Verification Testing of Technologies to Clean or Filter Ventilation Air

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ABSTRACT
Research Triangle Institute (RTI) is a partner in the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program, with responsibility for evaluation of control technologies for air pollution. Since 1995, ETV has developed testing protocols and verified the performance of innovative environmental technologies. RTI's Air Pollution Control Technology (APCT) Center has verified one add-on NOx control device, five baghouse filtration products, five dust suppressants, one emulsified fuel, nine mobile source devices and twelve paint overspray arrestors.

Because of the importance of indoor air quality, APCT is adding indoor air products as a new technology category to be considered for testing. This paper discusses RTI's participation in previous ETV-related programs and the contributions of the test protocols from those programs to the new APCT test plan for products that clean or filter ventilation air. The programs were an ETV Indoor Air Products pilot, an ETV Safe Buildings Air Filtration and Cleaning Technology effort and Technology Testing and Evaluation Program (TTEP) evaluation of biological inactivation efficiency by heating, ventilation and air-conditioning (HVAC) in-duct ultraviolet (UV) light systems. Results are presented from Safe Building filter testing and TTEP UV light systems as models of results for future APCT verifications.

INTRODUCTION
The U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program was created in 1995 to accelerate the entrance of new environmental technologies into the domestic and international marketplace by providing credible performance information to users making purchasing decisions. ETV primarily operates through public/private testing partnerships to evaluate or verify the performance of environmental technology in all media. The partners develop testing protocols and verify the performance of technologies that have the potential to improve protection of human health and the environment. ETV input into prioritization of technologies and test protocols is provided by stakeholder groups consisting of technology buyers, sellers, permitters, consultants, financiers, exporters and others within each sector. Program documents, including test plans, technology performance reports, and verification statements are available on the ETV website (www.epa.gov/etv). The program is voluntary and any technology vendor may participate within the selected technology

verification categories. High levels of quality data are assured through the implementation of the ETV Quality Management Plan which is compatible with both American and internationally accepted quality standards. All ETV partners must have their own quality management plan that is in compliance with EPA's plan. EPA does not certify, compare or approve products; verification means a careful examination and testing using a specific protocol under well-defined conditions and with adequate quality assurance procedures.

The ETV Air Pollution Control Technology (APCT) Center is operated through a cooperative agreement between the Research Triangle Institute (RTI) and EPA. An APCT pilot program was started in 1997 and the APCT Center was established in 2001. APCT evaluates control technologies for both stationary and mobile air pollution sources and indoor air pollution. APCT has a stakeholder advisory council made up of experts in the air pollution control field and includes representatives from state and local agencies, developers/vendors, buyers/users, environmental associations, consultants, and EPA. Technology-specific technical panels review testing protocols and provide advice on performance and testing issues for technologies. In the APCT Center, candidate technology categories are prioritized based on the importance of the air pollution problem addressed, commercial availability, availability of emission test methods, interest of developers/vendors in paying for a portion of verification costs, and potential market demand for the technology.

The APCT Center has verified products in the following technology categories: NO_X control technologies for stationary sources (one verification), baghouse filtration products (15 verifications), dust suppression and soil stabilization products (five verifications), emulsified fuels (one verification), mobile sources (nine verifications), and paint overspray arrestors (12 verifications). http://www.epa.gov/etv/centers/center5.html.

With the support of the stakeholders, RTI added indoor air products to the APCT list of technology categories because many vendors were asking for tests of their innovative products designed for improving indoor air quality.

PRIOR INDOOR AIR TECHNOLOGY TESTING ACTIVITIES

The test protocols/methods/plans developed by RTI for earlier programs are discussed below. RTI has tested air-cleaning and filtration devices under each of the programs discussed. First, there is a discussion of the standard that is the basis for these test protocols. This standard is based on research RTI did for EPA and for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

ASHRAE Methods

The American National Standards Institute (ANSI)/ASHRAE Standard 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*[1] (ASHRAE 52.2) is a standardized laboratory test method for measuring the filtration efficiency of ventilation air filters used in residential and commercial buildings. This includes residential furnace filters, pleated panel filters common in commercial applications, and high capacity bag filters. Prior methods (e.g., ASHRAE 52.1[2]) were designed to evaluate filters for their ability to protect heating, ventilation, and air-conditioning (HVAC) equipment from dust and to prevent stains on air diffusers, ceilings, and walls. These tests were not aimed at evaluating a filter relative to its ability to filter respirable size particles.

The ASHRAE 52.2 test is performed by placing the filter, typically having face dimensions of 61 x 61 cm in a test duct. The airflow in the duct is set at a constant value depending upon filter type. A test aerosol is then injected upstream of the filter while a particle counter is used to count the number of particles upstream and downstream of the filter in 12 size ranges from 0.3 to 10 μm in diameter. The ratio of the downstream counts to the upstream counts is used to compute the filtration efficiency for each of the 12 channels. Based on the filtration efficiency results and final pressure drop of the filter, the filter receives a Minimum Efficiency Reporting Value (MERV). 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.

One aspect of the ASHRAE 52.2 method that differs from prior standards is the incorporation of a "conditioning" step. Traditionally, a filter's efficiency was measured in its clean condition and after dust loading to 25, 50, 75, and 100% of final resistance (as in the ASHRAE 52.1 standard). The conditioning step is an added procedure that comes between the initial efficiency measurement and the 25% dust-loading step. The purpose of the conditioning step is to reveal decreases in filtration efficiency that a filter may undergo during the early stages of dust loading, before dust collection on the filter leads to increased filtration efficiency. Laboratory and field studies indicate that some electrostatically charged filters may undergo substantial decreases in efficiency as they are exposed to aerosols[3]. An earlier paper[3] discussed RTI studies on the conditioning step. The ASHRAE Standard 52.2 test is performed using a solid-phase (i.e., dry) potassium chloride (KCl) aerosol. The filters are loaded using ASHRAE dust, composed of 72% Society of Automotive Engineers (SAE) fine, 23% powdered carbon, and 5% cotton linters.

Indoor Air ETV

RTI was the partner for the indoor air quality ETV pilot. The pilot began with a general meeting for industry and other interested organizations in December 1996. The final documents for the first two programs were issued in September 1999. Test protocols were written and verified, but no products were tested. One product area was focused on the emissions from commercial furniture. The protocol has been used by other companies for testing products. The other two areas were general ventilation filters and electronic air cleaners. The test method used for filters was a modified version of ASHRAE 52.2. The method was developed before ASHRAE 52.2 had final approval. Documents for this project can be found at http://www.epa.gov/etv/centers/center7.html.

ETV's Safe Buildings Air Filtration and Cleaning Technology Effort

EPA's National Risk Management Research Laboratory (NRMRL) contracted with RTI to establish a homeland-security related ETV Program for products that clean ventilation air. With input from stakeholders, RTI developed the "Test/Quality Assurance Plan for Biological Testing of General Ventilation Filters[4]." Fourteen general ventilation air filters were tested and the reports are published on the EPA website http://www.epa.gov/etv/verifications/vcenter10-1.html.

The test program measured the culturable bioaerosol removal efficiency of general ventilation filters. Two tests were required to accomplish this goal. First, the ASHRAE Standard 52.2 test was performed on one filter of the test filter type to determine MERV of the filter. Next the biological test using three different bioaerosols and an inert aerosol test on both clean and fully dust-loaded filter were performed on a second filter. Results for the fourteen filters are shown in Tables 1 and 2. Product names are not given because the ETV Program does not allow product comparisons. Results of the inert tests were given as graphs in the verification reports and can be found on the EPA website http://www.epa.gov/etv/verifications/vcenter10-1.html.

Table 1. Descriptions of general ventilation filters.

Filter	Filter type	Media	Minimum Efficiency Reporting Value (MERV)
A	12-inch pleated	fiberglass	16
B	12-inch V-cell	wet-laid fiberglass paper	15
C	30-inch, 8-pocket	micro-glass	15
D	28-inch, 8 pocket	synthetic	14
E	12-inch, rigid cell	synthetic	14
F	12-inch V-cell	polypropylene	14
G	V-Cel	glass microfiber	14
H	12-inch V-cell	polypropylene	12
I	4-inch mini-pleat panel	polypropylene	12
J	4-inch mini-pleat panel	fiberglass	12
K	1-inch ring panel	polyester, tackified	8
L	1-inch panel	polyester, tackified	7
M	2-inch pleated panel	synthetic	7
N	2-inch pleated panel	poly-cotton blend	7

TTEP Evaluation of Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems

EPA's National Homeland Security Research Center (NHSRC) Technology Testing and Evaluation Program (TTEP) is helping to protect human health and the environment from adverse impacts resulting from acts of terror by carrying out performance tests on homeland security technologies. Under TTEP subcontract to Battelle, RTI evaluated the bioaerosol inactivation efficiency of HVAC in-duct ultraviolet (UV) light systems that operate on a "fly-through" basis. That is, they are designed to destroy bioaerosols in the flowing air stream as it passes through the device.

UV lamps have been used to inactivate airborne microorganisms for many years. Much of the early work was directed at the control of very infectious microorganisms (particularly *Mycobacterium tuberculosis*, the causative agent of tuberculosis), often in medical facilities. Wavelengths within the short wave, or C band of UV light (UVC), were found to be the most effective germicidal light wavelengths. UVC usually is generated by use of UVC fluorescent lamps. These lamps use electrical discharge through low-pressure mercury vapor enclosed in a glass tube that transmits UVC light (primarily at the mercury wavelength of 253.7 nm). Because this wavelength has been found to be about the optimum for killing microorganisms, UVC from mercury lamps also is referred to as UVG to indicate that it is germicidal. UVG has been shown to inactivate viruses, mycoplasma, bacteria, and fungi when used appropriately.

Table 2. Bioaerosol Control Efficiency for general ventilation filters

Filter/ MERV	Filter Status	Pressure Drop, Pa (in. H_2O)	Efficiency for Removal of B. atrophaeus , %	Efficiency for Removal of S. marcescens, %	Efficiency for Removal of MS2 phage, %
A/16	Clean	236 (0.95)	99.4	99.5	99
A/16	Dust Loaded	478 (1.92)	99.7	99.8	100
B/15	Clean	137 (0.55)	98	98	97
B/15	Dust Loaded	348 (1.40)	99.5	99	100
C/15	Clean	104 (0.64)	99	99	95
C/15	Dust Loaded	348 (1.40)	99	99	99
D/14	Clean	82 (0.331)	91	91	96
D/14	Dust Loaded	348 (1.4)	98	98	100
E/14	Clean	91 (0.366)	85	90	94
E/14	Dust Loaded	348 (1.40)	99	99	100
F/14	Clean	104 (0.42)	89	83	87
F/14	Dust Loaded	348 (1.40)	99	99	99
G/14	Clean	134 (0.54)	94	95	96
G/14	Dust Loaded	348 (1.40)	99.8	99.9	100
H/12	Clean	77 (0.31)	69	64	73
H/12	Dust Loaded	348 (1.40)	99	99.5	99
I/12	Clean	94 (0.38)	64	74	70
I/12	Dust Loaded	247 (1.00)	88	92	93
J/12	Clean	211 (0.85)	73	81	78
J/12	Dust Loaded	428 (1.72)	93	93	89
K/8	Clean	142 (0.57)	54	58	57
K/8	Dust Loaded	283 (1.14)	74	83	79
L/7	Clean	126 (0.51)	27	56	57
L/7	Dust Loaded	267 (1.08)	67	76	87
M/7	Clean	112 (0.45)	48	60	64
M/7	Dust Loaded	229 (0.92)	88	91	98
N/7	Clean	62 (0.25)	25	45	40
N/7	Dust Loaded	247 (1.00)	83	88	91

Numerous past studies of UVC to inactivate microorganisms have been conducted for a variety of purposes and with a variety of methods. No standard method exists for evaluating culturable bioaerosol inactivation by these devices. However, as part of the project entitled, "Defining the Effectiveness of UV Lamps Installed in Circulating Air Ductwork" funded by the Air-Conditioning and Refrigeration Technology Institute (ARTI), RTI developed a test method for measuring culturable bioaerosol inactivation efficiencies by UV lights.[5] This method was based on RTI's extensive experience in the development of particulate testing methods of various air-cleaning devices and earlier UV testing.

The TTEP testing is ongoing. Tests, reports and reviews have been completed for eight products; the results are shown in Table 3. The TTEP test/QA plan[6] and reports will be published on the EPA website.

Table 3. Bioaerosol inactivation efficiencies by HVAC in-duct UV Systems measured in TTEP program.

Prod. No.	Lamps	Dosage (μW-s/cm^2)	Measured irradiance	Power (w)	B. atrophaeus %	S. marcescens %	MS2 phage %
1	1	247 (208 – 304)	310 $\mu W/cm^2$ at 162 cm[a]	53	4	99	39
2	4	295 (249 - 363)	480 $\mu W/cm^2$ at 162 cm[a]	94	0	>99.8	46
3	4	582 (490 - 716)	1190 $\mu W/cm^2$ at 161 cm[a]	169	9	>99.96	75
4	12	7,651 (6,443 – 9,416)	1,940 $\mu W/cm^2$ at 145 cm[a]	755	71	>99.98	98
5	8	3180 (2678 - 3914)	1710 $\mu W/cm^2$ at 126 cm[a]	568	40	>99.98	82
6	5	16,439 (13,843-20,223)	1200 $\mu W/cm^2$ at 133 cm[a]	944	93	>99.97	99
7	6	19,826 (16,696–24,401)	6800 $\mu W/cm^2$ at 161 cm[a]	421	96	>99.96	99
8	6	42,342 (35,656–52,113)	1620 $\mu W/cm^2$ at 136 cm[b]	748	>99.89	>99.94	>99.88
9							

[a] Irradiance measured at 0.93 m3/sec (1970 cfm)
[b] Irradiance measured at 0.14 m^3/sec (300 cfm)

FUTURE VENTILATION AIR VERIFICATIONS BY ETV'S APCT CENTER

In 2006 APCT added indoor air products as a technology category, with the first products those that clean or filter ventilation air. People spend as much as 90% of their time indoors, especially people in sensitive populations and indoor air may be more polluted than outdoor air[7].

APCT now has an approved test plan for single-pass devices used for aerosols in ventilation ducts. This test plan has roots in the previous RTI projects discussed above. The current test plan was developed for general ventilation air filters, but was designed broadly enough that a simple addendum may be added for testing other devices, such as UV systems. Vendors will be able to select any or all of the following tests:

- ASHRAE 52.2-type testing for particles from 0.3 – 10 µm,
- Filtration efficiency for inert particles from 0.03 – 10 µm, and
- Bioaerosol filtration efficiency for fungi, bacteria, and virus.

Other test plans will be developed based on vendor interest.

The ASHRAE 52.2 and inert testing will be performed as they were for ETV-HS testing. The bioaerosol tests for TTEP and ETV-HS were conducted using three organisms, consisting of two bacteria (spore-forming *Bacillus atrophaeus* and the vegetative bacterium *Serratia marcescens)* and one bacterial virus (MS2). Generally, vegetative bacteria are readily killed and bacterial spores are more difficult. The spore form of the bacteria *Bacillus atrophaeus* (formerly *B. subtilis* var. *niger* and *Bacillus globigii* or BG) was used as the surrogate 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, 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 0.02 – 0.03 µm size range, the test particle size for the virus tests spanned a range of sizes (polydispersed bioaerosol) in the micron range. For the APCT tests, *Bacillus atrophaeus* and MS-2 will be used. The vegetative bacteria *Staphylococcus epidermidis* is a common gram-positive 0.5 - 1.5 µm spheres organism and will be the representative vegetative bacterium. A fungal spore (2 - 3.5 µm spheres), *Aspergillus versicolor* was added for the tests. *Aspergillus versicolor* is frequently reported as a causative agent of hypersensitivity pneumonitis and has been found in and isolated from a number of problem buildings.

The information reported will be similar to information shown in the tables of this paper. Additional information will also be presented as relevant for individual devices. While RTI has focused its ETV efforts on technologies where there are several products that could be tested in a batch, this IAQ effort is designed so that individual, innovative technologies can be tested.

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KEY WORDS

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