Air Filtration Media—Evaluations of Fiber-Shedding Characteristics Under Laboratory Conditions and in Commercial Installations

M.W. Shumate

J.E. Wilhelm
Member ASHRAE

ABSTRACT

Quantitative methods were developed to measure the fiber-shedding characteristics of various types of commercially available air filtration media. One method was developed and used to perform long-term monitoring of commercial installations. The other method was designed to measure the extent of fiber shedding under scientifically controlled laboratory conditions.

Similar results were obtained using either test method. Test results showed that all media evaluated shed a minimal amount of fiber with some of the fibers being respirable. These results showed fiber shedding was negligible compared to the number of fibers and/or particulate present in ambient air.

INTRODUCTION

Since the energy crisis in the early 1970s, many buildings have been modified to be more energy efficient. One of the results has been the creation of "tighter" buildings, buildings with less air infiltration. In many cases, the result has been a reduction in the total amount of outside air passing into buildings. Conversely, this means contaminants such as dirt, fibers, skin cells, and microbiological agents generated inside are not removed as rapidly from building environments without effective filtration.

Various types of air filtration media have been incorporated in air distribution systems that reduce the amount of dust contaminants from outside or recycled air and improve building air quality. Filters are typically classified as to their efficiency using an ASHRAE dust spot or arrestance test (ASHRAE 1976). The application and use of these various classes of filtration media have been well documented and are available from the manufacturers of finished filters. Air filters are effective in minimizing air particulate quality problems in buildings. Filter systems equal to or greater then 85% efficient have been extremely valuable in providing clean air (AIA 1987; CAMFIL 1984; AFF 1989; Nadolny 1991).

High-efficiency rated filters are currently manufactured from either organic (synthetic) or inorganic (fiberglass) fibers. Questions as to their possible shedding, the amount of fibers released into buildings, and health implications have been posed. The purpose of this study was to develop a test methodology and provide meaningful information on potential fiber exposure.

Quantitative test methods were developed and validated to measure fiber shedding for various types of air filtration media. For field evaluation, one method was developed for measuring fiber shedding of fiberglass filters. We were not able to develop an adequate method for quantitatively monitoring fiber shedding from organic air filtration media due to background contamination. The other method developed evaluated both organic fiber and fiberglass air filtration media in a controlled laboratory environment.

FIELD TESTS

Field tests evaluated complete air filtration systems, which generally included a prefilter and a final filter.

Each field evaluation included monitoring of the existing filter system, changing the filters, and monitoring for 24 hours, 5 to 7 days, and 21 to 23 days after installation. In all cases, the system was monitored in front of and behind the filtration system. Monitoring in front of the filtration system generally meant testing outside air. Monitoring behind the filtration system was done either immediately after the filters or downstream in vacant office space.

Before initiating any monitoring program, the system was visually inspected. All connectors and filters were inspected to ensure they were properly installed and any broken clips or seals were identified for replacement during the changing of the filters.

At least two collection pumps were used at each monitoring station and run continuously for 24 hours with sampling filters being replaced approximately every 12 hours. The use of multiple collection pumps and periodic changing of the collection filters ensured that a reasonable number of samples would be available for analysis. The only disadvantage to changing the collection filters was the decrease in the limits of detection. Collection pumps were set to run from 0.12 to 0.17 L/s (0.25 to 0.35 ft^3/min). Collection filters were a 0.8-micron cellulose membrane filter approximately 24.5 mm (1 in.) in diameter. Each collection filter was sealed before use to prevent contamination and sealed after use to retain the collected sample. After collection,

Monroe W. Shumate is a Manager for marketing technical service and **John E. Wilhelm** is a Senior Research Engineer with the Manville Sales Corporation, Denver, CO.

each sample was sent to the microscopy laboratory for analysis using scanning electron microscopy (SEM).

Slight modifications to this technique concerning filter size and pump capacity were utilized to perform field trials that compared favorably to this methodology. This collection system was preferred since it used standard equipment available to hygiene laboratories.

LABORATORY EVALUATION

Previous laboratory tests of fiber shedding of fiberglass air filtration media showed that a special protocol was necessary in order to minimize the effects of background contamination and still be above the limits of detection. For glass this was accomplished by ashing the sample and partially burning away the dust (Gamboa et al. 1988). This method could not be used on organic fiber air filtration media since the collected fiber would be destroyed.

For a controlled laboratory analysis, the use of clean air was required to minimize the effect of contamination. This was accomplished by prefiltering the test air through HEPA filters. Laser particle count measurements showed that filtration could reduce particle counts greater then 0.19 microns, the smallest measurement for a particle counter, in the test air from around 50 particles per cc to 0.0006 particles per cc (Shumate and Wilhelm 1990).

In order to maximize the release of shed particles, test conditions had to be greater then those encountered under normal use. An airflow 50% greater than normally encountered in commercial systems was chosen as the standard airflow for this analysis. By controlling the airflow rate, isokinetic sampling would be obtained. A sample size of 0.09 m^2 (1 ft^2) was chosen as being sufficient to minimize any variability of the media while keeping the sample and test apparatus to a reasonable size.

Equipment

A 0.09 m^2 (1 ft^2) area test rig was developed to push air through a precleaned metal duct system. By maintaining positive pressure within the system, no unfiltered air could leak into the test chamber. The test configuration is shown in Figure 1.

Sufficient chamber length was used to supply laminar airflow to the test sample. Air leaving the test sample passed through an 8-in.-diameter mixing orifice to ensure homogeneous air for the samples collected for microscopic analysis. The blower was connected to a variable-speed motor and pressure measurements across a laminar flow device were used to set the airflow.

All incoming air was passed through two HEPA filters, which provided clean and consistent air quality. Maintaining air quality was crucial to ensure that only material shed from the air filtration media was monitored.

Isokinetic sampling of the airstream at a rate of 0.83 L/s (1.76 ft^3/min) was conducted to determine the amount of material shed from the air filtration media. An 80-mm filter, with a pore size of 0.4 μm was used to collect samples for SEM analysis.

Methodology

Testing of samples involved several steps:

1. Setting appropriate airflow for the test chamber.
2. Placing air filtration media in the test chamber.
3. Setting up the sampling apparatus.
4. Starting the shedding test.

The blower and the pump for sample collection were turned on simultaneously, and the blower was maintained at a flow rate of 16.5 L/s (35 ft^3/min) throughout the duration of the six-hour sampling period.

At the end of the test, the filter was removed from the test chamber and submitted to the microscopy laboratory for measurements of fiber length and diameter using a standard SEM methodology.

Sample Preparation and SEM Analysis

Samples collected in the field tests were concentrated by ashing the original filter and refiltering onto a smaller filter (Gamboa et al. 1988). Sample preparation is as follows:

1. Remove filter from sampling canister and place in crucible.
2. Place crucible in oven at 427 °C for 12 hours.
3. Using distilled water, redisperse the residue and deposit onto a 0.2 μm (25 mm diameter) grated filter.
4. Mount damp filter onto SEM stub and allow to dry.
5. Sputter with gold-palladium to provide conductive surface.

For the laboratory evaluation, this system was modified from the ashing technique, since one set of test samples contained organic fibers (Shumate and Wilhelm 1990). Sample preparation is as follows:

1. Remove filter from sampling canister and place into beaker filled with distilled water.
2. Ultrasonically wash filter in distilled water for 10 minutes.
3. Remove filter and rinse into same beaker.
4. Filter all of dispersed sample onto a 0.2 μm (25 mm diameter) grated filter.
5. Mount damp filter onto SEM stub and allow to dry.
6. Sputter with gold-palladium to provide conductive surface.

SEM analysis uses the following protocol:

1. Examine membrane in the SEM at low magnifications (200–400×) to determine uniformity of dispersion. If uniform, determine fiber density of filter by counting 200 random fields (40 μm × 50 μm at 2000×). Count all fibers in each field of view. If necessary, use higher magnifications to check each field for fine fibers.

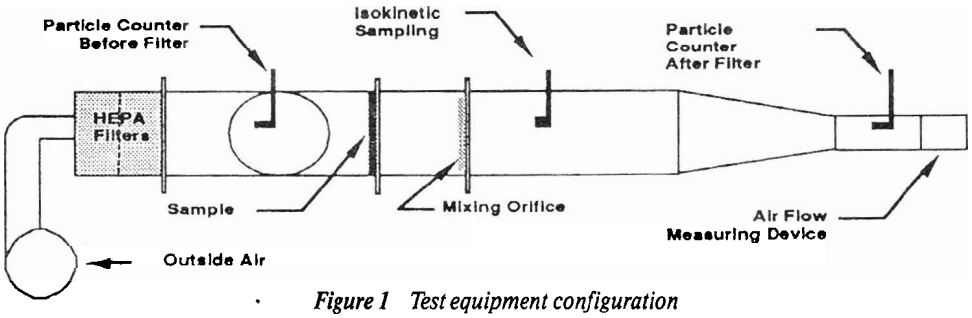

Figure 1 Test equipment configuration

2. Determine fiber length and diameter distribution by measuring all fibers that pass through each field of view while scanning the sample at 2000×. Measure the length at 2000× and the diameter at 5000×. Examine 200 fields or 100 fibers, whichever occurs first.

3. Perform fiber counting and size distributions on a scanning electron microscope equipped with an image analysis system.

At the present time there are no standardized methods for the SEM analysis of fibers. The analytical method followed was based on the World Health Organization's *Reference Method for Measuring Airborne Man-Made Mineral Fibers* (1985). The technique was modified to accommodate the use of an image analysis system.

The protocol for the SEM portion of laboratory evaluations for organic and inorganic fibers was reviewed by an independent laboratory, which was satisfied that the methods and procedures described followed acceptable scientific methodology for this type of study (Krewer and Millette 1990).

The minimum fiber detection level for a single fiber using the SEM and volume of air monitored varied from 0.0003 fibers/cc (for field trials) to 0.00005 fibers/cc (for laboratory evaluations). Levels of reliable detection or quantification would be greater.

RESULTS

A total of four field evaluations were conducted. Two of the studies were identical in that the same building was monitored twice (Versen 1987a,b). For the third study, two separate HVAC systems from the same building were evaluated (Versen et al. 1988). In all of these trials, the collection sites were immediately in front of and behind the filter banks. This location was chosen to reduce potential contamination from fiberglass-lined ducts. For the fourth study, the air ducts were not lined and the monitoring stations were located at the inlet outside air duct and in office space on various floors (Christensen et al. 1990). Studies were conducted in a low-rise and high-rise office building and in a hospital. The efficiency of the filters changed ranged from 85% to 95% efficient. Test results are shown in Table 1.

Test results show that the number of fibers shed was equal to or less than the number of glass fibers present in the outside air. The number of glass fibers in the outside air was consistent with those measured in a previous study by the World Health Organization (WHO 1990; Balzer et al. 1971). One test for Building 2 showed fiber counts greater than those measured in any other test. This result was considered to be suspect and possibly due to contamination. Since it was not repeated in any other study, it was considered to be an outlier (data outside the norm or expected) and was not included in the analysis.

For the laboratory tests, a minimum of three separate runs were made for each type of filtration media evaluated. For this analysis, two 95% rated air filtration media were tested. Samples of fiberglass air filtration media with backing were evaluated, along with samples of synthetic (polycarbonate/polyester) air filtration media. Test results are shown in Table 2.

Generally, a respirable fiber is one that is less than 3 μm in diameter with a length-to-diameter ratio greater than 3:1. Based upon this definition, respirable fibers were observed as part of the samples collected from both types of air filtration media.

Review of these analyses showed that both products shed an extremely small number of fibers. Due to the variation of the measured fiber diameter and fiber length, it is believed that the

TABLE 1
Scanning Electron Microscopy Analysis of Samples Collected Before and After Fiberglass Air Filters Were Changed (Fibers/cc)

			Outside Air Intake		
Building Sites	24 hours Before		24 hours ------After Filter Change--------	5-7 days	21-23 days
1a*	---		ULOD**	---***	---
1b	---		0.0005	<0.0001	<0.0001
2	---		---	---	---
3	0.0009		ULOD	0.0005	ULOD
		Directly	After Filtration		
Building Sites	24 hours Before	During Change	24 hours ------After Filter Change--------	5-7 days	21-23 days
1a	---	---	0.007	---	0.0013
1b	---	---	0.0017	0.0008	0.0004
2a#	0.01	0.0004	0.002	---	---
2b	0.0007	0.007	0.0003	---	---
			Monitors in Office		
Building Sites	24 hours Before		24 hours ------After Filter Change--------	5-7 days	21-23 days
3a##	0.0004		ULOD	ULOD	0.0003
3b	0.0004		ULOD	0.0005	ULOD

Note: * Same building tested twice; 1a in 1979 and 1b in 1987 low-rise building, 3 floors.
** ULOD, under limits of detection, no fibers observed in 200 fields.
*** --- no measurements taken or available
# Testing on two HVAC systems in the same building (high-rise building greater than 50 floors).
Test in hospital; 3a in soiled linen hold room close to HAVC system, 3b in examination room farthest from HVAC system.

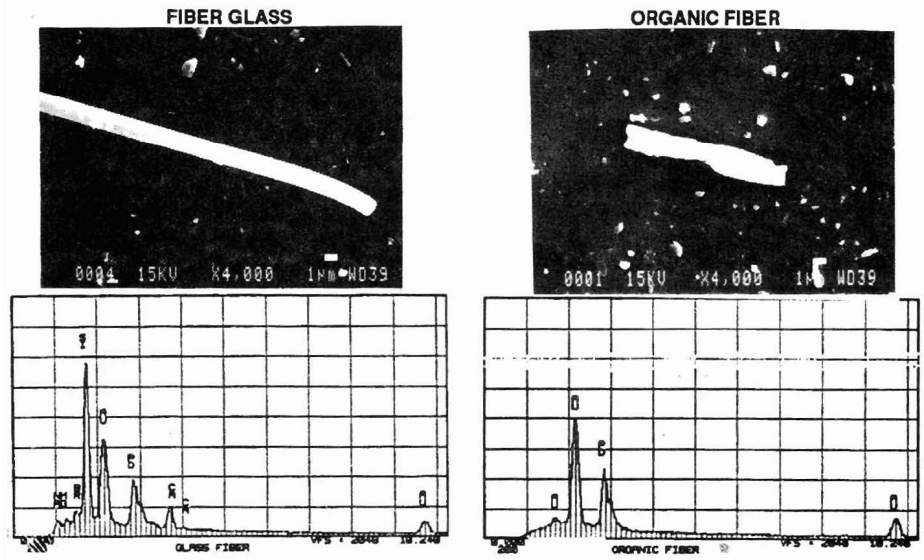

Figure 2 Scanning electron micrographs and elemental analysis for fiberglass and organic fibers

fibers measured for each evaluation came primarily from the respective media samples in the monitoring station.

SEM analysis included the identification of fibers by morphology and elemental analysis (Figure 2). The number of fibers present was so small that only elemental analysis using the SEM equipment could be performed. The fibers collected from the fiberglass air filtration media showed a chemistry and morphology indicative of fiberglass. The fibers collected from the organic air filtration media showed the morphology of a polycarbonate fiber. The elemental analysis showed only the presence of gold and palladium; it was not capable of detecting the presence of carbon. The absence of detectable elements in the fibers collected from the evaluation of the organic media, along with the morphology identification of a polycarbonate fiber, led to the conclusion that the fibers were organic.

For comparison, an additional series of tests was run to determine the amount of each type (organic or inorganic) of fiber present in outside air. For this evaluation, the same equipment was used as was used in the laboratory study, but the duration and volume of air collected was reduced. Total time for collection was limited to 90 minutes at a collection rate of 0.69 L/s (1.47 ft^3/min). Samples were concentrated in a manner similar to that used in the laboratory test. Care had to be taken to maximize concentration and not have the dust particulate obscure any fibers. Due to the limited duration of these tests and the method of concentration, the minimum fiber detection level ranged from 0.002 to 0.0005 fibers per cc. These results are compared to laboratory tests in Table 3. The majority of these fibers fell into the range that was considered to be respirable, and the majority of the fibers counted were organic.

There was no significant difference in fiber shedding between filter media. In fact, the number of fibers released compared to the number of fibers present in the environment was one to two orders of magnitude lower than the total number of fibers present in the outside air. Compared to the amount of previously measured particulate in outside air, this would represent less then 15/10,000 of one percent.

Test results of laboratory evaluations compared to field tests were similar. Table 4 shows that the difference in the majority of the tests was small and that even the outlier for the field test was equal to or less than the total number of fibers measured in outside air.

The World Health Organization's Working Group on Indoor Air Quality concluded, as part of its study, that current airborne man-made mineral fiber (MMMF) concentrations in indoor environments represent an insignificant risk (WHO 1990). The number of respirable airborne MMMF referenced in the WHO report was similar to that measured in these field and laboratory tests. Based on this comparison, the amount of fiber measured from the shedding evaluation represents an insignificant risk to indoor air quality.

CONCLUSIONS

A scientific methodology was successfully developed to quantitatively measure fiber shedding from various types of air filtration media.

Results show that all types of air filtration media tested released a minimal number of respirable fibers and that the number of fibers shed was one to two orders of magnitude lower than the total number of fibers measured in outside air. Results

TABLE 2
Scanning Electron Microscopy Analysis Fiber Characterization of Fibers Shed from Air Filtration Media

Product	Fiber Glass	Organic Fibers
Fiber Diameter Ave., um	1.0	2.0
Fiber Diameter Range, um	0.2-8	0.3-24
Fiber Length, Ave., um	25	22
Fiber Length, range, um	2-110	3-65*
Fibers/cc	0.0007	0.0003

* Some fiber lengths were greater than the field of view.

from laboratory tests were similar to those obtained in field evaluations (normal day-to-day conditions).

The results show that shedding of fiber from these types of air filtration media represents an insignificant risk to indoor air quality.

ACKNOWLEDGMENTS

The writers would like to take this opportunity to thank the following people for their participation in this project:

- K. Smith and F. D'Ovidio, Microstructural Analysis Group, Manville Technology Center
- P. Fennell and N. Bassett, Air Filtration Development Group, Manville Technology Center
- Dr. W. Bunn, J. Chase, R. Versen, and D. Christensen, HS&E Group, Manville Technology Center
- R. Hattersley, Product Manager, Engineered Products Division, Manville Sales Corporation.

REFERENCES

AIA. 1987. *Guidelines for construction and equipment of hospital and medical facilities*, 1987 ed. American Institute of Architects.

American Air Filter (AAF). 1989. Air Filtration Efficiency Comparison Test RFD-1-240.

ASHRAE. 1976. *ASHRAE Standard 52-72, Methods of testing air cleaning devices used in general ventilation for removing particulate matter.* Atlanta: Amercian Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Balzer, J., J.L. Blazer, and W.C. Cooper. 1971. "Fibrous glass-lined air transmission systems: An assessment of their environmental effects." *American Industrial Hygiene Association Journal*, pp. 512-518.

CAMFIL. 1984. Filter Engineering—E-1416.

Christensen, D.R., T. Calzavara, and M. Carter. 1990. Unpublished data from industrial hygiene survey of three-story hospital, conducted by Manville Industrial Hygiene Consulting Services.

Gamboa, R.R., B.P. Gallagher, and K.R. Matthews. 1988. "Data on glass fiber contribution to the supply airstream from fiberglass duct liner and fiberglass duct board." *Engineering Solutions to Indoor Air Problems*. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Krewer, J.A., and J.R. Millette. 1990. Letter review of SEM sampling and analysis protocol for paper entitled, "Fiber shedding characteristics of commercial air filtration media," conducted by McCrone Environmental Services Inc., Norcross, GA.

Nadolny, R.A. 1991. "Filtration system to keep mall's air clean." *Consulting/Specifying Engineer*, Mid-March.

Shumate, M.W., and J.E. Wilhelm. 1990. "Fiber shedding characteristics of commercial air filtration media." *Indoor Air '90, The Fifth International Conference on Indoor Air Quality and Climate*, Vol.3, pp. 157-162.

Versen, R.A., T. Conti, and J. Teft. 1988. Unpublished data from industrial hygiene survey of 56-story building, conducted by Manville Industrial Hygiene Consulting Services.

Versen, R.A. 1987. Unpublished data from industrial hygiene survey of three-story building tested in 1979, conducted by Manville Industrial Hygiene Consulting Services.

Versen, R.A. 1987. Unpublished data from industrial hygiene survey of 3-story building tested in 1987, conducted by Manville Industrial Hygiene Consulting Services.

WHO. 1985. *Reference method for measuring airborne man-made mineral fibers*. World Health Organization Environmental Health Monograph 4. World Health Organization.

WHO. 1990. Working Group on Indoor Air Quality: Inorganic Fibres and Other Particulate Matter. World Health Organization.

BIBLIOGRAPHY

ASHRAE. 1989. *ASHRAE Standard 62-89, Ventilation for acceptable indoor air quality*. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE. 1988. *ASHRAE handbook—1988 equipment*, chapter 10, "Air cleaners for particulate contaminants. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Hattersley, R.J. 1990. "Fiber glass air filtration media in hospital HVAC systems." Joint Commission Accreditation Health Care Organizations—Monographs. June.

TABLE 3
Scanning Electron Microscopy Concentration of Shed Fibers Compared to Fibers Present in Outside Air

Fiber Present/Shed	Fiber Concentration Total Organic and Inorganic Fibers (Fibers/cc)
Present in Test Lab	0.01
Outside Air	
Downtown Denver	0.01-0.002
Suburb Denver	0.02-0.04
Air Filtration Media	
Fiber glass	0.0007
Organic Fiber	0.0003

TABLE 4
Comparison of the Number of Fibers Shed from Various Types of Fiberglass Air Filtration Media in the Laboratory as Compared to Field Tests

Test Technique	Fiber Concentration (Fibers/cc)
Laboratory Test	0.0007
Field Test, Range	
Building 1	0.007-0.0004
Building 2	0.007-0.0003*
Building 3	0.0004-<0.0003

* Outlier not included