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COMPARISON AND PERFORMANCE OF STANDARD AND HIGH-PERFORMANCE FILTERS IN LABORATORY AND SCHOOL ENVIRONMENTS

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Abstract

Filters in HVAC systems remove particulate matter (PM), an important air pollutant associated with a wide range of health outcomes, especially in vulnerable and susceptible populations like children. School classrooms represent particularly important environments for children, who typically spend over 1,300 hours in school buildings each year, making schools the second most important microenvironment after the home. Unfortunately, environmental conditions and ventilation in many schools are inadequate, often much worse than in many other types of buildings. This study has the objective of evaluating whether high performance "drop-in" filters can improve indoor air quality in schools and other settings. In the laboratory, we tested new and used MERV 8 and MERV 13 filters, measuring pressure drop (following ASHRAE 52.2/ISO16890 series) and removal efficiencies $e\mathrm{PM}_1$, $e\mathrm{PM}_{2.5}$ and $e\mathrm{PM}_{10}$ (per ISO16890). The used filters were taken from two schools in the same school district in the U.S. Midwest. In several phases, using a case-crossover approach, we replaced filters in half of the building zones in these two schools with new MERV 8 filters, and the other half of the zones with MERV 13 filters. After 3 months, the MERV 8 and 13 filter assignments were reversed, and the air quality measurements were repeated. We compare results of laboratory and field tests using the two filter types, interpret results in terms of pollutant levels, building features, and other factors.

Keywords: air filter, HVAC system, particulate matter, schools

1 Introduction

Filters in heating, ventilation and air conditioning (HVAC) systems remove certain air pollutants from air that is passed through them, such as dust, small particles (e.g., $\mathrm{PM}_{2.5}$), pollen, allergens, animal dander, and fibers. When designed and used appropriately, filters can reduce indoor exposure to harmful air pollutants that arise from both indoor and outdoor emission sources (Du et al. 2011; Fisk and Chan 2017). Reduced exposure may improve lung function and reduce asthma symptom days, emergency department (ED) visits and hospitalizations (Baxter et al. 2011), which may lead to increased school attendance (Mizan et al. 2011) and improved academic achievement (Berman et al. 2018). The susceptibility of children suggests that interventions using enhanced air filtration to reduce pollutant exposures in homes and schools during childhood can yield large benefits (Martenies and Batterman 2018). In addition to filter type and rating, factors affecting indoor PM levels include the nature and strength of indoor and outdoor sources (Amato et al. 2014), the building envelope, and the HVAC system design and operation.

This study uses laboratory and field tests in schools to evaluate the performance of two types of HVAC filters. In the laboratory, we examined the performance of both new and used Minimum Efficiency Reporting Value (MERV) rated 8 and 13 filters using standard tests, e.g., ISO 16890 at nominal air flow rate. In the field, we studied two schools in a case-crossover study design to contrast the two filter types, measuring indoor environmental quality (IEQ) parameters including PM concentrations in each of the schools. We compare results of laboratory and field tests for the two types of filters, and interpret results in terms of pollutant levels, building features, and other factors.

2. Methods

2.1 Schools, filters, and indoor air monitoring

We evaluated PM levels and filter performance in two primary schools located in an urban school district in the U.S. Midwest over the 2016-17 academic year. The first school (designated as S15) had 39 classrooms and a design capacity of 954 kindergarten through 4th grade students; actual enrollment is 585 students. This building is served by eight AHUs, and each classroom has VAV terminal reheat boxes, an in-class thermostat, and openable and triple-glazed windows. The second school (S18) is a large 2-floor building with 31 classrooms and a design capacity of 758 kindergarten to 4th grade students and actual enrollment of 422. Classrooms had large operable double- or triple glazed windows. The building is served by a combination of central air handlers, blower coil units (BCU), and unit ventilators (UVs). Filter changes and HVAC maintenance in this building are inconvenient due to the large number of air handling units, the location of the BCUs (above classroom ceilings), and difficulty replacing filters in the UVs (due to the disassembly required).

Four of the 3rd and 4th grade classrooms were selected in each school to measure IEQ parameters over 5-day periods. The classrooms had an average of 25 students and 1 teacher. Walk-through inspections in each school and classroom were conducted to evaluate mechanical systems, classroom dimensions, and features that might affect PM levels. IEQ measurements were obtained 5 weeks after filters were installed. PM concentrations were measured as integrated samples collected over the school day (8:30 am to 3:30 pm) at 15 L min-1 using 1 µm 47 mm dia PTFE filters (SKC, Eighty-Four, PA, USA). In addition, we monitored optical particle number counts in 0.3-1.0 µm and 1-5 µm dia size ranges, measured every 1-min using calibrated instruments (GT-521, MetOne, Grants Pass, OR). Side-by-side tests confirmed comparability of measurements. Sampling details are reported elsewhere (Du et al. 2011).

Each school was provided with new pleated filters with MERV 8 and MERV 13 ratings in sizes required by the existing mechanical equipment (e.g., 20×20×2, 16×20×2, and 20×24×2 inch). According to ISO 16890, size specific PM removal efficiencies for MERV 8 filters are 15 and 55% for 1 – 2.5 and 2.5 – 10 µm dia, respectively (ePM$_{2.5}$ and ePM$_{10}$), and 45 and 75% for MERV 13 filters. Filters were provided by the same manufacturer (except for filter 10), installed by school personnel, and used for 12-15 week periods, with filter placements and scheduling following our directions. Both new and used filters were obtained for laboratory tests and shipped to the laboratory for analysis.

2.2 Laboratory filter tests

Ten filters were tested. We characterized pressure drop at a minimum of four air flow rates following ASHRAE 52.2/ISO 16890 series (ASHRAE 2017) and determined fractional removal efficiency in the size range between 0.09 and 10 µm for per ISO 16890 at a nominal air flow rate (face velocity of 2.54 m/s). Results are based on up- and downstream optical particle size (OPS) measurements of KCl particles from 3 and 10 µm diameter (TSI 3330) and di-ethyl-hexyl-sebacate (DEHS) particles from 0.09 to 1.0 µm dia (PMS Las-X II). In addition, we characterized performance at the half the nominal air flow rate for two new filters to evaluate the electrostatic enhancement factor.

3 Results

3.1 Laboratory tests

Table 1 summarizes results for the 10 tested filters, including the ePM ratings. New filters met their MERV ratings. For the MERV 8 filters, fractional removal efficiencies were 6, 49 and 81% for PM in size ranges of 0.3-1.0, 1-3 and 3-10 µm dia, respectively, surpassing the ASHRAE criteria of 20 and 70% for 1-3 and 3-10 µm, respectively (no 0.3-1.0 µm criterion is specified for MERV 8 rated filters). When new, these filters actually met MERV 9 ratings (35 and 75% removal for 1-3 and 3-10 µm dia PM, respectively). For the new MERV 13 filter, removal efficiencies were 58, 89 and 95% for 0.3-1.0, 1-3 and 3-10 µm, respectively, surpassing the ASHRAE minimum criteria of 50, 85 and 90%.

***Table 1**: Summary of fractional removal efficiency for new and used filters.*

	Particle size range [nm]			Labeled MERV 8			Labeled MERV 13		
	Lower	Upper	Geometric	New	Used Filters		New	Used Filters	
Test	Limit	Limit	Mean	Mean	Mean	St.Dev	Mean	Mean	St.Dev
Size	300	400	346	-1.5	3.3	1.7	42.1	22.1	7.1
Range 1	400	550	469	0.8	7.1	2.6	53.2	30.4	6.7
Fractional	550	700	620	5.5	14.2	2.3	62.6	40.7	7.1
Removal	700	1000	837	18.1	25.4	4.2	73.5	54.7	6.0
	Average			**5.7**	**12.5**	**2.7**	**57.8**	**37.0**	**6.7**
Size	1000	1300	1140	31.5	37.3	5.7	82.9	68.2	4.0
Range 2	1300	1600	1442	41.1	45.1	5.6	86.9	74.8	2.6
Fractional	1600	2200	1876	52.2	53.5	5.6	90.8	80.8	2.3
Removal	2200	3000	2569	69.3	64.7	4.9	94.2	86.8	1.5
	Average			**48.5**	**50.1**	**5.5**	**88.7**	**77.6**	**2.6**
Size	3000	4000	3464	79.9	71.8	2.7	95.1	88.2	1.6
Range 3	4000	5500	4690	83.5	74.5	0.5	95.1	87.3	2.3
Fractional	5500	7000	6205	83.5	74.8	0.8	94.7	85.0	2.4
(%)	7000	10000	8367	78.1	74.3	3.0	93.8	84.4	3.5
	Average			**81.3**	**73.8**	**1.8**	**94.7**	**86.2**	**2.4**
***e* PM**	***e*** **PM_1**	1000		**-0.1**	**7.0**	**2.7**	**46.7**	**24.1**	**6.5**
Rating	***e*** **$PM_{2.5}$**	2500		**15.9**	**21.1**	**3.1**	**60.1**	**41.2**	**5.2**
(%)	***e*** **PM_{10}**	10000		**56.9**	**54.8**	**2.0**	**83.7**	**71.7**	**2.9**

The four used MERV 8 filters had similar performance, suggesting that building and environmental differences in the study were not significant influences. For these filters, removal efficiency slightly increased for smaller particles (by 2 to 7%), but slightly decreased (by 7%) for larger (3-10 µm dia) particles, suggesting particle shedding or bouncing. Despite these changes, these filters maintained the removal efficiencies specified for their MERV 8 rating over the study period. The four used MERV 13 filters also showed consistent results, but performance dropped for each size range by 7 to 21%, and these filters dropped to MERV 10 or 11 equivalent. The decrease in the removal efficiency was largest for the smaller particles. These trends reflect the loss of electrostatic charge on the filter fibrous material, as shown elsewhere (Lehtimäki and Heinonen 1994; Raynor and Chae 2004).

3.2 PM measurements in the schools

The filter-based PM concentrations, representing total suspended particles (TSP) in the classrooms, averaged 14 ± 8 µg/m^3, slightly above outdoor levels (12 ± 5 µg/m^3). While no statistically significant changes in PM levels with filter replacements were seen, at school S15, indoor levels of $PM_{0.3\text{-}1}$ and $PM_{1\text{-}5}$ were reduced more (12-20%) from outdoor levels with the MERV 13 filters than with the MERV 8 filters. However, no decrease was apparent at school S18 where PM levels in several classrooms increased. These inconsistent results likely reflect changing occupancy and activities in the classrooms. In addition, the difficulty of replacing filters at school S18 may have led to non-compliance with study protocols.

4 Conclusions

Over the study period, MERV 8 filters maintained their rated performance based on the lab tests. While these filters had little effect on PM_1, $ePM_{2.5}$ and ePM_{10} were 21 and 55%, respectively. In contrast, while initially meeting their rating, the efficiency of MERV 13 filters decreased with use: ePM_1

decreased from 47% (new filter) to 24% (12 weeks' use); *e*$PM_{2.5}$ from 60 to 41%, and *e*PM_{10} from 84 to 72%. Use of the higher rated filters appeared to reduce PM levels in one of the two schools, although changes were not statistically significant.

To ensure high removal efficiency of PM below 2.5 μm dia, it is essential to rely on mechanical filtration mechanisms. This can be accomplished by providing adequate physical space for filters, thus allowing acceptable airflow resistance using filter media comprised of sufficiently fine fibers that can remove small particles without relying on electrostatic mechanisms.

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