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Influence of ventilation and air filtration system on indoor air quality within a residential apartment in Hanoi, Vietnam

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KEYWORDS

CO_2
$PM_{2.5}$
ventilation
Filtration
Residential apartment

ABSTRACT

Most households in major cities in Vietnam use air conditioning equipment for better indoor thermal comfort. However, to save electricity cost, the houses' rooms are often closed when the air conditioner is running. This habit causes the raising of indoor CO_2 concentration especially during the sleep night time. Therefore, mechanical ventilation is recommended to provide fresh air in. However, high polluted particle outdoor will follow outdoor air to get in the room. To comprehensively solving the above issues, the combination of central ventilation and air purification system have been applied. Their influence on indoor air quality within a residential apartment were tested and evaluated in this study. When the central ventilation and air filtration system was operated, not only indoor CO_2 concentrations but also indoor $PM_{2.5}$ concentrations were reduced significantly compared to those when the system was turn off. On the other hand, the study also found that the air purification capacity of the ventilation and filtration system was strongly depend on the air flow of the system, it increased when raising the air flow going through the system.

1. Introduction

Elevated indoor CO_2 levels are indicative of insufficient ventilation in occupied spaces and correlate with elevated concentrations of pollutants of indoor origin. Adverse health and well-being outcomes associated with elevated indoor CO_2 levels are based on CO_2 as a proxy, although some emerging evidence suggests CO_2 itself may impact human cognition. On the other hand, epidemiological studies have consistently shown the relation between fine particle concentrations (presented by mass concentrations of $PM_{2.5}$ and PM_{10}) and increase in both morbidity and mortality in respiratory and cardiovascular [1-5].

Due to economic development and uncontrolled urbanization process, ambient air pollution in major cities in Vietnam, such as Hanoi, Ho Chi Minh city is increasing. In the recent years, most households in major cities in Vietnam use air conditioners for better indoor thermal comfort. However, to save electricity cost, the houses' rooms are often closed when air conditioner is running. This habit causes the raising of indoor CO_2 concentration, especially during the sleep night time. Therefore, mechanical ventilation is recommended to provide fresh air in. Although, high outdoor polluted particle will follow fresh air to get in the room. To solve these problems, a central ventilation with machenical filters was applied to public buildings [6, 7] and residential houses [8, 9]. Alevy et al. have found that the effectiveness of filters was strongly depended on the ventilation rate and the runing time of the system; higher filter efficience when larger ventilation rate and longer running time [9]. While the influence of ventilation and filtration system in residences in Hanoi on indoor air quality is not available. Hence, to fill the gaps, this study aims to: 1) Explore the variation of indoor air quality within a residential apartment, where a central ventilation and filtration system was applied; 2) Assess the influence of this equipment on indoor air quality.

2. Methodology

2.1. Study area and measured locations

Study area is in Hanoi, capital city of Vietnam, with its locations, geographic and climate conditions was described in detail in [10]. In Hanoi, motorbikes are the main transport mode that people use for travelling. The number of motorbikes and cars in Hanoi has increased rapidly in recent years, surpassing the growth rates of population, GDP, and the growth of automobiles will continue to grow for years ahead. Recently, high rise apartments were also raised rapidly to satisfy the living demand of high population. Of which, many buildings are located close to busy traffic roads. Hence, one apartment installed the central ventilation and filtration system in level 12 of a high-rise apartment building closed to the busy National Express way No.1B, 100 m from the West were chosen to test.

2.2. Test equipment and AP monitors

2.2.1. Test equipment

Test equipment is a central ventilation and filtration system. It is named AIRSAFE. The equipment's flow rate is 1200 m^3/h and its . Its purifier consists of the primary and HEPA filters. The system works on the principle of one-way outdoor air filtration, operating according to the mechanism of creating positive pressure, making the pressure in the room higher than the surrounding pressure. When continuously

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supplying fresh, clean outdoor air into the room, indoor old air will be slowly pushed out of the room through the door slots. The detail layout of the system is showed in Figure 1.

2.2.2. AQ monitors and their quality assurance

Three AirVisual Pro Monitor (IQ Air, Switzerland) were used in this study. They are low-cost optical particle counters, monitoring temperature (0 °C to 40 °C), PM (0.3- 2.5 µm), CO_2 (400 - 10,000 ppm) and relative humidity (0- 95 %). The AirVisual uses a SenseAir S8 sensor for CO_2 measurement. This is a miniature, non-dispersive infrared (NDIR) and individually calibrated ABC sensor with an accuracy of ± 0.02 % volume CO_2 ± 3 % of reading. A $PM_{2.5}$ sensor is AirVisual own co-developed sensor called AVPM25b. It can detect particles from 0.3 µm to 2.5 µm. The accuracy range is ± 8 % of reading. It uses a small fan to draw air inside the laser and through light scattering phenomenon, the sensor can calculate the concentration of particles. The light refraction is analyzed by the photo-sensor algorithm to output $PM_{2.5}$ and PM_{10} values.

These sampling devices have proven to be appropriate for monitoring both outdoor and indoor air quality and also has been used in other air quality studies, such as monitoring the second-hand smoke level through quantification of the $PM_{2.5}$ concentration. No correction factor was applied to AirVisual data as a previous calibration study indicated this is not needed for monitoring SHS, even at much higher concentration levels [11-15].

2.3. Measurement procedures

The tests were conducted in two periods: one in the rainy summer from 27 May to 7 June 2023, the other in the dry autumn from 9 to 18 October 2023. To test the air purification, the V&F system was operated according to 3 modes: V&F system was turned off (V&F_OFF); 2) V&F system was turned on with full/high air flow rate (V&F_HF); and 3) V&F system was turned on with half/low air flow rate (V&F_LF). The detail operation schedule is presented in Table 1.

Table 1. The detail operation schedule of the V&F system.

Measure period	V&F system's operation modes		
	V&F_OFF	V&F_LF	V&F_HF
Rainy summer	28/5/2023 – 31/5/2023	4/6/2023-7/6/2023	3/6/2023-4/6/2023
Dry autumn	12/10/2023-14/10/2023	14/10/2023-18/10/2023	9/10/2023-12/10/2023

Three Air Visuals were used to measure continuously and simultaneously both indoor and outdoor CO_2 and $PM_{2.5}$ concentrations. One AirVisual was located next to the inlet of the AIRSAFE in the balcony for outdoor monitoring. Other two AirVisual were located in the living room and bedroom to measure their indoor air quality, respectively. The detail locations of the AirVisual are showed in Figure 1.

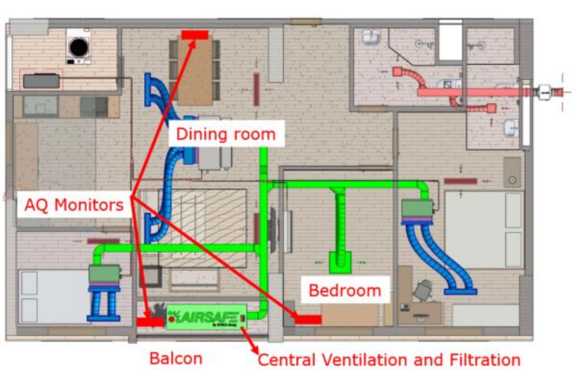


Figure 1. Locations of the test V&F system and AQ monitors.

2.4. Data preparation and analysis

After sampling at each period, the data were downloaded, inspected, and archived. All associated information such as weather conditions, operation schedule of the equipment were entered corresponding to the monitoring period. The collected data of each measured period were classified by each operation mode of the V&F system.

Descriptive statistical analysis was presented as mean, standard deviations (SD), median, and min-max. The ratios of pair of indoor and outdoor CO_2 and $PM_{2.5}$ concentrations were calculated on a sample-by-sample basis, and then averaged (not calculated as the ratio of the means). All statistical comparisons consisting of t-test and one-way ANOVA were performed with SPSS version 20 (SPSS Inc.), with a 5 % level of significance ($p < 0.05$).

3. Results and discussion

3.1. The summary of indoor and outdoor air quality

Overall indoor and outdoor CO_2 and $PM_{2.5}$ during the rainy summer and dry autumn are presented in Table 2. Their variation are shown in Figure 2 and Figure 3, respectively.

While average outdoor CO_2 concentration in the Summer (422 ± 13 ppm) was not significantly different compared to that in the August (425 ± 13 ppm) ($p > 0.05$), average outdoor $PM_{2.5}$ concentrations in rainy summer (20.5 ± 12.5 µg/m^3) was significantly lower than that in the dry autumn (25.8 ± 22.2 µg/m^3) ($p < 0.05$). The lower $PM_{2.5}$ in rainy season compared to those in dry season was also reported in Hanoi in previous publishes [16, 17].

In general, CO_2 concentrations in the living room and bedroom were always significantly higher than those outdoor during both the summer and autumn. Interesstingly, the CO_2 levels in the bedrooms were significantly higher than those in the living room. It could be explained that the frequent present of the occupants in the bedroom. On the other hand, the air exhchange rate of the living room was higher than the bedroom due to the living room next to other rooms and balconies, and its doors were usually opened.

Table 2. Statistic descriptive of indoor and outdoor AQ.

Rooms	Parameters	During Summer				During August			
		Mean	SD	Max	Min	Mean	SD	Max	Min
Living room	Temp. (°C)	31.6	0.6	33.2	29.0	28.5	0.7	30.1	27.0
	RH (%)	71.8	6.7	91.7	54.0	65.4	5.1	78.8	53.0
	CO_2 (ppm)	596.8	153.3	1040.7	401.1	610.4	174.5	1917.1	391.9
	$PM_{2.5}$ (µg/m^3)	71.8	6.7	91.7	54.0	8.5	12.6	118.3	0.0
Bedroom	Temp. (°C)	29.1	2.1	32.3	23.5	27.5	1.3	30.2	25.2
	RH (%)	66.5	9.8	85.9	49.0	68.2	6.7	82.0	45.1
	CO_2 (ppm)	714.8	254.5	2293.3	400.1	667.1	215.4	1330.9	398.6
	$PM_{2.5}$ (µg/m^3)	10.3	15.1	341.9	0.1	5.0	8.0	79.6	0.0
Outdoor	Temp. (°C)	29.7	2.0	35.4	25.2	26.2	2.1	32.1	23.1
	RH (%)	80.6	8.8	99.0	51.6	72.9	8.8	90.2	53.0
	CO_2 (ppm)	421.7	13.5	518.1	383.1	425.2	13.1	479.3	404.2
	$PM_{2.5}$ (µg/m^3)	20.5	12.5	100.6	2.4	25.7	22.1	159.5	4.3

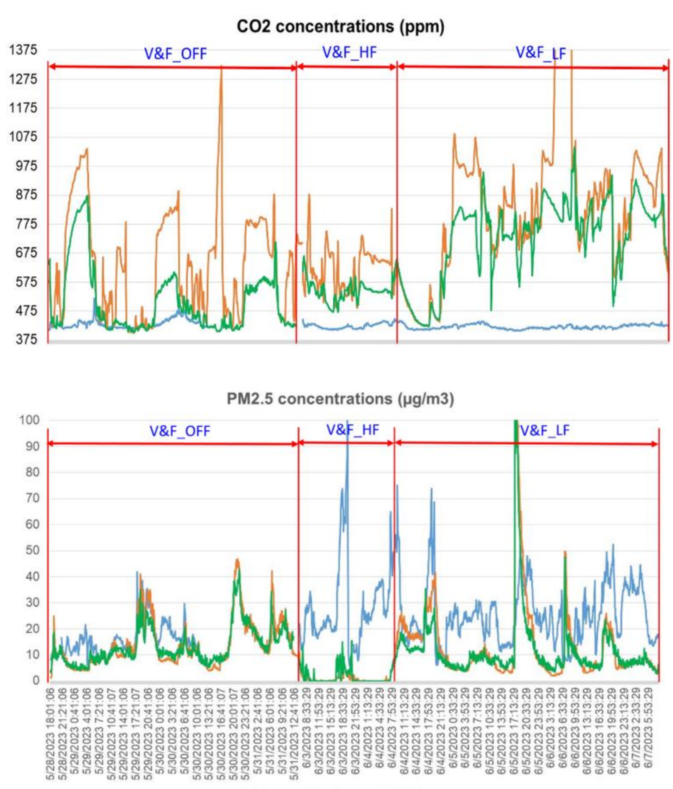
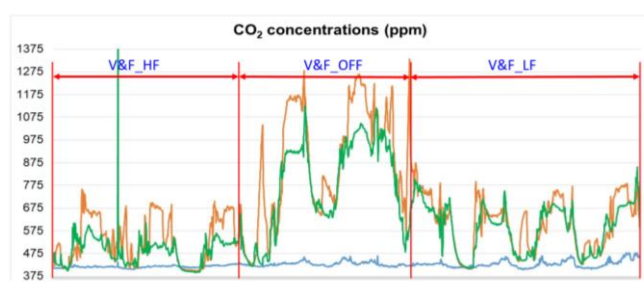
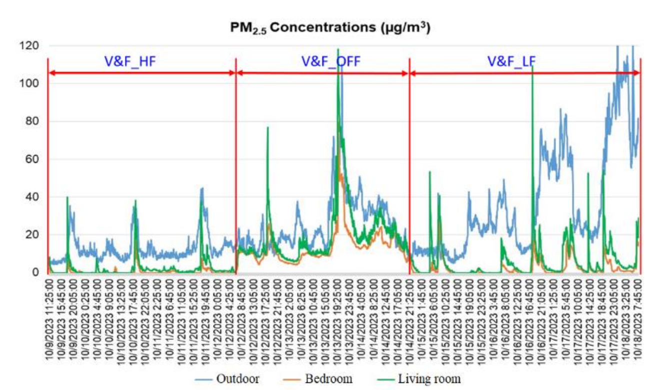


Figure 2. Variation of CO_2 and $PM_{2.5}$ concentrations during the Summer.



(a)



(b)

Figure 3. Variation of CO_2 (a) and $PM_{2.5}$ (b) concentrations during the August.

3.2. The Influence of the Central Ventilation and Filtration system on IAQ

3.2.1. Influence on CO_2

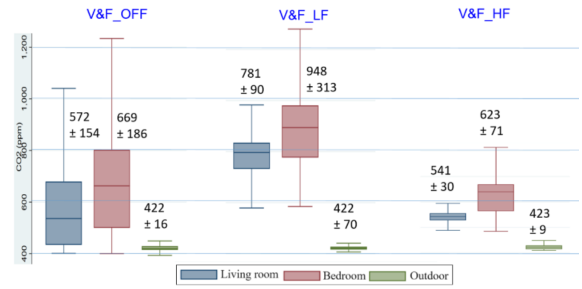
Overall indoor living room and bedroom and outdoor CO_2 concentrations and their I/O ratios during the Summer and August under different running modes of the V&F system were showed in Figures 4 and 5, respectively.

The variation of indoor CO_2 concentrations was strongly influenced by the V&F operation modes. They were lower when turned on the V&F system, especially V&F system run with high flow rate. Interestingly, during August, when the V&F system turned off, the indoor CO_2 was significantly raising and higher than those in the Summer. It could be explained that the windows were always opened for better natural ventilation when the V&F system and air conditioners were turned off in the Summer. However, the windows were usually closed to prevent higher outdoor particle pollution even V&F system was not operated.

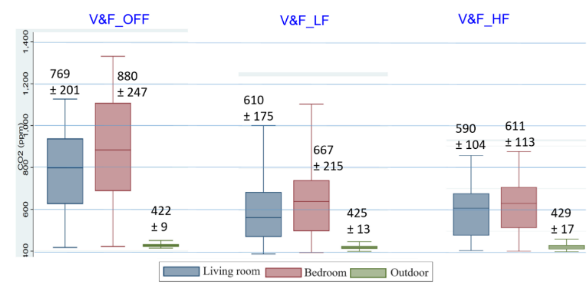
In the Summer, Indoor living room and bedroom CO_2 concentrations were lowest during the V&F system run with high flow rate (541 ± 30 ppm and 632 ± 30 ppm). While their indoor CO2 concentrations were highest during the V&F system run with low flow rate (781 ± 90 ppm and 948 ± 313 ppm). The indoor living room and bedroom CO_2 concentrations during the V&F system Off were 572 ± 154 ppm and 669 ± 186 ppm, respectively.

In the August, when the V&F system was turned on with low and high flow rates, the indoor CO_2 concentrations in the living room (610 ± 175 ppm and 590 ± 104 ppm, respectively) and the bedroom (667 ± 215 ppm and 611 ± 113 ppm, respectively) were significantly reduced and lower than those when the V&F system turned off (709 ± 201 ppm and 880 ± 247 ppm).

The indoor to outdoor ratios of CO_2 in the living room and bedroom compared to those outdoor were strongly confirmed the capacity of V&F system to dilute indoor CO_2 when bringing fresh outdoor air in. When the V&F turned on with high flow rate, the ratios of indoor to outdoor CO_2 concentrations for both seasons in the living room (1.28 ± 0.0.6 and 1.37 ± 0.22, respectively) and in the bedroom (1.47 ± 0.17 and 1.42 ± 0.24, respectively) were lowest. While the V&F system turned on with low flow rate, the I/O ratios for the living room and the bedroom during the August (1.43 ± 0.39 and 1.56 ± 0.49, respectively) were still significantly lower than those when the V&F turned off (1.79 ± 0.45 and 2.05 ± 0.56, respectively). However, the I/O ratios for the living room and the bedroom during the Summer (1.8 ± 0.21 and 1.25 ± 0.74, respectively) were significantly higher than those when the V&F turned off (1.41 ± 0.38 and 1.60 ± 0.45, respectively). The higher indoor CO_2 concentrations when the V&F turned on with low flow rates compared to when it off could be due to the windows were immediately opened for better natural ventilation when the air conditioners and V&F system were not working during the hot summer.

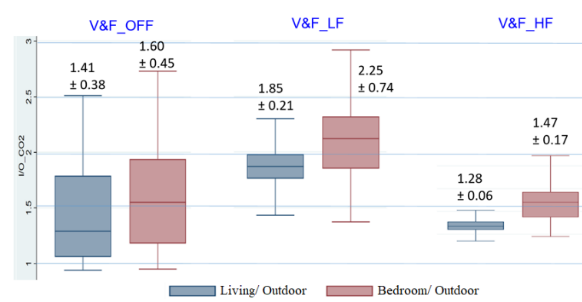


(a) During the Summer

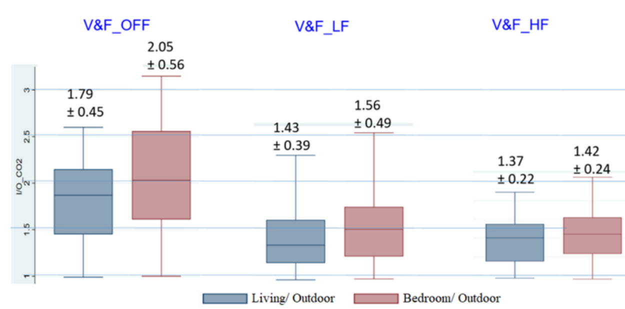


(b) During the August

Figure 4. CO_2 concentrations in the differences of the V&F system operations.



(a) During the Summer



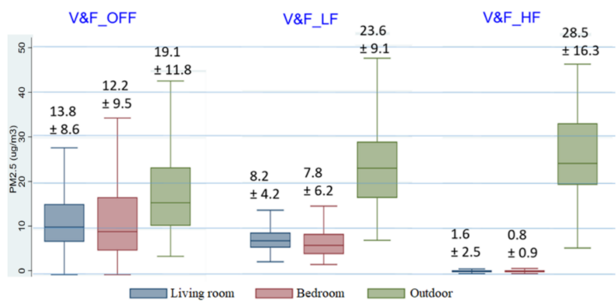
(b) During the August

Figure 5. I/O ratios of CO_2 concentrations in the differences of the V&F system operations.

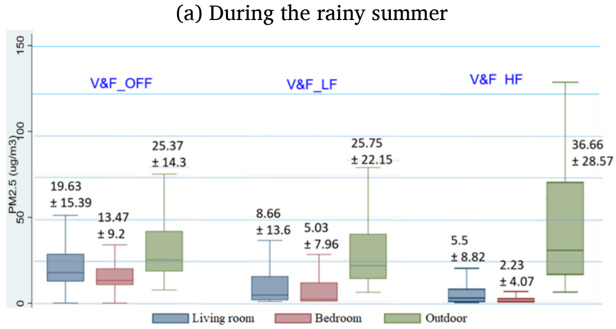
3.2.2. Influence on $PM_{2.5}$

Overall indoor living room and bedroom and outdoor $PM_{2.5}$ concentrations and their I/O ratios during the rainy summer and dry autumn under different running modes of the V&F system were shown in Figures 6 and 7, respectively.

In general, the trend of indoor $PM_{2.5}$ closely followed the outdoor for both seasons when the V&F system was not worked, but significantly reduced when the V&F was operated again. Indoor $PM_{2.5}$ concentrations in the living room and the bedroom were significantly reduced and lower compared to those when the V&F system was not operated. However, the indoor $PM_{2.5}$ concentrations in both the living room and bedroom when the V&F was run with high flow rate were significantly lower than those when the V&F was run with low flow rate. This finding is similar to those reported in previous studies [7, 9].

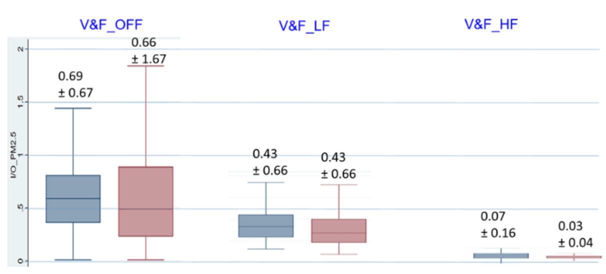


(a) During the rainy summer

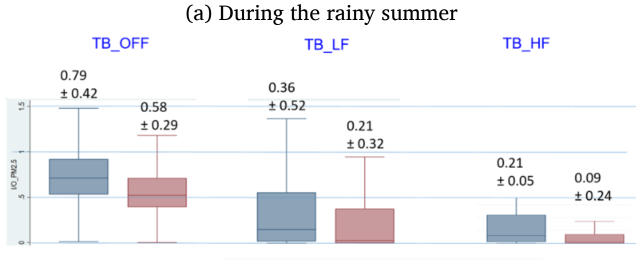


(b) During the dry autumn

Figure 6. $PM_{2.5}$ concentrations in the differences of the V&F system operations.



(a) During the rainy summer



(b) During the dry autumn

Figure 7. I/O ratios of $PM_{2.5}$ concentrations in the differences of the V&F system operations.

4. Conclusion

This study has quantified the impact of the central ventilation and air filtration system on indoor air quality in the residential apartment in Hanoi, Vietnam. When the central ventilation and air filtration system was operated, not only indoor CO_2 concentrations but also indoor $PM_{2.5}$ concentrations were reduced significantly compared to those when the system was turn off. On the other hand, the study also found that the air purification capacity of the ventilation and filtration system was strongly depend on the air flow of the system, it increased when raising the air flow going through the system.

This is the first time, the in-situ working capacity of the central ventilation and filtration in Hanoi was determined. These results are clear and convincing evidence to encourage the usage of the central ventilation and air filtration system within buildings, especially residential to protect their occupants' health.

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