NONWOVEN MATERIAL PERFORMANCE IN AIR FILTRATION APPLICATIONS

B. Dean Arnold, Senior Research Scientist, Kimberly-Clark Corporation

ABSTRACT

The establishment of air filter test methods that accurately reflect actual in-use filtration performance is of great significance to the air filtration and nonwovens industry. A key issue in this regard is understanding the elements that impact the performance of filter media 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 the air to be filtered and ultimately accumulated within the nonwoven filter media. 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.

INTRODUCTION

The utilization of nonwoven materials in filtration applications is becoming increasingly popular. Furthermore, nonwoven manufacturing capability has made significant strides in the last few years allowing for the production of filtration media that has both a performance and cost advantage over traditional materials for filter manufacture. In many instances, the nonwoven web can be specifically designed for optimal function for a specific application. Of particular importance is the use of nonwoven media for air filtration applications and characterization of its performance.

This paper describes the results of studies conducted to investigate the actual in-use performance of pleated HVAC filters, manufactured with electret and non-electret nonwoven media, when exposed to a variety of commercial and industrial as well as residential environments. Field studies were conducted in installations using 100% outdoor air, 100% indoor air, and a mixture of indoor/outdoor air. Results were compared with the filtration performance described by ASHRAE 52.2[1] characterization.

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 filter media 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 media performance became increasingly important.

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[2] was approved as the generally accepted test standard for air filter evaluation. This protocol measures the following performance parameters:

- Filtration efficiency to a challenge of atmospheric particles.
- The ability of the filter to remove synthetic dust from an air stream.
- 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 Standard J726 Fine, 23% Powdered Carbon, and 5% Milled Cotton Linters. It is determined 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 nonwoven filter media comprising the pleat filter loads with contaminants.

The dust holding capacity is a measure of the amount of ASHRAE Test Dust that the filter will capture until a specified final pressure drop across the filter 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 specified size. 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 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 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 I) 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 measured 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 to determine the minimum efficiency reporting value (MERV) of the filter. See Table II.

TABLE I: ASHRAE 52.2 Particle Size Range

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 II: ASHRAE 52.2 Composite Average Efficiency Designation

Size Range Number	Particle Size Range (microns)	ASHRAE Efficiency Designation	Description
1	0.3 – 1.0	E_1	Average of loading curve composite minimums in 0.3 to 1.0 micron range.
2	1.0 – 3.0	E_2	Average of loading curve composite minimums in 1.0 to 3.0 micron range.
3	3.0 – 10.0	E_3	Average of loading curve composite minimums in 3.0 to 10.0 micron range.

The standard defines requirements for the minimum efficiency reporting value (MERV) which is dependent on the average composite minimum particle size efficiency in the size ranges defined in Table II. For the ASHRAE filtration efficiency range (up to 95% dust spot), the filter can receive a MERV value from 1 to 16. Table III 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[3].

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

MERV Range	ASHRAE 52.2 Composite Minimum Eff. Dependence	Examples
MERV 1 - 4	E_3	Furnace Flat Panel Filters
MERV 5 - 8	E_3	Pleated Filters
MERV 9 - 12	E_2, E_3	Box, Bag Filters
MERV 13 - 16	E_1, E_2, E_3	Box, Bag Filters

The use of ASHRAE 52.2 is best illustrated by example. Table IV shows an ASHRAE 52.2 data set. The particle size fractional efficiency, in each of the particle size ranges, for a clean filter is measured. This is the initial efficiency. The filter is then loaded with ASHRAE Test Dust, in an amount not to exceed 30 grams, to a pressure rise of 0.04" W.G. (whichever comes first), and the fractional efficiency is again tested. This represents the first loading or conditioning step. Loading of the filter and fractional efficiency characterization continues over four more pressure rise intervals until a final pressure drop across the filter is reached.

The minimum efficiency observed over the initial and five loading curves is identified for each particle size. This data set is denoted as the composite minimum efficiency (CME) curve. Working with the CME data, the average minimum efficiency in the 0.3 to 1.0 micron size range,

E_1, is 35.5% (Average of 25.4, 29.8, 38.6, 48.1). Average minimum efficiency in the 1.0 to 3.0 micron size range, E_2, is 66.3%, and E_3, average minimum efficiency in the 3.0 to 10.0 particle size range, is 86.8%. Given values for E_1, E_2, and E_3, this particular filter achieves MERV 11 performance when tested at a face velocity of 492 fpm (feet per minute).

Table IV: ASHRAE 52.2 Data Set, 24 X 24 X 2 Pleat Filter @ 492 fpm to a Final Resistance of 1.0" W.G.

Dust Load	Initial	1st Load	2nd Load	3rd Load	4th Load	5th Load	(CME)	
Size Range (microns)	Fractional Efficiency (%)						Composite Minimum Efficiency	
0.3 - 0.4	25.4	26.1	31.2	36.2	39.3	40.1	25.4	
0.4 - 0.55	29.9	29.8	36.9	42.1	43.9	45.8	29.8	
0.55 - 0.7	38.6	38.6	44.1	55.1	57.7	60.9	38.6	E_1
0.7 - 1.0	48.1	48.8	56.1	66.7	70.3	73.9	48.1	
1.0 - 1.3	56.2	60.7	66.4	75.5	79.3	82.4	56.2	
1.3 - 1.6	61.0	66.4	73.3	80.1	82.1	85.3	61.0	
1.6 - 2.2	68.6	74.1	80.9	87.3	89.3	90.7	68.6	E_2
2.2 - 3.0	79.5	87.6	92.2	94.4	96.0	95.0	79.5	
3.0 - 4.0	84.4	95.6	96.9	97.6	98.4	98.2	84.4	
4.0 - 5.5	86.2	97.3	98.2	98.5	99.2	98.9	86.2	
5.5 - 7.0	87.8	98.4	98.4	99.2	99.2	99.0	87.8	E_3
7.0 - 10.0	88.7	98.3	98.9	99.3	99.3	99.3	88.7	

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. One key point is that the nonwoven media is now loading with real atmospheric contaminants instead of synthetic dust. Filters manufactured with charged-mechanical and uncharged-mechanical nonwoven 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 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 (E_3) range.

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. It is important to note that a new 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 Air Environment

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 nonwoven filter media became loaded in actual use. ASHRAE 52.2 characterization of the filter produced with charged-mechanical media predicts MERV 7 performance while that with the mechanical media received a MERV 6. ASHRAE 52.2 characterization of the filters produced from both types of media predicts a filtration efficiency increase as the filter becomes loaded with contaminants. Both filters were tested at a face velocity of 492 fpm and loaded to a final pressure drop of 1.0 "W.G. See Figures 1, 2, and 3.

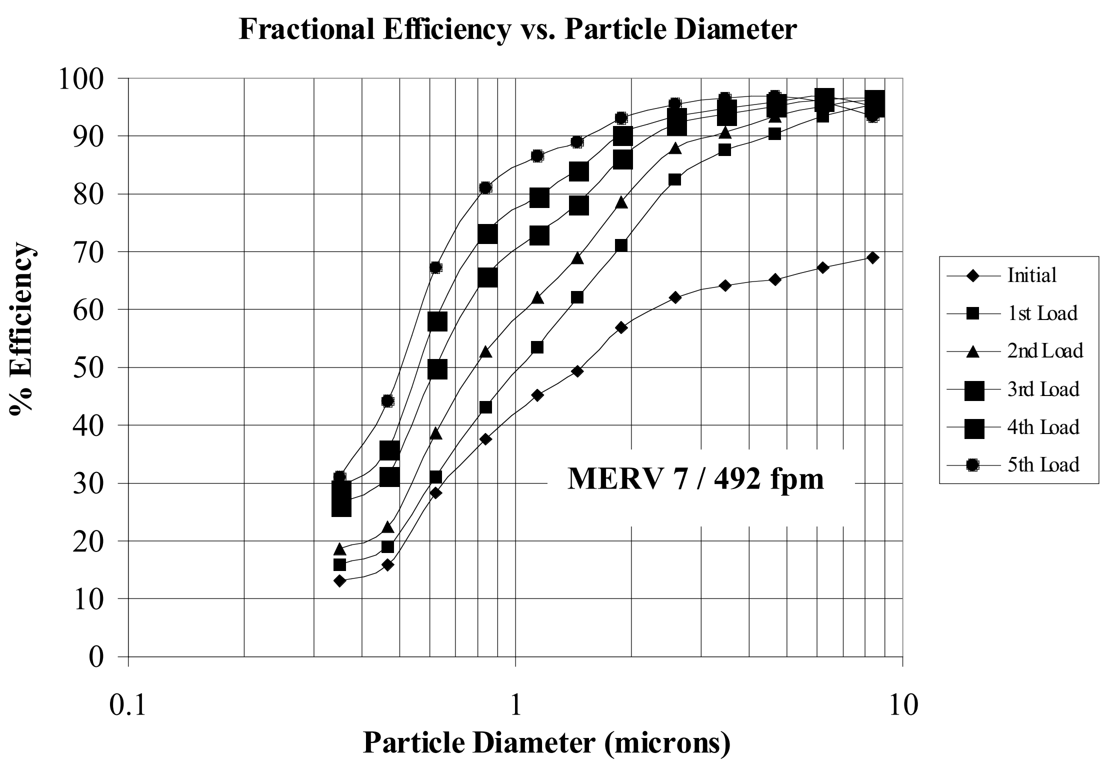

Figure 1: ASHRAE 52.2, 20" X 20" X 2" Pleat with Charged-Mechanical Media

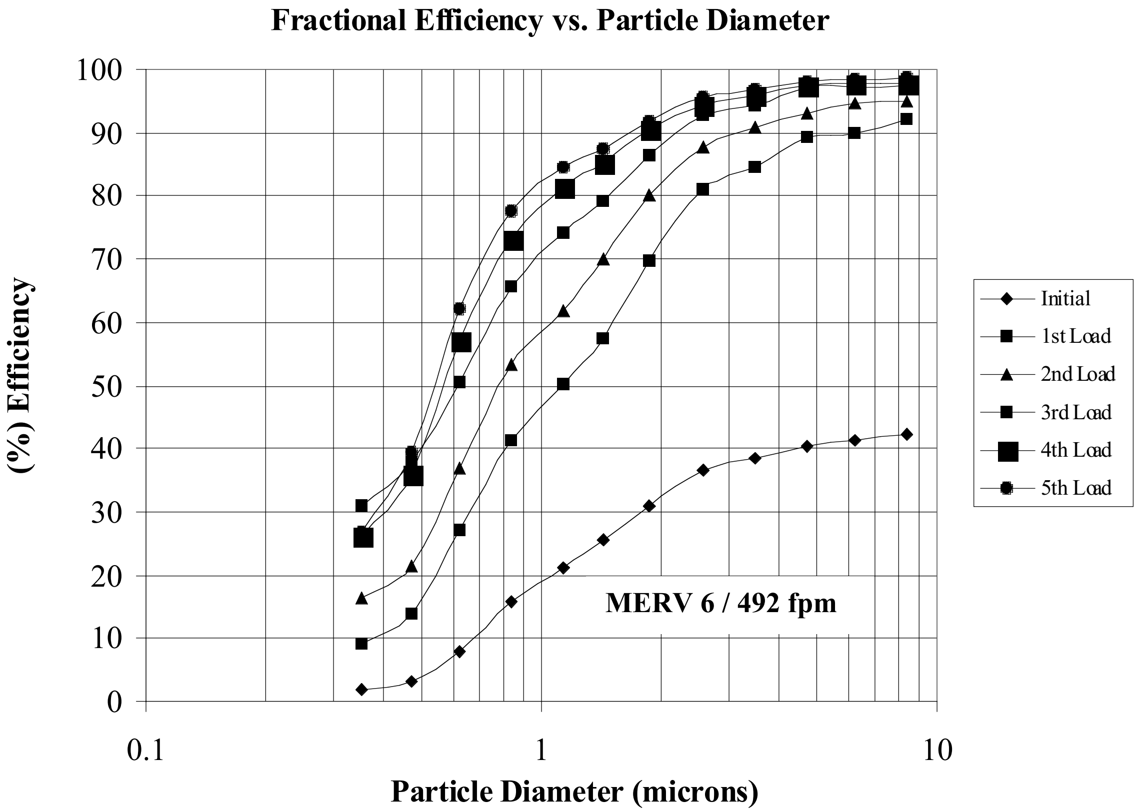

Figure 2: ASHRAE 52.2, 20” X 20” X 2” Pleat with Uncharged-Mechanical Media

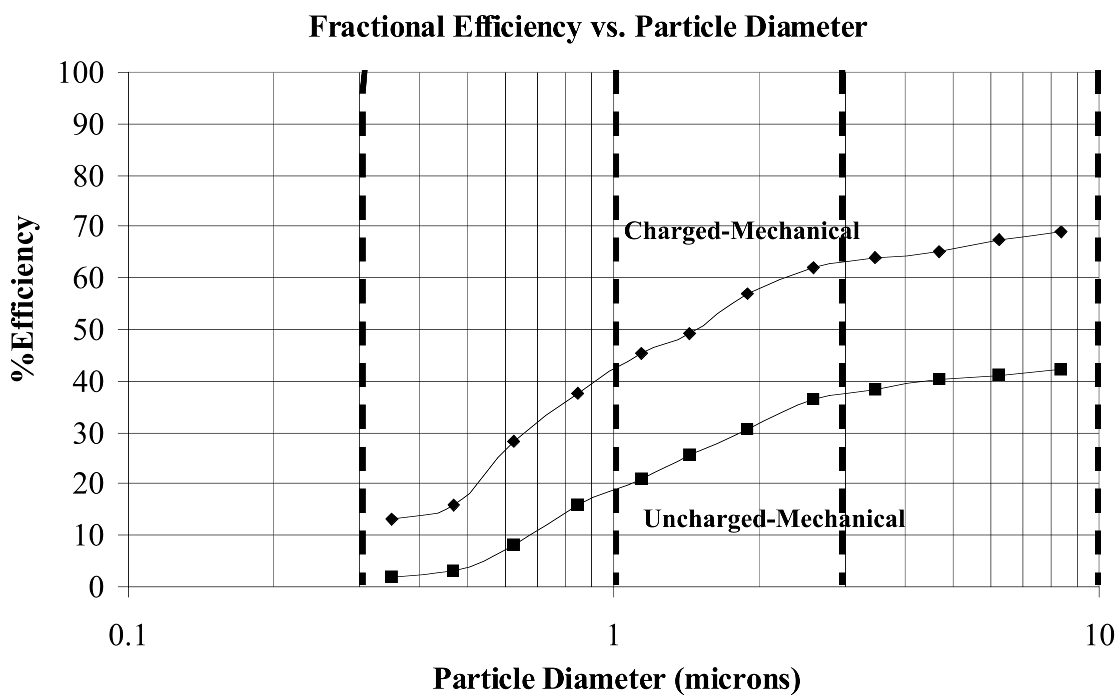

Figure 3: ASHRAE 52.2 Composite Minimum Efficiency Curve, 20” X 20” X 2” Pleat Filters

Actual filtration performance shows that the efficiency drops for the charged-mechanical media as it loads with atmospheric contaminants, but the MERV predicted by ASHRAE 52.2 is maintained over the in-service life. When the charged-mechanical nonwoven media is clean, electrostatic attraction is the controlling mechanism for particulate capture, but as the structure loads, the mechanical collection mechanism become dominant. The uncharged-mechanical filter builds mechanical efficiency as predicted by ASHRAE 52.2 characterization. See Figure 4.

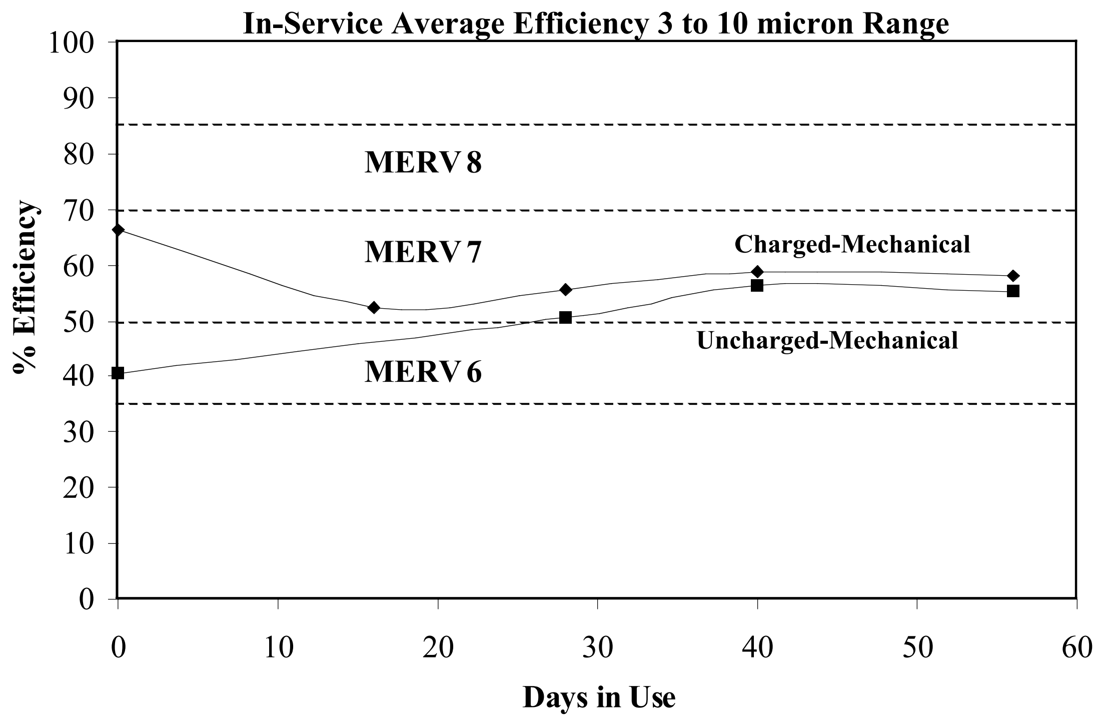

Figure 4: Pleat Filter Field Study, Hospital Site, 100% Outdoor Air

100% Indoor Air Environment

Pleat filters produced with charged-mechanical nonwoven media and filters manufactured using uncharged-mechanical media were tested at residential locations 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 with contaminants. See Figures 5, 6, 7 for ASHRAE results.

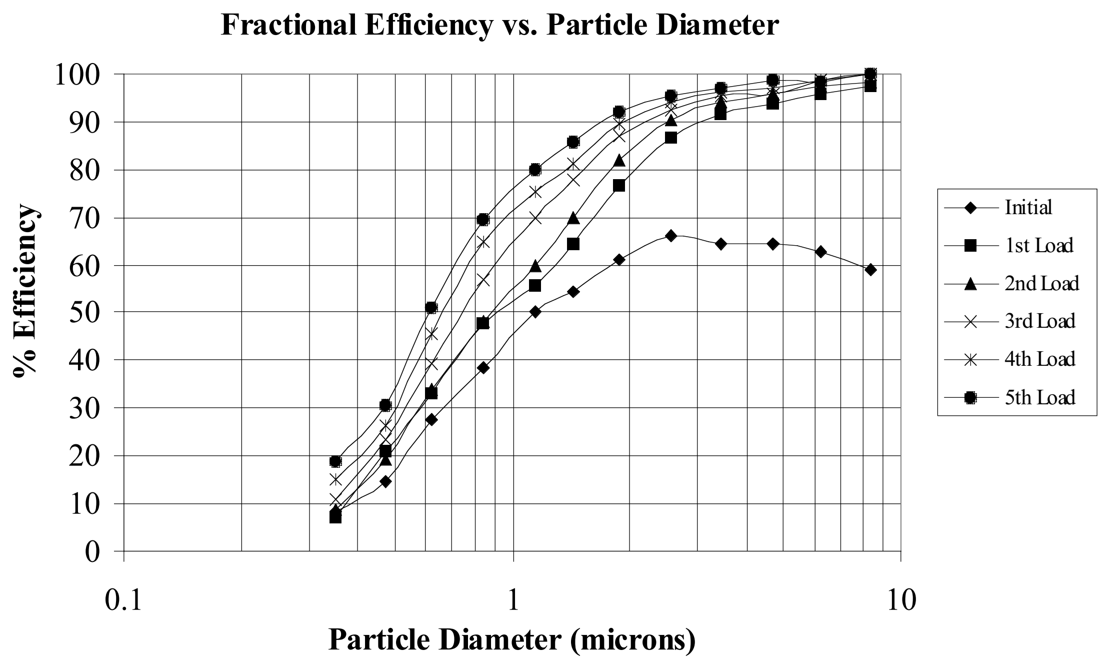

Figure 5: ASHRAE 52.2, Pleat Filter with Charged-Mechanical Media

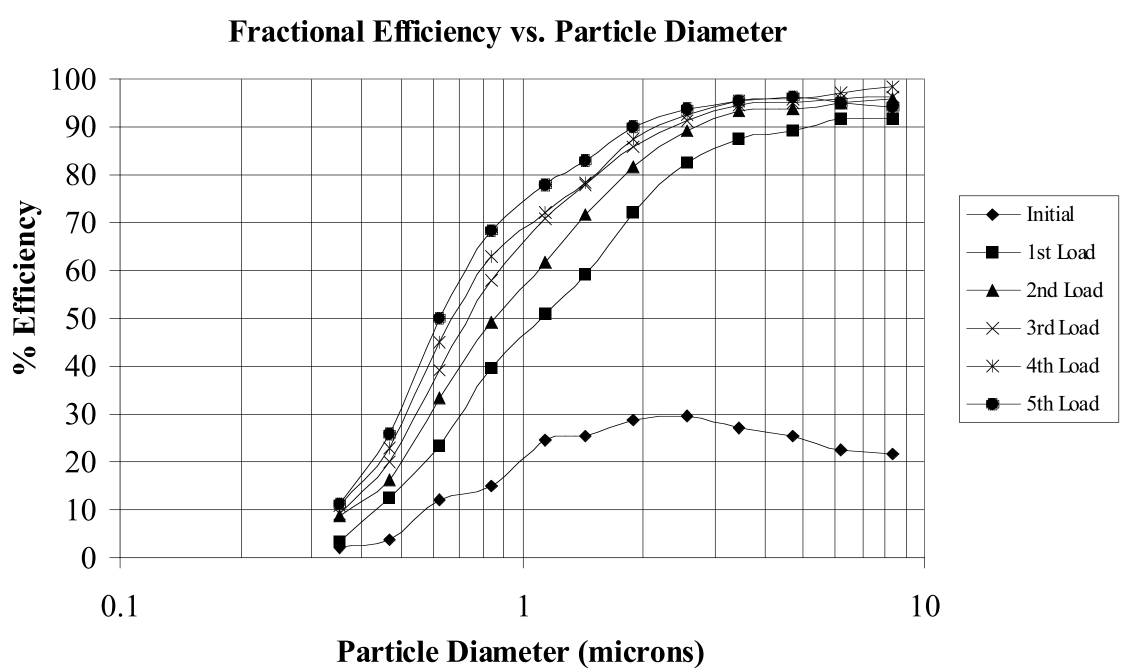

Figure 6: ASHRAE 52.2, Pleat Filter with Uncharged-Mechanical Media

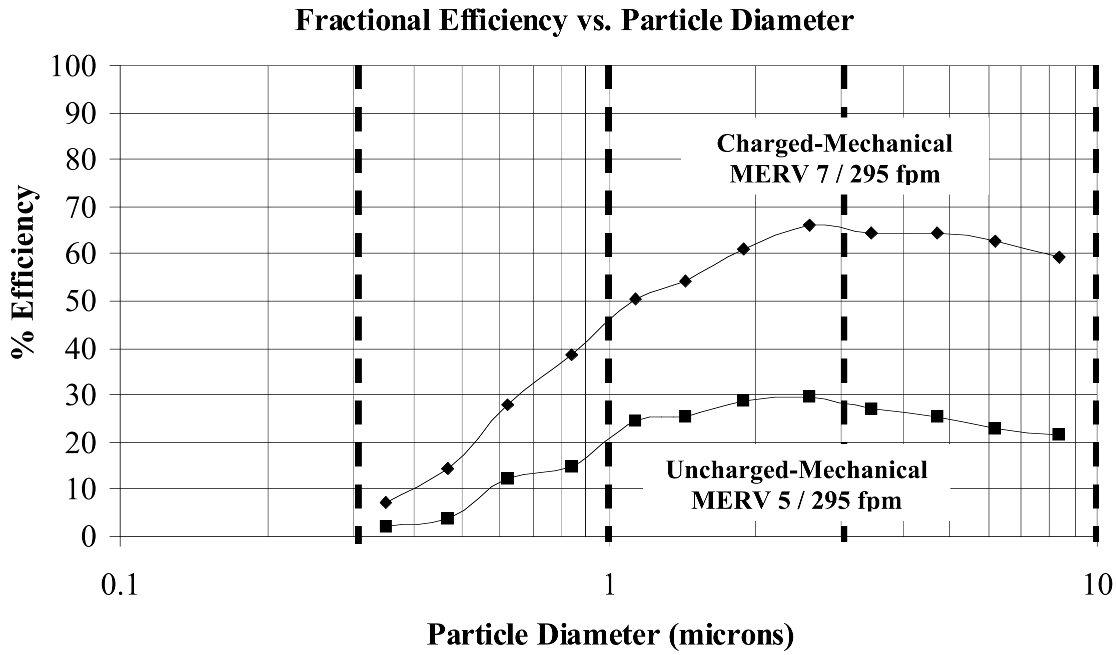

Figure 7: ASHRAE 52.2 Composite Minimum Efficiency Curve, Pleat Filters

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. The charged-mechanical nonwoven media continues to build in efficiency reaching MERV 11 performance as it approaches ninety days in service.

As in the 100% outdoor air case study, the minimum efficiency of the filter in the residential environment performs in the same range, in-use, as characterized by the ASHRAE 52.2 MERV for the corresponding filter.

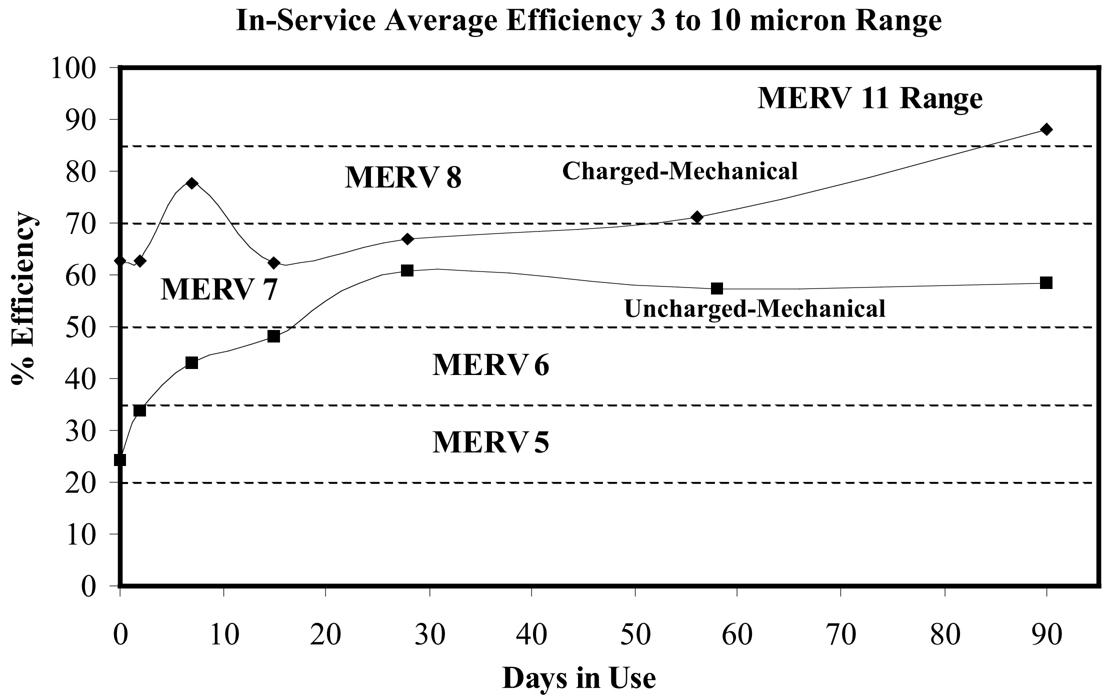

Figure 8: Pleat Filter Field Study, Residential Site, 100% Indoor Air

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 nonwoven media were utilized for comparison with those produced from uncharged-mechanical media. See Figure 9 for ASHRAE 52.2 results.

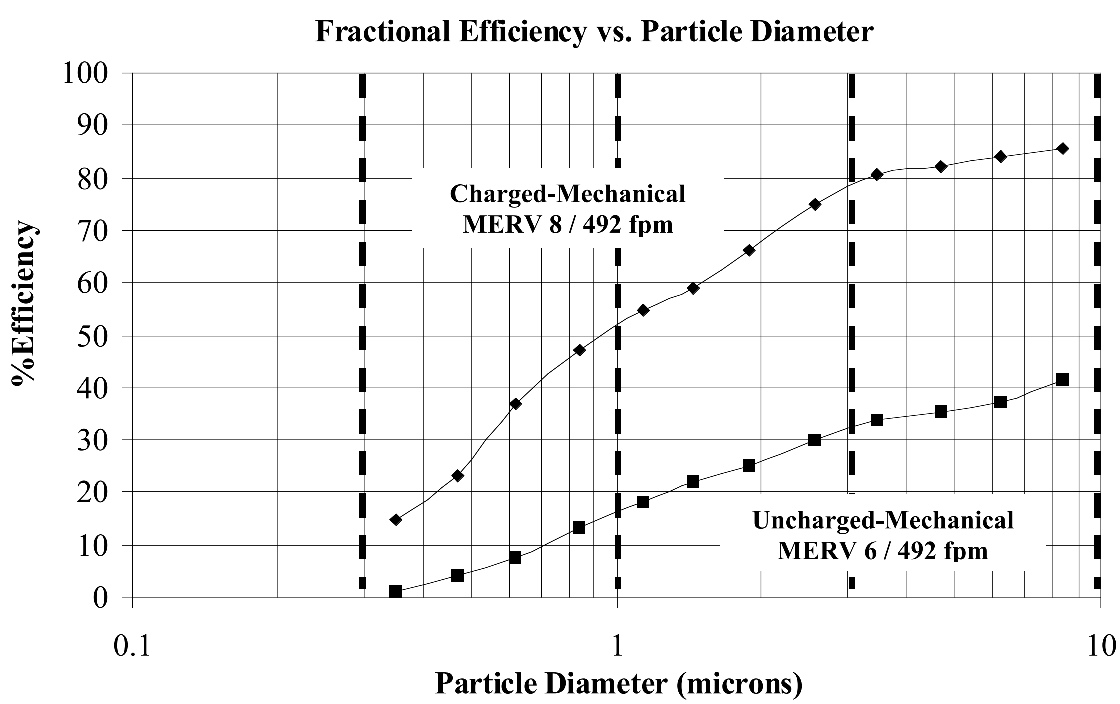

Figure 9: ASHRAE 52.2 Composite Minimum Efficiency Curve
24 X 24 X 4 Pleat @ 492 fpm to 1.0 "W.G.

Actual in-use performance shows results similar to previous case studies. See Figure 10.

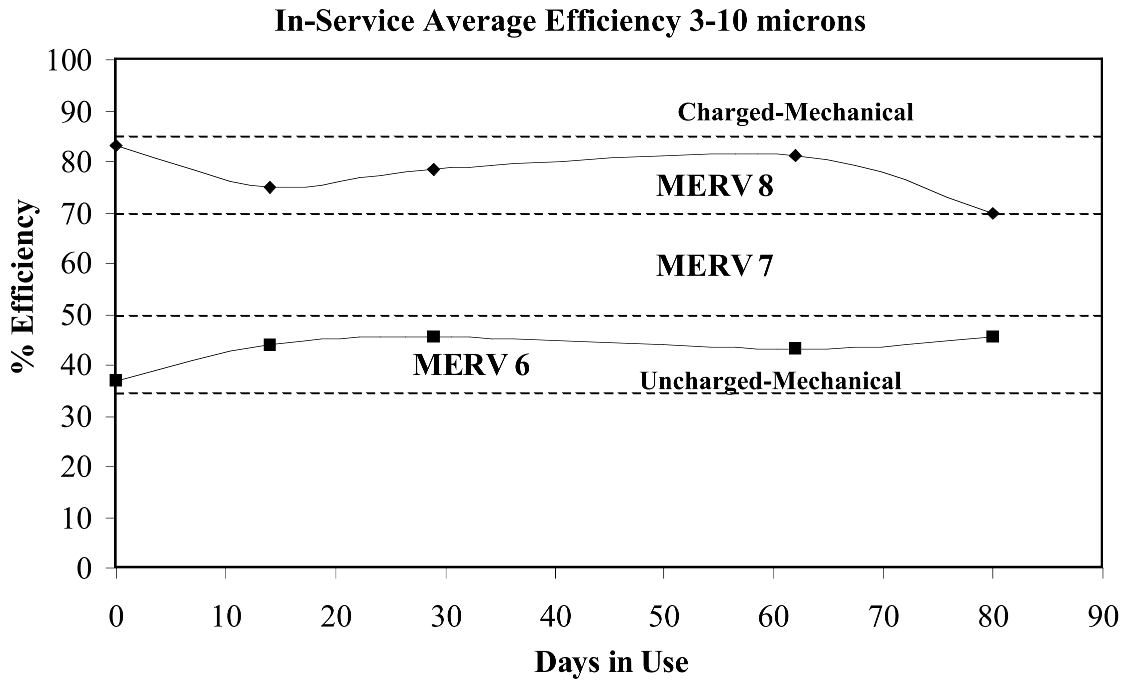

Figure 10: Pleat Filter Field Study, Office Site, Mixture Indoor/Outdoor Air

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 predicted the minimum efficiency filtration level observed in-use.

A nonwoven filter media that utilizes a combination of mechanical 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).

References

1. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. 1999, ANSI/ASHRAE Standard 52.2 “Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size”.

2. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc, 1992, ANSI/ASHRAE 52.1 – 1992, "Gravimetric and Dust-Spot Procedures for Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter".

3. National Air Filtration Association, 1996, NAFA GUIDE TO AIR FILTRATION, 2^{nd} Edition.