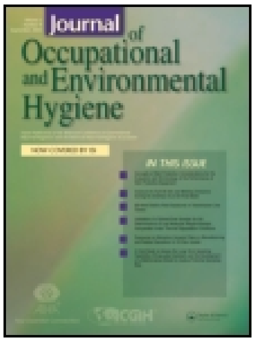

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Real-Time Evaluation of Ventilation Filter-Bank Systems

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This study evaluated two government facility ventilation systems. One was a metropolitan government office complex with a recirculation system where outside air was the makeup air; the other was a NIOSH facility that used 100% outside air with no recirculation. The methodology employed was a modified American Society of Agricultural Engineers standard (S525) for testing total enclosure filtration efficiency, in agricultural tractor cabs, with optical particle counters (OPC). The low-efficiency bag filters were tested when new and after being in the ventilation system for 3 months. The replacement medium-efficiency filters were evaluated for 6 months (the manufacturer's suggested change-out schedule). These eight-chamber, medium-efficiency filters had an increased filter surface area that resulted in increased airflow through the system. Unfortunately, these filters contained electrostatic filter media and lost filtration efficiency rapidly, which was subsequently confirmed in a 30-day study conducted to determine an appropriate change-out schedule for the eight-chamber bag filters. The study determined that less than 6 months' use was justified due to the reduced efficiency of the electrostatic filter media. The NIOSH facility's air handler #8 (100% outside air unit) was upgraded from electrostatic bag filters, which had a suggested 9-month change-out schedule, to V Bank mechanical, wet-laid, glass fiber filters. The results of a 3-year evaluation showed that the V Bank filters had better filter efficiency after 3 years of service than the electrostatic filters had at 9 months. Both studies employed matched OPC instruments to reduce instrument-to-instrument bias. The methodology is adaptable to monitoring the total efficiency of most air filtration systems, and results can help make decisions about upgrading filter performance

Keywords aerosol particles, control technology, filtration, indoor environment, optical particle counter, ventilation systems

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INTRODUCTION

Following terrorist attacks in 2001, NIOSH scientists evaluated ventilation systems, with particular emphasis on filter efficiency and the potential for upgrading existing systems. One concern dealt with the use of mechanical vs. electrostatic filter media. Kern et al. reported that "Lifetime testing indicates that glass media maintains its efficiency while synthetic media loses efficiency (discharge of enhanced media)."[1,p.12.1] The synthetic media referred to was made of synthetic polymer fibers and consisted of large-diameter fibers that rely on electrostatic capture to enhance filtration efficiency. It has been previously reported[2] that filter efficiency vs. dust load for electrostatic and fiberglass media gave comparable results when tested by the Eurovent 4/9 method. The experimental results from the current study agree with the findings of Kern and do not support the Eurovent 4/9 method results. The electrostatic synthetic media employed did lose filtration efficiency under real world test conditions in the ventilation systems.

Experimental studies[3–5] have documented a decrease in collection efficiency as particles deposit within the electrostatic filter media. Work on electrostatic filter media in actual applications has shown a loss of filter efficiency with exposure time.[6,7] A recent paper compared the performance of uncharged glass fiber filters with electrically charged polyolefin fiber filters in almost identical heating, ventilation, and air conditioning (HVAC) systems that were continually operated for more than 19 weeks.[8] The results found that the efficiency of the electrically charged filters declined, whereas the glass filter efficiency showed little change. The decline in filter efficiency was significant for submicrometer size particles.

The above findings agree with published work on electrostatic respirator filters. Electrostatic respirator filter media exposed to workplace aerosols (e.g., coal dust, foundry fume, carbon brick dust, lead battery dust) showed reduced performance.[5] Other researchers demonstrated that electrostatic N-95 respirator filter media could be adversely affected by intermittent exposure to sodium chloride aerosol.[9]In addition to reducing the efficiency of the filter media, a shift of the most penetrating particle size to larger particle diameter has been reported.[10]

A preliminary laboratory study of air handler bag filters was performed on new and used filters. These studies demonstrated that filter penetration of submicrometer particles constitutes the most critical most penetrating particle size range for fibrous filters. Aerosol penetration was measured using the respirator filter media testing criteria (42 CFR 84),[11] which uses a submicrometer dioctyl phthalate (DOP) or sodium chloride aerosol for determining filter efficiency. The use of these aerosol penetration tests were adopted for use in the current study. The sodium chloride and DOP filter penetration results confirmed that electrostatic bag filters lost filter efficiency with exposure to ambient aerosol particles.[12] Further, DOP liquid aerosol degraded these filters as a function of aerosol loading. Also, there was a shift of the most penetrating particle size to a larger particle size with this reduction in filter efficiency. The filter media made from glass microfibers, which is mechanical, did not suffer the same reduction in efficiency with aerosol loading.

The testing of real-time total system filtration efficiency (includes filter efficiency, filter frame holder leaks, faulty seals) presents a significant challenge. While the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and other standard-setting bodies have established well-defined standards and procedures for testing the efficiency of air-cleaning devices (i.e., filters), there are no available standards for *in situ* testing of total filtration unit efficiency.[13,14] NIOSH investigators have adapted the procedure found in the American Society of Agricultural Engineers (ASAE) Standard S525 for testing total enclosure filtration efficiency on agricultural tractor cabs.[15] Although each tested ventilation system was significantly larger than a filtration system on an agricultural tractor cab, simple inlet modifications (isokinetic sampling inlets) to the OPCs used for the ASAE procedure allowed successful testing of ventilation system filtration efficiency.

This article describes how OPCs can be used effectively to measure the *in situ* efficiency of air handling units. Reported are the results from upgrading filters in a metropolitan government building air handler. The upgraded filters were medium-efficiency, eight-chamber bag filters (ME8CB) that the manufacturer suggested be changed out after 180 days. The duration of this study was set to correspond with the change-out recommendation. The data indicated that a shorter change-out schedule was warranted. The subsequent 30-day continuous monitoring of this ventilation system's filtration efficiency confirmed the reduction in filter efficiency of the ME8CB electrostatic filters. A much shorter change-out schedule (<30 days) appeared justified. Finally, the results of a 3-year study on the performance of higher efficiency, minipleat, microglass V Bank filters installed in the NIOSH air handler unit #8 (NIOSH AH#8) are presented. This study further evaluated the methodology and determined the long-term duration of mechanical filters in a ventilation system with 100% outside air (no recirculation).

MATERIALS AND METHODS

Testing Equipment

Testing of the ventilation system was intended to determine the performance of the total filtration systems with different filters installed. Specifically, during normal operation, the filtration components were monitored for total efficiency in the particle size range from 0.3 μm to 3.0 μm optical diameter. Grimm OPCs measure the particle number concentration in 15 different size channels over the particle size range from .3–>20 μm. The testing method employed two Grimm model 1.108 portable dust monitors (Grimm Technologies, Inc., Douglasville, Ga.). These OPCs were each equipped with a Grimm model 1.152 isokinetic sampling probe that sampled parallel to the airstream at a rate of 1.2 L/min. Each isokinetic sampling probe has four inlet nozzles to choose from for sampling airflow velocity. The 3.0-mm nozzle opening was selected because this is the manufacturers recommendation for airflow velocities between 2–4 m/sec. All of the ventilation systems had air velocities between 2–4 m/sec (390 and 790 ft/min).

The Grimm OPC measures the number concentration of particles per unit volume of air by light scattering technology, dependent on a semiconductor laser as the light source. The OPC determines particle size based on the amount of light scattered by individual particles that enter the detector. The instrument operates from 4–45°C with a particle concentration range of 1–2,000,000 particle counts per liter. Sensitivity is 1 particle per liter and the instrument reproducibility is quoted as ±2%. Grimm OPCs are calibrated by the manufacturer by a three-step procedure consisting of verification calibration of laser optics, gravimetric correlation verification, and optical calibration cross reference. Step one of the calibration procedure verifies the optics against a "mother-unit" for proper size classification and distribution. The challenge aerosol in all cases was the ambient particles or dust that entered the HVAC system minus any large particles removed by the prefilters.

Ventilation and Filtration Equipment

Metropolitan Government Building (MGB)

This facility has multiple air handling systems, most of which are located in the penthouse, that draw outside air from intakes that are located near the roof. One of these units was randomly selected for evaluation. The unit employed air recirculation (variable but approximately 40% was normal). Similar filters were employed in all the systems and consisted of a prefilter for large particle removal and a bag filter for smaller particle removal. The prefilters were changed monthly; the bag filters were changed quarterly. The existing bag filters being used were a single-compartment bag (SCB) filter (Columbus Industries, Ashville, Ohio) consisting of media approximately 1.3 cm thick. The filter bank held 30 filters (6 across and 5 down) with the top row of 5 filters being smaller in size. These SCB filters were low-efficiency filters rated as 77% filtration efficiency at 3.0 μm and had basically no filtering capacity for 0.3-μm particles. The SCB filters were evaluated in the MGB ventilation system following initial installation and after 3 months exposure. These filters were upgraded with electrostatic Purolator D95 series (Henderson, N.C.) medium-efficiency, eight-chamber bag (ME8CB) filters (three chamber bags for the upper row), which had increased surface area and increased efficiency (see Figure 1). These new Purolator ME8CB filters were rated as 97% efficient at 1.0 μm and larger and reportedly had an efficiency of 74% at 0.3 μm, which is in the most penetrating particle size range (0.1–0.3 μm) for fibrous filters. Also, due to the increased surface area of the ME8CB filters, the average air velocity through the HVAC system increased from 1.04 m/sec (204 ft/min) to 3.05 m/sec (600 ft/min) as determined with a rotating vane anemometer (model 8324 VelociCalc Plus; TSI Inc., St. Paul, Minn.). A general schematic of the MGB ventilation system that contains the Grimm sampling locations is shown in Figure 2.

NIOSH Air Handler #8 (NIOSH AH#8)

This HVAC system is a constant volume system with a heat recovery and preheated/chilled water coil (Figure 2). Also shown are the Grimm sampling locations. The system operates 24 hours a day, 7 days a week, and is 100% outside air with no recirculation (all air exhausted). This air handler held 64 filter assemblies that were 61 cm × 61 cm (24 inches × 24 inches). The air handler consisted of two separate banks of filters containing eight filters in each of four rows. Originally, three different filter types were all simultaneously located in NIOSH AH#8 (see Figure 1). The three filter types included a six-bag electrostatic filter (AAF International DriPak 2000, Louisville, Ky.), a 12-bag electrostatic filter (Koch Filter Corporation Multi-Sak 12FZ 1295-AM, Louisville, Ky.), and a pleated V-panel design mechanical filter (Filtration Group

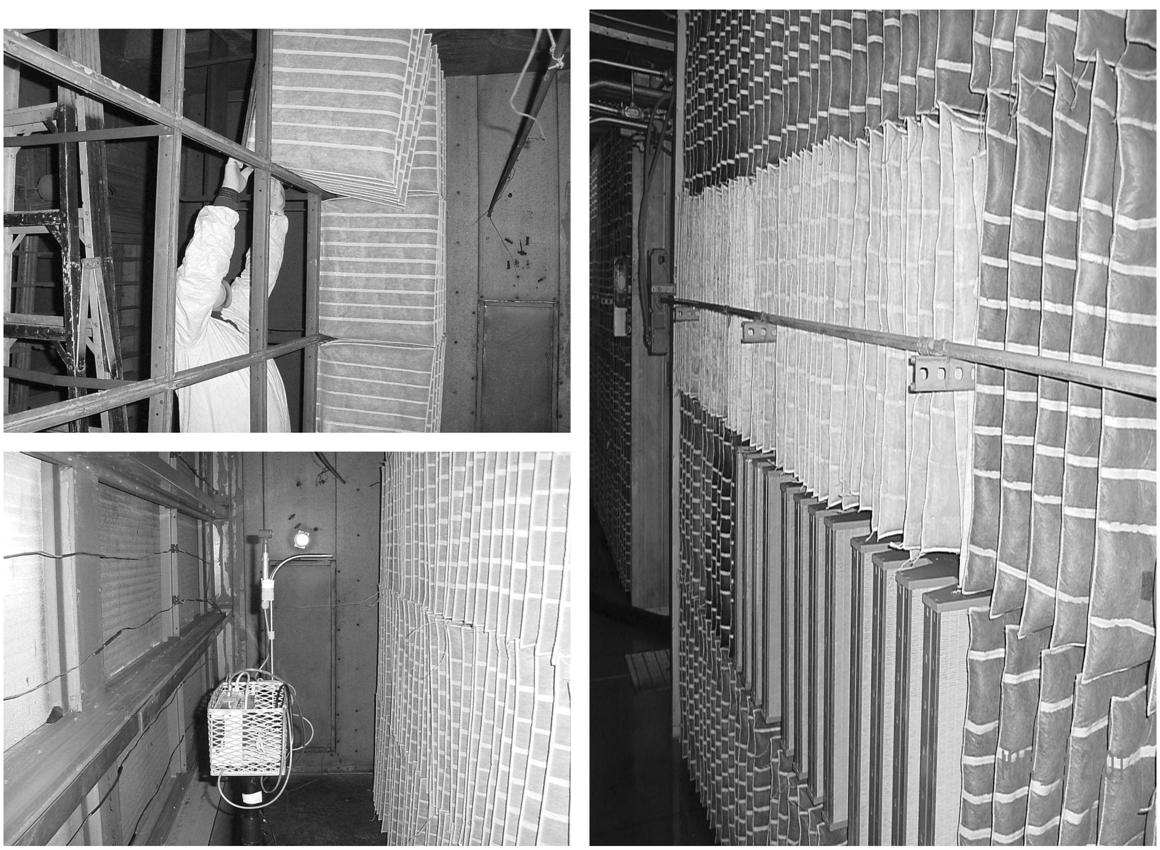

FIGURE 1. Left, OPC and bag filters in metropolitan government building; right, multiple bag and V Bank filters (NIOSH AH#8)

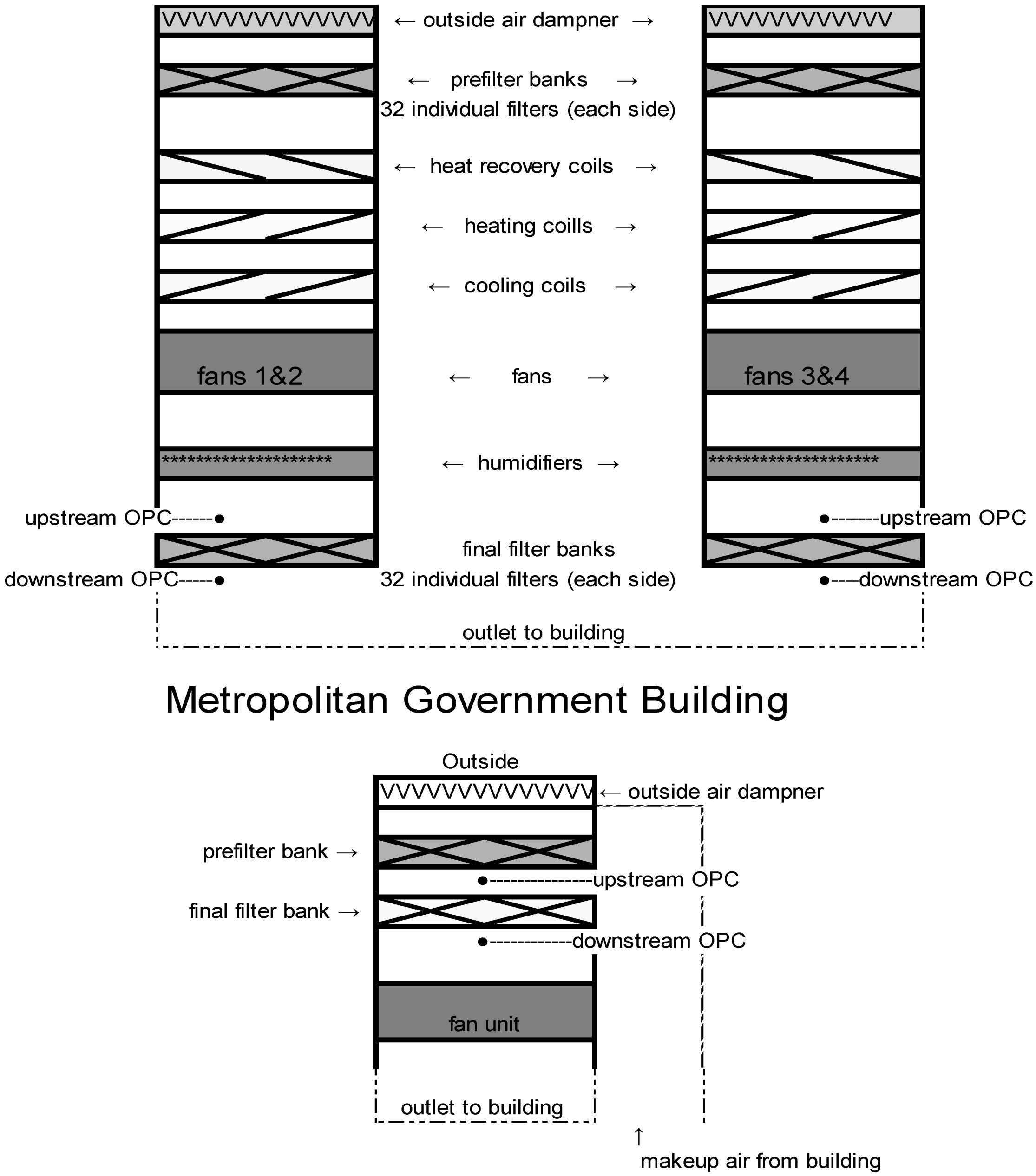

FIGURE 2. Schematic of air handler units

FP Mini-Pleat 4E412, Joliet, Ill.). The air velocities were measured approximately 20.3 cm (8 inches) downstream of the three different filter types using a rotating vane anemometer (TSI Model 8324 VelociCalc Plus) and ranged from 1.0 to 5.5 m/sec (205 to 1090 ft/min), depending on filter type. NIOSH AH#8 was then fitted with all mechanical V Bank filters and the airflow velocity was 2.6 m/sec (506 ft/min). Only laboratory penetration testing of media samples from the different bag filters were evaluated. Real-time testing in the ventilation system of each type of filter was not possible.

Evaluation Procedures

Prior to the site surveys, several identical OPC instruments were tested in the laboratory for equivalency. The manufacturer calibration and certification claims instruments are within ± 5% of each other for total particle counts. Thus, any two instruments should count the same number of total particles within a 10% error, regardless of particle size. Our units were calibrated as matching units to reduce instrument-to-instrument variability from 10% to half that value. Multiple OPCs were then run side by side for 5 days and paired units determined to further reduces potential bias resulting from instrument-to-instrument variability to ±2.5% in the range 0.3 to 3.0 μm. After the final laboratory comparisons, matched pairs of OPCs were selected for the testing. For this work, each pair was chosen because it produced the most comparable results between the OPCs in the pair. In one case, a new set of OPCs had to be used unexpectedly for a portion of the 3-year NIOSH study. In this case, the two OPC units were run side by side in the upstream side of the ventilation system for 5 days and a correction factor determined for each particle size. This correction factor was applied to these data to correct for instrument-to-instrument variability (for very limited data during the NIOSH AH#8 3-year study). The correction factor is the ratio of the responses between the two instruments when monitoring the identical aerosol challenge.

To conduct the testing, one of the paired OPCs was placed upstream of the filters to measure particle concentration data with an isokinetic sampling probe at the center of the filter bank; the probe was placed facing the airstream. The second paired OPC was placed downstream of the final filters to measure particle count data with an isokinetic sampling probe at the center of the filter bank. This probe faced the final filters. Both OPCs were located downstream of the blower motors. Thus, any particles generated by the fans (any motor-generated aerosol) could be measured as downstream particle concentration. In this way, all particles that penetrated the system by filter penetration, leakage around the filters, fan-generated aerosol, and/or leakage in the filter housing itself were registered by the OPCs. Once the OPCs were in place they were turned on and data collection began.

The ambient particles that entered the ventilation system at the air inlet provided sufficient challenge aerosol for the tests. The two matched OPCs were operated under normal conditions for at least 24 hours. A short time period was allowed for instrument stabilization. At the end of the testing period, data from both OPCs were downloaded to a portable computer and placed on a spreadsheet for analysis.

Data Analysis

Although the OPCs used for the surveys measured aerosol particle concentration in fifteen different size ranges (0.30–0.40 μm, 0.40–0.50 μm, 0.50–0.65 μm, 0.65–0.80 μm, 0.80–1.0 μm, 1.0–1.6 μm, 1.6–2.0 μm, 2.0–3.0 μm, 3.0–4.0 μm, 4.0–5.0 μm, 5.0–7.5 μm, 7.5–10 μm, 10–15 μm, 15–20 μm, and >20 μm) only particles in the interval 2.0–3.0 μm and less were evaluated because aerosol particles above 3.0 μm were not detected downstream of the filters. All of the particle count data were below the upper limit of detection for the OPCs (2,000,000 particles/L), so coincidence or instrument overloading was not an issue.

The percent filtration efficiency (E) of the ventilation system for each minute for each particle size interval was calculated:

$$E_n = \left[1 - \left(\frac{C_D}{C_U}\right)\right] \times 100$$

where n is the number for the minute of testing in each particle size range, C_D is the downstream aerosol particle concentration at minute n, and C_U is the upstream aerosol particle concentration at minute n.

Then, an overall mean efficiency ($\bar{E}$) and standard deviation for each particle size range was calculated.[16]

RESULTS AND DISCUSSION

The SCB filters from the metropolitan government building were evaluated after 3 months for filter efficiency with the OPCs (Table I). Also included in Table I is the data for new SCB filters. The Columbia Industries SCB filters are low-efficiency filters with minimal submicrometer filtration capability. The overall efficiency of the filter bank increases with time for these SCB filters, suggesting some mechanical efficiency for large particles. The large variability is the result of the low efficiency of these filters especially against submicrometer particles.

Immediately after the installation of the ME8CB Purolator D series electrostatic filters (74% efficient at 0.3 μm and 98% efficient for particle ≥1.0 μm), a 6-month study of the systems efficiency was begun. The study started in the beginning of November and follow-up data were collected December 17–18 (Days 40–41), February 20–21 (Days 105–106), March 27–28 (Days 140–141) and May 6–7 (Days 180–181). The efficiency data are presented in Table II and plotted in Figure 3. The average percentage efficiency at the five sampling points shows the drastic reduction in filter efficiency for the submicrometer particles. This filter media is electrostatic, and this behavior is typical for an electrostatic media. It must be noted that the filtration efficiency being monitored is the total system efficiency with one component being the filters' contribution. For example, leakage around filters, gasket leaks, and motor aerosol generation would be additional factors making up a portion of the total system efficiency.

Because of the rapid initial reduction in filter efficiency for these electrostatic bag filters, a continuous monitoring of these bag filters was done when new filters were installed. The filters were monitored continuously for 30 days, with the only exception being when the OPCs were downloading data (approximately every fifth day). Table III presents the average filtration efficiency data for the new and subsequent 5-day periods between instrument downloads. The average reduction in filter efficiency for the different particle sizes demonstrates the rapid drop in efficiency over the 30-day period. Especially noted is the dramatic reduction in system efficiency for the submicrometer particles.

The second ventilation system evaluated was the NIOSH AH #8. A previous laboratory based study evaluated the sub-micrometer aerosol penetration of the filter media used in the various air handler bag filters. The aerosol used was identical to that employed for testing respiratory filter media and is in the most penetrating particle size range for fibrous filters. The results showed that new filter media aerosol penetration ranged from less than 1% to greater than 10% depending on flow rate, media surface area, challenge agent particle size and

TABLE I. Filtration Efficiency of New and Used Columbia Industries Single-Compartment Bag Filter at a Metropolitan Government Building

Columbus Industries Single-Bag Filter	Average Filtration Efficiency (%)[A]							
	Average Particle Diameter Interval							
	0.30–0.40 μm	0.40–0.50 μm	0.50–0.65 μm	0.65–0.80 μm	0.80–1.0 μm	1.0–1.6 μm	1.6–2.0 μm	2.0–3.0 μm
New filter, December 18–19, 2001	7.9	14.5	24.3	26.8	24.6	39.2	39.9	52.3
Standard deviation	4.5	6.6	10.1	22.2	50.5	58.7	134.7	105.3
Used filter (3 months), November 6–7, 2001	13.4	15.2	26.3	26.8	41.8	69.2	79.8	92.5
Standard deviation	4.7	7.6	10.9	22.2	27.8	13.4	16.2	6.3

[A] The data are averages of all 1-min samples collected over 2-day periods.

TABLE II. Filtration Efficiency of Purolator Eight-Chamber Electrostatic Bag Filter During 6-Month Study at a Metropolitan Government Building

Purolator Eight-Chamber Bag Filter	Average Filtration Efficiency (%)[A] — Average Particle Diameter Interval 0.30–0.40 μm	0.40–0.50 μm	0.50–0.65 μm	0.65–0.80 μm	0.80–1.0 μm	1.0–1.6 μm	1.6–2.0 μm	2.0–3.0 μm
New Filter, November 7–8, 2001	79.1	82.4	89.2	93.3	96.7	98.7	99.3	99.8
Standard deviation	2.8	3.1	2.3	2.5	2.5	2.4	2.6	1.0
40–41 Days, December 17–18, 2001	45.8	56.2	70.0	79.1	88.8	95.2	97.1	99.4
Standard deviation	1.5	2.0	3.3	6.2	5.7	5.1	5.3	1.3
105–106 Days, February 20–21, 2002	50.7	59.3	69.6	83.8	93.1	98.4	99.7	99.9
Standard deviation	1.5	2.5	3.6	5.0	3.6	2.0	1.1	0.3
140–141 Days, March 27–28, 2002	40.3	47.8	56.7	74.6	86.2	95.9	98.0	99.5
Standard deviation	3.2	3.5	5.1	6.3	5.6	3.6	4.6	2.0
180181 Days, May 6–7, 2002	33.2	43.8	56.0	73.4	84.4	93.2	94.2	98.2
Standard deviation	3.1	4.0	6.3	7.6	7.0	5.6	7.1	2.5

[A] The data are averages of all 1-min samples collected over 2-day periods.

TABLE III. Filtration Efficiency for 30-Day Continuous Monitoring Study of Purolator Eight-Chamber Electrostatic Bag Filters at a Metropolitan Government Building

Purolator Eight-Chamber Bag Filter	Average Filtration Efficiency (%)[A] Average Particle Diameter Interval							
	0.30–0.40 μm	0.40–0.50 μm	0.50–0.65 μm	0.65–0.80 μm	0.80–1.0 μm	1.0–1.6 μm	1.6–2.0 μm	2.0–3.0 μm
New Filter, May 7–10, 2002	85.0	88.6	92.3	96.4	98.1	99.3	99.4	99.8
Standard deviation	2.9	2.3	2.3	2.3	2.3	1.8	2.6	1.4
3–7 Days, May 10–14, 2002	77.2	82.3	87.6	94.0	97.1	99.2	99.7	100.0
Standard deviation	5.6	8.0	11.5	10.2	7.3	3.1	1.9	0.4
7–11 Days, May 14–18, 2002	78.6	84.0	89.0	94.8	97.5	99.3	99.7	
Standard deviation	2.5	2.9	3.4	4.1	3.4	2.8	1.9	
11–16 Days, May 18–23, 2002	77.4	83.1	88.3	94.2	97.0	99.2	99.7	100.0
Standard deviation	1.2	1.8	3.2	5.0	5.3	3.3	3.5	0.8
16–21 Days, May 23–28, 2002	64.9	71.2	78.3	89.6	94.6	98.4	99.2	99.8
Standard deviation	5.9	5.5	5.3	4.4	4.0	2.7	3.6	2.2
27–30 Days, June 3–6, 2002	63.6	70.0	77.4	87.4	90.9	95.5	96.7	99.4
Standard deviation	2.7	2.9	4.6	10.3	24.6	21.8	25.4	5.0

[A] The data are averages of all 1-min samples collected continuously for 30 days.

TABLE IV. Filtration Efficiency of Filters for First 6 Months in NIOSH AH#8

	Average Filtration Efficiency (%)[A]							
	Average Particle Diameter Interval							
V-Bank Filters in NIOSH AH#8	**0.30–0.40 μm**	**0.40–0.50 μm**	**0.50–0.65 μm**	**0.65–0.80 μm**	**0.80–1.0 μm**	**1.0–1.6 μm**	**1.6–2.0 μm**	**2.0–3.0 μm**
August 13–17, 2001, - Med.								
Efficiency Bag Filters	24.8	28.0	30.0	45.8	58.2	78.1	89.9	97.2
Standard deviation	2.0	3.1	8.6	11.0	11.7	12.7	13.7	6.7
August 27–31, 2001								
New V Bank filters	69.7	74.5	80.8	85.7	89.9	91.8	92.4	96.9
Standard deviation	1.1	0.9	1.3	3.0	4.1	6.3	9.7	4.3
September 19–25, 2001								
V Bank at 1 month	62.7	68.5	76.6	82.2	86.6	88.6	91.4	95.7
Standard deviation	3.4	4.3	4.2	6.7	8.3	17.6	22.5	24.1
October 19–24, 2001								
V Bank at 2 months	66.7	72.8	79.9	81.2	86.5	91.2	93.6	97.8
Standard deviation	2.0	2.8	3.3	5.4	5.8	6.7	8.0	3.9
November 13–16, 2001								
V Bank at 3 months	61.7	65.5	74.1	77.5	84.0	89.6	92.2	97.3
Standard deviation	1.4	1.9	2.7	4.4	5.1	6.6	8.6	4.1
December 19–21, 2001								
V-Bank at 4 months	61.4	64.2	71.7	74.9	81.1	87.4	91.8	95.5
Standard deviation	2.0	3.7	5.0	8.9	11.0	13.4	15.8	13.7
January 22–25, 2002								
V Bank at 5 months	61.8	65.1	72.9	77.5	83.9	88.6	90.5	95.8
Standard deviation	3.3	3.7	3.8	6.4	7.3	9.5	13.6	10.4
February 25–March 1, 2002								
V Bank at 6 months	56.0	60.7	63.6	72.7	78.3	86.9	88.7	95.7
Standard deviation	1.5	2.8	4.8	8.1	10.1	12.2	23.1	13.6

[A] The data are averages of all 1-min samples collected.

TABLE V. Filtration Efficiency of Mechanical V-Bank Filters for Three Year Period in NIOSH AH#8

V-Bank Filters in NIOSH AH#8	Average Filtration Efficiency (%)[A]							
	Average Particle Diameter Interval							
	0.30–0.40 μm	0.40–0.50 μm	0.50–0.65 μm	0.65–0.80 μm	0.80–1.0 μm	1.0–1.6 μm	1.6–2.0 μm	2.0–3.0 μm
August 27–31, 2001								
- New Filters	69.7	74.5	80.8	85.7	89.9	91.8	92.4	96.9
- Standard deviation	1.1	0.9	1.3	3.0	4.1	6.3	9.7	4.3
February 25–March 1, 2002								
- at 6 Months	56.0	60.7	63.6	72.7	78.3	86.9	88.7	95.7
- Standard deviation	1.5	2.8	4.8	8.1	10.1	12.2	23.1	13.6
August 27–31, 2002								
- at 12 Months (Dry & Dusty)	54.5	60.1	63.6	75.1	80.3	86.8	88.6	96.0
- Standard deviation	1.6	2.0	4.1	8.7	11.8	13.6	17.6	12.2
February 27–March 3, 2003								
- at 18 Months	53.5	57.5	60.5	71.3	77.5	85.7	87.6	95.9
- Standard deviation	1.4	1.7	2.6	5.0	7.4	10.1	19.1	10.5
August 28–Sept. 2, 2003								
- at 24 Months (corrected)	50.8	56.4	62.6	68.4	74.3	82.7	86.7	95.0
- Standard deviation	1.9	2.8	3.3	6.8	9.9	11.1	14.6	8.3
February 25–March 1, 2004								
-at 30 Months (corrected)	53.2	52.9	57.0	65.3	71.1	82.8	88.0	95.8
- Standard deviation	1.7	3.0	4.2	6.9	8.7	9.5	14.0	7.1
August 25–30, 2004								
- at 36 Months	46.2	56.4	63.6	68.6	76.1	82.4	85.3	95.4
- Standard deviation	1.7	2.1	2.9	5.4	7.2	11.0	12.8	5.9

[A] The data are averages of all 1-min samples collected.

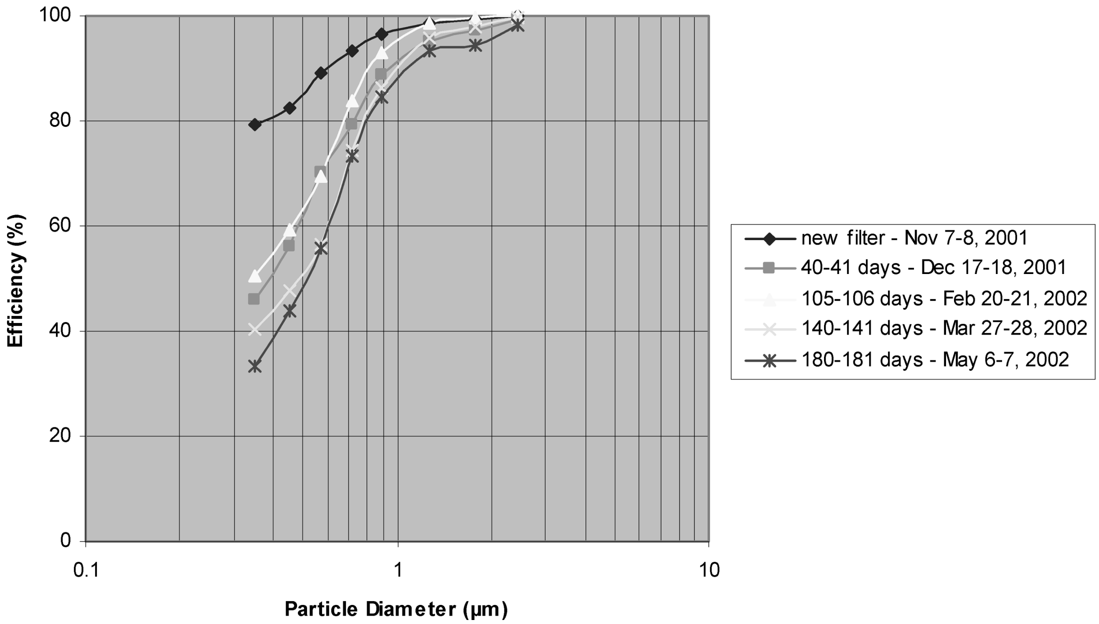

FIGURE 3. Average filtration efficiency of Purolator eight-chamber electrostatic bag filter during 6-month study at a metropolitan government building

challenge agent state (liquid or solid).[13] Aerosol penetration for the electrostatic media increased significantly after exposure in the air handler. The V Bank mechanical filters did not show the same reduction as the electrostatic media.

Based on the preliminary filter testing results, it was decided that the V Bank mechanical filters would be installed in all the air handler filter banks for the real-time study. It was felt that enhanced performance with a reduced number of filter changes would offset the higher initial cost of the filters. The filter bank was first evaluated with the existing electrostatic bag filters in place. These filters were scheduled to be changed at their regular 8-month sequence. The data for the used existing bag filters are presented in Table IV, along with the data for the first 6 months of the 3-year study with the V Bank filters in place. Some reduction in filtration efficiency was observed for the V Bank filters; this was not expected, since they are strictly mechanical filters. However, we monitored total system efficiency, which entailed filter efficiency plus other factors. It should be noted that the V Bank filter media is fragile and can be easily damaged and this is a possible explanation. The 6-month data of the 3-year study indicates that V Bank filter performance was better than electrostatic bag filter performance for approximately the same time interval (enhanced filtration efficiency achieved by installing the V Bank filters). The extended performance of the V Bank filters will be the critical test criteria, since the V Bank filters initially cost more.

The V Bank filter study was 3 years in duration. The data for the entire 3 years at 6-month intervals are presented in Table V. The V Bank filters performed better for the 3 years than the original electrostatic bag filters did for 8 months. Actually the V Bank filters could have been left in the ventilation system, since a significant increase in filter bank resistance was not observed (ranged from 47.2 to 87.0 Pa) over the entire 3 years. The trend in the data shows a reduction in efficiency for the smallest sized particles. As the particle size increased, less of a reduction in efficiency with time over the 3 years was observed.

CONCLUSIONS

This sampling procedure that used matched OPCs was capable of monitoring the systems total filtration efficiency for the particle size range 0.3 μm to 3.0 μm. All filter sets showed a reduction in efficiency with time, but the electrostatic filters gave a larger reduction in efficiency vs. time than the V Bank filters. In fact, the mechanical V Bank filters gave better total system filtration efficiency after 3 years than the electrostatic 8-month-old bag filters. This monitoring system can be used to determine change-out schedules for the filters based on real-time data. By routinely monitoring the total system efficiency following the installation of new filters, one will be able to determine when the particulate penetration is no longer acceptable, that is, when the filters need to be changed. After routine monitoring the system for two or three filter change-out cycles, an acceptable change-out schedule for this one system/filter combination will have been established. Any change in filter media would dictate the re-establishment of a new change-out schedule. In this situation, the mechanical V Bank filters outperformed the electrostatic filters. The V Bank filters were changed after 36 months but probably could have continued to function effectively (filter resistance was not a determining factor). Many factors contribute to the overall efficiency of the ventilation system, and each must be considered. The particle detection method used in this study allows for the routine evaluation of ventilation systems to verify that they are functioning properly. Total filtration system integrity that includes filter efficiency, gasket material integrity, weld integrity, fan motor aerosol generation, and filter rack integrity are all important factors to consider in total filtration system integrity.

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