Development of fan-filter unit to enhance IEQ in NV buildings during haze episode

David Kok Wai Cheong*, Kwok Wai Tham, Chandra Sekhar, Ganesh K. Parshetti

National University of Singapore, Singapore

*Corresponding email: bdgeckw@nus.edu.sg

SUMMARY
Exposure to particulate matter (PM) during the 2015 Southeast Asia haze episode raised an urgent need to maintain acceptable indoor PM levels of naturally ventilated buildings when outdoor PM levels reached unhealthy levels. Under this consideration, a fan-filter unit (FFU) has been developed to provide filtered outdoor air to indoor environments by removing airborne PM from outdoor air and meanwhile continuously pressurizing indoor spaces to reduce infiltration of outdoor air. This study explores size-resolved particle filtration efficiencies by conducting in-situ tests of FFU with filters of three ratings (i.e. MERV 7, MERV 11, and MERV 13) in a natural ventilated primary school classroom in Singapore. The results suggest that use of FFU plays a key role in mitigating indoor air pollutants, particularly PM during haze episodes. Moreover, appropriate use of higher rated MERV filters in FFU delivers exceptionally clean indoor air during severe haze period.

KEYWORDS
Haze, particulate matter, children, school health, elementary school

1 INTRODUCTION
From 1982, trans-boundary haze pollution has turned into a frequent phenomenon in Southeast Asia with the severe haze episodes in 1997–1998, 2006–2007, 2013 and 2015. This phenomenon was induced by dry climate during the season in July to October (Heil et al 2007; Vadrevu et al 2014; Cao et al. 2016). In Indonesian islands of Sumatra and Kalimantan forest, land fire is used by people to clear and convert the land into other agricultural purposes mainly for plantation of oil palm (Anderson and Bowen 2000, Gaveau et al 2014, Lestari et al 2014). These Forest and land fires caused trans-boundary air pollution to Singapore (Murdiyarso and Lebel 2007). A high concentration of aerosols is produced from fire that degrade the local air quality and reduce visibility. In October 2015, the highest concentration of PM$_{2.5}$ were recorded at 442 μg m$^{-3}$ (The Straits Times, 2015) and far exceeded the ambient air quality standards in Singapore referring to the World Health Organization (2006) which is 25.89 μg m$^{-3}$. During severe haze episodes, indoor air pollutants particularly PM can trigger short- and long-term
health problems, including asthma, respiratory tract infection and disease, allergic reactions, headaches, nasal congestion, eye and skin irritations, coughing and sneezing (Oberdorster et al. 1995; Mendell et al. 2005; Ntziachristos et al. 2007). Indoor air quality (IAQ) in naturally-ventilated school buildings may have an adverse effect on students’ health and even their learning performance. Children seem to be most vulnerable to the harmful effects of ambient air pollutants because their defence mechanisms are still evolving and they inhale a higher volume of air per body weight than adults (Salvi, 2007).

This paper reports the findings of a study conducted concerning the effectiveness of a FFU for the removal of indoor PM in a naturally-ventilated school classrooms during 2015 haze episode. The potential of FFU in filtering outdoor PM was explored by FFU installed with MERV 7, MERV 11 and MERV 13 filters. The main objective of this study is to evaluate the performance of a draw through FFU to remove indoor submicron (0.350-0.900 µm) and micron (2.5 µm) range particles by providing clean (filtered) outdoor air into the naturally ventilated hostel rooms during high outdoor pollution conditions.

2 MATERIALS/METHODS

2.1. FFU Design

The dimensions of the wooden framed FFU are shown in Figure 1. It is designed in the current research as a draw-through mode where filters and associated housing are provided at the rear of the fan in the fan chamber. Air filters with appropriate MERV ratings, i.e. MERV 7, MERV 11 and MERV 13, are incorporated with a fan in an embodiment comprising of a fan chamber and a bleed chamber to supply filtered outdoor air into the room, and inhibit ingress of external pollutants by means of room pressurization. The fan used in the FFU system is a 350 mm diameter KDK axial fan Model 35GSC (50 Hz). The fan speed is constant at 1420 RPM (735CFM) with fan unit consumption of 88W and noise level of 44dB. The dimension of the filters used in the FFU unit is 600mm × 600mm × 25mm.

![Figure 1. Schematics of FFU systems employed for the studies.](image)

2.2. Experimental setup

This study was conducted in October 2015, where haze levels were significantly higher in Singapore. Experiments were conducted at a Primary School classroom in Singapore. The room
is $9.6 \times 9.6 \times 3.4$ m with a volume of about $313$ m$^3$, and is located on the 3rd floor of the building. A corner room is chosen to ensure an unobstructed flow of air and therefore higher exposure to haze. A control room is selected on the 4th floor with identical orientation as the room on the 3rd floor. Two FFU prototypes were mounted on the louvered glass windows of the room on the 3rd floor as shown in Figure 2.

Figure 2. Layout of the school classroom chosen for the study.

The housing of the FFU prototype is airtight. Incandescent light bulbs were used to simulate heat gains from humans (60W per student $\times$ 40 students) at various locations in the classroom. In addition, two humidifiers (Gazz humidifiers) were used to simulate the relative humidity (RH) and temperature characteristics of human breath at a constant human volume flow rate. It provided a maximum humidification of 400/ml per hour. Ceiling fans were turned on during the experiment to simulate normal operation of the classroom. One set of the monitoring equipment is placed around the middle of the class while the other set is placed immediately outside the classroom as can be seen in Figure 2.

The I/O ratio directly represents the relationship between indoor and outdoor particle concentrations and is defined as:

$$I/O\ ratio = \frac{C_{in}}{C_{out}}$$

(1)

Where $C_{in}$ and $C_{out}$ are the indoor and outdoor PM concentration respectively.

Overall PM removal efficiency was determined using the equation:

PM Removal Efficiency $= 1 - I/O\ ratio \times 100$  \hspace{1cm} (2)
Overall PM removal efficiency of the system represents the fraction of PM that are removed from the outdoor air, in a quasi-equilibrium state, which takes into account the effects of the overall contribution by various factors (such as deposition, internal sources and processes).

3 RESULTS AND DISCUSSION

3.1. PM mitigation performance
The FFU has been deployed to provide ventilation to the hostel room during hazy condition and to improve the indoor air quality, as an alternative strategy to address the limitations of air purifiers and other equipment (Wei et al. 2011). Polluted indoor air with particulate matter is being replaced by suppling outdoor air that is being purified using the FFU with different MERV filters.

For the four major submicron particles size bins of 0.350-0.450 µm, 0.450-0.575 µm, 0.575-0.725 µm and 0.725-0.900 µm detected during haze episode, average background removal efficiency of the classroom under the condition of doors and windows fully closed with no FFU in operation (no outdoor air intake) was 43.6%, 35.8%, 42.9% and 42%, respectively. After the FFU was installed, average filtration efficiency for the three size bins reached 29.8%, 19.28%, 25.7% and 31% with MERV 7; 91.0%, 90.7%, 92.7% and 93% with MERV 11; 91.0%, 90.7%, 92.8% and 93.2% with MERV 13 (Fig. 3a). For micron size particle, i.e. PM$_{2.5}$, filtration efficiency was 50.5% under background condition, and 37.9%, 93.2%, 93.3% with MERV 7, MERV 11 and MERV 13 filter, respectively (Fig. 3b).

It is observed that MERV11 and MERV13 filters have provided similarly high filtration efficiencies that are far higher than the efficiency of MERV 7 filter. A FFU with MERV 11 or MERV 13 filter generally maintained more acceptable indoor particle levels as compared to MERV 7 filters. During the test period when outdoor PM$_{2.5}$ mass concentration was significantly elevated beyond the level of 80 µg/m$^3$, FFU with MERV 11 and MERV 13 filter consistently maintained constant indoor PM$_{2.5}$ concentration at a well below accepted range (3.9-5.9 µg/m$^3$).

Fig. 3. Filtration efficiency for a) particle from size ranges from 0.350 -0.900 µm and b) PM$_{2.5}$ by FFU using different type of MERV filters.
4 CONCLUSIONS
Indoor air quality of schools is of continuous concern not only to students and teachers but their parents during haze episode. Hence, mitigation of indoor pollutants is necessary to maintain a reasonable level of indoor air quality in schools. Investigations were carried in a school classroom installed with FFU during the haze period to understand its particulate matter removal efficiency. FFU installed with MERV 7, MERV 11 and MERV 13 filters were explored and results have clearly suggested with the use higher rated MERV 11 and/or MERV 13 filters in FFU, more than 90% filtration efficiency could be achieved with both submicron and micrometer range particles. Furthermore, the pressurization feature of the FFU helps to prevent ingress of PM via the building envelope, windows, doors, etc. In summary use of FFU improves IAQ better and can act to reduce exposure to harmful particulate matter during haze episode.

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6 REFERENCES