AIR FILTERS: REAL WORLD PERFORMANCE

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ABSTRACT
This paper describes the results of studies conducted to investigate the actual in-use performance of electret and non-electret pleated HVAC filters when exposed to a variety of commercial and industrial as well as residential environments in which they must operate. Field studies were conducted in installations using 100% outdoor air, 100% indoor air, and a mixture of recirculated (indoor) and makeup (outdoor) air. Results were compared with the filter performance described by ASHRAE 52.2 characterization.

INTRODUCTION
The establishment of air filter test methods that adequately reflect actual in-use filtration performance is of great significance to the air filtration industry. A key issue in this regard is understanding the elements that impact the performance of filters in the field and developing a test which adequately simulates these elements. One crucial element is the nature of the dust that is entrained in filtered air and ultimately accumulated within the filter. It is qualitatively understood that the properties of this dust, such as particle size distribution, affect filtration performance over time. Quantitative studies, however, are limited.

Atmospheric Composition
Particles in the atmosphere prevail in a variety of sizes and concentrations depending on location, time of year, and even time of day[1,2,3]. Studies of atmospheric particles show that their distribution is bimodal in nature consisting of a fine and coarse fraction. Coarse particles, which are about 2.5 microns and larger, consist primarily of natural environmental dusts. The finer fractions (less than 2.5 microns) are the result of human activity resultant from combustion products, emissions, etc.[4]. Table 1 shows the relative particle sizes typically found in the atmosphere[5].

Particle Size (microns)	Mean Particle Diameter (microns)	Percent by Particle Number	Percent by Weight
10 - 30	20	0.005%	28%
5 - 10	7.5	0.175%	52%
3 - 5	4	0.25%	11%
1 - 3	2	1.07%	6%
0 - 1	0.5	98.5%	3%

TABLE 1: Typical Atmospheric Particle Size Distribution

For filter specification purposes, it is prudent to understand the impact of particle size on the ability of air to suspend and convey particles. Intuitively, larger dust particles settle quickly while smaller particles stay suspended or settle very slowly. Particles with diameters less than

0.1 microns tend to behave like gases and stay suspended indefinitely in the atmosphere[6]. Particles in the 0.1 to 1.0 micron range have negligible settling characteristics while those in the 1.0 to 10 micron range tend to settle but are kept suspended by air currents. Particles 10 microns and larger normally settle out of the atmosphere. Thus filter designs typically concentrate on the ability to capture particles which are less than 10 microns in diameter.

HVAC Filter Characterization

The definition of performance attributes to be achieved is important to any product design application. For the air filtration industry, the important factors to consider for filter product design are as follows:

1. Filtration Efficiency, which defines how well the product will remove the contaminants of interest.
2. Dust holding capacity, which characterizes the life of a filter and thus, to a degree, the cost associated with filter replacement.
3. Filter resistance to airflow, thus a measure of the energy requirements and cost associated with operation.

Initially, the performance of an air filter was judged by the success in solving a particular ventilation problem. As the industry expanded and the number of manufacturers increased, a standard method to evaluate and predict filter performance became increasingly important. Fortunately, the automotive industry had already developed a test dust and method for evaluating the filtration performance of carburetor intake filters. This test dust, commonly known as Standardized Air Cleaner Test Dust, was originally developed from Arizona road dust since the majority of the automobile manufacturers had winter proving grounds in Arizona. Today this dust is commonly known as Standard Air Cleaner Test Dust, Fine or SAE (Society of Automotive Engineers) Fine. This dust is predominantly silica with a mass mean diameter of about 8 microns. Table 2 shows the particle size composition of SAE fine as well as its contribution to the ASHRAE Test Dust mixture used for filter characterization.

Particle Size Range (microns)	% by Weight SAE Fine	% by Weight Contribution in ASHRAE Test Dust
0 - 5	38.8 %	28.0%
5 - 10	18.1 %	13.0%
10 - 20	16.0 %	11.5%
20 - 40	18.1 %	13.0%
40 - 80	9.0 %	6.5%

TABLE 2: SAE Fine Composition

Through the efforts of several agencies and evolution of evaluation practices, the first air filter test standard was developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) in 1968 (ASHRAE 52-68). The method was updated in 1976 to address issues with the initial standard. This resulted in publication of ASHRAE 52-76. Due to the method of testing dust spot efficiency, ASHRAE 52-76 required significant time for filter evaluation. Thus, ASHRAE 52.1-1992[7] was approved as the generally accepted test standard for filter evaluation. The ASHRAE 52.1-1992 standard details all aspects of the test procedure and apparatus. This protocol basically measures the filtration efficiency of a filter against a challenge of atmospheric particles, the ability of the filter to remove synthetic dust from the atmosphere, and the filtration device dust holding capacity.

The measured ASHRAE 52.1 efficiency is more commonly referred to as the atmospheric dust spot efficiency. The dust spot efficiency protocol measures the effectiveness of a filter to remove the staining portion of atmospheric contaminants by comparing the opacity of target filter paper upstream and downstream of the filter under evaluation.

The measure of the ability of an air filter to remove synthetic dust from the atmosphere is referred to as arrestance. Arrestance is a characterization of the effectiveness of the filter to remove ASHRAE Test Dust comprised of 72% SAE Fine (Standardized Air Cleaner Test Dust, Fine), 23% Powdered Carbon, and 5% Cotton Linters. Arrestance is indicative of a filter's ability to remove the coarse particle fraction from the atmosphere. It is measured by feeding a known amount of ASHRAE Test Dust upstream of the target filter and comparing it with the weight gained by a HEPA filter placed downstream of the filter being characterized. ASHRAE Test Dust is also used to load the filter being evaluated at various intervals to simulate pressure rise in actual use for a determination of the filtration characteristics as the filter soils in the field.

The dust holding capacity is a measure of the amount of ASHRAE Test Dust that the filter will capture until a specified pressure drop is reached. The basic test sequence is as follows:

1. The pressure drop of a clean filter is measured at 50%, 75%, 100%, and 125% of rated air flow.
2. Initial atmospheric dust spot efficiency is tested on a clean filter.
3. The filter is loaded with ASHRAE Test Dust at various intervals until a final pressure drop is reached, or other conditions are met, measuring the atmospheric dust spot efficiency and arrestance at each segment along the loading sequence.
4. At the end of the test, the average efficiency, average arrestance, and dust holding capacity are calculated.

While ASHRAE 52.1 provides useful information about the ability of an air filter to remove synthetic dusts and the discoloration portion of fine dusts from the atmosphere, it does not provide information about the ability of a filter to remove particles of a certain particle size. The characteristic of a filter to remove known particle size fractions from the atmosphere is commonly referred to as fractional efficiency. Critical operations, such as the manufacture of microelectronic devices, require this type of information for proper filter selection. Furthermore, with the heightened awareness of the issues regarding indoor air quality (IAQ) control, the ability of a filter to remove the respirable particle size portion of atmospheric contaminants is becoming increasingly important. In 1991, ASHRAE awarded Research Triangle Institute a contract to evaluate the feasibility of characterizing a filter based on its ability to remove particles within particular, measurable, diameter ranges. Such a standard, ASHRAE 52.2, was published in 1999. ASHRAE 52.2-1999[8] details the test protocol, apparatus, and method to assess the ability of an air filter to remove particle fractions from an air stream.

ASHRAE 52.2 utilizes laboratory generated potassium chloride dispersed in air as the challenge aerosol. Particle counters both upstream and downstream of the target filter under consideration measure and count particles in 12 size ranges (Table 3) to determine fractional efficiency. The standard also details a method of loading the air filter with synthetic test dust (ASHRAE Test Dust) to simulate loading in actual use. In addition to measuring the performance of a clean filter, particle size fractional efficiency curves are developed at incremental dust loadings. This set of incremental loading fractional efficiency curves is used to develop a composite curve that identifies the minimum efficiency in each particle size range. The minimum efficiency composite values are averaged in three size ranges (0.3 to 1.0 microns, 1.0 to 3.0 microns, and 3.0 to 10.0 microns) to determine the minimum efficiency reporting value (MERV) of the filter. See Table 4.

Size Range (microns)	Geometric Mean (microns)
0.3 – 0.40	0.35
0.4 – 0.55	0.47
0.55 – 0.7	0.62
0.7 – 1.0	0.84
1.0 – 1.3	1.14
1.3 – 1.6	1.44
1.6 – 2.2	1.88
2.2 – 3.0	2.57
3.0 – 4.0	3.46
4.0 – 5.5	4.69
5.5 - 7.0	6.2
7.0 – 10.0	8.37

TABLE 3: ASHRAE 52.2 Particle Size Range

Size Range Number	Particle Size Range (microns)	ASHRAE Efficiency Designation	Description
1	0.3 – 1.0	E1	Average of loading curve composite minimums in 0.3 to 1.0 micron range.
2	1.0 – 3.0	E2	Average of loading curve composite minimums in 1.0 to 3.0 micron range.
3	3.0 – 10.0	E3	Average of loading curve composite minimums in 3.0 to 10.0 micron range.

TABLE 4: ASHRAE 52.2 Composite Average Efficiency Designation

The standard defines requirements for the minimum efficiency reporting value which is dependent on the average composite minimum particle size efficiency in the size ranges defined in Table 4. For the ASHRAE filtration efficiency range (up to 95%), the filter can receive a

MERV value from 1 to 16. MERV values from 17 to 20 are also suggested in the ASHRAE 52.2 standard, but these would classify HEPA and ULPA filters which are tested by IEST-RP-CC001.3[9]. Table 5 shows the variety of MERV categories along with the dependence on the composite minimum efficiency average in the described size ranges. Filters in the 1 to 4 MERV range are very low efficiency filtration devices with their rating primarily dependent on their average arrestance as characterized by ASHRAE 52.1.

MERV Range	ASHRAE 52.2 Composite Minimum Eff. Dependence	Examples
MERV 1 - 4	E3	Furnace Panel Filters
MERV 5 - 8	E3	Pleated Filters
MERV 9 - 12	E2, E3	Box, Bag Filters
MERV 13 - 16	E1, E2, E3	Box, Bag Filters

TABLE 5: ASHRAE 52.2 Minimum Efficiency Reporting Values (MERV)

In order to demonstrate the effectiveness of the ASHRAE 52.2 standard to accurately predict the actual in-use performance of pleated HVAC filters, field studies were performed to compare the results against the performance predicted by the test method. Both electrostatic and non-electrostatic pleat filters were used in these studies. The pleat filters used in the study typically fall in the ASHRAE 52.2 MERV 5 to MERV 8 range. Therefore, the particle size range of interest for the purpose of this investigation is the 3.0 to 10 micron (E3) range.

HVAC FILTRATION FIELD STUDIES

A field study was conducted to demonstrate the actual in-use performance of pleated HVAC filters for comparison with the performance predicted by ASHRAE 52.2 characterization. Filters manufactured with a charged-mechanical media and uncharged-mechanical media were subjected to operating environments which utilize 100% outdoor air, 100% indoor air, and a mixture of recirculated (indoor) and makeup (outdoor) air. The purpose of the exercise was to expose the filters to a variety of environments in which they must constantly operate for commercial and industrial as well as residential applications. Factors critical to filtration performance such as uniform air flow through the filter and adequate edge sealing to prevent partial filter bypass were maintained. It is important to note that a different filter of each type was sampled at each test interval. These filters were removed from their operating environment and shipped to an independent laboratory for ASHRAE 52.2 characterization. Thus it is necessary to point out that possible filter to filter variability and potential filter dust cake disruption may have resulted in increased variability.

100% Outdoor

Pleated filters were installed in the prefilter bank of a two stage filtration system servicing a hospital located in the Chicago area. Filters remained in the unit for a total time of two months, but were removed at various time intervals to characterize the filtration performance as the filter became loaded in actual use. ASHRAE 52.2 characterization of the filters produced from both types of media predicts a filtration efficiency increase as the filter becomes loaded in use. Furthermore, ASHRAE 52.2 characterization of the filter produced with charged-mechanical media predicts higher performance (MERV 7) than that manufactured from uncharged-mechanical media (MERV 6). Both filters were tested at a face velocity of 500 fpm and loaded to a final pressure drop of 1“ W.G. See Figures 1, 2, and 3.

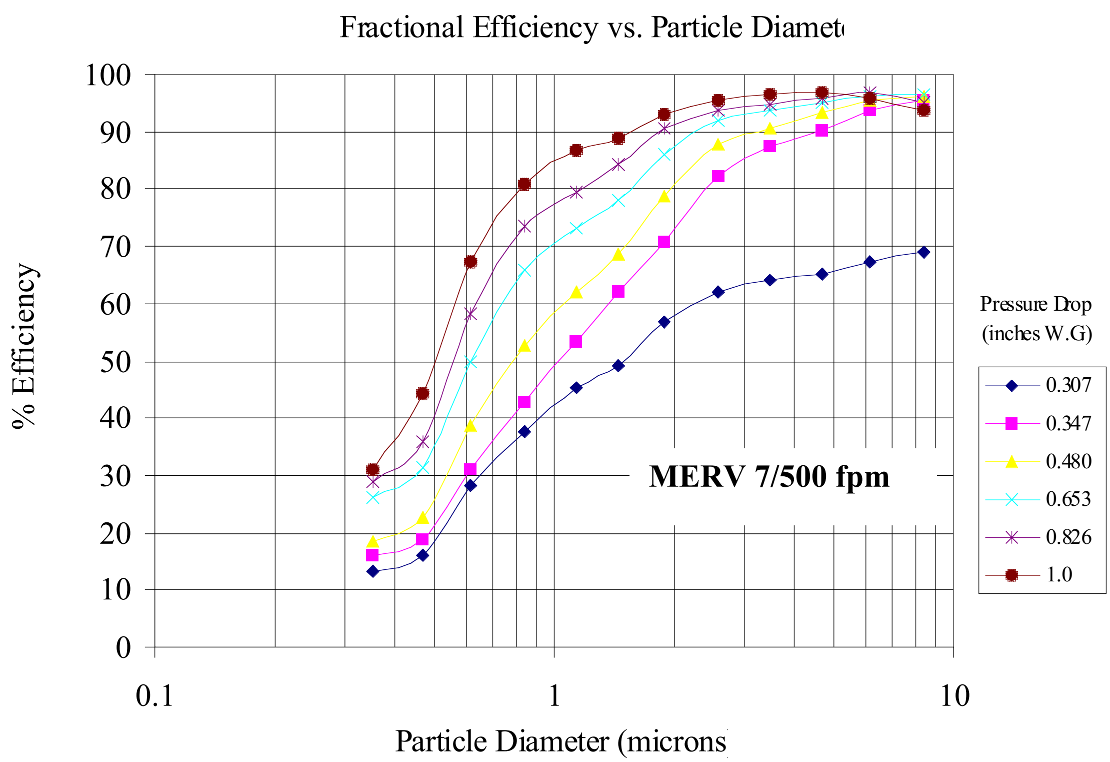

Figure 1: ASHRAE 52.2, 20” X 20” X 2” Pleat with Charged-Mechanical Media

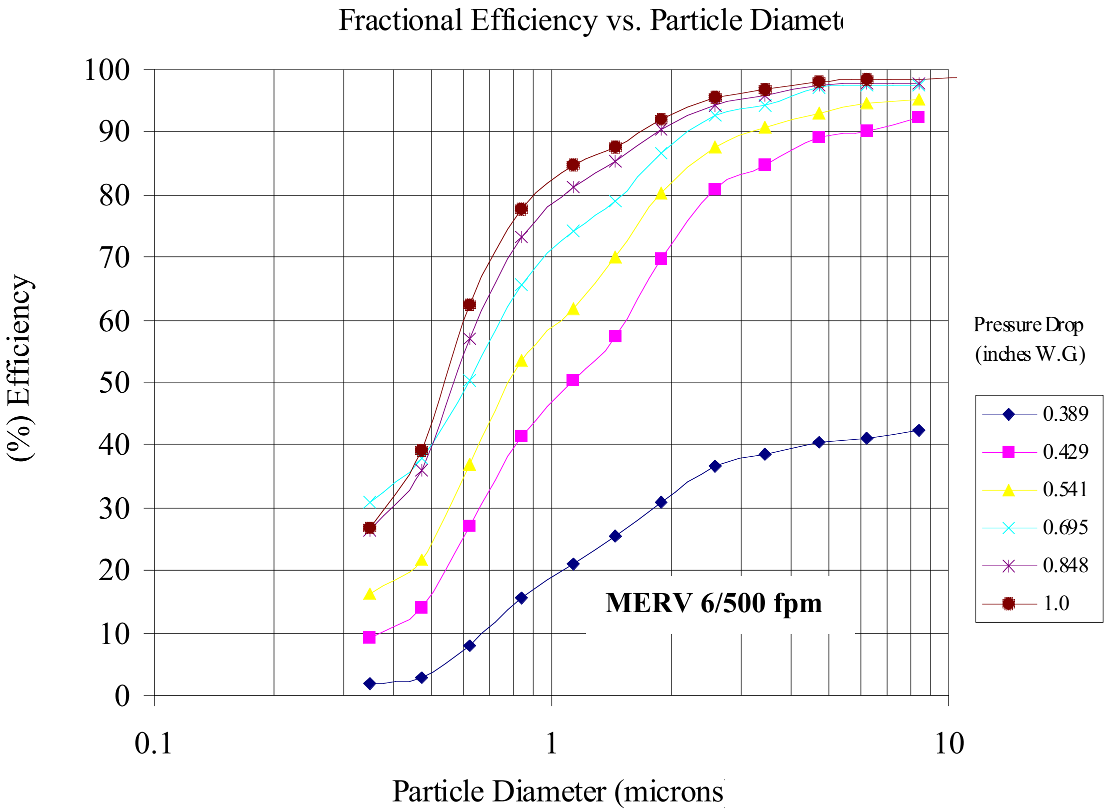

Figure 2: ASHRAE 52.2, 20" X 20" X 2" Pleat with Uncharged-Mechanical Media

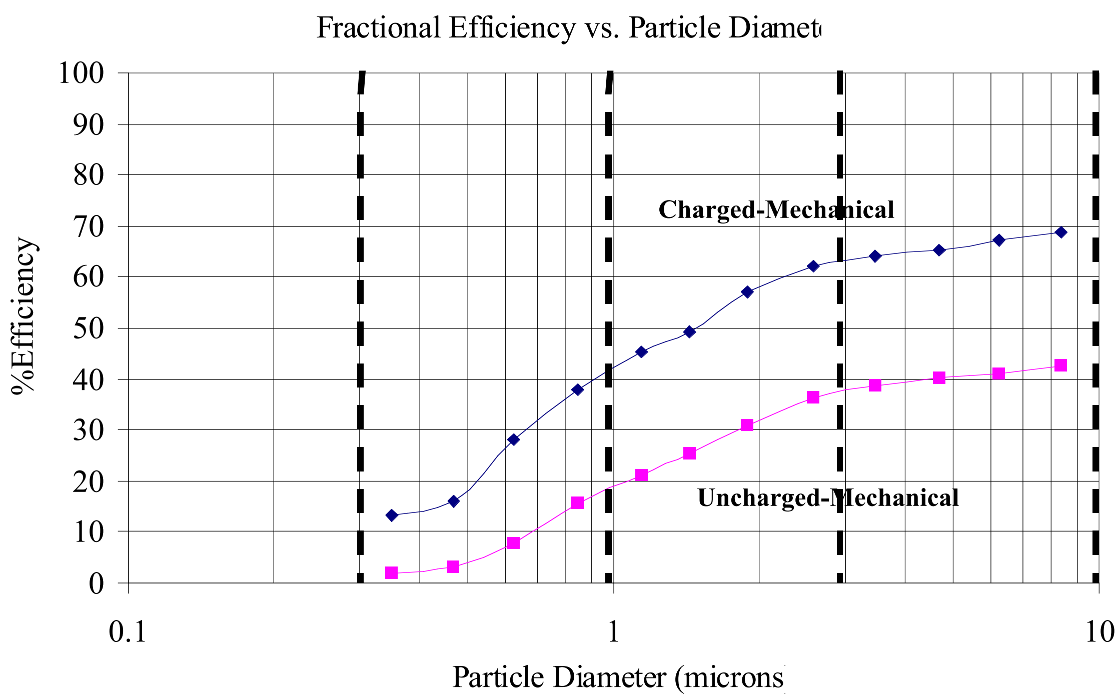

Figure 3: ASHRAE 52.2 Composite Minimum Efficiency Curve, 20" X 20" X 2" Pleat Filters

Actual filtration performance shows that the filter produced with charged-mechanical media yields a higher initial efficiency than that produced with the uncharged-mechanical media, and the MERV value predicted by ASHRAE 52.2 for the filter with charged-mechanical media is maintained over the service life. The uncharged-mechanical filter builds mechanical efficiency as predicted by ASHRAE 52.2 characterization. See Figure 4.

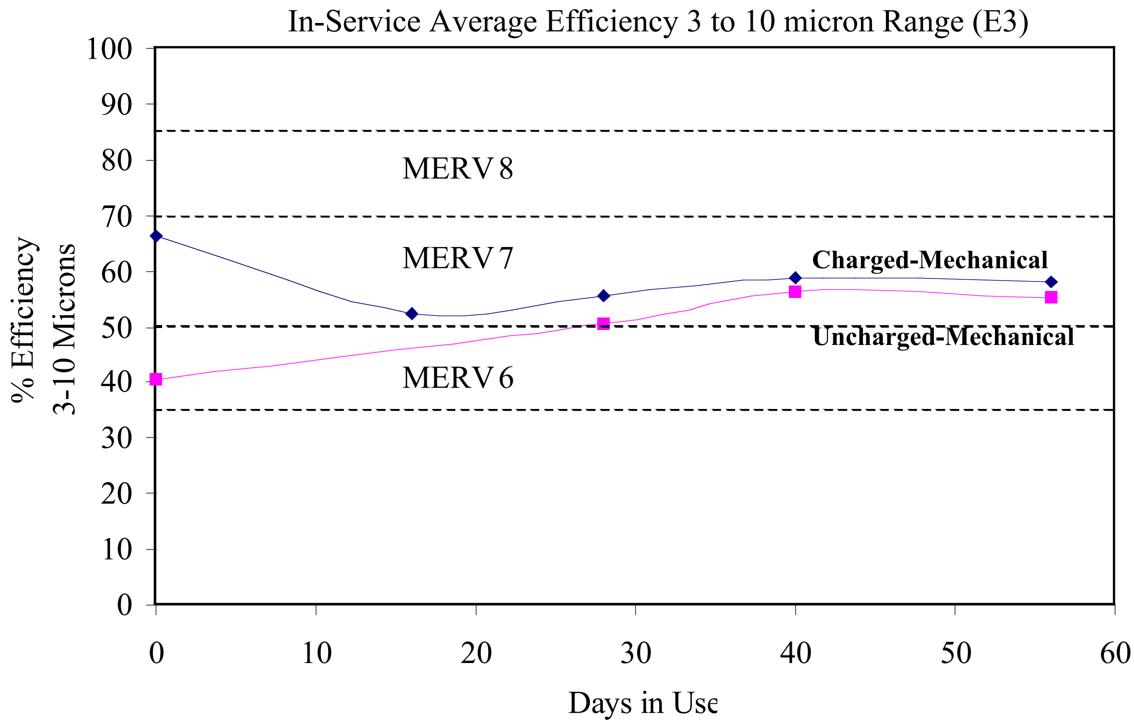

Figure 4: Pleat Filter Field Study, Hospital Site, 100% Outdoor Air

For this particular field study, the filter produced with the uncharged-mechanical media relied solely on a mechanical efficiency mechanism. The filter produced with the charged-mechanical media utilized an electrostatic charge to yield a high initial efficiency and a mechanical structure to sustain the efficiency over the life of the filter.

100% Indoor Air

Pleat filters produced with charged-mechanical media and filters manufactured using uncharged-mechanical media were tested at a residential location in the Atlanta area. ASHRAE 52.2 characterization predicts a steady increase in filtration efficiency as the filters made with both media types become loaded. The filter produced with charged-mechanical media exhibits higher initial and enhanced overall performance when compared to that produced from the uncharged-mechanical media. See Figures 5, 6, 7.

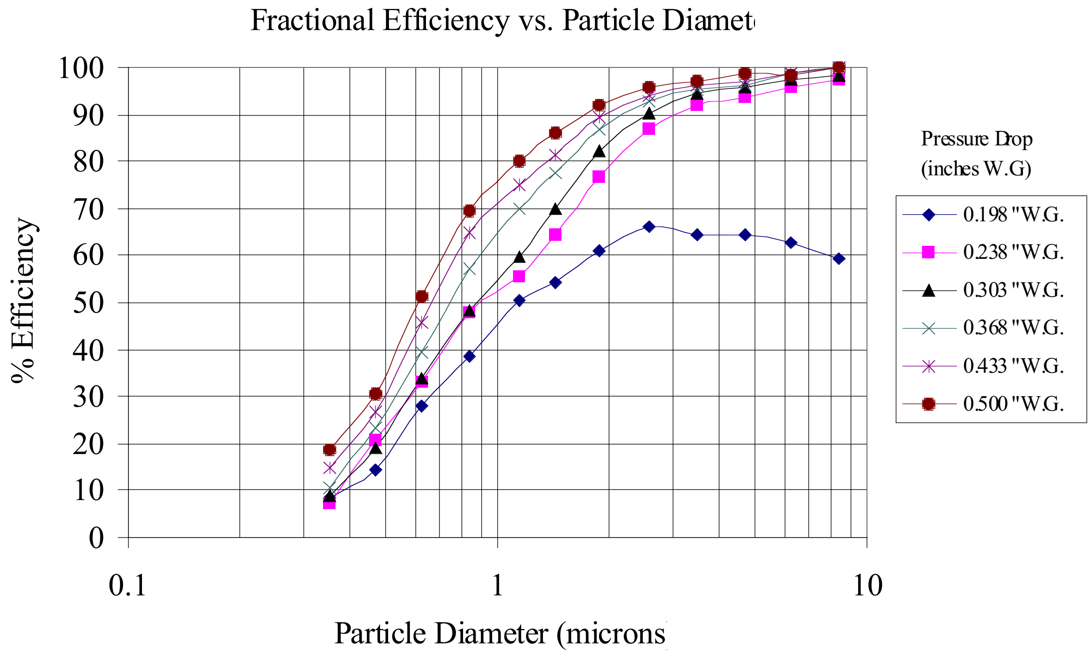

Figure 5: ASHRAE 52.2, Pleat Filter with Charged-Mechanical Media

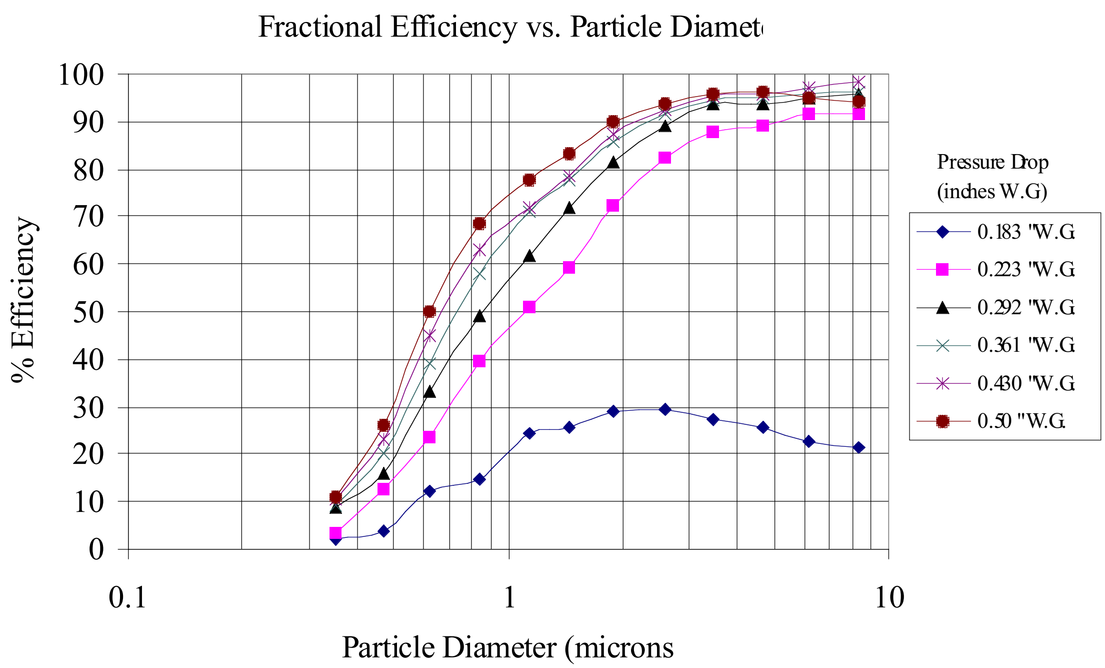

Figure 6: ASHRAE 52.2, Pleat Filter with Uncharged-Mechanical Media

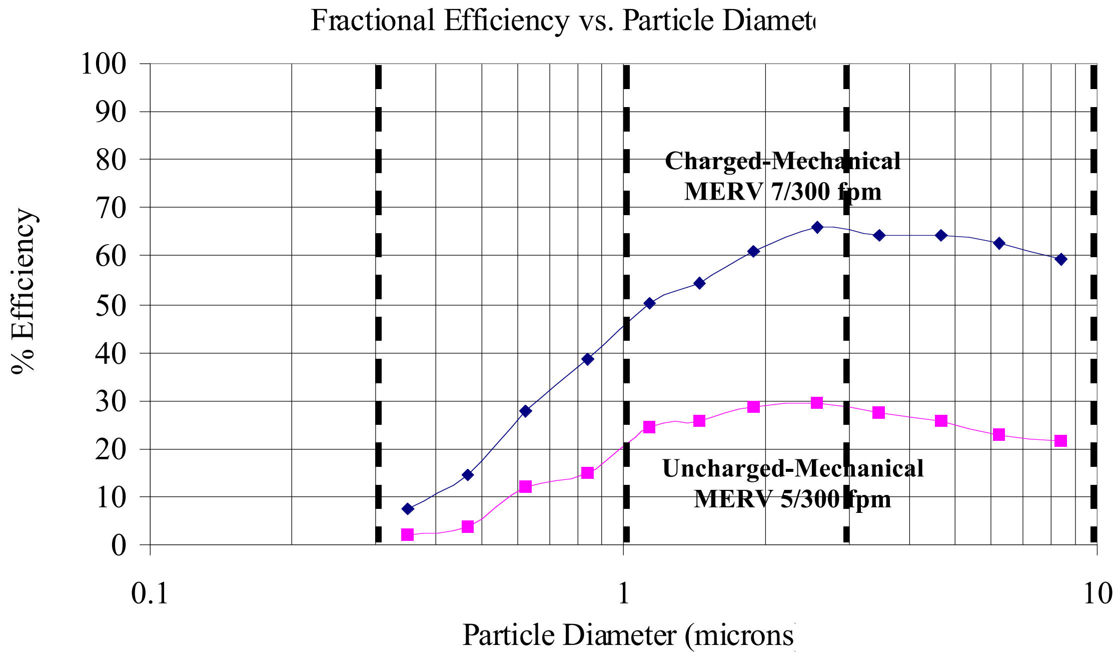

Figure 7: ASHRAE 52.2 Composite Minimum Efficiency Curve, Pleat Filters

Actual in-use performance for the filter with charged-mechanical media shows the electrostatic mechanism controlling initially with the subsequent build of mechanical efficiency (Figure 8). The filter produced with uncharged-mechanical media shows the steady build of mechanical efficiency requiring approximately one month of operation time to approach the performance of the filter produced with charged-mechanical media. As in the 100% outdoor air case study, the minimum efficiency of the filter from the field study is in the same range as characterized by the ASHRAE 52.2 MERV for the corresponding filter.

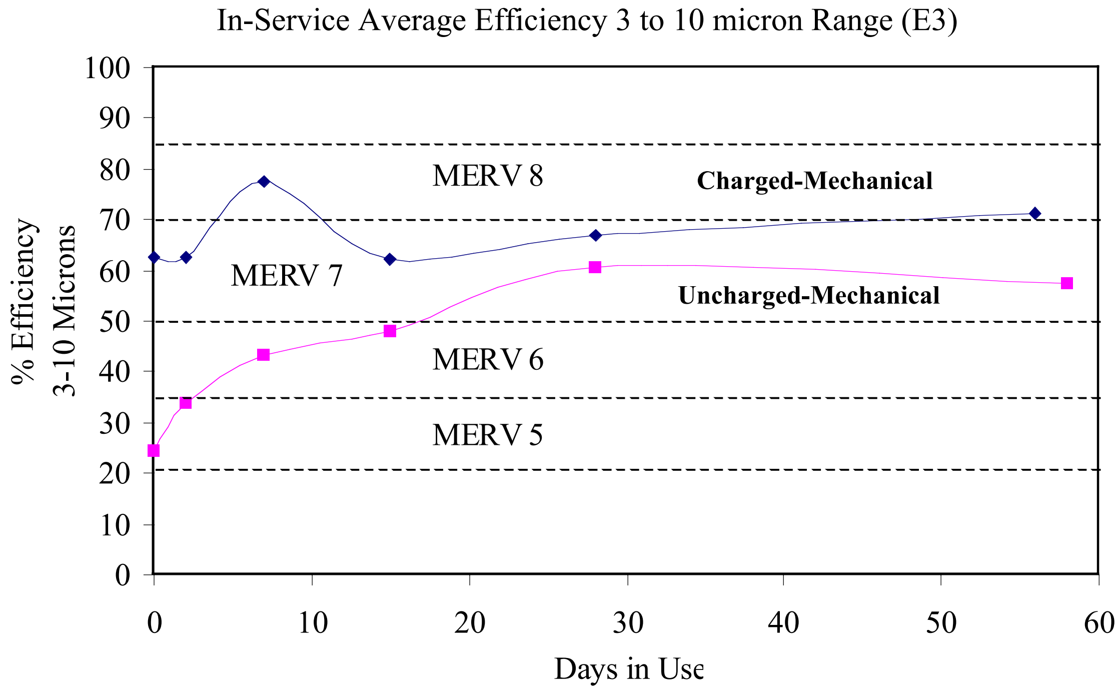

Figure 8: Pleat Filter Field Study, Residential Site, 100% Indoor Air

Mixture of Outdoor and Indoor Air

An additional field study was performed in an office building in the Atlanta area. Pleat filters produced with charged-mechanical media were utilized for comparison with those produced from uncharged-mechanical media. ASHRAE Standard 52.2 predicted performance characteristics of these filters are comparable to the previous cases. See Figure 9.

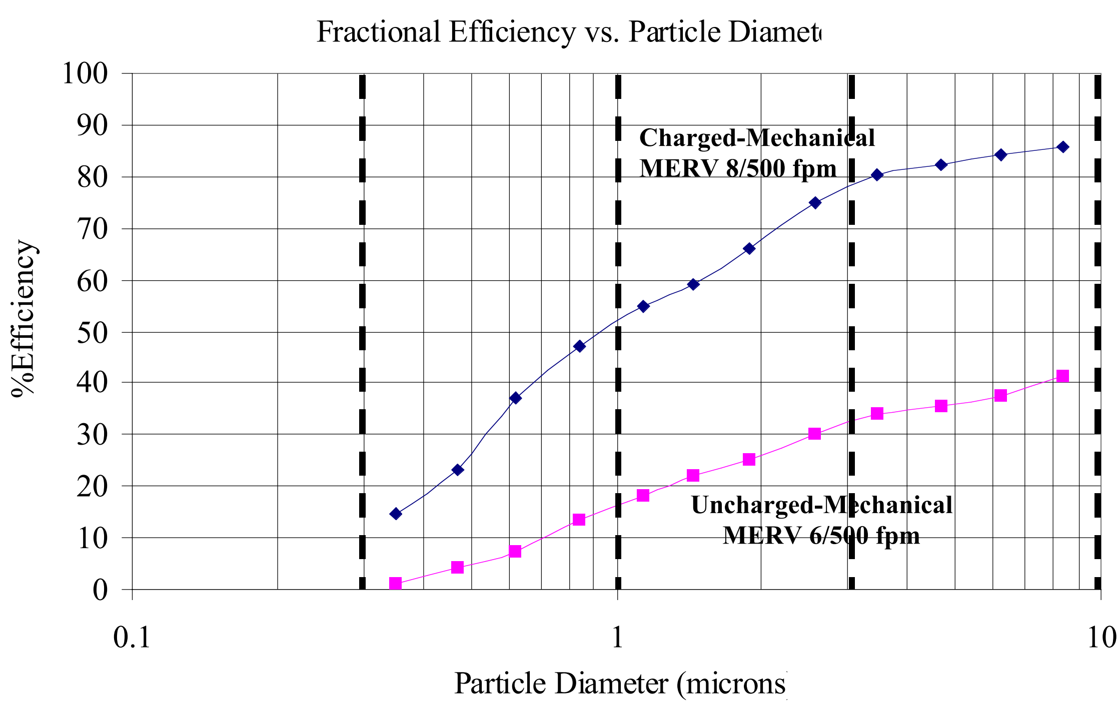

Figure 9: ASHRAE 52.2 Composite Minimum Efficiency Curve

Actual in-use performance shows higher filtration efficiency for the filter produced with the charged-mechanical media (Figure 10). Again, the efficiency of the filters in the field was accurately characterized by the ASHRAE 52.2 MERV.

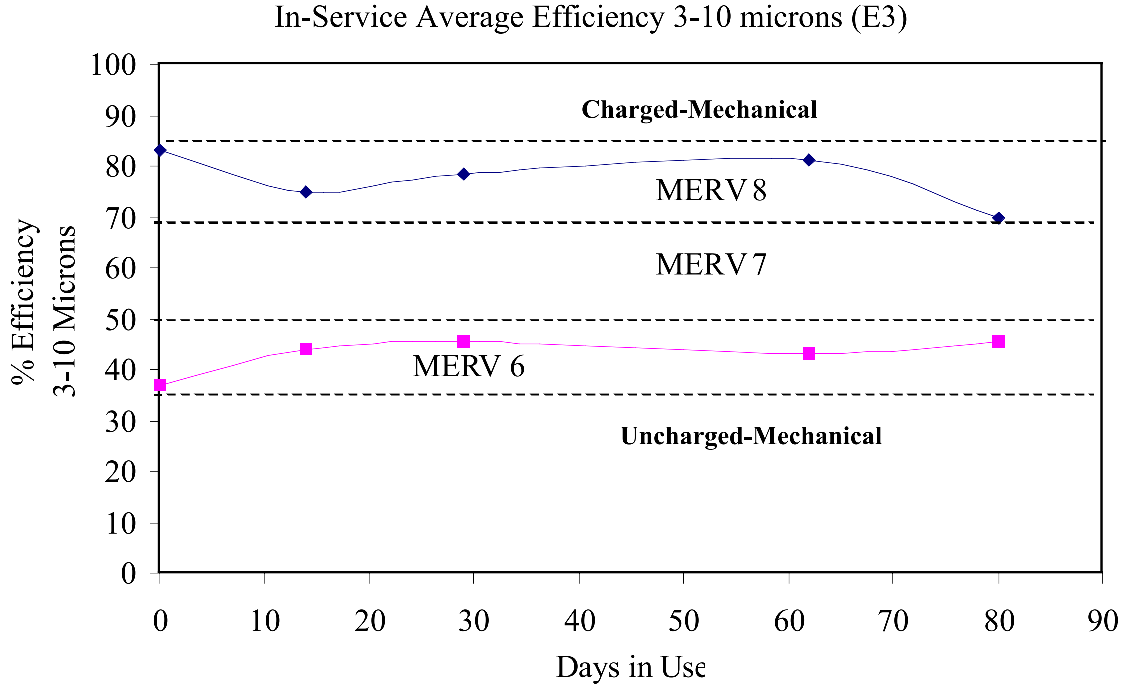

Figure 10: Pleat Filter Field Study, Office Site, Mixture Indoor/Outdoor Air

SUMMARY AND CONCLUSIONS

ASHRAE has two filter test standards that can both be used to learn different information about filter performance.

For the filters included in this field study, the ASHRAE 52.2 MERV accurately represents the minimum efficiency filtration level observed in-use.

The combination of the gradient structure and electrostatic charge provides a means of achieving high initial efficiency (due mostly to the charge) and sustained high efficiency (due mostly to the structure).

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