is related to adverse effects on respiratory and cardiovascular health [3]. In particular, young students are more sensitive and vulnerable to indoor air pollutants [4, 5]. This is because young people breathe faster than adults and their lungs are more readily exposed to pollutants due to their organ-to-body size ratio [6]. In addition, high indoor $PM_{2.5}$ concentrations can have a significant impact on the academic performance of students [7]. For students, school is the main indoor environment where they spend 7–8 hour a day; therefore, reducing the indoor $PM_{2.5}$ concentration is of utmost importance.

Carbon dioxide ($CO_2$) concentration is used as an indicator of indoor air quality [8]. Factors that affect the indoor $CO_2$ concentration level include the total number of occupants, occupancy period, and room size. The $CO_2$ concentration in school classrooms increases with the presence of more students mainly due to an increased number of respiring young people. An excessive increase in the $CO_2$ concentration indoors indicates a lack of ventilation. Insufficient ventilation can hinder the academic performance of students by leading to poor concentration due to a high $CO_2$ concentration in the classroom [9, 10]. Although natural ventilation is advantageous in lowering the indoor $CO_2$ concentration, it is difficult for natural ventilation to occur on days with a high outdoor fine dust concentration due to its inflow. Mechanical ventilation should be used to improve indoor air quality by considering indoor $PM_{2.5}$ and $CO_2$ concentration levels on days with poor air quality [11].

Noise is unwanted sound that can cause annoyance to people. Excessive noise can be disruptive to communication with others [12]. Schools are spaces where students receive education, and excessive noise can impair students' attention, language learning, mathematical performance, and memory. Therefore, controlling noise is necessary to help students distinguish and concentrate on classroom content [13, 14].

Some schools are using air purifiers and heat recovery ventilators (HRVs) to improve indoor air quality for students. In older schools in Korea, stand-alone ventilation systems are typically installed and used. This is because it is difficult to install ceiling or wall-mounted ventilation systems in existing schools, and minimizing construction to avoid disrupting students is a priority. However, one issue with these systems is that the noise generated from their operation interferes with classes. As a result, even though indoor air quality can be improved, some classes do not operate air purifier or ventilation systems. Therefore, with outdoor air quality worsening, natural ventilation frequency decreases, resulting in insufficient ventilation in school classrooms, and the number of days with deteriorating indoor air quality continues to increase.

This study aimed to propose a ventilation operation method for the appropriate improvement of indoor air quality through CONTAMW simulation while minimizing students' disturbance from noise from air purifier and ventilation systems in existing old classrooms.

## 2 Methods

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### 2.1 CONTAMW model setting

To conduct the CONTAMW simulation, the conditions for outdoor data collection were set as follows. First, the weather data were collected for a total of 3 days; March 10–12 in 2021, when the outdoor $PM_{2.5}$ concentration was highest in Seoul, South Korea. A weather data file (WTH) and contaminant data file (CTM) were obtained from the Korean Meteorological Administration. Weather data included five elements–air temperature, absolute humidity, air pressure, wind direction, and wind speed. CTM consisted of $PM_{2.5}$ and $CO_2$ concentrations, and CTM data were obtained from Air Korea. The classroom model was set with a floor area of 69 m$^2$, which is the typical classroom size in Korea, and the floor height was assumed to be 3 m and the volume 207 m$^3$. The number of students in a classroom was set as 25, which is the maximum number of students in a school in OECD countries. The number of students was set at 25 during class time and 15 during recess. The $CO_2$ generation rate per capita was set at 18.6 L/h at 1.2 met condition [12]. For the $CO_2$ analysis, the amount of infiltration in the classroom was set as follows. The measured values obtained from the blower door test at school A in Korea were used. The amount of infiltration in the classroom of school A was about 960 m$^3$/h at 4 Pa, the effective leakage area (ELA) was 1,035 cm$^2$, and the ELA for the windows, doors, and walls was set by referring to the CONTAMW library. HRV could be set to 150, 250, or 400 cubic meters per hour (CMH). Ventilation facilities in CONTAMW were assumed to be MERV 13 level, which is the actual filter for ventilation facilities.

To interpret the inflow of $PM_{2.5}$, the penetration factor (p) and deposition rate (k) of the classroom model were set. The penetration factor is the rate at which $PM_{2.5}$ in the outdoor air enters a room through cracks or gaps in the building envelope, and the deposition rate indicates the rate at which $PM_{2.5}$ is deposited on floors and walls indoors. The penetration factor was set to 0.8 and the deposition rate to 0.04, which were obtained through actual measurements in a classroom of school A. The CONTAMW classroom model is shown in Fig. 1 and Table 1.

**Table 1.** CONTAMW input data

| | | | |
|---|---|---|---|
| ZONE | Classroom A | Floor area | 69 m$^2$ |
| | | Volume | 207 m$^3$ |
| | | Height | 3 m |
| | | Occupancy | 25 |
| | | Occupancy schedule | 8:50–14:50 (recess: 10 min, 15 students in the classroom) 25 in the classroom |
| Mechanical Ventilation | HRV | Generation ($CO_2$) | 18.6 L/h ·person |
| | Air purifier | Removal rate ($PM_{2.5}$) | 780 CMH |
| Airflow path | Leakage area data | Flow Coefficient(C) | 0.556 |
| | | Flow exponent (n) | 0.126 |
| | | Penetration factor | 0.8 |
| | | Effective leakage area | 1,035 cm$^2$ |

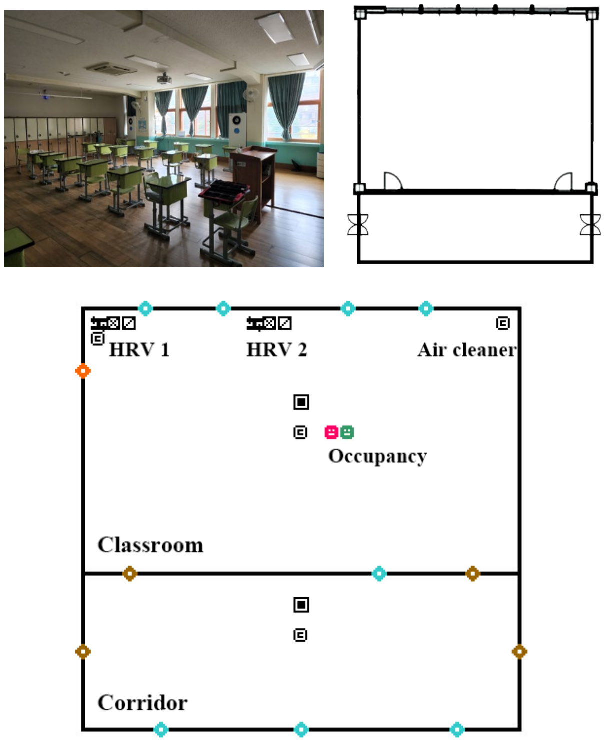


**Fig. 1.** Actual classroom and CONTAMW classroom model

### 2.2 Noise measurement of air purifier and ventilation systems

Air purifier and ventilation systems were selected by examining their noise level compared to the rated air volume of products currently available in the market. The background noise level in the classroom was measured by obtaining values from 5 locations marked with red dots at a height of 1 meter from the floor in Fig. 2 for a duration of 5 minutes, and the obtained values were averaged to determine the overall background noise level in the classroom. Next, the noise value occurring at each seat was calculated to consider the disturbance of the noise using the noise value of the selected mechanical equipment. The value was calculated through the noise value calculated using equations (1) and (2). The calculation results were reflected when considering the arrangement of air purifier and ventilation systems. The noise generated by operating mechanical equipment for each seat in the classroom was measured and reviewed when operating the air purifier and ventilation systems when the room was unoccupied. All noise values measured were corrected considering the background noise in the classroom.

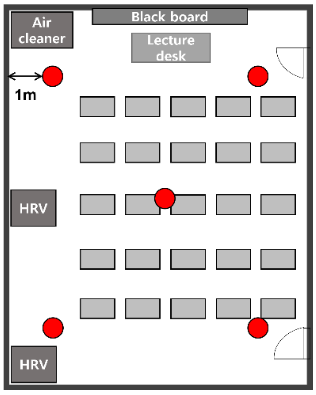


**Fig. 2.** Background noise measurement locations in the classroom

$$L_2 = L_1 + 10\log\left(\frac{r_1}{r_2}\right)^2 \quad \cdots (1)$$

$$L = 10\log\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + \cdots + 10^{\frac{L_n}{10}}\right)\ (dB) \quad \cdots (2)$$

Here, L and $L_n$ represent the size of the noise source, and $r_1$ and $r_2$ are the distances from the noise source (when $r_1 < r_2$).

The air volume of the air purifier and ventilation system was controlled to confirm whether it could be operated below 45 dB(A), which is the starting point of annoyance for the Environmental Protection Agency (EPA) indoor noise standard.

### 2.3 Classification of ventilation method cases

In this study, ventilation methods in classrooms were classified into four cases as shown in Table 2 in order to propose an appropriate ventilation operation method. Ventilation methods were largely divided into the natural ventilation method (NV method) and mechanical ventilation method (MV method). In the NV method, the time for opening the windows in the classroom was set differently. Meanwhile, in the MV method, the air volume of the air purifier was fixed and the air volume of the ventilation system was set differently. The removal rate of the air purifiers in all cases was fixed at 780 CMH. Considering that it is the day in the year with the worst outdoor air in Seoul, South Korea, the air purifier was set to the same air volume in all cases.

The NV 1 method was when natural ventilation was performed throughout class. The NV 2 method was when natural ventilation was performed for 30 min by opening a window 20 min after class started. Considering that the number of students decreased during recess, the $CO_2$ concentration in the classroom during recess also decreased. After class started, the indoor $CO_2$ concentration gradually increased due to the $CO_2$ generated by the respiration of students.

There were two methods of mechanical ventilation. The MV 1 method was when the mechanical ventilation system was operated at 250 CMH, which is an air volume that did not exceed 45 dB(A) during the occupancy period. The MV 2 method was used during the occupancy period, and was when the air volume was set to 250 CMH during class and 400 CMH during recess.

**Table 2.** Case classification

| Case | Setting | |
|---|---|---|
| NV 1 (Natural Ventilation 1) | 2 Window open | 50 min during class |
| NV 2 (Natural Ventilation 2) | 2 Window open | Opening the window 20 min after class started for 30 min |
| MV 1 (Mechanical Ventilation 1) | Air purifier | 780 CMH |
| | HRV | 250 CMH |
| MV 2 (Mechanical Ventilation 2) | Air purifier | 780 CMH |
| | HRV | 250 CMH during class (400 CMH for 10 min during recess) |

Based on the results of the CONTAM simulation by comparing the above four ventilation methods, an appropriate arrangement and ventilation operation plan for air purifiers and ventilation systems in nonairtight old school classrooms was created, and it was reviewed in comparison with the WHO indoor air quality ($PM_{2.5}$, $CO_2$) standard and EPA indoor noise annoyance standard.

## 3 Results

### 3.1 Background noise in the classroom and noise from the mechanical ventilation system

The background noise of the classroom, averaged at five points from the window and center of the classroom, was 38 dB(A). Noise during natural ventilation was not considered because the external situation was different each time. The noise values generated when operating a mechanical ventilation system are shown in Fig. 3. The noise value here represents the loudness of the noise generated when the air volume of the air purifier was operated at 780 CMH and the air volume of the ventilation system was 250 CMH.

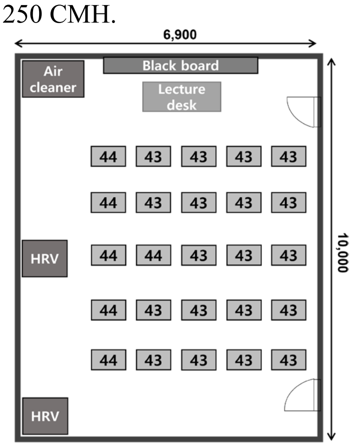


**Fig. 3.** Maximum noise values generated during mechanical ventilation(dBA)

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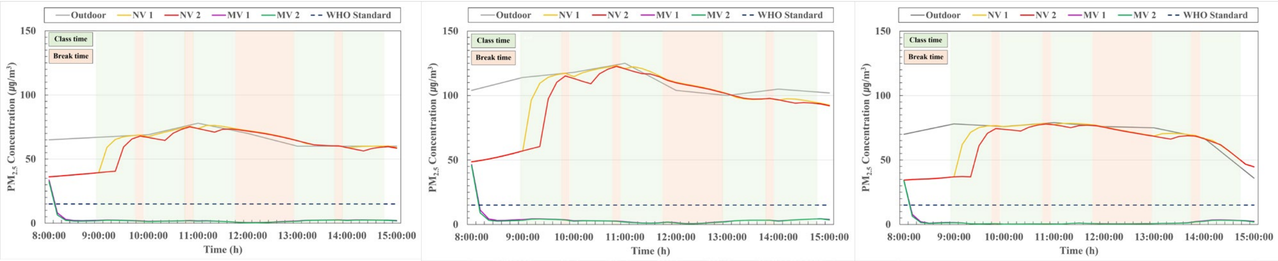
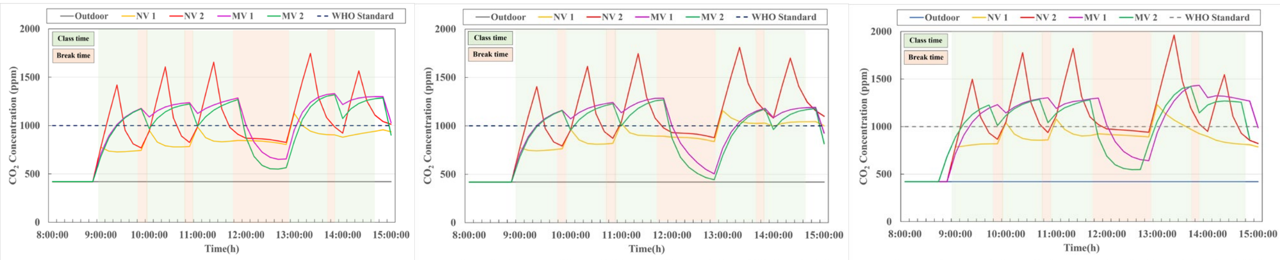



(a) March 10, 2021 (b) March 11, 2021 (c) March 12, 2021




(e) March 10, 2021 (f) March 11, 2021 (g) March 12, 2021

**Fig.4** PM2.5 and CO2 Concentration change according to ventilation method

The average level of noise generated when mechanical ventilation was operated in the classroom was approximately 43.4 dB(A). The noise level of the ventilation system when the air volume of the ventilation system was operated at 400 CMH was approximately 47 dB(A). Noise levels that exceed the EPA standard of 45 dB(A) indoors start to cause activity disturbances and annoyance. These levels of noise are considered disruptive to conversations and other activities, such as sleep, work, and recreation, that are part of the normal human condition. Recess is characterized as students not

focusing on their studies compared to during class. In addition, considering that the general conversational sound between students during recess is about 60 dB(A) on average, it was determined that the air purifier and ventilation system may be operated with an air volume of 400 CMH during recess.

### 3.2 $PM_{2.5}$ and $CO_2$ concentrations in the classroom

Fig. 4 shows the results of $PM_{2.5}$ concentration changes in a classroom with poor airtight performance based on different ventilation methods. The average outdoor $PM_{2.5}$ concentration was 82 μg/m$^3$, and the maximum was 125 μg/m$^3$, indicating very poor air quality levels. In the case of the NV 1 method, the indoor/outdoor (I/O) ratio for PM2.5 during the student occupancy period was about 0.90, confirming that the indoor and outdoor $PM_{2.5}$ concentrations were almost the same. The average concentration during the three-day occupancy period was approximately 75 μg/m$^3$. In particular, the average concentration during the occupancy period on March 11, 2021, was 95 μg/m$^3$, indicating a very high indoor $PM_{2.5}$ concentration. It was confirmed that the NV 1 method did not meet the WHO indoor $PM_{2.5}$ concentration standard. On the other hand, when ventilation was performed through the NV 1 method, the average $CO_2$ concentration during the occupancy period was 827 ppm, and the maximum was 1,229 ppm. Compared to the WHO indoor $CO_2$ concentration standard of 1,000 ppm, this was found to be a very good level. In the case of the NV 2 method, the I/O ratio decreased by about 4% to 0.87 compared to the NV 1 method. The average concentration of $PM_{2.5}$ during the occupancy period was 72 μg/m$^3$, which was still high. The NV 2 method also did not satisfy the WHO indoor $PM_{2.5}$ concentration standard. When ventilation was performed by the NV 2 method, the average $CO_2$ concentration during the occupancy period was 1,043 ppm and it was confirmed that a good level of $CO_2$ indoor air quality could be maintained compared to the WHO indoor $CO_2$ standard concentration. However, there were cases where the indoor maximum $CO_2$ concentration rose to 1,961 ppm. After recess and 10 min before class started, the maximum $CO_2$ concentration reached a high level because all the students were in the room and the windows were closed without ventilation. If the natural ventilation schedule at this time was additionally conducted for 10 min before the class started at 13:00, it was judged that the indoor $CO_2$ concentration could be reduced.

In the case of the MV 2 method, the I/O ratio for $PM_{2.5}$ was very low, at 0.036. During the non-occupancy period, air purifier and ventilation systems were not in operation, so the indoor $PM_{2.5}$ concentration was relatively high at 08:00. When ventilation was conducted using the MV 2 method, the average concentration of $PM_{2.5}$ during the occupancy period was approximately 2.9 μg/m$^3$, which allowed the maintenance of the indoor $PM_{2.5}$ concentration at a very low level, and was confirmed to meet the WHO indoor $PM_{2.5}$ standard of ≤ 15 μg/m$^3$. In the case of the MV 2 method, the average indoor $CO_2$ concentration during the occupancy period was 1,003 ppm, which was judged to meet the WHO indoor $CO_2$ standard. During the occupancy period, the maximum indoor $CO_2$ concentration was found to be 1,433 ppm.

In the case of the MV 2 method, the I/O ratio for $PM_{2.5}$ was 0.034, which was almost the same as that of the MV 1 method. The average $PM_{2.5}$ concentration during the occupancy period at this time was 2.7 μg/m$^3$, which was a

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very low level. It was confirmed that the WHO indoor $PM_{2.5}$ concentration standard was satisfied when the MV 2 method was used. The average concentration of indoor $CO_2$ during the occupancy period was 951 ppm when ventilation was performed by the MV 2 method. The maximum indoor $CO_2$ concentration during the occupancy period was 1,420 ppm.

### 3.3 Adequacy assessment of ventilation methods

It was found that the NV 1 and NV 2 methods were the most effective methods compared to other ventilation methods for managing indoor $CO_2$ concentration. However, for managing the indoor $PM_{2.5}$ concentration, it was judged that the inflow of $PM_{2.5}$ could not be reduced. A high concentration of indoor $PM_{2.5}$ can have a very harmful effect on the health of growing students, so natural ventilation was judged to be an inappropriate ventilation method for this purpose. It is appropriate to use the NV method on days with low outdoor air $PM_{2.5}$ concentration ($\leq$ 15μg/$m^3$). In the case of natural ventilation by opening a window, it is recommended to operate an air purifier at the same time for simultaneous ventilation.

To compare the suitability of two mechanical ventilation systems, the power consumption of the ventilation equipment was compared. The power consumption of the ventilation equipment varies depending on the airflow rate, and the results are shown in Table 3 for airflow rates of 150CMH, 250CMH, and 400CMH. When ventilating with MV 1 and MV 2 systems for one month in an occupied space, the power consumption was calculated to be 10.62 kWh for MV 1 and 16.62 kWh for MV 2. The difference in power consumption between the two ventilation systems is 6 kWh, indicating that MV 1 is approximately 63% more efficient than MV 2 in terms of power consumption. This confirms that the ventilation system of MV 1 is appropriate for days when outdoor air quality is poor.

## 4 Conclusions

This study proposes a method of improving indoor air quality in an old school classroom by using air purifiers and ventilation systems as appropriate ventilation measures when outdoor $PM_{2.5}$ concentrations are very high. Through CONTAMW simulation, it was determined that operating air purifiers and ventilation systems with the MV 1 ventilation method could maintain a certain level of indoor air quality during class time without being disturbed by noise, while considering high outdoor $PM_{2.5}$ concentrations and students' daily routines. This study analyzed only the three days with the highest outdoor fine dust concentration in March, 2021 using the CONTAMW program. It is necessary to analyze indoor air quality by verifying the model through calibration between actual and simulated data while considering the detailed behavior of students and ventilation methods in actual school classrooms.

As a result, this study helped develop a method for minimizing student disturbance from noise by operating air purifier and ventilation systems so that noise in non-airtight school classrooms does not exceed 45 dB(A) based on simulations, taking outdoor conditions into consideration. This study also suggests an effective method for improving indoor air quality.

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