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Field Testing of General Ventilation Devices and Systems for Particles Removal Efficiency and Pressure Drop

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Abstract

The prevalence of indoor occupancy in human societies today bring with it considerable issues pertaining to the indoor environment of enclosed residential and commercial spaces. Indoor air quality is one of those aspects of indoor environment that requires attention as persistent exposure to poor air quality can cause allergenic, visual and respiratory problems for occupants, inhibiting productivity and well-being. Today's air filtration marketplace includes products, offered in many configurations, that present various advantages and disadvantages when compared to other air filter offerings. There are also different types of media incorporating varying principles of particle capture, each with its own advantage when applied in a ventilation and air conditioning application. How can filter users differentiate manufacturers' claims and make intelligent decisions as to what products are applicable to meet their needs? Historically, many depended upon test reports. Unfortunately, today's testing laboratory methodologies may not give a true barometer of a filter's performance over time, as these filters are not tested under real life conditions. While high-efficiency filters can adequately address airborne contaminants, it is at the cost of increased energy on the air conditioning system. In this study, a comparison (in-situ test) was made between mechanical fine V-Bank air filters (ePM1 55% / F7) and Electrostatic Precipitators (Polarized filters) on the pressure drop incurred while ensuring adequate removal efficiency and satisfactory air quality for occupants. It was found that over 7 months of measurement at the tested airflow, no measurable increase in pressure drop was observed for the specimen mechanical filter, while the ESP (polarized filters) saw increasing pressure drop as the study progressed.

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Keywords: *Mechanical air filtration, Electrostatic precipitator*

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1. Introduction

People spend more than 90 percent of their time indoors, at home, at work, at shopping centres or in their vehicles. It is widely accepted that indoor environment is important to public health and that a high level of protection against adverse health effects due to inadequate quality of the indoor environment should be assured. Indoor Air Quality (IAQ) refers to the quality of air within an air-conditioned environment. The quality of indoor air is determined mainly by the indoor thermal environmental conditions and the levels of indoor airborne contaminants. It is of concern because most people spend the majority of their time indoor. It is well recognized the impact of unhealthy levels of indoor air contaminants on “Sick Building Syndrome” (SBS) often manifesting in occupants as ocular, nasal, cutaneous irritations, allergies and respiratory problems. While filters can adequately remove such contaminants from outdoor air, the resistance incurred in the air handling results in reduced energy efficiency due to the pressure loss across the filter. Additionally, this pressure drop increases the longer the filter is used due to accumulation of particulate.

Air filtration techniques can be divided into six types based on particle removal efficiency: Coarse, Medium, Fine, Efficiency Particulate Air (EPA) filters, High Efficiency Particulate Air filter and Ultra Low Penetration (ULPA) filter. Following ISO 16890 standards, Coarse-medium-fine has been regrouped 4 groups: Coarse-PM10-PM2.5-PM1. EPA and ULPA filters are classified according to their efficiency at the most penetrating particle size (MPPS). EPA has particle removal efficiencies $\geqslant$85% (E10) to $\geqslant$99.5% (E12), and ULPA has $\geqslant$99.9995% (U15) to $\geqslant$99.999995% (U17), according to the EN1822:2009 standard for air filter classification. The MPPS size is typically between 0.1 and 0.2 micron, but for some filters, like membrane filters, it may also be lower.

Medium filters at 0.4 micron, they typically have removal efficiency below 35%. Average over the life when dust loading with a standardized test dust, they have 40-60% (M5) or 60-80% (M6) efficiency at 0.4 micron. On PM2.5 they typically have 50-60% (M6) or <50% (M5). On PM10 they typically have >50% (M5) or >60% (M6) [1]. At present, air filters constitute the most commonly used of air purifiers, often made of material as diverse as non-woven nano fibre [2], glass fibre [3] and even stainless steel wire mesh [4]. Fine filters, such as the one used in this study typically have minimum particle removal efficiencies of 35-70% at 0.4μm, and average efficiencies of 80-95% at 0.4μm, during the course of their lifespan as defined by EN779:2012. ISO 16890 defines ePM1 filters as fine filters, typically have minimum particle removal efficiencies of 50-95% at PM1. Refer to the ASHRAE 52.2 standard, where fine filters would correspond to MERV 13A to MERV16A, and have typical efficiencies defined for 0.3-1, 1-3 and 3-10μm. On the other hand, in electrostatic (ES) filters, which combine electrostatics, washable and filtration type devices, purifies air by attracting and trapping particulates with static electricity. Electrostatic precipitators are effective at destroying fungal spores and work best with particle sizes above 1μm and generally have lower removal efficiencies than mechanical filters [1]. Wen et al. [5] defined a key energy performance parameter for mechanical and electrostatic filters and deduced that ESPs performed better than mechanical filters due to lower pressure drop. Jaworek et al. [6] reviewed and tested the efficiencies of two-stage ESPs and found higher fractional removal efficiency for PM2.5 particulate higher than 95% compared to traditional methods. Feng et al. [7] developed a novel enhanced electrostatic filtration system with a pin-filter media-conductive plate configuration that improved removal efficiency without increasing pressure drop. Most of the studies concluding better performance of ESPs focused on laboratory-scale experiments using flat filters. A flat filter cannot be used directly in a practical filtration system because of the relatively high filtration velocity. High filtration velocity would lead to low efficiency and high pressure loss, according to classic filtration theory [8,9]. In practical applications, a flat filter is pleated in order to increase the filtration area. Nevertheless, there is no available literature related to electrostatic enhanced pleated air filter. Furthermore, few studies of theoretical and numerical models for electrostatic enhanced air filters have been published, even though flat/pleated filters without the electrostatic effect have been thoroughly investigated by means of experimental, theoretical and numerical methods [10,11].

In this study, field testing (in-situ) of fine mechanical filters and electrostatic precipitators (polarized filters) will examine their pressure difference and particle removal efficiency under constant airflow to determine the filter performance under live conditions. This testing will also determine if said devices meet air quality compliant to the Code of Practice for Indoor Air Quality for Air-Conditioned Buildings (SS554:2009), Singapore Standards Council published by SPRING.

Nomenclature

AHU	Air handling unit
ESP	Electrostatic Precipitator (Polarized filter)
IAQ	Indoor air quality
ΔP	Pressure difference across filter (in Pa)
Q	Airflow rate (in m^3/s)
SBS	Sick building syndrome
ULPA	Ultra-low particulate air (filter)

2. Experimental Setup

Two identical air-handling units (AHUs) serving similar separate areas were selected for the test at one of the building in NTU, Singapore. In one unit (AHU1), existing filters in use were replaced by the test filters while the other (AHU2) remained as a control. To ensure consistency of parameters, the existing used electro-static precipitators (ESP) on the control unit were replaced by new filters for accurate comparison against the test filters.

The IAQ of the areas served by each AHU were measured at the start and end of the phase while the particulate removal efficiency and pressure difference across the filters were measured approximately once every 50 days. Commencing from the installation of the mechanical filters at AHU1, an in-situ test measuring the particulate removal efficiency and pressure difference was conducted every 55 days on average. The schematic diagram of filter arrangement, fan location, cooling coils, fresh air intake, return air, and supply air is shown in Fig. 1. Fresh air is drawn in from the outside, passing through primary filtration into an area called the *plenum*. The return air is also ducted to same *plenum* where mixed air passes through a secondary filtration system. The secondary filtration system is the test specimen for the present study and samples were recorded across the secondary filters. The photograph of installed mechanical and ESPs (Polarized filters) in AHU1 and AHU2 is shown in Fig. 2. Both AHUs serve areas of approximately $500m^2$ in size and having similar activities. The cooling load and air circulation requirement is also similar. Specification of both AHU and test filters are given in Table 1. To measure particle count and pressure drop across filters, AHU Sampling tubing was inserted to the pre- and post-filter locations at (as pictured) both AHUs during each test, which were then connected to an *AeroTrak particle counter* for the pre- and post-filter particle count, and a *TSI DP-Calc Manometer* for the pressure difference. The particulate removal rate of the filters was recorded at different sizes: 0.4, 0.6, 0.8, 1.6 and 3.2μm.

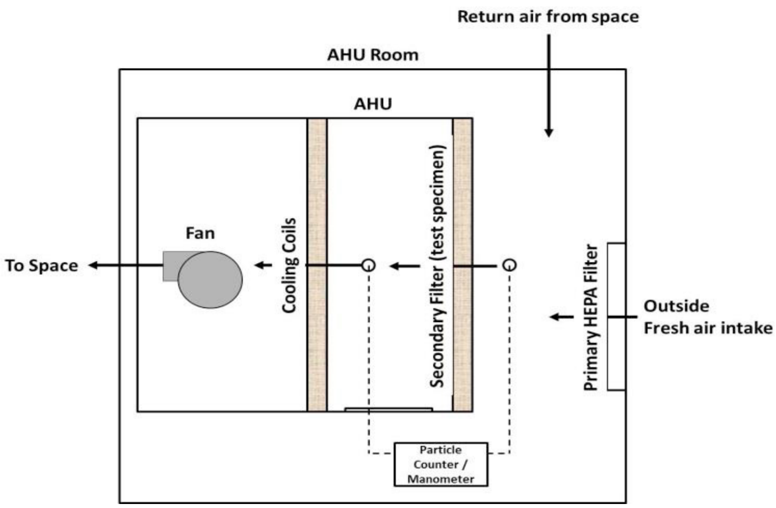

Fig. 1: Experiment Schematic diagram.

Fig. 2: Installed mechanical filters at AHU1 (Left) and ESP (Polarized filters)at AHU2 (Right).

Table 1: Specifications for AHU and test filters.

	AHU Specifications	
Dimensions [W x H]	2.84 x 2.26m	
Airflow rate [cmh]	42163 @ 2.5ms^{-1} face velocity	
Cooling capacity	326kW	
	Fine Filter	ESP (Polarized filter)
Dimensions [W x H x D]	592mm x 592mm x 296mm	609mmx 609mm x 50mm
Power consumption	-	2.8W
Rating	F7	-
Specified removal efficiency @ 0.4µm	80 – 90%	97%

3. Results and Discussion

Air flowrates for both AHUs were adjusted to be as close as possible so that pressure drop comparisons would be comparable around 4.45 – 4.75m^3/s at an average of 4.60m^3/s for AHU1 and 4.66m3/s for AHU2. In general, the removal efficiencies and pressure drop were observed to be largely constant over the course of the study for the Mechanical filters at AHU1. For the ESPs (Polarized filters) at AHU2, however, a clearly lower average removal efficiency of 39.7% was observed. The ESP (Polarized filters) only reduces the particle concentration by 13% on average, at 0.4 micron, while the mechanical filters reduce it to less than half (55% eff on average). For large particles, the mechanical filter reduces the particle concentration 10-20 times, while the ESP (Polarized filters) reduces large particles to about a quarter (at 3.2 micron). The variation of removal efficiency for different particle sizes (0.4, 0.6, 0.8, 1.6 and 3.2µm) and pressure difference during in-situ test is shown in Fig. 3 and Fig. 4.

An overall higher average pressure drop was also observed for the ESPs (Polarized filters) at 58.96Pa as compared to the Mechanical filters at 21.74Pa. While the Mechanical filters maintained a fairly consistent pressure drop within the range of 20 - 23Pa throughout, the ESP (Polarized filters) recorded a gradually increasing pressure drop as the study progressed, increasing from 49.1Pa to a final measurement of 76.5Pa. At no point in the study was the ESP (Polarized filters) recorded to have lower pressure drop than the Mechanical filters. Detailed results are summarized in Table 2.

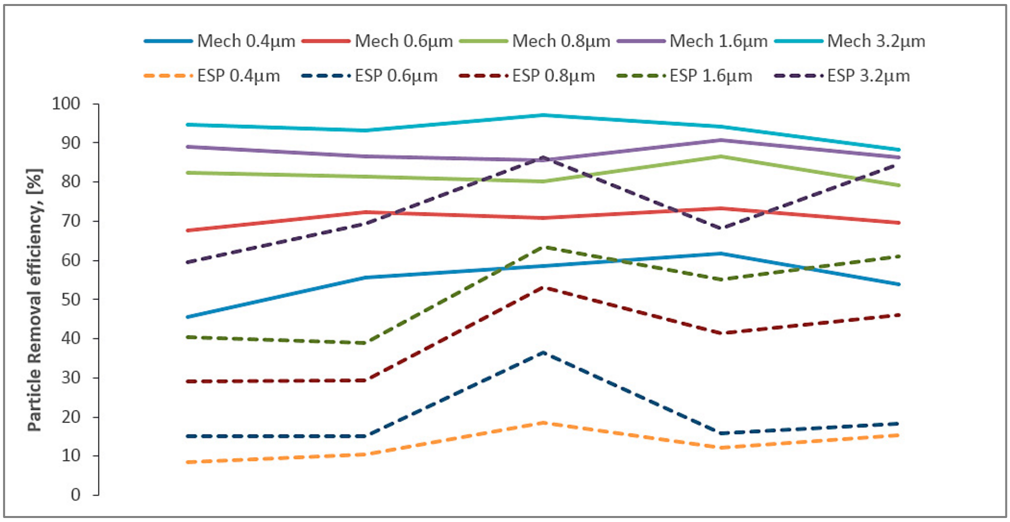

Fig. 3: Removal efficiency at different particle size for Fine filter and ESPs (Polarized Filters)

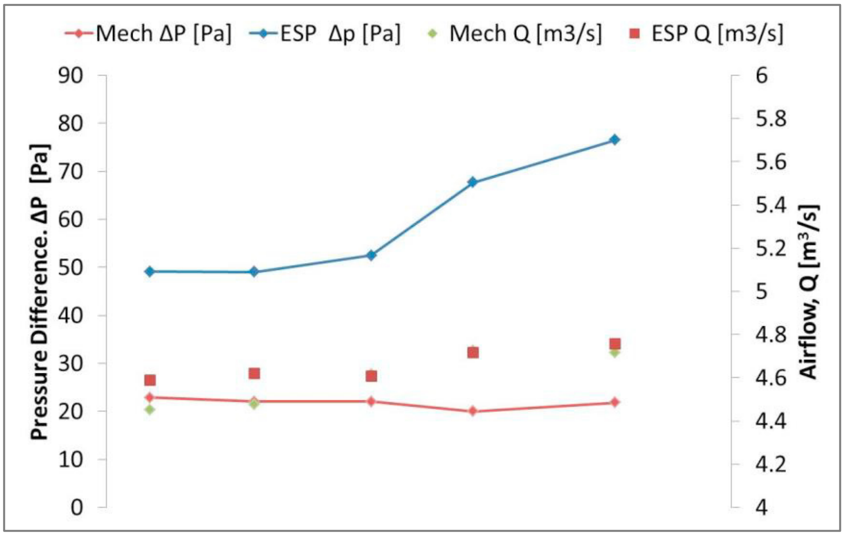

Fig. 4: Airflow and pressure difference for Fine filter and ESP (Polarized filters).

Table 2: Results for Pressure difference and removal efficiency at varying particle sizes.

	AHU1(Mechanical Filter)							AHU2 (ESP Polarized filters)						
	ΔP [Pa]	Q [m^3/s]	Average Removal Efficiency [%]					ΔP [Pa]	Q [m^3/s]	Average Removal Efficiency [%]				
Date			0.4 µm	0.6 µm	0.8 µm	1.6 µm	3.2 µm			0.4 µm	0.6 µm	0.8 µm	1.6 µm	3.2 µm
24/08/17	23	4.4	45.6	67.6	82.3	88.9	94.8	49	4.5	8.6	15.1	29.1	40.4	59.7
13/10/17	22	4.4	55.6	72.3	81.4	86.5	93.2	49	4.6	10.5	15.1	29.4	38.9	69.3
08/12/17	22	4.6	58.6	70.9	80.3	85.5	97.1	53	4.6	18.5	36.4	53.3	63.4	86.3
26/01/18	20	4.7	61.7	73.2	86.5	90.6	94.2	68	4.7	12.1	15.8	41.3	55.2	68.1
04/04/18	22	4.7	54.0	69.6	79.3	86.3	88.4	77	4.7	15.4	18.4	46.2	60.9	84.5

4. Conclusion

The present study has conducted using two identical AHUs in NTU, Singapore. Performance of two different filtration system mechanical and ESP (Polarized filters) were evaluated and compared under living lab conditions. It was ensured that the flowrates were kept as close as possible to compare the pressure drops of both filters fairly. The results show that in addition to having higher removal efficiencies at all particle sizes, the Mechanical filters still showed lower, consistent pressure drop over the course of the study while the ESP (Polarized filters) showed continually increasing pressure drop. Higher pressure drop leads to higher fan energy requirement to circulate same amount of air. As for air quality, all IAQ measurements over the course of the study were well within the limits set by SS554:2009 for both AHUs 1 and 2.

5. Acknowledgements

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