Journal of Building Engineering 41 (2021) 102367

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: http://www.elsevier.com/locate/jobe

The impact of airflow and air purification on the resuspension and removal of deposited particulate matter

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ARTICLE INFO

Keywords:
Particulate matter
Indoor air quality
Air purification
Deposition
Resuspension

ABSTRACT

Air purifiers are a popular tool to manage indoor particulate matter; however, their effectiveness with respect to resuspending and removing particles that have been deposited on surfaces is limited. This study proposed and evaluated a method of removing both suspended and deposited particulate matter using an air purifier in conjunction with an airflow source. First, the effectiveness of the air purifier with respect to removing deposited particulate matter was determined in a static environment and under forced airflow. Then, the removal efficiency of the purification system was evaluated under varying airflow orientations and velocities. Results showed that the air purifier contributed to particulate matter resuspension and removal, and the efficiency was significantly improved under forced resuspension due to airflow generation. The orientation of the airflow was found to have an impact on the resuspension and removal efficiency of particulates, and four-way airflow was more effective compared to one-way airflow. This was attributed to four-way flow increasing the airflow diffusion radius compared to one-way flow. A flow velocity of 5 m/s or greater was necessary to resuspend deposited particulate matter. These findings illustrate that forced resuspension is an effective means of reducing deposited particulate matter in indoor environments, and four-way airflow with a wide diffusion radius and a velocity of 5 m/s or higher are the optimum conditions for this purpose.

1. Introduction

In modern societies, people spend more than 80% of their time indoors, increasing their exposure to potentially hazardous indoor particulate matter (PM). Consequently, numerous studies have focused on reducing exposure to PM and its influence on the human body [1,2]. World Health Organization (WHO) guidelines recommend indoor concentrations of less than 10 and 20 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively, in line with atmospheric concentrations [3]. In South Korea, the government has made efforts to reinforce indoor PM management by implementing the Indoor Air Quality Management Act and Enforcement Regulations (Ministry of Environment Decree No. 858, partial revisions on April 3rd, 2020). Furthermore, they have recommended that indoor concentrations of $PM_{2.5}$ and PM_{10} should be maintained below 100 and 50 μg/m^3, respectively [4,5]. With growing concerns over the toxicity of PM and the health of indoor environments, various studies have been conducted regarding the reduction of indoor PM [6–8]. Respiratory and cardiovascular mortality has been attributed to PM, and the risk is higher for physically weak people, such as children and the elderly [9,10]. Furthermore, the International Agency for Research on Cancer (IARC) has classified PM as a group 1 carcinogen [11].

Dust can be classified into total suspended particles (TSP), PM (PM_{10}), and fine PM (FPM; $PM_{2.5}$) based on particle size criteria of 50, 10, and 2.5 ㎛, respectively [12]. Outdoor PM is generated by both natural (e.g. fire, yellow dust, and volcanic eruptions) and artificial (power plants, industrial facilities, and automobiles) sources [13]. Conversely, indoor PM tends to be generated by indoor activities such as cooking, which involves heating; smoking; occupant movement; and motion, and cleaning [14]. Some indoor PM is deposited on surfaces and may impact the human body via resuspension due to changes in airflow caused by ventilation, ducts, and indoor activities [15,16].

Airflow (aerodynamic force) is a disturbance factor that affects the resuspension of indoor PM in addition to vibration (mechanical force) and static electricity (electrostatic force). Indoor PM is deposited by gravity and adhesion and is resuspended by airflow, vibration, and static electricity [17,18]. Resuspended PM may have a potential impact on occupants; for example, it can be inhaled by children when it suspended to their height [19]. If PM deposited on the floor is not resuspended, it is

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https://doi.org/10.1016/j.jobe.2021.102367
Received 26 October 2020; Received in revised form 26 February 2021; Accepted 27 February 2021
Available online 11 March 2021
2352-7102/

less likely to impact the human body [20]; however, FPM in particular can be easily resuspended by indoor activities and ventilation [21,22]. Therefore, it is necessary to reduce both deposited and suspended PM. To date, ventilation (natural and mechanical ventilation) and air purifiers have been mainly used to reduce indoor PM [23]. Air purifiers reduce indoor pollutant concentrations by filtering gaseous and particulate pollutants that are present in the air [24,25]. However, current air purification technologies can only remove suspended PM and do not address deposited PM.

Grinshpun et al. [26]. found that air purifiers could be used to reduce suspended PM in indoor spaces; however, residual PM can be deposited on indoor surfaces, impacting indoor air quality following resuspension. Golkarfard and Talebizadeh [27] used an airflow analysis simulation to investigate the deposition and suspension of indoor PM during the use of radiator and a floor heating systems; however, they did not consider the resuspension and reduction of PM. Chen et al. [28]. studied the deposition of indoor PM during the use of two types of cooling devices and confirmed that the deposition rate of indoor PM was high. Because their study focused on the behavior and deposition locations of indoor PM, the removal of deposited PM was not thoroughly investigated. These previous studies have investigated the deposition and resuspension characteristics of indoor PM to a certain extent; however, research with respect to the reduction of PM deposited on indoor surfaces is lacking.

Recent studies have considered the resuspension of particles by mechanical vibration and analyzed the degree of vibration, adhesion, and gravity applied to particles using simulations [29]. Ahmed at al [30]. studied the effects of floor materials on the resuspension of particulate matter. They found that resuspension was more dependent on floor hardness rather than roughness, and resuspension was the greatest from ceramic tiles compared PVC and linoleum flooring. Ahmed at al [31]. conducted experiments to study the effect of walking inside a wooden chamber on resuspension. They found that PM10 was more actively resuspended compared to PM2.5 and PM1.0, and that wooden flooring caused more resuspension than linoleum flooring. Suihua at al [32]. examined the effect of relative humidity on the resuspension of particulate matter by particle size. When the relative humidity was 60–70% resuspension was higher compared to drier or more humid conditions. Furthermore, people walking had a greater impact on the resuspension of larger particles.

Numerous studies have investigated the likelihood and causes of PM resuspension. However, few studies have investigated the direct removal of deposited PM to reduce resuspension. Consequently, this study aims to investigate the impact of a forced resuspension method to effectively remove deposited PM. This study can be used as basic research for indoor air quality improvement by removing deposited PM that could adversely affect occupants. It can also be applied to air purification devices to improve the efficiency of indoor PM removal.

2. Methods

In this study, we propose a method to improve the PM removal efficiency of air purifiers through the forced resuspension of deposited PM. The experiment was conducted in three stages. The first stage involved verifying the impact of resuspending deposited PM by measuring the background PM concentration of the mock-up with and without operating the air purifier and then measured the PM concentration during the operation of the air purifier with and without forced resuspension. The second step determined the most effective wind direction for the resuspension of deposited PM and the third step identified the most effective wind speed for resuspension. The same purifier was used in each experiment stage.

2.1. Mock-up construction

The experiment was performed in a laboratory mock-up inside an experimental building located in Dongjak-gu, Seoul. A mockup with dimensions 2000 × 1800 × 2200 mm (width × depth × height) and a volume of 7.92 m^3 was constructed. To minimize external influences, the corners, windows, and doors inside and outside the mockup were sealed, and a 200 mm expanded polystyrene insulation layer was inserted in the walls to prevent heat exchange with the outside environment. Temperature and humidity inside the mockup were maintained at approximately 22 °C ± 0.5 °C and 55% ± 5%, respectively.

Generally, indoor PM is resuspended by airflow generated by disturbances in the air and surface layer from indoor activities such as ventilation and occupant movement [33,34]. In this study, PM was resuspended using a generated airflow (aerodynamic force) and PM was generated using an incense burner. A DUSTTRAK 8530 PM measuring instrument was installed at a height of 1.2 m representing the breathing height of occupants when seated [35], a TESTO 480 hot ball probe (Ø 3 mm) was used for airflow measurement, and a HB-R1002 was used as an airflow generator for forced resuspension of the deposited PM. Fig. 1 shows the experimental setup for steps one to four and Table 1 provides the detailed specifications of the equipment used.

2.2. Experimental procedures and conditions

Experiments were performed in three steps to examine PM reduction under different experimental conditions.

2.2.1. Verifying the impact of PM resuspension

For measuring the background PM concentrations of the mock-up air purifier, the PM concentration in the mockup was allowed to build to a maximum of 1200 μg/m^3 using the incense burner as an emission source. The emission source was then removed and PM was allowed to decrease to 30 μg/m^3 to facilitate PM deposition. During this process, the reduction of suspended PM was examined with the air purifier turned off (A) and (A'). The final concentrations of resuspended PM

Fig. 1. Image of the experimental apparatus.

Table 1
Measuring equipment specifications.

Model	DUSTTRAK 8530		TESTO 480 (Hot ball probe)		HB-R1002	
Equipment Specifications	Concentration (mg/m^3) Particle size (μm)	0.001–400 0.1–10	Temperature-NTC (°C) Measuring range (m/s) Accuracy (at 22 °C)	−20–70 0–10 ± (0.03 m/s + 5% of mv)	Capacity Static pressure Velocity	240 m^3/h 30mmAq 0–10 m/s
						

were measured by generating an airflow of 10 m/s. Table 2 summarizes this phase of the experiment.

To measure the PM concentration with and without forced resuspension, the PM concentration in the mockup was allowed to build to a maximum of 1200 μg/m^3 using the incense burner as an emission source, for approximately 10 h. Then, the air purifier was turned on. During the operation of the air purifier, the reduction of deposited PM was measured when there was no forced resuspension (B) and when airflow was generated to cause forced resuspension (B'). The final concentrations of resuspended PM were measured by generating an airflow of 10 m/s. Table 3 summarizes this phase of the experiment.

2.2.2. Determining the most effective wind direction for resuspension

To determine the most effective wind direction for resuspension, the PM concentration in the mockup was allowed to build to a maximum of 1200 μg/m^3 using the incense burner as an emission source. The emission source was then removed and PM was allowed to decrease to 100 μg/m^3 to facilitate PM deposition. Then, airflow and the air purifier were operated simultaneously. One-way (90, 180, 270, and 360°) and four-way airflow was generated based on the polluted air inlet of the air purifier. The final concentration of resuspended PM was measured by generating an airflow of 10 m/s. Table 4 summarizes this step of the experiment.

2.2.3. Determining the most effective wind speed for resuspension

To determine the most effective wind speed for resuspension, the PM concentration in the mockup was allowed to build to a maximum of

Table 2
Summary of the experimental method in the first phase of the verification step.

Procedures		Without Air purifier (A)	With Air purifier On (A')	Duration
Generation	Background PM conc. 1200 μg/m^3	✓	✓	135–847 min
Deposition	PM deposited to 30 μg/m^3	✓	✓	5 min
Removal	Air purifier On		✓	10 min
Resuspension	Indoor activities inc. walking, moving	✓	✓	10 min
Stabilization	Stabilization of PM conc.	✓	✓	20 min
Concentration	Measuring PM conc.	✓	✓	1 h

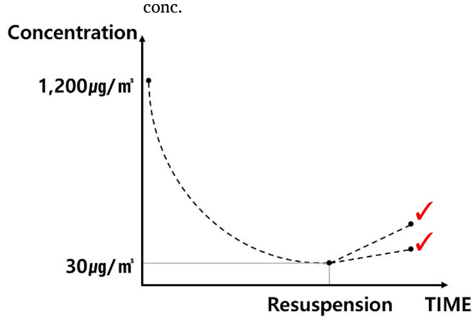


Table 3
Summary of the experimental method in the second phase of the verification step.

Procedures		No resuspension (B)	Resuspension (B')	Duration
Generation	Background PM conc. 1200 μg/m^3	✓	✓	10 h
Deposition	PM deposition	✓	✓	
Resuspension & Removal	Airflow 10 m/s generation		✓	5 min
	Air purifier turned on	✓	✓	
Stabilization	Stabilization of PM conc.	✓	✓	20 min
Concentration	Measuring PM conc.	✓	✓	1 h

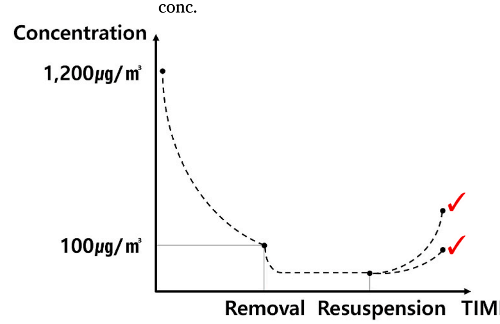
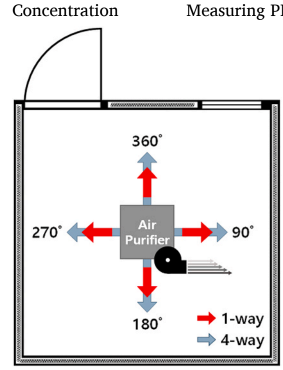


Table 4
Summary of the experimental method used to determine the most effective wind direction.

Procedures		Duration
Generation	Background PM conc. 1200 μg/m^3	209–1000 min
Deposition	PM deposited to 100 μg/m^3	(Avg: 517 min)
Resuspension & Removal	Airflow generation one-way (90, 180, 270, and 360°) and four-way Air purifier turned on	5 min
Stabilization	Stabilization of PM conc.	6 h
Concentration	Measuring PM conc.	1 h



1200 μg/m^3 using the incense burner as an emission source. The emission source was then removed and PM was allowed to decrease to 30 μg/m^3 to facilitate PM deposition and airflow was generated. The permissible wind speeds for indoor air outlets are 2.5–3.8 m/s for houses, apartments, and bedrooms; 2.5–4.0 m/s for private offices; 5.0–6.3 m/s for general offices, and 10.0 m/s for commercial space on the first floor [36]. Accordingly, the permissible indoor wind speed was increased from 1 to 7 m/s in steps of 1 m/s to generate airflow. Table 5 summarizes this experimental step.

3. Results

3.1. Verifying the impact of PM resuspension

3.1.1. Background PM concentrations of the mock-up air purifier

The PM concentrations measured with and without the air purifier are shown in Fig. 2.

When the air purifier was not operating (Case A), it took approximately 14 h (847 min) for the PM concentration to decrease from 1200 to 30 μg/m^3, and the concentration of resuspended PM was 109 μg/m^3.

When the air purifier was operating (Case A'), it took approximately 2 h and 15 min (135 min) for the PM concentration to decrease from of 1200 to 30 μg/m^3, and the concentration of resuspended PM was 85 μg/m^3.

Fig. 3 shows the final concentrations (shaded area) for cases A and A', and the maximum, minimum, and average PM concentrations are displayed in Table 6.

Without the air purifier (A), the maximum, minimum, and average PM concentrations were 109, 30, and 60 μg/m^3, respectively, indicating that 90.92% of PM was removed (based on the peak concentration of 1200 μg/m^3). Airflow resuspended 79 μg/m^3 of PM.

With the air purifier (A'), the maximum, minimum, and average PM concentrations were found to be 85, 30, and 48 μg/m^3, respectively, indicating that 92.92% of PM was removed. Airflow resuspended 55 μg/m^3 of PM.

There was a maximum (mean) difference of 24 μg/m^3 (12 μg/m^3) in the concentration of resuspended PM when the air purifier was used. Changes in the minimum concentration do not appear to be significant. These results indicate that the air purifier decreased the concentration of resuspended PM as it removed suspended PM, thereby reducing deposited PM.

3.1.2. PM concentrations with and without forced resuspension

Fig. 4 shows the PM concentration during the operation of the air purifier with (B') and without (B) forced resuspension of deposited particles. After 10 h of PM deposition, the air purifier was operated for 5 min.

With no forced resuspension (B), the PM concentration was reduced to 0 μg/m^3 by the air purifier, and the concentration of resuspended PM at the end of the experiment was 72 μg/m^3.

With forced resuspension(B'), the PM concentration was increased to 70 μg/m^3 by the combined action of the air purifier and forced airflow, and the concentration of the resuspended PM at the end of the experiment was 25 μg/m^3.

Fig. 5 shows the PM concentration over time for Cases B and B' for the last 60 min of the experiment (red shaded area in Fig. 4) and Table 7 shows the maximum, minimum, and average PM concentrations for the same period (see Table 8).

With no forced resuspension (B), the PM concentration was reduced from 12 to 0 μg/m^3 by the air purifier, and this concentration was maintained for approximately 20 min. The maximum, minimum, and average values of the final concentration were 72, 0, and 44 μg/m^3, respectively, indicating that 94.00% of PM was removed.

With forced resuspension (B'), the PM concentration rapidly increased from 20 to 70 μg/m^3; however, the concentration was then reduced to less than 10 μg/m^3 by the air purifier and this was maintained for approximately 20 min. The maximum, minimum, and average values of the final concentration were 25, 8, and 15 μg/m^3, respectively, indicating that 97.92% of PM was removed.

With forced resuspension during the operation of the air purifier, the maximum and average PM concentrations were reduced by 47 and 29 μg/m^3 compared to operation of the purifier with no forced resuspension. Furthermore, 50% of resuspended PM ranged from 20 to 60 μg/m^3 with no forced resuspension, and 50% of resuspended PM ranged from 10 to 20 μg/m^3 with forced resuspension (Fig. 6). This indicates that forced resuspension during the operation of the air purifier contributed to the relatively low concentrations of resuspended PM at the end of the experiment because the deposited PM was removed.

3.2. The most effective airflow direction

We compared the impact of one-way (90, 180, 270, and 360°) and four-way airflow on PM concentration following deposition and the results are shown in Fig. 7. It took between 4 and 16 h for the maximum PM concentration of 1200 μg/m^3 to decrease to 100 μg/m^3. When the PM concentration was 100 μg/m^3, the air purifier was operated and airflow was generated at the same time. The PM concentration was rapidly reduced from 100 to 10 μg/m^3 by the air purifier; however, this level gradually increased over the duration of the experiment (6 h) due to airflow stabilization. We attribute this to convection caused by the indoor–outdoor temperature difference.

Fig. 8 shows the final concentrations (red shaded area in Fig. 7) of the deposited PM under different airflows once the air purifier was activated, and the maximum, minimum, and average PM concentrations are shown in Table 7 (see Fig. 9).

The final concentrations for each wind direction were 38 (90°), 40 (180°), 52 (270°), 41 (360°), and 26 μg/m^3 (four-way). Based on the peak concentration of 1200 μg/m^3, the overall removal efficiencies were: 270° (95.67%) < 360° (96.58%) < 180° (96.67%) < 90° (96.83%) < four-way (97.83%).

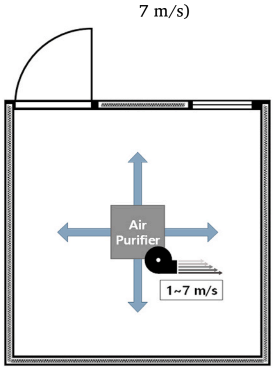
The results indicate that four-way airflow is more effective in removing deposited PM compared to one-way airflow. This appears to be because four-way flow increases the airflow diffusion radius compared to the one-way airflow, despite the reduction in airflow velocity.

3.3. Most effective airflow velocity

We compared airflow from 1 to 7 m/s to determine the most effective velocity for the resuspension of deposited PM. Fig. 10 shows variations

Table 5
Summary of the experimental method used to determine the most effective wind speed.

Details		Duration
Generation	Background PM conc. 1200 μg/m^3	1 h
Deposition	PM deposited to 30 μg/m^3	14 h
Concentration	Measuring PM conc. by wind speed (1, 2, 3, 4, 5, 6, and 7 m/s)	1 h



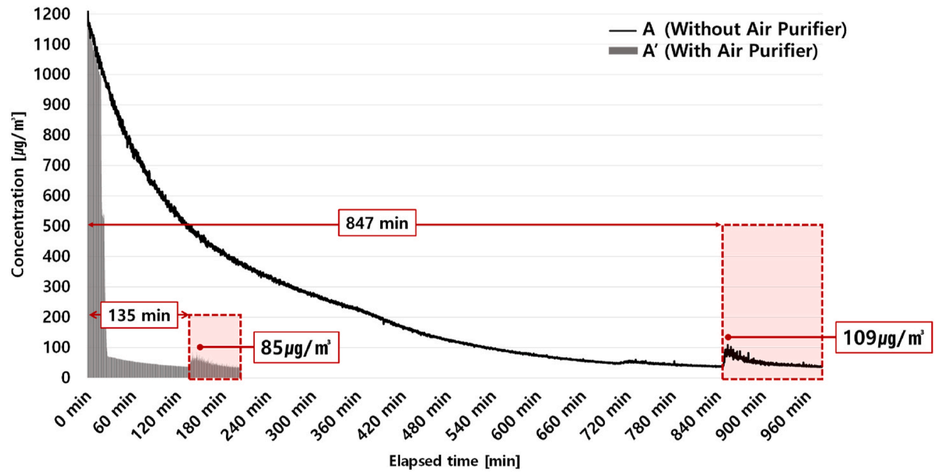


Fig. 2. Background particulate matter (PM) concentrations without the mock-up air purifier (A) and with the mock-up air purifier (A′).

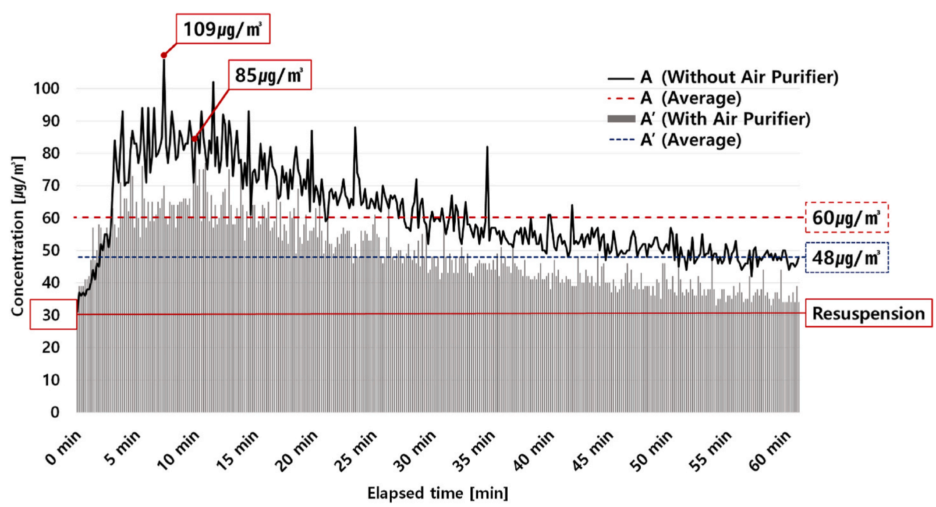


Fig. 3. PM concentrations over time for Cases A and A′ following resuspension.

Table 6
Maximum, minimum, and average PM concentrations for conditions A and A' following resuspension (μg/m3).

	Without Air purifier (A)	With Air purifier (A′)	Difference
Maximum	109	85	24
Minimum	30	30	0
Average	60	48	12

in the PM concentrations over time under different airflow velocities. Generally, particle resuspension did not occur for velocities of 1–4 m/s.

Fig. 11 shows the concentration distribution of resuspended PM, while Table 9 shows the maximum, minimum, and average concentrations.

When the airflow was 1–4 m/s, the maximum concentrations were 35 (1 m/s), 33 (2 m/s), 34 (3 m/s), and 32 μg/m^3(4 m/s) and the minimum concentrations were 30 (1 m/s), 29 (2 m/s), 24 (3 m/s), and 27 μg/m^3 (4 m/s). Below 4 m/s, the highest maximum (minimum) concentration was 35 μg/m^3 (30 μg/m^3), similar to the concentration at the beginning of airflow generation. This indicates that resuspension did not occur at these velocities. We attribute this to the occurrence of PM deposition. When the airflow was 5–7 m/s, the maximum concentrations were 117 (5 m/s), 102 (6 m/s), and 112 μg/m^3 (7 m/s) and the minimum concentration was 30 μg/m^3 (5–7 m/s). Furthermore, when the airflow was 5 m/s or more, the maximum concentrations were higher than 100 μg/m^3 and the minimum concentration was 30 μg/m^3, which is the concentration at the beginning of the airflow generation. This indicates that airflow of 5 m/s or higher deposited PM to be resuspended.

The resuspension efficiency of deposited PM was 16.67 (1 m/s), 10.00 (2 m/s), 13.33 (3 m/s), 6.67 (4 m/s), 290.00 (5 m/s), 240.00 (6 m/s), and 273.33% (7 m/s), indicating that the PM concentration increased by 2.4–2.9 times when the airflow was 5 m/s or more. This can be attributed to the occurrence of resuspension at flow speeds of 5 m/s or higher.

4. Conclusion

This study examined the removal efficiency of deposited indoor PM by inducing forced resuspension in conjunction with an air purifier. The removal and resuspension of the deposited PM were examined under the following conditions.

(a) Firstly, we compared the removal efficiency of deposited PM with and without the operation of an air purifier. Without the air purifier, the maximum, average, and minimum PM concentrations were 109, 60, and 30 μg/m^3, respectively, and when the air purifier was used, the maximum, average, and minimum PM concentrations were 85, 47, and 30 μg/m^3, respectively. Operating

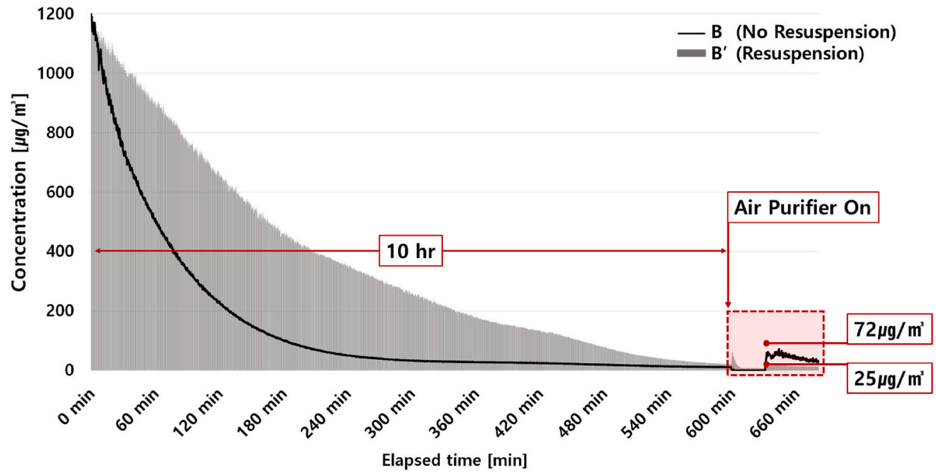


Fig. 4. PM concentrations over time showing 10 h of deposition and 5 min of purifier operation with (B′) and without (B′) forced resuspension.

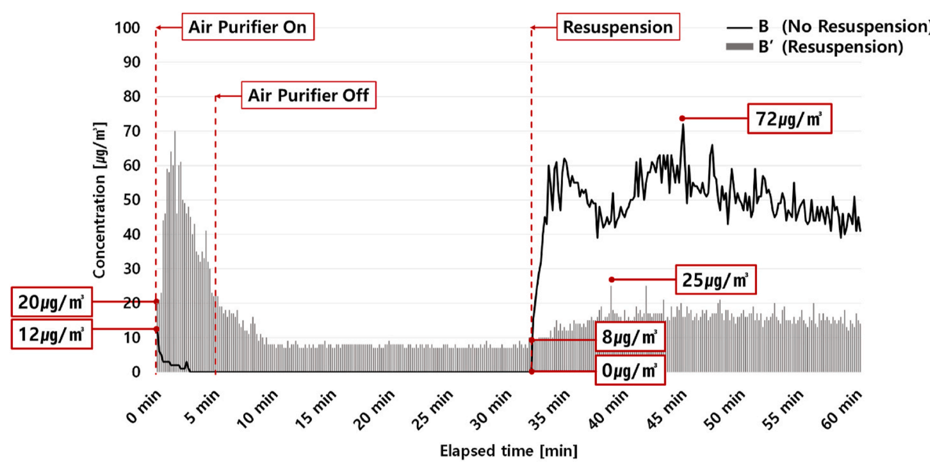


Fig. 5. PM concentrations over time for Cases B and B′ during the last 60 min of the forced suspension experiment (red shaded area in Fig. 4). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 7
The maximum, minimum, and average PM concentrations (for Cases B and B') (μg/m3).

	Without airflow (B)	With airflow (B′)	Difference
Maximum	72	25	47
Minimum	0	8	8
Average	44	15	29

Table 8
Maximum, minimum, and average PM concentrations (μg/m3) and removal efficiencies (%) under different airflow conditions.

	One-way				Four-way
	90	180	270	360	
Maximum	38	40	52	41	26
Minimum	24	29	32	27	13
Average	28	34	40	33	17
Efficiency	96.83	96.67	95.67	96.58	97.83

the air purifier resulted in a maximum PM removal difference of 24 μg/m^3, confirming that air purifier operation contributed to PM resuspension and removal.

(b) Secondly, we compared the removal efficiency of deposited PM with and without forced resuspension due to airflow. Without

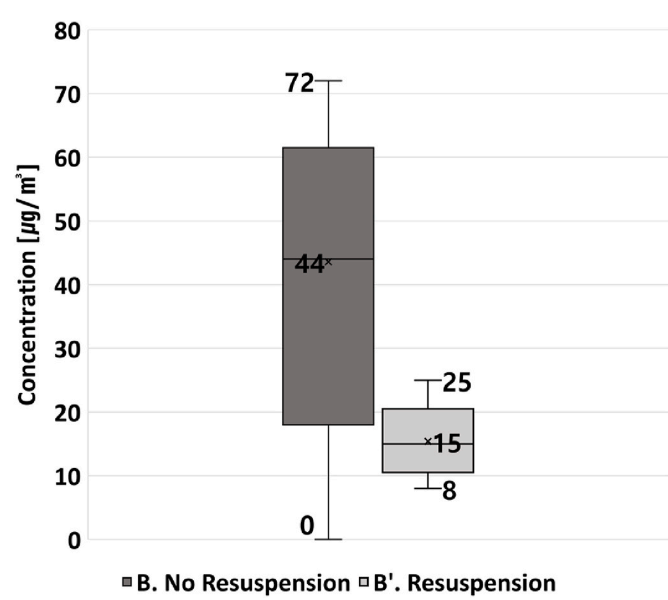


Fig. 6. Distribution of the final PM concentrations following resuspension (for Cases B and B′).

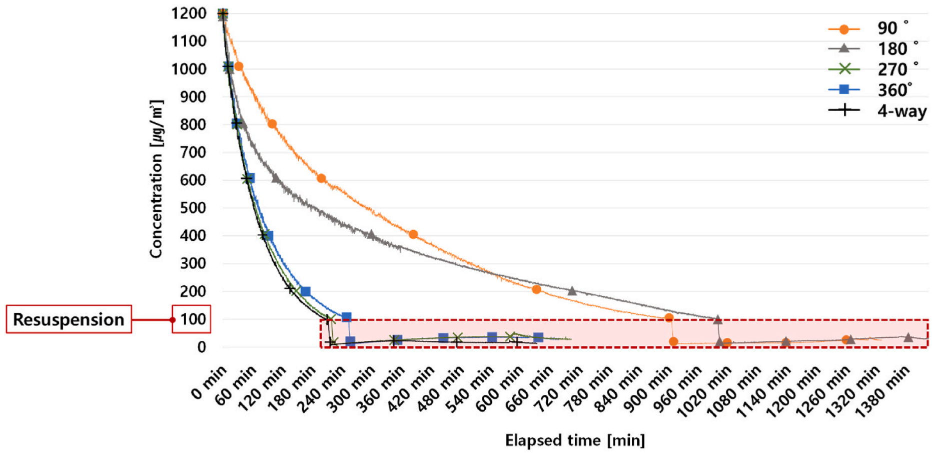


Fig. 7. PM concentrations over time using one-way and four-way air flow with air purification following deposition.

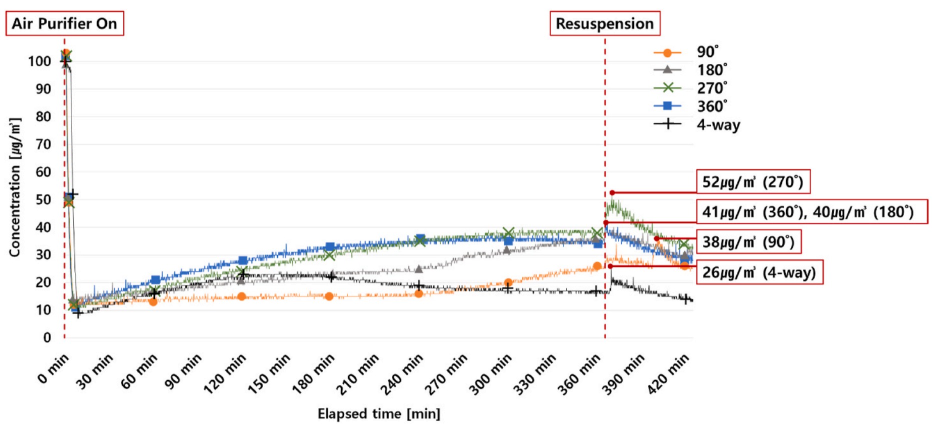


Fig. 8. Final PM concentrations (red shaded area in Fig. 7) of the deposited PM under different airflows following activation of the air purifier. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

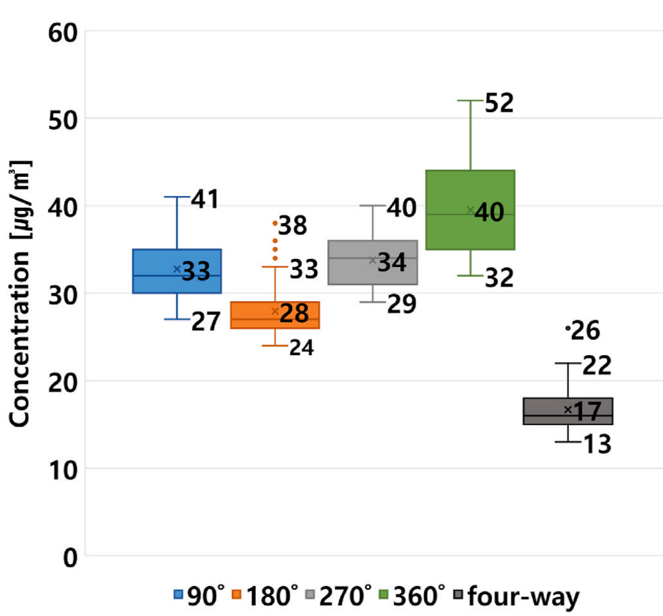


Fig. 9. Distribution of the final PM concentrations under different airflow conditions.

forced resuspension, the maximum, average, and minimum PM concentrations were 72, 44, and 15 μg/m^3, respectively, and 94.00% of deposited PM was removed. With forced resuspension, the maximum, average, and minimum PM concentrations were 25, 15, and 8 μg/m^3, respectively, and 97.92% of deposited PM was removed. Furthermore, forced resuspension during the operation of the air purifier resulted in a maximum and average PM reduction of 47 and 29 μg/m^3, respectively.

(c) Thirdly, we evaluated the impact of airflow direction on the removal efficiency of deposited PM. Results indicated that four-way airflow was more effective in removing deposited PM compared to one-way airflow. We attribute this to four-way flow increasing the airflow diffusion radius compared to one-way flow, despite the reduction in airflow velocity.

(d) Finally, we evaluated the impact of airflow velocity (1–7 m/s) on the removal efficiency of deposited PM. The maximum concentrations of resuspended PM at each wind speed were 35 (1 m/s), 33 (2 m/s), 34 (3 m/s), 32 (4 m/s), 117 (5 m/s), 102 (6 m/s), and 112 μg/m^3 (7 m/s), corresponding with a resuspension efficiency of 16.67 (1 m/s), 10.00 (2 m/s), 13.33 (3 m/s), 6.67 (4 m/s), 290.00 (5 m/s), 240.00 (6 m/s), and 273.33% (7 m/s). The resuspension of PM increased by 2.4–2.9. times at wind speeds of 5 m/s or higher, indicating that a wind speed of 5 m/s or higher was necessary for the resuspension of deposited PM.

In this study, we investigated a forced resuspension method for the effective removal of deposited indoor PM. Based on our results, we

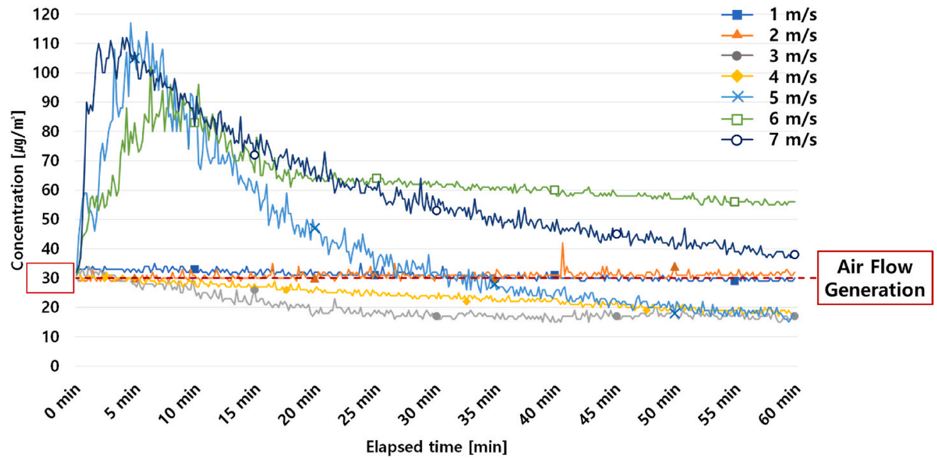


Fig. 10. Concentration of resuspended PM over time under different airflow velocities.

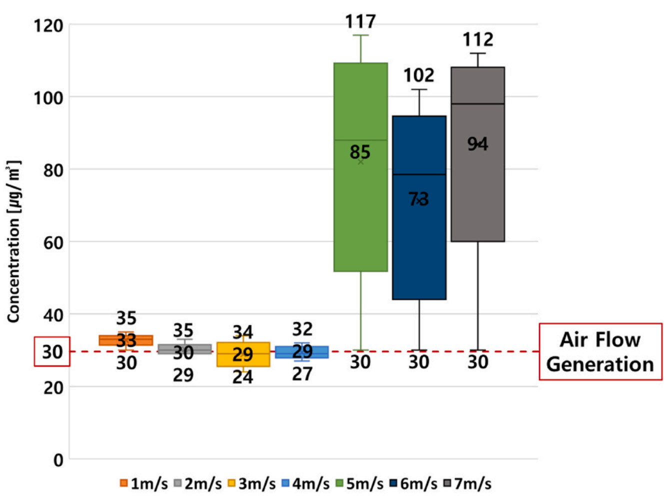


Fig. 11. Distribution of the final concentration of resuspended PM under different airflow velocities.

Table 9
The maximum, minimum, and average concentrations of resuspended PM by airflow velocity (μg/m3).

	1 m/s	2 m/s	3 m/s	4 m/s	5 m/s	6 m/s	7 m/s
Maximum	35	33	34	32	117	102	112
Minimum	30	29	24	27	30	30	30
Average	33	30	29	29	85	73	94

conclude that forced resuspension is an effective means of reducing deposited PM, and four-way airflow with a wide diffusion radius and a velocity of 5 m/s or higher are the optimum conditions for this purpose. However, our results were obtained from experiments carried out in a limited space. Consequently, further studies in office or residential spaces are necessary to explore the potential practical applications of our findings. Furthermore, the amount of PM generated and removed will vary depending on the installation environment (e.g. offices or residential spaces) and the occupants who utilize these spaces will also play a significant role. Therefore, further research related to adaptive measures that can control and facilitate PM generation and removal according to the installation environment and occupants is also required.

Author statement

All authors contributed equally.

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All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. 2019R1A6A3A0109551712).

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