

The efficiency and pressure drop of filters made from synthetic fibres carrying electrostatic charges and filters made from uncharged glass fibres were measured repeatedly for more than 19 weeks in operating HVAC systems. Results showed efficiency reductions as large as 40% for the filters made from charged fibres whereas the efficiency of filters made from uncharged fibres changed little.

Clean filters were sent to a testing laboratory for efficiency measurements according to ASHRAE Standard 52.2-1999. When the filters experienced accelerated dust loading according to the ASHRAE procedure, the efficiency of both the glass and synthetic fibre filters increased. Efficiency reductions like those observed for the charged filters during actual use were not replicated by this standard test.

# Dust Loading on Electrostatically Charged Filters in a Standard Test and a Real HVAC System

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**A**irborne particles pose a variety of health concerns for building occupants. Higher exposure to atmospheric particles smaller than 2.5  $\mu\text{m}$  in diameter has been related to higher death rates due to lung cancer and cardiopulmonary illness [1]. Recent deaths among postal and office workers were caused by inhalation of airborne anthrax spores. Exposure of building occupants to chemical, biological, and radiological aerosols released by terrorists is a new concern. Thus, the importance of air filters used in heating, ventilating, and air-conditioning (HVAC) systems has never been more apparent than it is now.

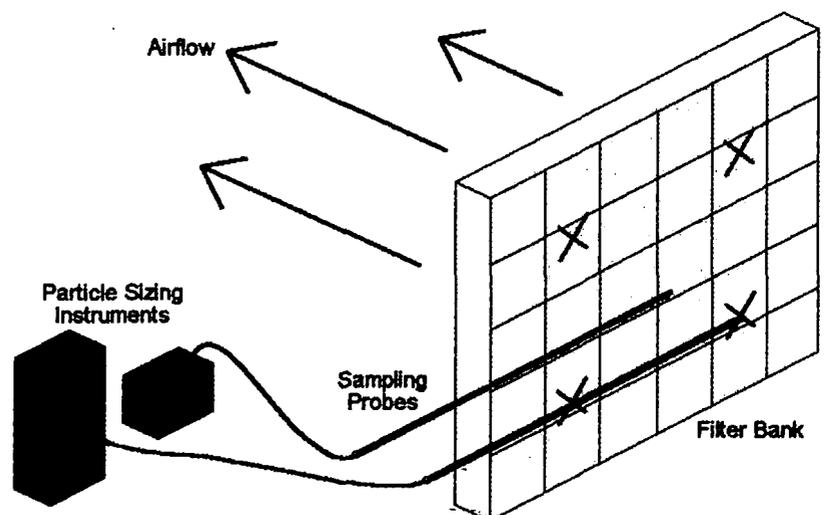
Purchasers of air filters need reliable and pertinent data to make informed decisions when buying filters. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 52.2-1999 [2], which establishes a method for testing filter efficiency as a function of particle size, offers a way for filter suppliers to provide some of these data for their customers. By generating potassium chloride particles and counting and sizing them upstream and downstream from a test filter, the efficiency of the filter can be calculated in 12 particle diameter increments. The standard also describes a procedure in which a synthetic dust comprised of mineral particles, carbon black, and cotton linters is loaded incrementally onto the test filter with efficiency being measured again after each incremental loading. The purpose of the dust loading test is to simulate changes in the performance of the filter as it might be used in a real HVAC system.

Many filters used in HVAC systems are made from synthetic fibres that carry electrostatic charges. The advantage of electrostatically enhanced fibres, which can be produced in a variety of ways, is that they can attract particles carrying opposite charges more effectively than neutral fibres. In addition, the

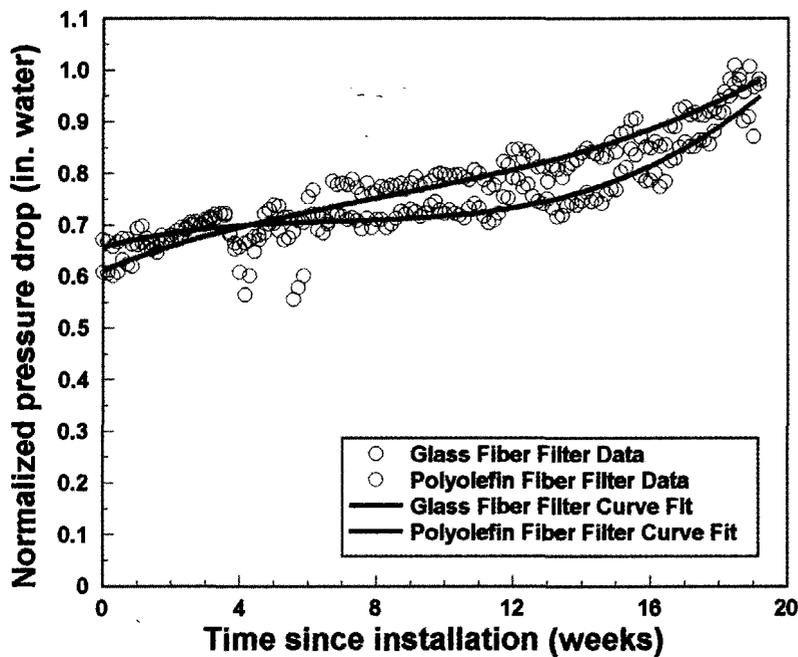
charged fibres can induce a charge gradient across neutral particles or even similarly charged particles to collect them more effectively than neutral fibres can.

## Background

Researchers have studied the performance of filters made from charged fibres as they collect solid particles. Jodeit & Löffler [3] found that efficiency decreased initially as electret filters made from coarse polypropylene fibres collected high concentrations of quartz particles in an accelerated laboratory experiment. After reaching a minimum, the efficiency increased. However, the efficiency of electret filters made from fine polycarbonate fibres exhibited only a steady increase when exposed to the



**Figure 1: Simplified diagram of the test set up. Air samples were drawn directly upstream and downstream from the points on the filter bank marked with an X.**



**Figure 2: Normalized pressure drop vs time for the glass and polyolefin fibre filters used in the HVAC systems. A third-order polynomial has been drawn through the data for each kind of filter.**

same quartz particles. The difference in performance between the two kinds of filters may have occurred because the fine polycarbonate fibres collected particles more effectively by mechanical methods. Lathrache *et al* [4] measured efficiency reductions followed by efficiency increases when filters made from both spun and split fibres carrying electrostatic charges were loaded with high concentrations of sodium chloride particles in laboratory tests.

Several studies have indicated that particle size and composition help to determine the extent of efficiency reduction as filters made from charged fibres collect particles. Baumgartner & Löffler [5] discovered that split fibre electret filters exhibited efficiency declines when exposed to both coarse quartz particles and fine salt particles in accelerated particle loading tests. However, they found that filters made from electrostatically spun fibres showed efficiency reductions when loaded with fine salt particles, but only efficiency increases when loaded with the coarse quartz particles. Walsh & Stenhouse [6, 7] ran laboratory experiments that demonstrated that the reductions in efficiency for electrostatically enhanced filters depended on particle size and composition. These authors asserted that small particles caused more efficiency loss because they clogged the filters more effectively than the large particles. They also suggested that particles with greater electrical permittivity, the ability to store electrical charge, were more likely to cause reductions in efficiency. Brown *et al* [8] evaluated the ability of different types of electrically charged respirator filters to collect different kinds of particles generated in workplaces. They discovered that the amount of efficiency loss depended on the type of particles collected.

Lathrache *et al* [4] and Baumgartner & Löffler [5] both noted that spun fibre electret filters exhibited less reduction in efficiency than split fibre electret filters. Barrett & Rousseau [9]

explored differences among electrostatically charged filter media by comparing a tribocharged medium, a fibrillated electret film medium and a blown microfibre medium as they were loaded with sodium chloride particles in laboratory tests. They found that the efficiency of the blown microfibre medium decreased less than the efficiency of the other media.

Taken together, these accelerated particle loading studies suggest that HVAC filters made from fibres carrying electrostatic charges may exhibit efficiency reductions when they are used in HVAC systems. However, no one has published data to show if these reductions occur in real ventilation units. Therefore, one purpose of this research was to compare the performance of filters made from charged synthetic fibres to uncharged glass fibre filters as they collected atmospheric particles in real HVAC systems.

For electrostatically charged media, ASHRAE Standard 52.2 [2] noted that the minimum efficiency observed with the standard's dust loading procedure might be higher than the minimum efficiency that occurs during real use. Thornburg [10] discussed the need for a better conditioning procedure in Standard 52.2 to replicate conditions in which HVAC filters are utilized. Thus, a second purpose of this research was to determine how closely the dust

loading procedure used in ASHRAE Standard 52.2 replicates filter performance in operating HVAC systems.

## Methods

The performance of filters made from glass fibres carrying no inherent charge and filters made from polyolefin fibres carrying an electrostatic charge was evaluated for more than 19 weeks in operating HVAC systems. These two nearly identical systems were located in a large laboratory and office building.

The air handling units used to test the filters were each sized to deliver a maximum of 60 000 cfm (102 000 m<sup>3</sup>/h) of 100% outdoor air to the building. The intakes to the systems were located within 10 m of each other above a lightly traveled road. From the intakes, the air was drawn downward into the air handling units. In each system, the air then passed through a bank of thirty 2 ft x 2 ft (0.61 m x 0.61 m) pre-filters before entering the blower. Tests performed according to ASHRAE Standard 52.2-1999 indicated that the pre-filters collected greater than 90% of incoming particles 3 µm in diameter or larger after minimal dust loading. Upon exiting the blower and passing through a mist humidification system that was turned off throughout the test, the air encountered the 30 primary test filters. In each unit, the 2 ft x 2 ft (0.61 m x 0.61 m) filters were arrayed in five rows and six columns as illustrated in Figure 1. Upon leaving the filters, the air passed through the air conditioning and heating systems before being distributed to the building. The air flow and temperature delivered by the systems were adjusted by computer control to meet the requirements of the building environments.

The polyolefin fibre filters were made from meltblown polyethylene and polypropylene fibres. The filter medium was formed into 15 pleats, each 28 cm deep and 54 cm tall, that

were glued into frames. When measured by the ASHRAE 52.1-1992 dust spot efficiency test, the polyolefin fibre filters were nominally 90-95% efficient. They were installed in one of the air handling units in random order. The glass fibre filters also had 15 pleats that were 28 cm deep and 54 cm tall. In addition, they were also nominally 90-95% efficient when measured by the ASHRAE 52.1-1992 dust spot efficiency test. These filters were installed in the other air handling unit in random order.

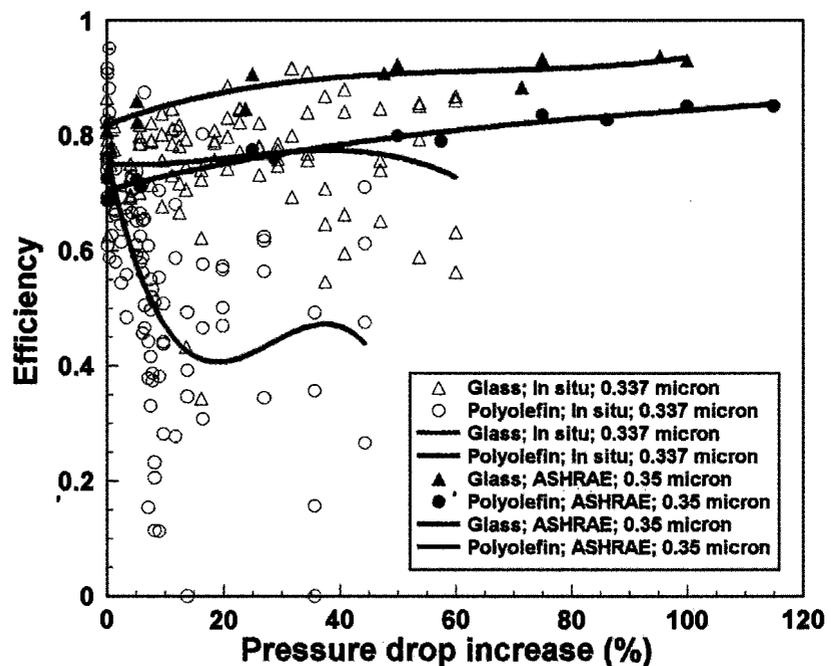
After the filters were installed, 26 sets of efficiency measurements were made during the next 19 weeks + one day. For each set of tests, the efficiency of the filters was measured at the four locations marked with an X on Figure 1. To calculate efficiency, particles were counted and sized upstream and downstream from both sets of filters. Air samples were drawn through the walls of the air handling units using two 3.7 m long, sharp-edged probes oriented perpendicular to the flow and to gravity. The probes, one located upstream from the filter and the other downstream, had inside diameters of 0.95 cm. The sampling locations were chosen by dividing the cross section of the filter bank into four quadrants and then centering a sampling point in each of the quadrants. The probes were connected to particle sizing instruments using 1.5 m lengths of plastic tubing, with inside diameters of 1.27 cm.

Two instruments were utilized to measure particle sizes and concentrations upstream and downstream from the filters. For larger particles ranging from 0.504 to 3.05 µm in diameter, an Aerodynamic Particle Sizer (APS) Model 3310 time-of-flight instrument (TSI Inc, MN, USA) was used. For particles between 0.117 and 0.457 µm in diameter, a Differential Mobility Particle Sizer (DMPS) electrical mobility instrument (TSI Inc) was utilized. In each test, a single sample was taken with each instrument at the four locations upstream and the four locations downstream from the filters.

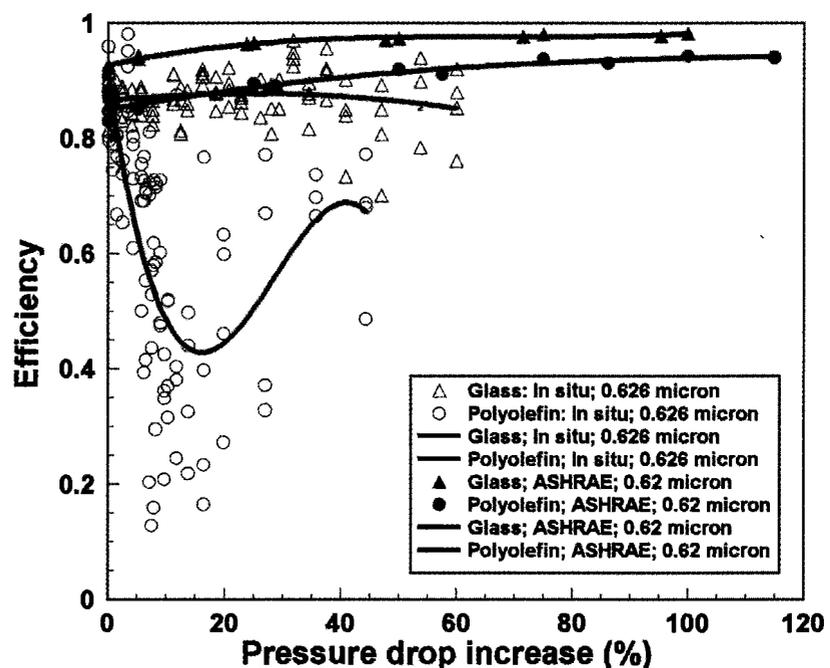
For each pair of readings taken in the same quadrant upstream and downstream from the filters, the efficiency,  $\eta$ , was calculated for each particle diameter according to the expression:

$$\eta = 1 - \frac{C_{down}}{C_{up}}$$

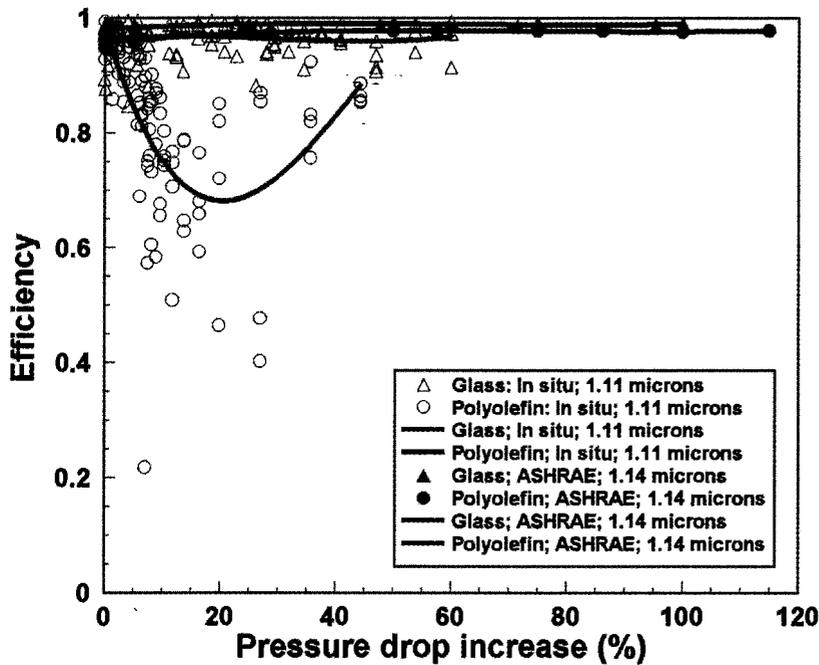
in which  $C_{down}$  is the downstream particle count and  $C_{up}$  is the upstream particle count. For each filter type, this provided four efficiency readings in each size interval.



**Figure 3: Efficiency versus pressure drop increase caused by dust loading for particles approximately 0.34 µm in diameter. Data are provided for glass and polyolefin fibre filters measured *in situ* in the HVAC systems, and according to ASHRAE Standard 52.2-1999. Third-order polynomials have been drawn through each set of data.**



**Figure 4: Efficiency versus pressure drop increase caused by dust loading for particles approximately 0.62 µm in diameter. Data are provided for glass and polyolefin fibre filters measured *in situ* in the HVAC systems and according to ASHRAE Standard 52.2-1999. Third-order polynomials have been drawn through each set of data.**



**Figure 5: Efficiency versus pressure drop increase caused by dust loading for particles approximately 1.1 µm in diameter. Data are provided for glass and polyolefin fibre filters measured *in situ* in the HVAC systems and according to ASHRAE Standard 52.2-1999. Third-order polynomials have been drawn through each set of data.**

Pressure drop across the filters was recorded once per hour by the computer control system. These readings were normalized using the fan rotational speed to adjust the pressure drop to the maximum air flow through the unit. The fan speed was recorded by the computer control system once per hour at the same time as the pressure drop.

At the conclusion of the test period, two unused glass fibre filters and two unused polyolefin fibre filters were shipped to a testing service for measurements according to ASHRAE Standard 52.2-1999 [2]. The efficiency and pressure drop of these filters, which were selected randomly before the test began, were measured when the filters were clean and then after five subsequent loadings with ASHRAE test dust. The airflow through each filter during the tests was 1968 cfm (3346 m<sup>3</sup>/h).

**Results**

Figure 2 shows normalized pressure drop for the test filters versus time for the entire test period. For each day, the 24 hourly pressure drop readings were averaged to produce the data shown in Figure 2. Third-order polynomial equations were fit to the data to obtain the curves presented. For the first two weeks of the test, the pressure drop for the glass fibre filters was lower than the pressure drop for the polyolefin fibre filters. However, the pressure drop for the glass fibre filters was higher from six weeks through the remainder of the test. For the entire test, pressure drop for the glass fibre filters increased 60% from 0.61 in. H<sub>2</sub>O (152 Pa) to 0.98 in. H<sub>2</sub>O (244 Pa). The polyolefin

fibre filter pressure drop rose 44% from 0.66 in. H<sub>2</sub>O (163 Pa) to 0.95 in. H<sub>2</sub>O (236 Pa).

For each of the 26 occasions efficiency was measured for each kind of filter, pressure drop was read from the curves displayed in Figure 2. With this information, the *in situ* efficiency measurements were plotted against pressure drop in Figures 3, 4, & 5 for both the glass fibre and polyolefin fibre filters for particles with diameters of 0.337 µm, 0.626 µm and 1.11 µm, respectively. Third-order polynomials were drawn through the data for each kind of filter on each figure. When the pressure drop increase was zero, corresponding to clean filters, the efficiency of the polyolefin fibre filters was similar to the efficiency of the glass fibre filters. As particles collected and pressure drop increased, the efficiency of the uncharged glass fibre filters remained almost constant. However, efficiency decreased substantially at all three particle sizes for the charged polyolefin fibre filters. After a 15-20% increase in pressure drop, the efficiency decline halted and the efficiency began to rise as the pressure drop increased further.

Presented also in Figures 3, 4 & 5 are the efficiency results obtained when the filters were tested according to ASHRAE Standard 52.2-1999. The particle sizes displayed for these tests (0.35 µm, 0.62 µm and 1.14 µm) are close to the particle diameters presented for the *in situ* data. For the glass fibre filters, the efficiency measured according to the ASHRAE protocol was higher than the

efficiency measured in the HVAC system when the filters were clean. Moreover, the efficiency of the uncharged glass fibre filters increased with dust loading in the ASHRAE Standard tests, especially for particles with 0.35 µm and 0.62 µm diameters, whereas the *in situ* tests showed no substantial efficiency change for the glass fibre filters.

The initial efficiency for the polyolefin fibre filters measured according to the ASHRAE Standard was similar to the efficiency for the clean filters measured in the HVAC systems. However, in contrast to the dramatic efficiency reductions measured *in situ*, the polyolefin fibre filter efficiency increased steadily with the accelerated dust loading in the ASHRAE Standard's test procedure.

**Discussion**

The results in Figures 3-5 show that the polyolefin fibre filters installed in the HVAC system exhibited large decreases in efficiency, while the efficiency of the glass fibre filters held steady. These efficiency reductions are consistent with other authors' findings from accelerated particle loading tests [3-9]. The effectiveness of the electrostatic charges on the polyolefin fibre filters was reduced with particle loading. The relatively low efficiency for the polyolefin fibre filters may partially explain why the pressure drop increase shown in Figure 2 was smaller for these filters than for the glass fibre filters.

Figures 3, 4 & 5 show a significant difference between the field measurements and the ASHRAE Standard 52.2-1999 tests

for the influence of dust loading on filter performance. This discrepancy indicates that the loading procedure utilized in the ASHRAE Standard method does not simulate the dust loading experienced by filters used in at least some HVAC systems.

These efficiency differences with loading may be caused by differences between the atmospheric particles collected by HVAC systems and the dust used in the ASHRAE Standard 52.2-1999 tests. Most of the mass in the ASHRAE test dust was contributed by particles with diameters larger than 1  $\mu\text{m}$ . However, most of the mass in the particles collected by the filters in the real HVAC systems was contributed by particles that were smaller than 1  $\mu\text{m}$  in diameter. The particles encountering the filters in the real HVAC systems were smaller because most of the atmospheric particles were small in diameter and because the pre-filters in the HVAC systems collected almost all particles larger than 3  $\mu\text{m}$  in diameter. The smaller atmospheric particles may have been more capable of rendering the electrostatic charges ineffective than the ASHRAE test dust.

The composition of the atmospheric particles may have also contributed to the differences in performance of the charged polyolefin fibre filters *in situ* and in the tests conducted according to the ASHRAE Standard. In an urban setting, many of the particles entering an HVAC system are derived from combustion sources and from chemical processes occurring in the atmosphere. These particles are chemically and physically different than the mineral particles, carbon black, and cotton linters comprising the synthetic test dust.

The *in situ* test results represent the performance of two particular kinds of filters collecting atmospheric particles in one location during one period of time. The results may not be the same for all filters that carry electrostatic charges or in all locations. However, the test filters were similar to filters used in many HVAC systems and the particles collected during the test were similar to atmospheric particles collected in many HVAC systems.

## Conclusions

Filters made from uncharged glass fibres and filters made from polyolefin fibres that carry an electrostatic charge were used continuously in virtually identical HVAC systems for more than 19 weeks. Filtration efficiency and pressure drop were measured repeatedly with time.

Results show that the efficiency of the polyolefin fibre filters declined substantially during the test, while the efficiency of glass fibre filters changed little. The data suggest that the benefits of the electrostatic charges on the polyolefin fibres diminished with time as dust built up on the fibres and rendered the charges ineffective.

Efficiency changes measured with particle loading for the filters in the air handling units did not match the efficiency changes measured on the same kinds of filters as dust was loaded according to ASHRAE Standard 52.2-1999. Increases in efficiency were measured for both kinds of filters with the accelerated dust loading in the standard tests, whereas the efficiency declined substantially for the polyolefin fibre filters and remained nearly the same for the glass fibre filters as they collected atmospheric particles for more than 19 weeks.

At a time when efficient filters are required to prevent particles that can harm human health from passing through HVAC systems, the changes in efficiency noted for filters made from fibres that carry electrostatic charges are a concern. Filter manufacturers and suppliers need to produce filters that perform acceptably for their entire period of use. In addition, persons responsible for selecting filters used in HVAC systems need data from manufacturers and suppliers that reflect the performance of their filters in HVAC systems accurately.

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