Environmental Technology Verification

Test Report of Control of Bioaerosols in HVAC Systems

Columbus Industries
SL-3 Ring Panel

Prepared by

Research Triangle Institute

Under a Contract with
U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

Research Triangle Institute

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**VENTILATION MEDIA AIR FILTER**
APPLICATION:	**FILTRATION EFFICIENCY OF BIOAEROSOLS IN HVAC SYSTEMS**
TECHNOLOGY NAME:	**SL-3 Ring Panel**
COMPANY:	**Columbus Industries**
ADDRESS:	**2938 St. Rt. 752 Ashville, OH 43103-0257** **PHONE: 740-983-2552 FAX:**
WEB SITE:	**http://www.colind.com/main.htm**
E-MAIL:	**mhaufe@colind.net**

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works with recognized standards and testing organizations; stakeholder groups which consist of buyers, vendor organizations, permitters, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative and improved technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

EPA's National Risk Management Research Laboratory contracted with the Research Triangle Institute (RTI) to establish a homeland-security-related ETV Program for products that clean ventilation air. RTI evaluated the performance of ventilation air filters used in building heating, ventilation and air-conditioning (HVAC) systems. This verification statement provides a summary of the test results for the Columbus Industries SL-3 Ring Panel media air filter.

VERIFICATION TEST DESCRIPTION

All tests were performed in accordance with RTI's "Test/Quality Assurance Project Plan: Biological Testing of General Ventilation Filters," which was approved by EPA. The following tests were performed:

- Bioaerosol filtration efficiency tests of the clean and dust-loaded filter. Three bioaerosols were used in the testing:
  - The spore form of the bacteria *Bacillus atrophaeus* (BG), a gram-positive spore-forming bacteria elliptically shaped with dimensions of 0.7 to 0.8 by 1 to 1.5 μm,
  - *Serratia marcescens*, a rod-shaped gram-negative bacteria with a size of 0.5 to 0.8 by 0.9 to 2.0 μm, and
  - The bacterial virus (bacteriophage) MS2 dispersed as a micrometer-sized polydisperse aerosol.
- Inert aerosol filtration efficiency tests consisting of an American National Standards Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 52.2-1999 type test (0.3 to 10 µm) and extended fractional efficiency measurements down to 0.02 µm particle diameter on both clean and dust-loaded filter.
- ASHRAE 52.2 test providing filtration efficiency results (average of the minimum composite efficiency) for three size ranges of particles: E1, 0.3 to 1.0 μm; E2, 1.0 to 3.0 μm; and E3, 3.0 μm to 10 μm.

Figure 1. Photograph of the Columbus Industries SL-3 Ring Panel media filter.

VERIFIED TECHNOLOGY DESCRIPTION

As shown in Figure 1, the Columbus Industries SL-3 Ring Panel media air filter has nominal dimensions of 0.61 x 0.61 x 0.03 m (24 x 24 x 1 in.). The filter is a ring panel with green and white polyester tackified media and an internal frame. The Columbus Industries part number is P302424.

VERIFICATION OF PERFORMANCE

Verification testing of the Columbus Industries SL-3 Ring Panel media air filter began on October 2, 2003 at the test facilities of RTI and was completed on November 4, 2003. The results for the bioaerosol filtration efficiency tests are presented in Table 1 for the clean and dust-loaded filter. Table 2 presents the results of the ASHRAE 52.2 test. All tests were conducted at an air flow of 0.93 m3/sec (1970 cfm).

Table 1. Bioaerosol Filtration Results

Filter Condition	Pressure Drop Pa (in. H_2O)	Filtration Efficiency for Removal of *B. atrophaeus* , %	Filtration Efficiency for Removal of *S. marcescens, %*	Filtration Efficiency for Removal of MS2 phage, %
Clean	142 (0.57)	54	58	57
Dust loaded	283 (1.14)	74	83	79

Table 2. Summary of ASHRAE 52.2 Test

Filter	E1 0.3 to 1.0 μm, %	E2 1.0 to 3.0 μm, %	E3 3.0 to 10 μm, %	Minimum Efficiency Reporting Value (MERV)
Columbus Industries SL-3 Ring Panel	15	65	81	8 at 0.93 m^3/sec (1970 cfm)

The quality assurance officer reviewed the test results and the quality control data and concluded that the data quality objectives given in the approved test/QA plan were attained.

This verification statement addresses two performance measures of media air filters: filtration efficiency and pressure drop. Users of this technology may wish to consider other performance parameters such as service life and cost when selecting a media air filter for bioaerosol control. In accordance with the test/QA plan[1], this verification is valid for 3 years following the last signature added on the verification statement.

Original signed by E. Timothy Oppelt 2/11/2004
E. Timothy Oppelt Date
Director
National Homeland Security Research Center
Office of Research and Development
United States Environmental Protection Agency

Original signed by David S. Ensor 1/23/2004
David S. Ensor Date
Director
ETV-HS
Research Triangle Institute

Environmental Technology Verification

Test Report of Filtration Efficiency of Bioaerosols in HVAC Systems

Columbus Industries
SL-3 Ring Panel

Prepared by:

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Engineering and Technology Unit
Research Triangle Park, NC 27709

GS10F0283K-BPA-1, EPA Task Order 1101
RTI Project No. 08787.001

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Notice

This document was prepared by the Research Triangle Institute (RTI) with funding from the U.S. Environmental Protection Agency (EPA) via the General Service Administration Contract No. GS10F0283K per EPA's BPA-1, Task Order 1101. The document has undergone RTI's and EPA's peer and administrative reviews and has been approved for publication. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.

Foreword

The Environmental Technology Verification (ETV) Program, established by the U.S. Environmental Protection Agency (EPA), is designed to accelerate the development and commercialization of new or improved environmental technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify the performance of commercially ready environmental technologies through the evaluation of objective and quality-assured data so that potential purchasers and permitters are provided with an independent and credible assessment of the technology that they are buying or permitting.

EPA's National Risk Management Research Laboratory contracted with the Research Triangle Institute (RTI) to establish a homeland-security-related ETV Program for products that clean ventilation air. RTI developed (and EPA approved) the "Test/Quality Assurance Plan for Biological Testing of General Ventilation Filters[1]." The test described in this report was conducted following this plan.

Availability of Report

Copies of this verification report are available from

- Research Triangle Institute
  Engineering and Technology Unit
  PO Box 12194
  Research Triangle Park, NC 27709-2194

- U.S. Environmental Protection Agency
  Air Pollution Prevention and Control Division, E305-01
  109 T.W. Alexander Drive
  Research Triangle Park, NC 27711

Web site: http://www.epa.gov/etv/verifications

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Acronymns/Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
ASME	American Society of Mechanical Engineers
B	*Bacillus*
BG	*Bacillus atrophaeus* (formerly *B. subtilis var niger* and *Bacillus globigii*)
cfm	cubic feet per minute
CFU	colony forming unit(s)
cm	centimeter(s)
d_{50}	cutoff diameter, the aerodynamic diameter above which the collection efficiency of the sampler approaches 100%
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
ETL SEMKO	Electrical Testing Laboratories, Svenska Elektriska Materielkontrollanstalten AB
ETV	Environmental Technology Verification
F	Fahrenheit
fpm	feet per minute
HS	homeland security
in.	inch(es)
KCl	potassium chloride
kPa	kilopascal(s)
L	liter(s)
MERV	minimum efficiency reporting value
m	meter(s)
mm	millimeter(s)
mL	milliliter(s)
min	minute(s)
μm	micrometer(s)
NAFA	National Air Filtration Association
nm	nanometer(s)
OPC	optical particle counter
QA	quality assurance
QC	quality control
Pa	pascal(s)
PFU	plaque forming unit(s)
psig	pounds per square inch gauge
RTI	Research Triangle Institute
SAE	Society of Automotive Engineers
SMPS	scanning mobility particle sizer

Acknowledgments

The authors acknowledge the support of all of those who helped plan and conduct the verification activities. In particular, we would like to thank Ted Brna, EPA's Project Manager, and Paul Groff, EPA's Quality Assurance Manager, both of EPA's National Risk Management Research Laboratory in Research Triangle Park, NC. We would also like to acknowledge the assistance and participation of

- Our stakeholder group for their input,
- Al Veeck and the National Air Filtration Association (NAFA), and Intertek ETL SEMKO, especially Theresa Peck, for their help in acquiring the filters, and
- Columbus Industries for donating the filters to be tested.

For more information on the Columbus Industries SL-3 Ring Panel filter, contact

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1.0 Introduction

EPA's National Risk Management Research Laboratory contracted with the Research Triangle Institute (RTI) to establish a homeland-security-related ETV Program for products that clean ventilation air. RTI convened a group of stakeholders representing government and industry with knowledge and interest in the areas of homeland security and building ventilation. The group met in December 2002 and recommended technologies to be tested. RTI then developed (and EPA approved) the "Test/Quality Assurance Plan for Biological Testing of General Ventilation Filters[1]." The first round of tests included ten different filters. The tests described in this report were conducted following this plan.

2.0 Product Description

As shown in Figure 1, the Columbus Industries SL-3 Ring Panel media air filter has nominal dimensions of 0.61 x 0.61 x 0.03 m (24 x 24 x 1 in.). The filter is a ring panel with green and white polyester tackified media and an internal frame. The Columbus Industries part number is P302424.

Figure 1. Photograph of the Columbus Industries SL-3 Ring Panel Media Filter.

3.0 Test Procedure

The test program measured the culturable bioaerosol removal efficiency of general ventilation filters. Three tests were required to accomplish this goal. First, the American National Standards Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Standard 52.2[2] test was performed on one filter of the test filter type to determine the minimum efficiency reporting value (MERV) of the filter. ASHRAE designed the MERV to represent a filter's minimum performance over multiple particle sizes. In general, a higher MERV indicates higher filter efficiency. Most commercial filters and high end home filters are now marketed using the MERV. After determining the MERV, the biological test using three different bioaerosols and an inert aerosol test on both a clean and fully dust-loaded filter were performed on a second filter. All tests were at an air flow rate of 0.93 m^3/sec (1970 cfm) to conform to the conditions described in ASHRAE Standard 52.2.

All testing was performed in a test duct as specified in ASHRAE Standard 52.2. A schematic of the test duct is shown in Figure 2. The test section of the duct is 0.61m (24 in.) by 0.61m (24 in.) square. The locations of the major components, including the sampling probes, device section (filter holder), and the aerosol generator (site of aerosol injection) are shown.

The inert test and the ASHRAE Standard 52.2 test were performed using a solid-phase (i.e., dry) potassium chloride (KCl) aerosol. The filters were loaded using ASHRAE dust, composed of 72% Society of Automotive Engineers (SAE) fine, 23% powdered carbon, and 5% cotton linters. The final pressure drop was determined by the Standard's requirements.

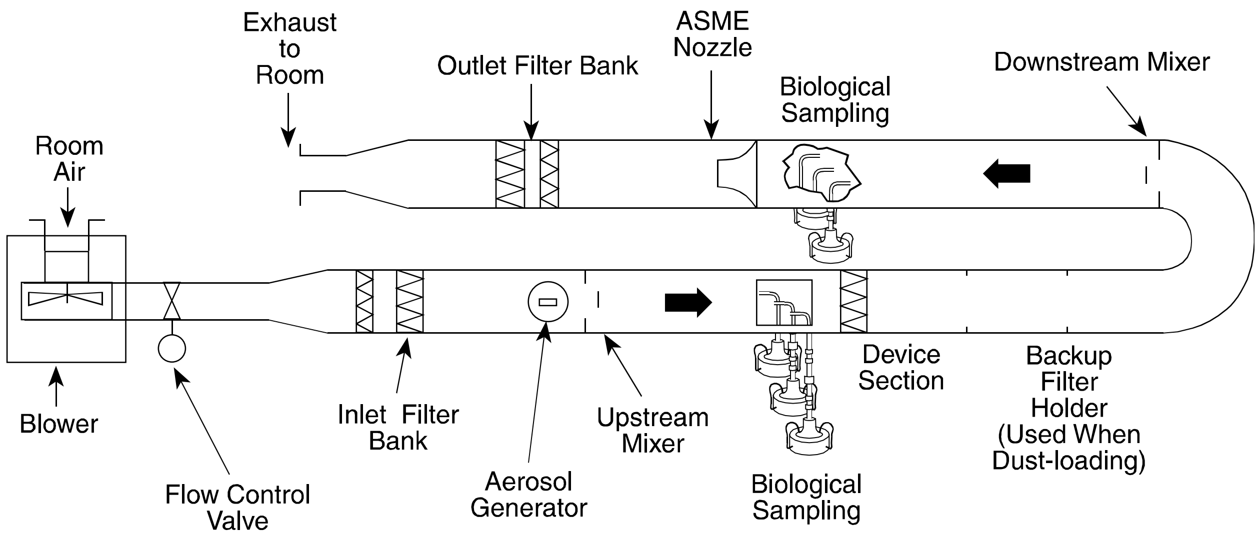

Figure 2. Schematic of Test Duct. Filter is placed in device section.

The bioaerosol tests were conducted using three microorganisms, two bacteria and one bacterial virus. The spore form of the bacteria *Bacillus atrophaeus* (formerly *B. subtilis var niger* and *Bacillus globigii* or BG) was used as the simulant for gram-positive spore-forming bacteria. The BG spore is elliptically shaped with dimensions of 0.7 to 0.8 by 1 to 1.5 μm. *Serratia marcescens* was used as the surrogate for rod-shaped gram-negative bacteria. *S. marcescens* is 0.5 to 0.8 by 0.9 to 2.0 μm.

The bacterial virus (bacteriophage) MS2 (0.02 to 0.03 μm), having approximately the same aerosol characteristics as a human virus, was used as a surrogate for the viruses of similar and larger size and shape. Although the individual virus particles are in the submicrometer size range, the test particle size planned for the virus tests will span a range of sizes (polydispersed bioaerosol). This test was not designed to study the removal efficiencies for single individual virus particles; rather, it was designed to determine the removal efficiencies for virus particles as they are commonly found indoors. A representative challenge would be a micrometer-sized, polydispersed aerosol containing the phage because:

- The aerosols created from sneezing and coughing vary in size from < 1 to > 20 μm, but the largest particles settle out and only the smaller sizes remain in the air for extended periods for potential removal by an air cleaner;
- Few viruses have been found associated with particles less than 1 μm; and
- Nearly all 1 - 2 μm particles are deposited in the respiratory tract, while larger particles may not be respired.

Bacteria suspension preparation for the aerosolization process required that the specific test organism be grown in the laboratory and the suspension prepared for aerosol generation in the test rig. The microbial challenge suspensions were prepared by inoculating the test organism on solid or liquid media, incubating the culture until mature, wiping organisms from the surface of the pure culture (if solid media), and eluting them into sterile diluent to a known concentration.

The bacterial virus challenge was prepared by inoculating a logarithmic phase broth culture of the host bacteria with phage and allowing it to multiply until the majority of the host bacteria were lysed. The mixture was centrifuged to remove the majority of the cell fragments. The resultant supernatant was the phage stock and was used as the challenge aerosol. The concentration of the phage stock was approximately 1 x 10^9 or higher plaque forming units per milliliter, (PFU)/mL.

The challenge organism suspensions were aerosolized using a Collison nebulizer (BGI, Waltham, MA) at 103.4 kPa (15 psig) air pressure. The nebulizer generates droplets with an approximate volume mean diameter of 2 μm. The nebulizer output stream was mixed with clean, dry air to create the dry aerosolized microbial challenge. The particle diameter after the water evaporates depends on the solids content of the suspension. Particle size was determined by the size of the suspended organism (if singlets).

Upstream and downstream sampling of the bacteria was accomplished using a one-stage Andersen viable bioaerosol sampler. The one-stage Andersen sampler is a 400-hole multiple-jet impactor operating at 28 L/min. The cutoff diameter (d_{50}) is 0.65 μm.– the aerodynamic diameter above which the collection efficiency of the sampler approaches 100%. After sampling, the petri dishes were removed from the sampler and incubated at appropriate times and temperatures for the test organism being used. Colony forming units (CFUs) were then enumerated and their identity confirmed.

The microbial viruses were collected in AGI-30s. The AGI-30 is a high velocity liquid impinger operating at a flow rate of 12.3 to 12.6 L/min. The d_{50} is approximately 0.3 μm. The AGI-30 is the sampler against which the other commonly used bioaerosol samplers are often compared.

For the inert aerosol filtration efficiency measurements, the particle sizing measurements were made with two particle counting instruments: a Climet model 500 spectrometer/optical particle counter (OPC) covering the particle diameter size range from 0.3 to 10 μm in 12 particle sizing channels and a TSI scanning mobility particle sizer (SMPS) to cover the range from 0.03 to 0.5 μm. Depending upon the quality of the data from any individual test, the SMPS can sometimes reliably quantify particles even small than 0.03 μm, and when this is the case, those smaller sizes are reported here. The ability to quantify sizes smaller than 0.03 μm is determined as defined in Table A2 of test/QA plan. According to the test/QA plan, a data control parameter for the SMPS requires that the standard deviation on upstream counts be computed for each efficiency test based on the upstream particle counts and that the standard deviation be less than 0.30 before the data is used. The lower size ranges for the SMPS are included in the verification report only if they meet the data control parameter.

Quality Control (QC) procedures for running the test duct and the measuring equipment are defined in the test/QA plan.

Replicates of the filters to be tested were obtained directly from the vendor's warehouse by Intertek ETL SEMKO – an independent organization recommended by the industry – on July 23, 2003 following the NAFA *Product Certification Program Procedural Guide*[3]. A minimum of four replicates of the filter device were procured, and were provided to RTI. The four replicates were used as shown in Table 1.

Full details of the test method can be found in RTI's test/QA plan[1].

Table 1. Numbers of Filters and Expected Utilization

Tests	Filter #			
	1	2	3	4
ASHRAE Standard 52.2[2] test	X			
Initial efficiency for an inert aerosol		X		
Initial efficiency for three bioaerosols		X		
Dust load to final pressure drop with ASHRAE dust		X		
Efficiency for inert aerosol after dust-loading		X		
Efficiency for three bioaerosols after dust-loading		X		
Reserve filter[a]			X	X

[a]Filters # 3 and # 4 have been kept in reserve to be used if needed.

4.0 Test Results

The bioaerosol filtration efficiency results are found in Table 2.

Table 2. Bioaerosol Filtration Results for Filter # 2

Filter Condition	Pressure Drop Pa (in. H_2O)	Filtration Efficiency for Removal of *B. atrophaeus*, %	Filtration Efficiency for Removal of S. *marcescens, %*	Filtration Efficiency for Removal of MS2 phage, %
Clean	142 (0.57)	54	58	57
Dust-loaded	283 (1.14)	74	83	79

The ASHRAE filtration efficiencies and the MERV are shown in Table 3. The filtration efficiencies (average of the minimum composite efficiency) are presented by particle size groupings: E1, 0.3 to 1.0 μm; E2, 1.0 to 3.0 μm; and E3, 3.0 μm to 10 μm. The full ASHRAE 52.2 test results are provided in the Appendix.

Table 3. Summary of Removal Efficiency Using ASHRAE 52.2 Test for Filter # 1

Filter	E1 0.3 to 1.0 μm, %	E2 1.0 to 3.0 μm, %	E3 3.0 to 10 μm, %	MERV
Columbus Industries SL-3 Ring Panel	15	65	81	8 at 0.93 m^3/sec (1970 cfm)

The filtration efficiency for inert particles is plotted so that the efficiencies for particles from about 0.03 to 10 μm can be observed (Figure 3). Note that this is a logarithmic (base 10) scale on the X axis. Two instruments were used to obtain the measurements. The SMPS was used to measure particles up to 0.5 μm and the OPC was used for particles from 0.3 to 10 μm. There is good agreement in the size range covered by both instruments. These measurements were made on a filter when clean and then when dust-loaded.

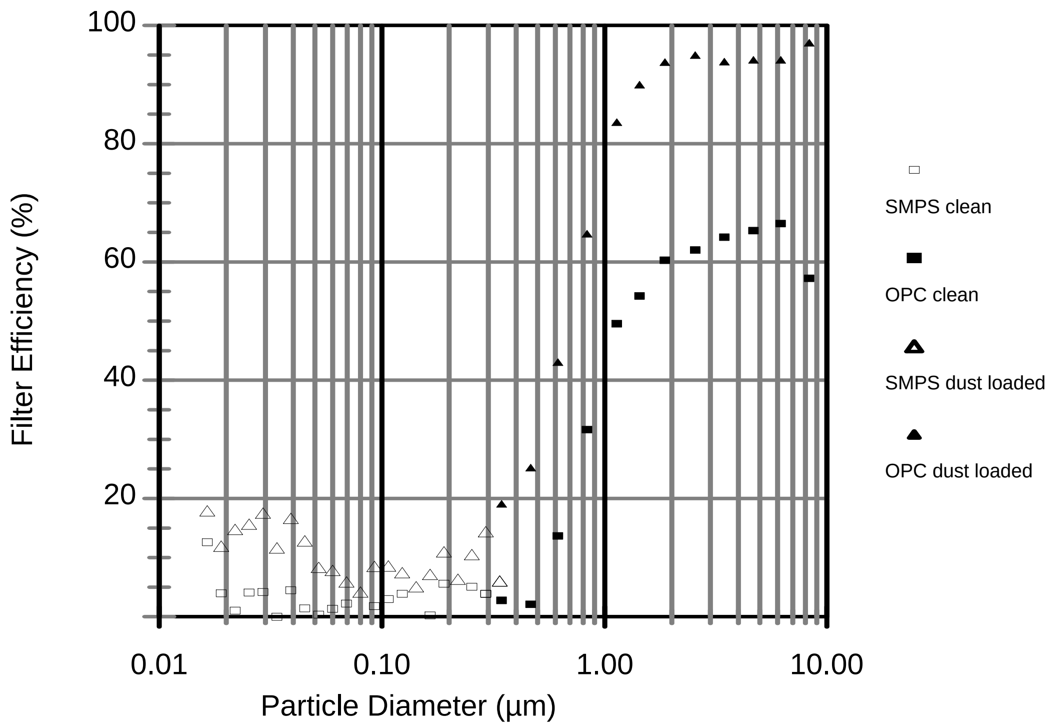

Figure 3. Summary of the Inert Aerosol Filtration Efficiency Data for the Clean and Dust-Loaded Filter, # 2.

The quality assurance officer has reviewed the test results and the quality control data and has concluded that the data quality objectives (DQOs) (Table 4) given in the approved test/QA plan have been attained.

Table 4. DQOs for Precision of Filtration Efficiency Measurements for Culturable Bioaerosol

Data quality objective	Test organism		
	Spore-forming bacteria (*B. atrophaeus*)	Vegetative bacteria (S. *marcescens*)	Bacterial virus (MS2 phage)
Precision of filtration efficiency, %	± 8[a]	± 11[a]	± 13[a]

[a] Based on +/- one standard deviation of penetration computed from the coefficient of variance upstream and downstream culturable counts.

5.0 Limitations and Applications

This verification report addresses two performance measures of media air filters: filtration efficiency and pressure drop. Users may wish to consider other performance parameters such as service life and cost when selecting a general ventilation air filter for their application.

In accordance with the test/QA plan[1], this verification is valid for 3 years following the last signature added on the verification statement.

6.0 References

1. RTI. 2003. *Test/QA Plan for Biological Testing of General Ventilation Filters*. Research Triangle Institute, Research Triangle Park, NC.

2. ANSI/ASHRAE Standard 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

3. NAFA (National Air Filtration Association). 2001. *Product Certification Program Procedural Guide* Approved Version 1, Second Revision, February 2001. Virginia Beach, VA.

ASHRAE 52.2 TEST REPORT

Manufacturer: Columbus Industries
Product Name: SL-3 Ring Panel
ETV Filter ID: COL2-A

RTI Report No. BX10020301

Test Laboratory:
RTI
919-541-6941

ASHRAE Std. 52.2 Air Cleaner Performance Report Summary

This report applies to the tested device only.

Laboratory Data

RTI Report No.	BX10020301	Date	02-Oct-03
Test Laboratory	Research Triangle Institute		
Operator	Link	Supervisor	Owen/Hanley
Particle Counter(s):	Brand: Climet	Model	500

Device Manufacturer's Data

Manufacturer	Columbus Industries		
Product Name	SL-3 Ring Panel		
Product Model	P302424		
Test requested by	EPA/ETV		
Sample obtained from	NAFA		
Catalog rating:	Airflow rate: NA	Initial dP (in. wg)	NA
Specified test conditions:	Airflow (cfm): 1970	Final dP (in. wg)	1.16
	Face Velocity (fpm): 493		

Device Description

Nominal Dimensions (in.):	24 x 24 x 1 (height x width x depth)		
Generic name	ring panel	Media color	green/white
Amount and type of adhesive	NA		
Other attributes	tackified, wire internal frame		

Test Conditions

Airflow (cfm)	1970	Temperature (F)	70	RH (%)	56
Face Velocity (fpm)	493	Final Pressure Drop (in. wg)	1.16		
Test aerosol type:	KCl				
Remarks					

Resistance Test Results

Initial resistance (in. wg)	0.58	Final resistance (in. wg)	1.16

Minimum Efficiency Reporting Data

Composite average efficiencies	E1	15	E2	65	E3	81

Air cleaner average Arrestance per Std 52.1: NA

Minimum efficiency reporting value (MERV) for the device: 8 @ 1970 cfm

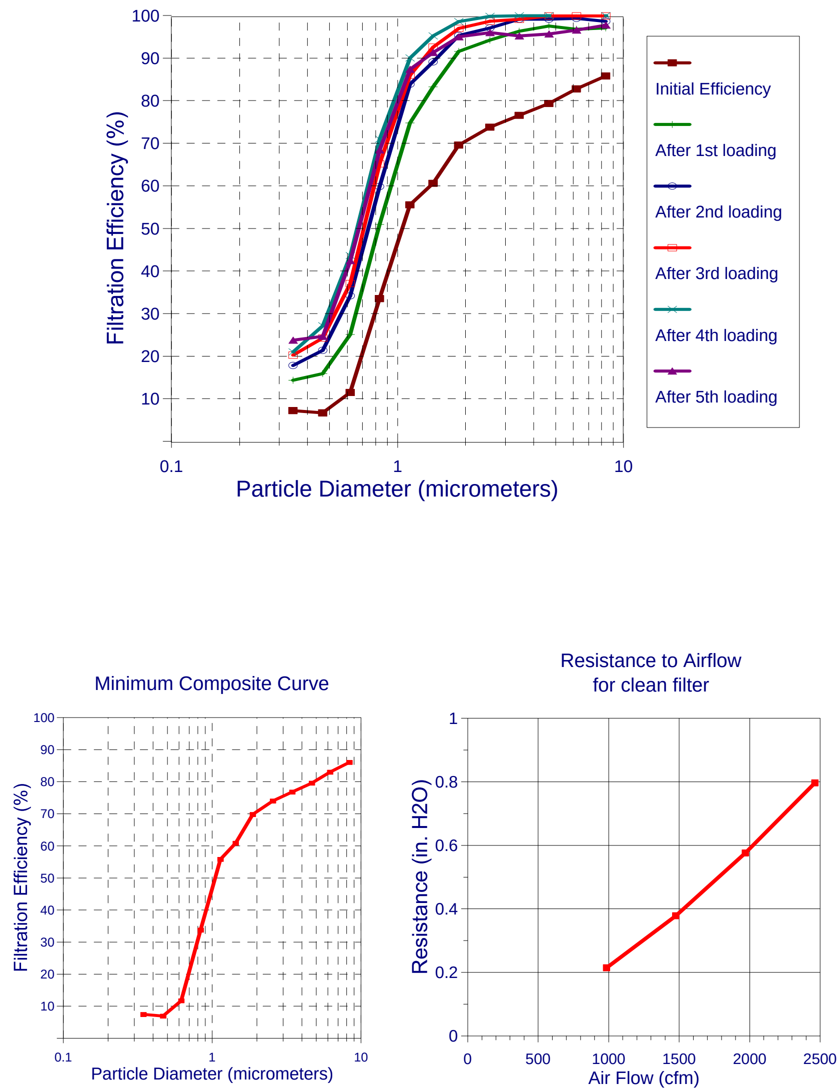

Figure A-1. Filtration Efficiency and Flow Resistance Curves for Columbus Industries SL-3 Ring Panel Filter.

TABULATED DATA SUMMARY
Report No. BX10020301
Research Triangle Institute

Summary of Test Conditions:

Product Manufacturer	Columbus Industries
Product Name	SL-3 Ring Panel
Nominal Dimensions (in.)	24 x 24 x 1
Airflow (cfm)	1970
Final Resistance (in. H2O)	1.16

Efficiency (%) per Indicated Size Range

OPC Channel Number		1	2	3	4	5	6	7	8	9	10	11	12
Min. Diam. (µm)		0.3	0.4	0.55	0.7	1	1.3	1.6	2.2	3	4	5.5	7
Max. Diam. (µm)		0.4	0.55	0.7	1	1.3	1.6	2.2	3	4	5.5	7	10
Geo. Mean Diam. (µm)		0.35	0.47	0.62	0.84	1.14	1.44	1.88	2.57	3.46	4.69	6.20	8.37
	Run No.												
Initial efficiency	BX10020302	7	7	12	34	56	61	70	74	77	80	83	86
after first dust load	BX10020303	15	16	25	51	75	83	92	94	97	98	97	97
after second dust load	BX10020304	18	22	34	60	84	89	96	97	99	99	100	99
after third dust load	BX10030201	20	24	37	65	86	93	97	99	99	100	100	100
after fourth dust load	BX10060301	21	27	44	71	90	95	99	100	100	100	100	100
after fifth dust load	BX10070301	24	25	43	69	87	91	95	96	95	96	97	98
Minimum Composite Efficiency (%)		7	7	12	34	56	61	70	74	77	80	83	86

E1 = 15 (E1 is the average of the minimum composite efficiency values for particle diameters from 0.3 to 1 µm.)
E2 = 65 (E2 is the average of the minimum composite efficiency values for particle diameters from 1 to 3 µm.)
E3 = 81 (E3 is the average of the minimum composite efficiency values for particle diameters from 3 to 10 µm.)

MERV : 8

Resistance to Airflow for Clean Filter:

Airflow (%)	Airflow (m3/s)	Airflow (cfm)	Air Velocity (fpm)	Air Velocity (m/s)	Resistance (in. H2O)	Resistance (Pa)
50	0.465	985	246	1.251	0.22	53
75	0.697	1478	369	1.876	0.38	94
100	0.930	1970	493	2.502	0.58	143
125	1.162	2463	616	3.127	0.80	198

Resistance to Airflow with Loading at 0.93 m3/s (1970 cfm)

	Resistance (in. H2O)	Resistance (Pa)
Initial	0.58	143
After first dust load	0.61	152
After second dust load	0.72	180
After third dust load	0.87	216
After fourth dust load	1.01	252
After fifth dust load	1.16	289

Weight Gain of filter after completion of dust loading steps 88.3 g