Comparison of performance of heat recovery ventilator and air purifier in reducing indoor PM10 concentrations in a classroom

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Abstract. Recently, outdoor particulate matters have become a serious problem in Korea. Pollutants exhausted from industrial plants and dust transported from adjacent regions contribute to the peaks in fine particle concentration. Indoor air quality is affected by ambient air pollution. Common methods for maintaining good IAQ from harmful outdoor particles are either through the usage of an air purifier (AP) or to install a filter in the heat recovery ventilator (HRV) system. It is important to evaluate the PM10 concentrations in a room using APs and HRVs depending on various system parameters, such as building air-tightness, indoor generation characteristics, and system filter efficiency. The purpose of this study is to compare the performance of AP with that of HRV in reducing PM10 levels in a classroom based on computer simulation. Results show that the filter efficiency of HRV should be increased to over 0.8 under the reference condition in order for the HRV to be compatible with the AP. Increasing the airflow rate of HRV is not an effective way of increasing its filter performance to outperform an AP. We found that HRV performs better as compared to AP in an indoor environment under dusty conditions with the generation rate of over seven times compared to the reference condition.

1 Introduction

People living in urban areas spend more than 90% of their time in indoor environments, where air pollution could be far greater as compared to outdoor environments. Indoor air pollution occurs as a result of physical, chemical, and biological factors. It is determined by the local outdoor air quality, building characteristics, ventilator systems, and indoor human activities [1, 2].

School is an important microenvironment representing both the density and activity level of its occupants. Students spend most of their time during a day in classrooms; furthermore, children are more sensitive to air pollution than adults because they breathe higher volumes of air as compared to adults owing to their low body weight and developing immune systems [3].

Particulate matter (PM) is one of the most common pollutants that could potentially degrade air quality of classrooms [4]. Indoor PM levels are derived from both indoor and outdoor sources. They are influenced by several variables, such as air exchange rates and infiltration processes, outdoor air pollution levels, the type and intensity of indoor activities, and particle sizes [5].

Common methods to reduce indoor particle concentrations are to either use air purifiers (AP) [6] or to install filters in heat recovery ventilator (HRV) systems [7]. HRV replaces indoor air with fresh outdoor air which sometimes contains a large number of particulate matters. It is important to understand the concentrations in a room with the help of APs and HRVs depending on various system parameters such as building air-tightness, indoor contaminant generation rates, HRV airflow rates, and filter efficiencies.

2 Methodology

2.1 Contaminant model

The present model for indoor PM10 concentration calculation is using mass balance equation, taking account the volume of the building, air exchange rate, internal sources, internal sinks and outdoor concentration under transient conditions. The model is based on the first order ordinary differential equation and it is valid for complete mixing conditions [8].

The simple governing mass balance equation can then be written as:

$$V\frac{dC}{dt} = \dot{M}_{ecxh} + \dot{M}_{source} - \dot{M}_{sink} \tag{1}$$

where V is the volume of the room, C is the concentration of particles in indoor space, C_o is the concentration of

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particles in outdoor air, $\dot{M}_{ecxh}$ is the total net rate of particles introduced to the space from outdoor, $\dot{M}_{source}$ and $\dot{M}_{sink}$ are the internal source and sink strengths respectively.
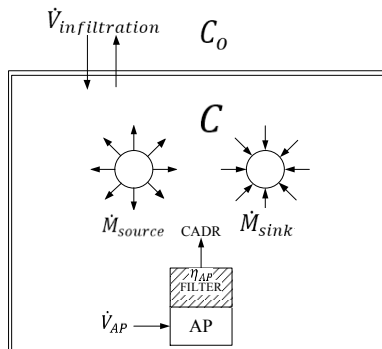
Fig. 1. Classroom model with an air purifier.
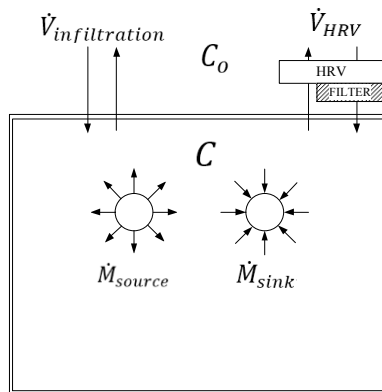
Fig. 2. Classroom model with heat recovery ventilator.

The incoming particle rate ($\dot{M}_{ecxh}$) is determined by infiltration from the crack ($\dot{V}_{inf}$) and ventilation system (i.e. HRV system) ($\dot{V}_{HRV}$), formulated as follow:

$$\dot{M}_{ecxh} = \dot{V}_{inf}[PC_o - C] + \dot{V}_{HRV}[((1 - \eta_{HRV})C_o) - C] \qquad (2)$$

where P is the penetration factor through building envelopes, C_o is the outdoor particle concentration, and η_{HRV} is the filter efficiency of HRV.

The internal source ($\dot{M}_{source}$) is determined by indoor particles generation rate per person ($\dot{m}$) and number of occupants (N) as shown in Eq. 3. The term representing sinks in Eq. 1 ($\dot{M}_{sink}$) includes particles removal by air cleaners as well as sink effects occurring as a result of adsorption on the inner surfaces of the building and can be written as shown in Eq. 4, where k_n is the deposition rate on internal surfaces of the building walls, $\dot{V}_{AP}$ is the airflow rate of AP, and η_{AP} is the filter efficiency of AP.

$$\dot{M}_{source} = \dot{m} N \qquad (3)$$

$$\dot{M}_{sink} = k_n CV + \eta_{AP} \dot{V}_{AP} C \qquad (4)$$

The space model considered is a typical classroom in Korea with a total volume of 200 m³ (height of 3 m) [9].

We used CONTAM software to simulate indoor PM$_{10}$ concentration for a period of 24 hours on January 27, 2017, when outdoor PM$_{10}$ concentration was the worst during the year. The hourly ambient concentration was obtained from a data station located near the Gireum station in Seoul. We considered two scenarios in this study: the first case is a classroom with an AP installed (Fig. 1), and the second case is a classroom with an HRV installed (Fig. 2).

2.2 Building parameters

Several building parameters, such as infiltration rate, penetration factor, deposition rate, and indoor generation rate were considered to simulate the reference conditions. Each value was obtained from several numbers of studies as shown in Table 1.

Table 1. Building parameters used to simulate the reference conditions.

Parameters	Units	Value
Infiltration rate [9]	ACH	0.94
Penetration factor [10, 11, 12, 13]	-	1
Deposition rate [13, 14]	h⁻¹	0.65
Indoor generation rate [15]	mg/h-person	1.2

The indoor particle generation rate depends on human activities in an occupied space. In this study, we assume a typical occupant to be seated and moved moderately within the classroom.

Activities in the classroom start from 09.00 in the morning and finish by 21.00 at night. The total number of occupants in the classroom is 42 with fraction 0.7 and 0.15 at 17.00 to 21.00 and 09.00 to 17.00 respectively.

2.3 System parameters

2.3.1 Heat recovery ventilator

The main function of heat recovery ventilator (HRV) is to introduce outdoor fresh air to indoor space and not to reduce or filter contaminants from the outdoor air. In this study, the HRV was turned on at 09.00 in the morning when the class started and was turned off at 21.00 when all occupants had left the room.

Based on the ASHRAE standard, the outdoor airflow required for the room under consideration shall be no less than 860 m³/h or 4.3 ACH with the minimum efficiency reporting value of 6 or 40% of the filter efficiency for commercial buildings [16].

2.3.2 Air purifier

Air purifiers (AP) are often rated based on clean air delivery rate (CADR), which is a product of the airflow rate and filter efficiency. Based on the Korean Air Cleaner Association standard, we can obtain the recommended AP airflow rate or CADR using equation 5 [17].

$$CADR \ (m^3/h) = \frac{A \ (m^2)}{7.92} \times 60 \qquad (5)$$

From the above equation, the CADR of the AP for the room under consideration is 506 m^3/h with a typical filter efficiency of 99%. For comparison purposes, the AP was operated according to the same schedule with the HRV.

3 Result & Discussions

Figure 3 shows the results for one of the worst day during a year. The outdoor PM$_{10}$ concentration is nearly 300 µg/m^3 during the day. The indoor PM$_{10}$ concentration increases as school activities start in the morning. The indoor PM$_{10}$ concentration with AP installed in the room is slightly above 100 µg/m^3, whereas the PM$_{10}$ concentration with HRV installed in the room is almost 200 µg/m^3. The presence of dusty air in the outdoor environment contributes significantly to increase PM$_{10}$ concentration in indoor space, and it is greater than the indoor particle generation rate. If the HRV filter efficiency is increased to 80%, then the daytime PM$_{10}$ concentration would be nearly the same with the AP results.

The indoor CO$_2$ level is greater than 2000 ppm in case of AP operation without mechanical ventilation, whereas it is less than 1000 ppm in case of HRV operation. In terms of CO$_2$ concentration, HRV is superior to AP, since outdoor fresh air is not enough only by infiltration. The CO$_2$ result would be the same regardless of the outdoor PM$_{10}$ concentration as far as the mechanical ventilation is not provided. The result for HRV would also remain the same regardless of the HRV filter efficiency since the particle filter does reduce CO$_2$ concentration.
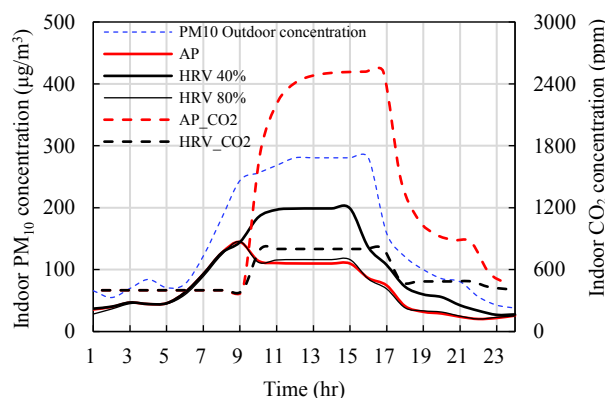
**Fig. 3** Indoor PM$_{10}$ and CO$_2$ concentrations for the worst day of a year.

Because every building has different characteristics such as infiltration rate and/or filter efficiencies, we investigate the effect of infiltration rate on I/O ratio with respect to HRV filter efficiency to obtain the best HRV condition to compete with AP performance. As the infiltration rate increases, as shown in Fig. 4, the I/O concentration ratio also increases. With the increased filter efficiencies of HRV, the I/O ratios decrease. We can observe that when the infiltration rate is less than 0.8 ACH

and the filter efficiency of HRV is 80%, the result obtained is comparable with the one obtained using AP.
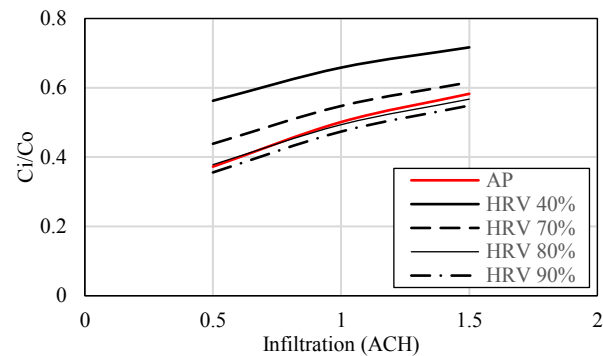
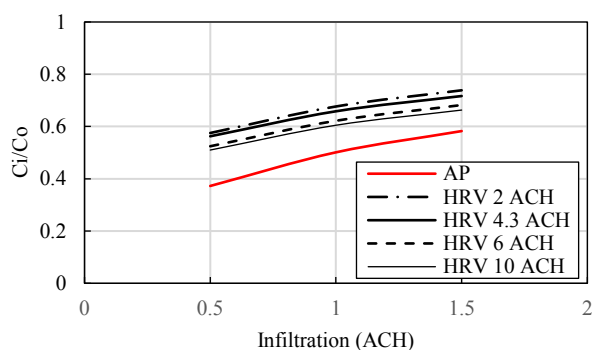**Fig. 4** Effect of infiltration rate on I/O PM$_{10}$ ratio depending on the HRV filter efficiency.

The indoor generation and the outdoor entrainment are the main sources of indoor PM$_{10}$. If the internal generation rate increases due to the presence of active occupants, the concentration increases dramatically. Figure 5 shows the effect of generation rate on I/O ratio. The result shows that HRV performs better at higher activity levels as compared to AP. For the indoor generation rate is over seven times compared to the typical activity level under the reference condition (seated with moderate movement), the default HRV efficiency of 40% shows the same I/O ratio with air purifier case.
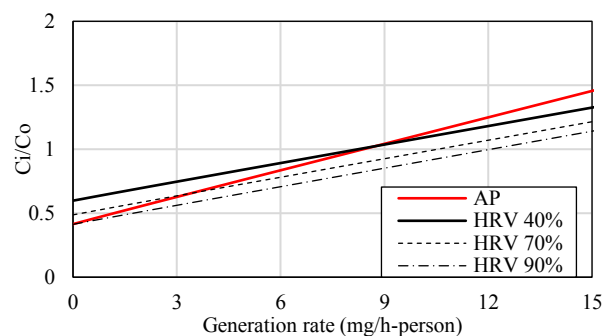
Fig. 5 Effect of generation rate on I/O PM$_{10}$ ratio depending on HRV filter efficiency.

Other results show that HRV with a filter efficiency of 70% has a better performance in terms of reducing indoor PM$_{10}$ concentration in a classroom when the students are seated with intensive movements and paperwork with a generation rate of more than 3 mg/h-person. However, when the filter efficiency of HRV increases to 90% it shows better performance compared to AP during every student activity and building infiltration rates (Fig. 4 and Fig. 5).

Figure 6 present the effect of HRV airflow rate on I/O ratio. As shown in the figure, the I/O ratio decreases until it approaches the I/O ratio of AP result. However, it can be concluded that increasing HRV airflow rate is not a very effective way of improving indoor concentration so long as the HRV filter efficiency is as low as 40%. Increased airflow rates cause more particle contaminants to penetrate through the filter and increase indoor PM$_{10}$ concentration.

Fig. 6 Effect of infiltration rate on I/O PM_{10} for various HRV airflow rates.

4 Conclusions

The indoor PM_{10} results obtained using HRV and AP was compared to evaluate a typical classroom condition in Korea.

For the HRV to be compatible with the AP, the filter efficiency of HRV should be increased to over 80% under reference conditions.

Increasing the airflow rate of HRV is not an effective way of reducing indoor PM_{10} concentration without increasing HRV filter efficiency, which also increases HRV fan power consumption.

HRV shows better performance as compared to AP in an indoor environment under dusty conditions with high activity levels at a generation rate of over seven times as compared with the reference condition (seated with moderate movement).

APs are generally effective in reducing indoor particle concentration level, especially in case of bad outdoor PM_{10} days. Conversely, HRVs are effective in eliminating indoor-generated particles for days with moderate PM_{10} concentrations under reference conditions.

Our future work will focus on optimizing the control methods for both PM and CO_2 concentrations under the influence of various building characteristics and outdoor weather conditions.

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