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Environmental and Sustainable Technology Evaluation: Mold-Resistant Armacell Insulation – Armacell LLC, AP Armaflex Black

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Acronyms and Abbreviations

ACH	air changes per hour
ADQ	audit of data quality
ASTM	American Society for Testing and Materials
AATCC	American Association of Textile Chemists and Colorists
a_w	water activity
CFU	colony forming unit
DNPH	2,4-dinitrophenylhydrazine
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
ESTE	environmental and sustainable technology evaluations
ERH	equilibrium relative humidity
ETV	environmental technology verification
g	gram(s)
GC/MS	gas chromatography/mass spectrometry
ISO	International Organization for Standardization
MC	moisture content
ML	microbiology laboratories
ML SOP	microbiology laboratory standard operating procedure
QA	quality assurance
QAM	quality assurance manager
QAPP	quality assurance project plan
QC	quality control
QMP	quality management plan
RH	relative humidity
RTI	Research Triangle Institute (RTI International)
sec	second(s)
SOP	standard operating procedure
spp	species
t	temperature in degrees Celsius
TOP	technical operating procedure
T/QAP	test/quality assurance plan
TSA	technical system audit
TVOC	total volatile organic compounds
VOCs	volatile organic compounds
Φg	microgram(s)
Φm	micrometer(s)
UL	Underwriters Laboratories

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1.0 INTRODUCTION

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental and Sustainable Technology Evaluation (ESTE) Program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The ESTE program is intended to increase the relevance of Environmental Technology Verification (ETV) Program projects by responding to near-term needs identified by the U.S. EPA program and regional offices.

The ESTE program involves a three step process. The first step is a technology category selection process conducted by ORD. The second step involves selection of the project team and gathering of project collaborators and stakeholders. Collaborators can include technology developers, vendors, owners, and users. They support the project through funding, cost sharing, and technical support. Stakeholders can include representatives of regulatory agencies, trade organizations relevant to the technology, and other associated technical experts. The project team relies on stakeholder input to improve the relevance, defensibility, and usefulness of project outcomes. Both collaborators and stakeholders are critical to development of the project test and quality assurance plan (TQAP), the end result of step two. Step three includes the execution of the verification and quality assurance and review process for the final reports.

This ESTE project evaluated microbial resistant building materials. EPA's National Risk Management Research Laboratory contracted with the Research Triangle Institute (RTI) to establish an ETV/ESTE Program for microbial-resistant building materials. RTI convened a group of stakeholders representing government and industry with knowledge and interest in the areas of mold resistant building materials. The group met in May and July 2006 and recommended technologies to be tested. RTI then developed (and EPA approved) the "Test/Quality Assurance Plan for Mold-Resistant Building Material Testing [1]." The tests described in this report were conducted following this plan.

Fungal growth and the resulting contamination of building materials is a well-documented problem, especially after the reports from New Orleans and the U.S. Gulf Coast post Hurricane Katrina. However, contaminated materials have been recognized as important indoor fungal reservoirs for years. For example, contamination with fungi has been associated with a variety of materials including carpet, ceiling tile, gypsum board, wallpaper, flooring, insulation, and heating, ventilation and air conditioning components[2-5].

Exposure to fungi may result in respiratory symptoms of both the upper and lower respiratory tract such as allergy and asthma[6]. Everyone is potentially susceptible. However, of particular concern are children with their immature immune systems and individuals of all ages that are immunocompromised[7,8].

One approach to limiting exposure is to reduce the levels of fungi in the indoor space. For some sensitive individuals, limiting exposure through avoidance is an effective control method; however, avoidance is not always possible or practical. The investigation, development, and application of effective source controls and strategies are essential to prevent fungal growth in the indoor environment. Mold resistant building material is a potentially effective method of source control.

Figure 1-1 illustrates the combination of moisture and nutrients required for microbial growth on a material. Sufficient nutrients for growth may be provided by the material itself or through the accumulation of dust on or in the material. When sufficient nutrients are available, the ultimate determinant for microbial growth is availability of water. The more hygroscopic a material (e.g. wallboard) is, the more impact on the overall hygroscopicity the surface treatments may have.

A building is not a sterile environment, nor should it be. In fact, a building is frequently a reservoir for microorganisms. While many different types of microorganisms occupy indoor spaces, it is well-recognized that fungi can colonize and amplify on a variety of building materials if sufficient nutrients and moisture are present. These contaminated materials are known to be important indoor reservoirs. Fungal growth on natural and fabricated building materials can be a major source of respiratory disease in humans. Commonly, sufficient nutrients are available and water is usually the growth factor most limiting the establishment and growth of microbial populations. Sufficient moisture for growth may become available through water incursion from leaks and spills, condensation on cold surfaces, or absorption or adsorption directly from the indoor air. The amount of water required is not large, and materials that appear dry to cursory inspection may be capable of supporting microorganism growth.

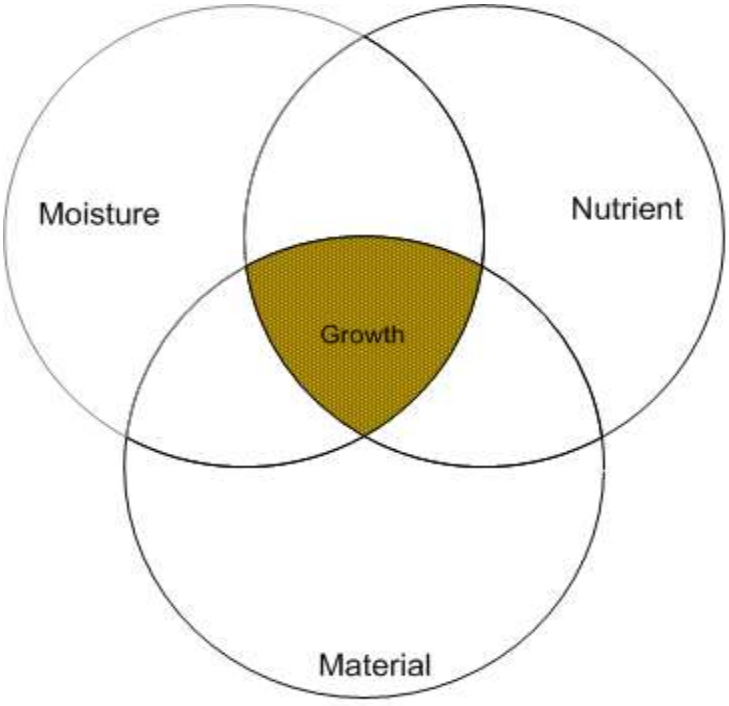

Figure 1-1. Diagram illustrating the conditions required for fungal growth on a material.

2.0 VERIFICATION APPROACH

The ESTE test program measured the mold resistance of Armacell AP Armaflex Black insulation. Since the EPA program office wanted testing performed on mold-resistant building materials, and Armacell markets this insulation material as such, it was a good candidate for testing. Tests for emissions of VOCs and formaldehyde were also performed. An overview of the emissions procedures is found in the Appendix. The detailed test methods can be found in RTI's test/QA project plan[1].

2.1 TEST MATERIAL

The following description of the product was provided by the vendor and was not verified.

AP Armaflex Roll Insulation is a black flexible closed-cell, fiber-free elastomeric thermal insulation. It is furnished with a smooth skin on one side which forms the outer exposed insulation surface. The expanded closed-cell structure makes it an efficient insulation for ductwork, large piping, fittings, tanks and vessels. AP Armaflex products are made with Microban® antimicrobial product protection for added defense against mold on the insulation.

Figures 2-1 and 2-2 show the top and bottom surfaces of the material.

Figure 2-1. Top (outer) surface of material

Figure 2-2. Bottom (inner) surface of material

2.2 TEST METHODS AND PROCEDURES

Mold resistance testing was performed following the guidelines outlined in ASTM 6329[9]. This method was developed as part of a more comprehensive project to apply indoor air quality engineering to biocontamination in buildings. One of the primary goals was to develop a scientific basis for studying indoor air biocontaminants. Available methods, including those from ASTM, AATCC, and UL, for evaluating the resistance of a variety of materials to fungal growth were surveyed. Although the basic principles were similar, a major concern was the way growth on the different materials was evaluated. Although quantitative methods for inoculation were employed by most of the methods, all assessed growth qualitatively as the endpoint. ASTM 6329[9] evaluates growth quantitatively as the endpoint. The method has been successfully used to evaluate fungal resistance on a variety of materials including ceiling tiles and HVAC duct materials [10-13].

2.2.1 Test Organisms

Selecting the "correct" test organism is critical to any test, therefore selection criteria were developed. The selection criteria used to choose the appropriate test organisms for this study were:

(1) the reasonableness or likelihood of the test material being challenged by that particular organism when in actual use, and

(2) that they cover the range of ERHs (equilibrium relative humidities) needed and bracket the ERHs where fungal growth can occur.

Two fungi were used as test organisms, *Aspergillus versicolor* and *Stachybotrys chartarum*. Each of them met the criteria. *S. chartarum* requires high levels of available water to grow and has been associated with a number of toxigenic symptoms. *A. versicolor* is a xerophilic fungus and capable of growing at lower relative humidities. Both are from the RTI culture collection (CC). The CC number for *S. chartarum* is 3075 and the organism was received from EPA NERL. *A. versicolor* is CC #3348, and it is a field isolate. Prior to initiation of the testing, their identification was confirmed by standard techniques.

2.2.2 Static Chambers

Clear plastic desiccators served as the static environmental chambers. The desiccators are sealed so there is no air exchange and the desiccators serve as good static chambers. A saturated-salt solution of potassium chloride was used to maintain the humidity of the 85% ERH chamber. Sterile water was used for the 100% ERH chamber. Temperature was externally controlled and maintained at room temperature. Prior to use, the chambers were decontaminated and characterized. The ERH in each

chamber was monitored with a hygrometer (Taylor model number 5565) that was placed inside the chamber.

2.2.3 Test Design

The Armaflex Black insulation was cut aseptically with a razor blade into small pieces (at least 4 cm x 4 cm). Because ASTM 6329 calls for a reference material similar to the test material, the reference material chosen for comparison was insulation purchased in a local home improvement chain store. The material was not autoclaved or sterilized in any way prior to inoculation. Therefore, in addition to the test organism inocula, any organisms naturally on both the top and bottom surfaces of the material had the opportunity to grow if conditions were favorable for growth. The test organisms are inoculated by pipette directly onto the surface of each test piece in sufficiently high numbers to provide an adequate challenge, but at a level that is realistic to quantify. The tests ran for 12 weeks. During the 12 week test period, data from four test dates, labeled Day 0, Week 1, Week 6, and Week 12 were evaluated. Day 0 samples provided the baseline inoculum level. A sufficient number of test pieces were inoculated simultaneously for all four test dates. All pieces for one material and one test organism were put in the same static chamber. The chambers were set to 100% equilibrium relative humidity (ERH) for the tests with *S. chartarum* and at 85% for *A. versicolor.* On each test date (including Day 0), five replicates of the test material pieces were removed from the chamber, each was placed separately in a container with sterile buffer, and extracted by shaking. The resulting suspension of eluted organisms was plated and microbial growth on materials was quantified by manually enumerating colony-forming units (CFUs).

The numbers of CFUs eluted on week 1, 6, and 12 were compared to the baseline at Day 0. The numbers of CFUs on each date are expressed as $\log_{10}$. The results are reported as the log change in CFUs between Day 0 and Week 1, Day 0 and Week 6, and Day 0 and Week 12.

2.2.4 Sample Preparation and Inoculation

Small (at least 4 cm x 4 cm) replicate pieces of test mold resistant insulation material and reference insulation material were prepared and inoculated. To minimize error and demonstrate reproducibility, five pieces of each sample type were processed on each sampling date. Because there were four test dates, a minimum of 20 pieces were prepared simultaneously. Each piece was placed on a separate labeled sterile Petri dish.

The fungi challenge suspensions were prepared by inoculating the test organism onto solid agar media, incubating the culture at room temperature until mature, wiping organisms from the surface of the pure culture, and suspending them in sterile 18-Mohm distilled water. The organism preparation was viewed

microscopically to verify purity of spores (absence of hyphae). The test pieces were inoculated (usually with five 10 µL spots in an X configuration) by pipet onto the surface of the test piece and allowed to dry in the biosafety cabinet.

On each test date (including Day 0), the appropriate number of test pieces were removed from the static chamber, each placed in approximately 30 mL sterile buffer, and extracted by shaking using a vortex or wrist action shaker. The extract was diluted if needed and plated on agar media to determine the numbers of CFU.

2.2.5 Calculation of Mold Resistance

Changes in the numbers of CFU over time were quantified. The $\log_{10}$ number of CFUs from test date x were compared to the $\log_{10}$ number of CFU from Day 0 as follows:

$$\Delta\ log_{10}\ CFU = log_{10}\ CFU_{date\ x} - log_{10}\ CFU_{Day\ 0}$$

where:

Δ CFU = the change in log_{10} CFU between a test date (x) and Day 0

$log_{10}\ CFU_{date\ x}$ = number of CFU log_{10} on test date x

$log_{10}\ CFU_{Day\ 0}$ = number of CFU log_{10} on Day 0

The standard error of the means between the start date and the test date gives the statistical significance of the differences.

2.3 SUSTAINABILITY INDICATORS AND ISSUES

The verification organization requested information from the vendor that would, along with the test results for microbial resistance, assist in estimating impacts on solid waste disposal due to replacing building materials less frequently. Information was also requested on chemical additives that are claimed to confer microbial resistance. Also, the vendor was asked to provide any additional information relative to the environmental sustainability of the product such as recyclability/reusability of the product and disposability of the product and use of renewable resources or other criteria the vendor deemed relevant to the environmental sustainability of the product.

3.0 RESULTS

3.1 MOLD RESISTANCE

The results for the mold resistance tests are shown in Table 3-1. Growth is measured by culture and is defined as at least a 1 $\log_{10}$ increase in culturable organism over the baseline which was determined on Day 0.

Table 3-1. Log_{10} CFUs for test material (Armacell) and reference material (insulation) on each test date (Mean ± SD)

Armacell			
Week	***A. versicolor* 85% ERH**	***S. chartarum* 100% ERH**	**Growth of Naturally Occurring Fungi 100% ERH**
0	4.5 ± 0.3	5.1 ± 0.1	NG
1	4.1 ± 0.2	3.5 ± 0.8	NG
6	3.1 ± 0.3	3.5 ± 0.3	NG
12	3.0 ± 0.2	3.3 ± 0.4	NG
Reference Material			
Week	***A. versicolor* 85% ERH**	***S. chartarum* 100% ERH**	**Growth of Naturally Occurring Fungi 100% ERH**
0	4.6 ± 0.4	5.0 ± 0.2	< 3.2 ± 0.0*
1	3.8 ± 0.3	5.0 ± 0.1	< 3.2 ± 0.0*
6	3.2 ± 0.3	4.3 ± 1.0	4.8 ± 2.0
12	3.0 ± 0.5	4.2 ± 0.9	4.9 ± 2.3

NG = No Growth

* = < 3.2 indicates 0 CFU detected at the minimum detection limit

The numbers of CFUs on each test and reference piece were Log_{10} transformed and the mean and standard deviation calculated. The initial concentration is in the row labeled week 0 (day 0 inoculum). The results for the test organisms, *A. versicolor* and *S. chartarum* are in columns two and three. The fourth column gives the CFUs for the fungi (naturally occurring) that were on the unsterilized surface of the reference material at the initiation of the test.

Figure 3-1 shows the log change in *A. versicolor* and Figure 3-2 shows the log change in *Stachybotrys chartarum* on both the test and reference materials as well as the growth of naturally occurring fungi on the reference material.

Neither the test material nor the reference material inoculated with *A. versicolor* and incubated at 85% ERH showed growth during the 12 weeks of the test. It was important to check that none of the changes made to the test material to make it mold resistant actually enhanced the ability of mold to grow over the reference material.

Neither the test material nor the reference material inoculated with *S. chartarum* and incubated at 100% ERH showed growth during the 12 weeks of the test. The growth of a variety of fungal species on some pieces (naturally occurring on the sample) made it difficult to accurately assess the *S. chartarum* growth on the reference material. At Day 0 the numbers of naturally occurring fungi were below the detection limit on both the test and the reference materials. However, the growth of the naturally occurring fungi on the reference material became a notable quantity by week 6.

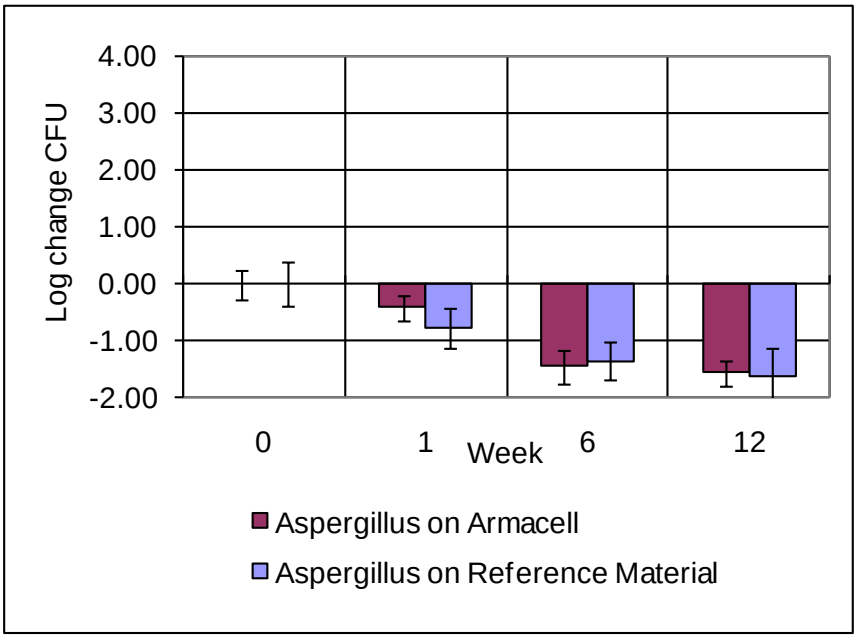

Figure 3-1. Log change in *Aspergillus versicolor* inoculated on the test material over 12 weeks on the insulation reference material and Armacell.

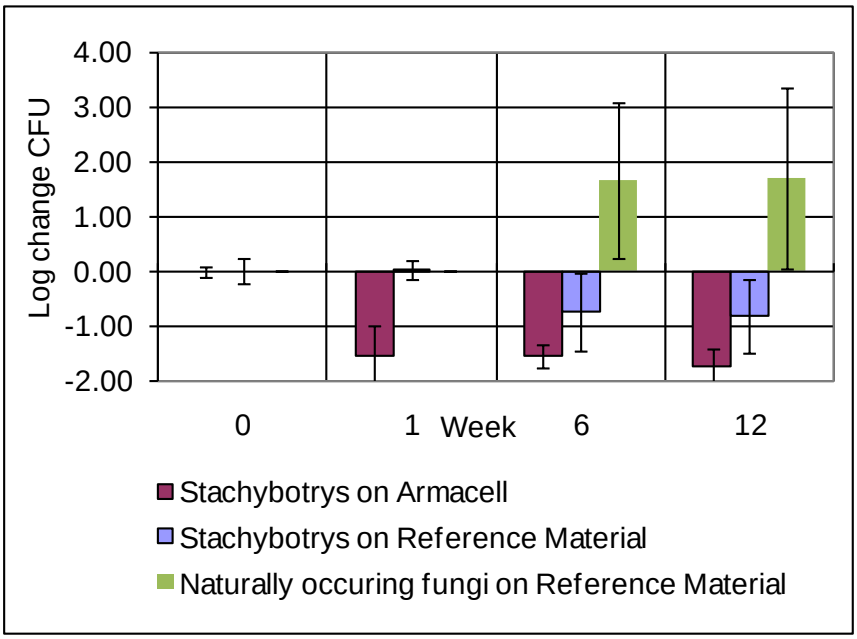

Figure 3-2. Log change in *Stachybotrys chartarum* inoculated on the test material over 12 weeks on the insulation reference material and Armacell.

3.2 EMISSIONS OF VOCs AND FORMALDEHYDE

The emissions of VOCs and formaldehyde test results are presented in the Table 3-2. A summary of the method is found in Appendix A[14].

Table 3-2. Test results for VOCs and formaldehyde emissions from Armacell

VOCs and Formaldehyde Emissions*	
Emission Types	Minimum emission results
Total VOCs	< 0.5 mg/m^3
Formaldehyde	<0.1 ppm
Individual VOCs	< 0.1 TLV

*Individual pollutants must produce an air concentration level no greater than 1/10 the threshold limit value (TLV) industrial workplace standard (Reference: American Conference of Government Industrial Hygienists, 6500 Glenway, Building D-7, Cincinnati, OH 45211-4438.

3.3 SUSTAINABILITY ISSUES

Sustainability is an important consideration in use of microbial resistant building materials. Armacell supplied the following information about the sustainability of the AP Armaflex Black insulation material:

- Armaflex is made with Microban antimicrobial product protection. The MSDS for Microban is included as an attachment to this report.
- Armacell is the first manufacturer of flexible technical insulation materials in the world to present an ecobalance analysis (Life Cycle Assessment): 140 times more energy is saved through the use of Armaflex products than is needed for the production, transport and disposal of the products
- Armflex is manufactured without the use of CFC's, HFC's or HCFC's.
- Indoor Air Quality-friendly: Fiber-free, formaldehyde-free, low VOCs, nonparticulating
- Armacell's environmental policy includes the principle of avoiding and reducing waste, recycling and using environmentally-friendly disposal methods.

4.0 DATA QUALITY ASSESSMENT

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

The DQO for the critical measurement, quantitation of fungal growth on an individual test date, is found in Table 4-1.

Table 4-1. Data quality objectives

Test	Parameter	DQO		
		Precision	Accuracy	Completeness
Mold Resistance	Quantitation of fungal growth on an individual test date	± 5-fold difference	10% of the plates will be counted by a second operator. ± 20% agreement between the operators	100%

This verification statement discusses two aspects of Mold-Resistant Building Material Testing, mold resistance and emissions of VOCs and formaldehyde. Users of this technology may wish to consider other performance parameters such as fire resistance, service life and cost when selecting a building material.

According to the test/QA plan[1], this verification statement is valid for three years following the last signature added on the verification statement.

5.0 REFERENCES

1. RTI (Research Triangle Institute). 2008. Test/QA Plan for Mold-Resistant Building Material Testing. Research Triangle Park, NC. http://www.epa.gov/etv/este.html
2. Morey, P.R., 1988, "Microorganisms in Buildings and HVAC Systems: A Summary of 21 Environmental Studies," Proceedings of the ASHRAE Conference on Indoor Air Quality, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Atlanta, GA, pp 10-24.
3. Reynolds, S.J,, A.J. Steifel, and C.E. McJilton, 1990, Elevated Airborne Concentration of Fungi in Residential and Office Environments, American Industrial Hygiene Association *Journal*, Vol. 51, pp 601-604.
4. Leese, K.E., E.C. Cole, and J.D. Neefus, 1992, Biocide Mitigation of a Mold Contaminated Building: An Initial Preventive Approach, Proceedings, American Industrial Hygiene Association Annual Meeting, Washington, DC.
5. Kozak, P.P., et al, 1980, Currently Available Methods for Home Mold Surveys. II. Examples of Problem Homes Surveyed, Annals of Allergy, Vol. 45, pp 167-176.
6. Garrett, M.H., Rayment, P.R., Hooper, M.A., Abramson, M.J., and Hooper, B.M. 1998, Indoor airborne fungal spores, house dampness and associations with environmental factors and respiratory health in children, *Clinical and Experimental Allergy*: 28: 459-467.
7. Rylander, R. and Etzel, R., 1999, Indoor mold and children's health. Environmental Health Perspectives Supplements:107: 465-517.
8. Gent, J.F., Ren, P., Belanger, K., Triche, E., Bracken, M.B., Holford, T.R., and Leaderer, B.P., 2002, Levels of household mold associated with respiratory symptoms in the first year of life in a cohort at risk for asthma. *Environmental Health Perspectives*: 110: A781-A786.
9. ASTM D6329-98(2003), Standard Guide for Developing Methodology for Evaluating the Ability of Indoor Materials to Support Microbial Growth Using Static Environmental Chambers, American Society for Testing and Materials, West Conshohocken, PA.
10. Foarde, K.K. and M.Y. Menetrez. 2002, Evaluating the Potential Efficacy of Three Antifungal Sealants of Duct Liner and Galvanized Steel as Used in HVAC Systems. *Journal of Industrial Microbiology & Biotechnology*. 29:38-43.
11. Foarde, K.K. and J.T. Hanley. 2001, Determine the Efficacy of Antimicrobial Treatments of Fibrous Air Filters. *ASHRAE Transactions*. Volume 107, Part 1. 156-170.
12. Chang, J.C.S., K.K. Foarde, and D.W. VanOsdell. 1995, Growth Evaluation of Fungi *(Penicillium and Aspergillus spp.)* On Ceiling Tile. *Atmospheric Environment*. 29:2331 2337.

13. Foarde, K., E. Cole, D. VanOsdell, D. Bush, D. Franke and J. Chang.1992, Characterization of Environmental Chambers for Evaluating Microbial Growth on Building Materials. In: IAQ '92 Environments for People, proceedings; 185-190.
14. ASTM. 2006. D5116-06, Standard Guide for Small Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products, American Society for Testing and Materials, West Conshohocken, PA.

Appendix A
VOCs and Formaldehyde Emissions Testing

EMISSIONS REPORT FOR AP ARMAFLEX BLACK MATERIAL

A single 7"x7" sample of AP Armaflex Black material was tested in the small (52.7 L capacity) emissions chamber subjected to an air exchange rate of 1 hr^{-1}. After equilibration of the sample for 6 hr, sequential samples for VOCs and carbonyls were collected from the chamber effluent for 20 and 120 minutes, yielding collection volumes of approximately 1.5 and 10 L for VOCs and 10 and 60 L for carbonyls. In addition to the test material, a chamber blank and emissions from a positive control material (vinyl show curtain liner) were also collected.

VOC samples were collected on Carbopack B cartridges and were analyzed by GC/MS on a DB-5 column programmed from 40E-225E at 5E/min. Calibration standards were prepared at two levels by flash loading of a VOC mixture in methylene chloride onto Carbopack B. In addition to quantitation of the individual analytes, total VOCs (TVOC) were determined by summing the integrated peak areas in the samples and blanks between the retention times of hexane and hexadecane. Two specific analytes, 4-phenylcyclohexene and styrene, were sought in each sample. Neither compound was detected in the samples or blanks. All detected analytes were quantitated against the toluene peak in the standards. No mathematical correction for the blanks was performed.

Carbonyl samples were collected on DNPH cartridges and were analyzed by HPLC/UV (365 nm) on a Supelcosil™ LC-18 column (Supelco #358298, 25 cm x 4.6 mm). The mobile phase consisted of (A) 45:55 acetonitrile:water and (B) 75:25 acetonitrile:water, using a 30 minute gradient from A to B and held at B for 5 minutes at a flow rate of 1 mL/min. Each cartridge was extracted by solid phase extraction (SPE) with 4 mL of acetonitrile and brought to a final volume of 5 mL with acetonitrile. Instrument calibration was accomplished using solutions prepared from a purchased aldehyde/ketone DNPH mix solution (15 µg/mL as formaldehyde, Supelco 47285-U) in acetonitrile. A six-point calibration curve was prepared with analyte amounts ranging from 18.8 to 600 ng/mL. Individual carbonyls were quantitated against the curve and corrected for blanks.

The results of the emission tests for VOCs and carbonyls are presented in Tables 1 and 2, respectively. For all samples, excluding the positive control, levels of VOCs and carbonyls were extremely small, near the detection limit for the method, and comparable to the levels found in the blanks.

Table 1. VOC emission results[a] for AP Armaflex Black® Material

Sample Id.	Toluene Chamber Conc. (mg/m^3)	TVOC Chamber Conc. (mg/m^3)	Toluene Emission Factor ($mg/m^2 \cdot hr$)	TVOC Emission Factor ($mg/m^2 \cdot hr$)
Chamber Blank[b]	<0.001	0.0470	0.0007	0.0829
Positive Control[b]	0.000	0.6708	0.000	1.1600
AP Armaflex Black[c]	<0.001	0.042 (0.030)	<0.001	0.074 (0.053)

[a] Mean (Standard deviation)
[b] Single determination
[c] Mean of 6 determinations

Table 2. Carbonyl emission results[a] for AP Armaflex Black® Material

Sample Id.	Formaldehyde Chamber Conc. (mg/m^3)	Total Carbonyls Chamber Conc. (mg/m^3)	Formaldehyde Emission Factor ($mg/m^2 \cdot hr$)	Total Carbonyls Emission Factor ($mg/m^2 \cdot hr$)
Chamber Blank[b]	<0.001	0.004	<0.001	0.007
Positive Control[b]	<0.001	0.013	<0.001	0.023
AP Armaflex Black[c]	0.001 (0.003)	0.012 (0.010)	0.002 (0.006)	0.021 (0.019)

[a] Mean (Standard deviation)
[b] Single determination
[c] Mean of 6 determinations

[1] Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products. American Society for Testing and Materials (ASTM) document D5116-97, 2008.

[2] Standard Operating Procedure for the Determination of Carbonyl and VOC Emissions from Building Materials Using a Small Environmental Chamber. RTI International document: EAR-LAB-001, 2010.

[3] Quality Manual for the AIHA Accredited Laboratory No. 100600. RTI International document: RTI/0290365/08-01, January 2010.

[4] Adsorbent Tube Injector System Operation Manual, Sigma-Aldrich/Supelco, Available at: http://www.youngwha.com/tech/upload/ATIS_system_T702019.pdf, 2010.

[5] Standard Operating Procedure for the Analysis of Volatile Organic Chemicals By Thermal Desorption/GC/MS, RTI International document: EAR-GLC-004, 2010.

[6] Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology). American Society for Testing and Materials (ASTM) document D5197-09, 2009.

[7] Standard Operating Procedure for the Extraction and Analysis of Formaldehyde-DNPH from Active and Passive Media by HPLC, RTI International document: EAR-GLC-003, 2010.