Proposed Standards and Guidelines for UVGI Air Disinfection

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INTRODUCTION

In spite of widespread use of ultraviolet germicidal irradiation (UVGI) for air disinfection applications, there are currently no consensus standards for the design, application, or testing of UVGI air disinfection systems. Several agencies and organizations are in a position to develop such documents, including the Centers for Disease Control (CDC), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), National Environmental Balancing Bureau (NEBB), and others, but none of these groups currently have plans to do so. As a first step in the direction of standards, guidelines are needed that address specifics of the design, operation, and testing of UVGI components and systems for commercial and health care applications. Such documents will provide a basis for the development of consensus standards analogous to ASHRAE Standard 52.2-1999 for rating filters and ASHRAE 90.1 for whole-building energy efficiency (ASHRAE 1999, 2001). This article outlines requirements for the guidelines and standards needed to ensure successful UVGI applications and reviews the availability of data for their development.

EXISTING GUIDELINES

A number of currently available documents provide information on aspects of UVGI system design, installation, and testing, but no comprehensive standard exists that can ensure that installed UVGI systems are safe and effective. Many components of a potential standard exist in piecemeal fashion in these documents. Guidelines are available from sources such as the Illumination Engineering Society of North America (IESNA) that address the design, testing and rating of UV lamps (IESNA, 2000; CIE, 2003). Electrical safety of UVGI components can be certified by testing laboratories such as UL and ETL in order to ensure they are suitable for operation inside ducts, plenums, or other locations. Safety and health hazards from UV exposure have been addressed by various agencies (NIOSH 1972; ACGIH 1991; AIHA 2001; IRPA 1985; NEHC 1992). Guidelines from the Centers for Disease Control (CDC) have addressed the use of UVGI for tuberculosis control and infection control but provide no specific design guidance (CDC 1994, 2003). Guidelines from the General Services Administration provide recommendations for using UVGI to control mold in mechanical HVAC systems, but without detailed technical information (GSA, 2003). The ASHRAE HVAC Design Manual for Hospitals and Clinics addresses the capabilities of UVGI but includes no specific guidelines (ASHRAE, 2003). The use of air treatment to mitigate bioterrorist threats has been addressed in several documents (NIOSH, 2002 & 2003, FEMA 2003, 2003a, & 2003b). Numerous books, catalogs, and publications have provided piecemeal information on the design and performance capabilities of UVGI in applications, but as yet no definitive guideline or standard has been proposed that would provide accurate and reliable design information (Kowalski and Bahnfleth, 2000a,b; Kowalski, et al., 2000; Philips 1985; VanOsdell and Foarde, 2002, Bolton, 2001).

UVGI System Applications

UVGI systems find increasing varieties of applications as a result of both real and potential airborne disease threats, including emerging diseases like SARS virus, increased resistance of some species such as *Staphylococcus aureus* and *Mycobacterium tuberculosis* to antibiotics, the continued threat of species-jumping diseases like avian flu, the ever-present problem of indoor mold growth coupled with increased incidence of asthma and allergies, the recognition of airborne vectors in food pathogens, and the threat of bioterrorism.

Table 1 provides a summary of where UVGI systems are applied today and what types of systems are typically used. The mold growth control systems referred to are often used for controlling microbial growth on cooling coils and air handling unit components.

TYPES OF UVGI SYSTEMS

The various types of UVGI systems may have different design and testing requirements. Figure 1 shows a breakdown of the most common types of UVGI systems used today. Each of these systems will of necessity require some degree of separate consideration in terms of performance and testing standards.

In addition to the types of UVGI systems, the variety of UVGI applications necessitates some variation in performance requirements. UVGI systems installed in commercial office buildings for biodefense will probably have different requirements than those installed in hospitals for nosocomial infection control, or those installed in homes for allergen control. Some systems may serve a dual purpose, disinfecting both the air stream and the internal Air Handling Unit (AHU) surfaces, as shown in Figure 2.

Table 1: UVGI Applications and System Types

Application	Type of UVGI System	Disinfection Type
Health Care	Surgical Site Infection Control	Air & Surface
	Isolation Wards & Rooms	Air
	General Hospital Areas	Air
	Emergency Rooms	Both
	AIDS Clinics	Air
	Equipment Disinfection	Surface
Commercial Buildings	Biodefense	Air
	Mold Growth Control	Surface
	Respiratory Disease Control	Air
	Mail Disinfection	Surface
	Building Remediation	Surface
Residential	Allergen & Pathogen Control	Air
	Mold Growth Control	Surface
Hotels	Allergen & Pathogen Control	Air
	Mold Growth Control	Surface
Schools	Respiratory Disease Control	Air & Surface
Airplanes	Respiratory Disease Control	Air
Ships	Disease Control	Air and Surface
Laboratories	Biohazard Control	Air & Surface
Animal Facilities	Airborne Biohazard Control	Air
Libraries & Museums	Mold Growth Control	Surface
	Allergen Control	Air
Sewage & Waste Facilities	Biohazard Control	Air & Surface
Food Industry	Biocontamination Control	Air & Surface
Agricultural Industries	Biohazard Control	Air & Surface
Industrial Facilities	Biohazard Control	Air & Surface
Prisons & Jails	Respiratory Disease Control	Air & Surface
Homeless Shelters	Respiratory Disease Control	Air & Surface

LABORATORY TEST RESULTS

In support of a UVGI standard, it will be necessary to assemble or develop reliable data on the performance of UVGI against microorganisms. Although there have been over a hundred laboratory experiments on the effectiveness of UVGI against viruses, bacteria, and fungi, most of these were performed in water or on surfaces. Tests of airborne disinfection rates suffer from experimental problems, including unrealistic operating conditions, heavy dependence on the test apparatus used, uncontrolled conditions, and sometimes arbitrary interpretation of results. The lack of standardization in laboratory tests on UVGI system has sometimes resulted in contradictory results. It will be necessary to establish laboratory testing guidelines to ensure results that are reproducible and reflect real world conditions. Perhaps a standard test apparatus will have to be designed that operates under controlled air velocity, air temperature, and relative humidity, and that can be used to give accurate, reproducible results for the UV rate constants of microorganisms. Such testing can be performed on the dozens of pathogens and allergens of current interest in indoor air quality and health care applications. The ultimate goal will be the development of a reliable database of airborne and surface UVGI rate constants or dosages necessary for disinfection and/or sterilization.

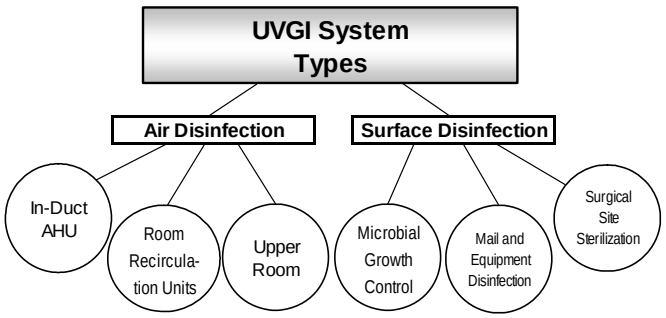

Figure 1: Breakdown of the most common UVGI system types.

Figure 2: Air disinfection system installed above cooling coils to provide simultaneous air and surface disinfection. Photo provided by Immune Building Systems, Inc. of New York.

PERFORMANCE CRITERIA

It is essential to define an acceptable range of performance for UVGI systems for any given application. Air filters are rated by various means, including such as the "minimum efficiency reporting value" (MERV) defined by ASHRAE Standard 52.2 (ASHRAE 1999). The concept of a similar rating system for UVGI air disinfection systems called a UVGI Rating Value (URV) has been previously proposed (Kowalski and Dunn, 2002, Kowalski, 2003). The URV for any given UVGI system is based on the UV dose produced, which is defined as the product of exposure time and irradiance and has units of $\mu J/cm^2$

(or μW-s/cm^2). Table 2 shows the proposed breakdown of UV doses used to define the URV. This breakdown is based on a general review of current installed UVGI systems and is open to revision if necessary. Table 2 also shows a sample of inactivation rates that would be obtained by the indicated URV. Any air disinfection system can be categorized by a URV, and, in fact, when the URV is matched to the MERV rating for the associated filter, a combined MERV/URV system will produce roughly equivalent removal rates for the entire array of pathogens and allergens.

Table 2: UVGI Rating Values and Typical Kill Rates

URV	UV Dose μJ/cm^2	Anthrax Kill, %	Influ-enza Kill, %	Small-pox Kill, %	TB Kill %
1	1	0	0	0	0
2	10	0	1	2	2
3	20	0	2	3	4
4	30	0	3	4	6
5	50	1	6	7	10
6	75	1	9	11	15
7	100	2	11	14	19
8	150	2	16	20	27
9	250	4	26	32	41
10	500	8	45	53	66
11	1000	15	69	78	88
12	1500	22	83	90	96
13	2000	28	91	95	99
14	3000	39	97	99	100
15	4000	49	99	100	100
16	5000	57	100	100	100
17	6000	63	100	100	100
18	8000	74	100	100	100
19	10000	81	100	100	100
20	20000	96	100	100	100
k (cm^2 μJ^{-1})		1.67 x 10^{-4}	1.187 x 10^{-3}	1.1528 x 10^{-3}	2.132 x 10^{-3}

AIR FILTRATION

UVGI air disinfection systems must include air filtration to protect the lamp from dust. Furthermore, fungal and bacterial spores that tend to be resistant to UVGI are often highly filterable and the combination of filtration and UVGI can effectively remove a broad range of airborne microorganisms. Filter specifications therefore form an integral part of the design of any UVGI system.

Fortunately, air filtration guidelines are already in existence and these can simply be referred to in the proposed standard. ANSI/ASHRAE Standard 52.2-1999 addresses methods for testing air-cleaning devices for removal efficiency by particle size, and provides the Minimum Efficiency Reporting Value (MERV) by which production filters are rated.

It is necessary to verify that filters are installed properly and do not leak or bypass air. A small amount of bypass air can result in a great reduction in filter efficiency. At a minimum, filters should be inspected to verify that all seals are tight and no holes or damage exist in the filter media. The next level of verification of filter performance is an in-place filter test. However, the cost of such a test may not always be justifiable, whereas the methods proposed herein for testing and commissioning the overall air treatment system will likely be sufficient to demonstrate the presence or absence of any significant filter bypass.

INSTALLATION AND MAINTENANCE REQUIREMENTS

Guidelines also need to address basic installation requirements, including safety considerations and maintenance. Placement or location of UV lamps, adherence to testing requirements for electrical components such as UL or ETL, the use of safety switches, use of reflective materials, and maintenance requirements can be consolidated from current practices. Often the manufacturers of such air cleaning equipment provide detailed guidance, but consensus minimum standards for installation should be defined to prevent misapplications and sub-standard installations. Safety requirements also impact the handling and disposal of UV lamps, especially those that contain mercury. In some applications, such as in the food industry, unbreakable lamps may be required.

TESTING AND COMMISSIONING

In addition to design and installation requirements, there is what may be the most important aspect of any UVGI application -- testing and commissioning. Protocols for testing and commissioning of UVGI systems need some degree of standardization to define acceptable performance, or at least, to rate the systems on some common scale. Testing and commissioning of UVGI systems is necessary to ensure that any installed system performs as designed. Various types of tests are possible, including verification of rating or UV output, challenge testing, and air sampling of before-and-after ambient airborne concentrations of natural building microflora, as summarized in Table 3.

The techniques and test protocols for air and surface sampling of microorganisms are in common use and various guidelines are available (Aerotech 2001; Vincent 1995; Boss and Day 2001, Jensen and Schafer 1994). These methods will be adapted and standardized for the particular application of air treatment systems in buildings and air handling units.

The criteria of acceptability for air sampling before and after UVGI installation can vary from building to building. The matter is complicated by the fact that no such standards exist for indoor air. For healthy commercial buildings, an acceptable level of fungal spores might be less than 300 cfu/m^3, based on the authors' review of various studies, although levels above 1000 cfu/m^3 are not necessarily harmful (ASHRAE, 2003; Kowalski, 2003). Similar levels may be acceptable for airborne bacteria in occupied buildings.

Table 3: Types of Tests for UV/Filtration Air Treatment Systems

Test	Measured Quantity	Target	Advantage	Disadvantage
Injection of Test Bio-aerosol Upstream	Upstream concentrations vs. downstream of system	Bacteria or Fungal Spores	True indicator of once-through performance	Unlikely to be permitted
Sampling of Natural Ambient Microflora	Upstream concentrations vs. downstream of system	Bacteria or Fungal Spores	Does not introduce any new airborne microbes	Airborne levels will converge to steady state and yield no useful results
	Before vs. After 1-2 weeks of system operation	Bacteria of Fungal spores	Simple	None
Photosensor Readings	Intensity Field	NA	Simple, no air sampling required	Disinfection must be assumed based on readings
Filter Bypass testing	Upstream concentrations vs. downstream of unit	Airborne particles	Guarantees filter performance if no leakage is detected	More costly than a simple visual inspection

The installation of a UVGI or filtration system would be expected to reduce indoor airborne levels below normal levels. Since some buildings may start with high levels and others with low levels, it is difficult to assign a specific criteria of acceptability, and it can only be advised that some significant reduction in airborne levels of both bacteria and fungi would be expected when air treatment systems are put into operation for a few days or weeks. In one hotel room, for example, the fungal spores measured an average of 300 cfu/m^3 during winter when the outdoor air was about 6 cfu/m^3. After retrofitting a UVGI system, levels dropped to about 12 cfu/m^3. These results are shown graphically in Figure 3. Of course, seasonal conditions might produce much higher levels of spores and 300 cfu/m^3 might prove to be an acceptable reduction in summer or fall.

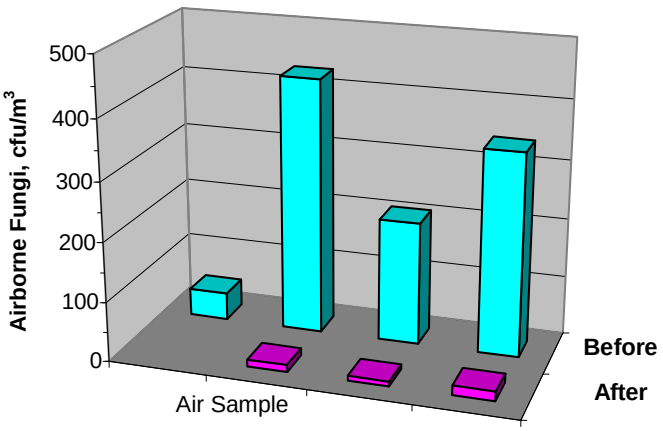

Figure 3: Results of one test on a hotel room with a UVGI system installed in recirculation mode. Levels of airborne fungal spores dropped significantly after two weeks of operation. Air sampling results provided by Immune Building Systems, Inc.

UVGI surface disinfection systems, such as are currently used to disinfect cooling coils, duct, and filters, also need to be standardized and this could be accomplished in the same guideline. Table 4 shows the basic types of testing that could be used for surface disinfection systems. Often, a UVGI system serves the dual purpose of both air and cooling coil or filter surface disinfection and in such cases surface sampling might be used in lieu of air sampling to demonstrate the effectiveness of the UVGI system.

Table 4: Types of tests for Surface Disinfection Systems

Test	Measured Quantity	Target	Advantage	Disadvantage
Surface Sampling	Before vs. After 1-2 weeks of system operation	Fungal spores and/or bacteria	True indicator of performance	Requires sampling expert and lab support
Duct Insulation Sampling	Before vs. After 1-2 weeks of system operation	Fungal spores and/or bacteria	True indicator of performance	Requires lab support
Photosensor readings	Intensity Field	NA	Simple, no sampling required	Disinfection must be assumed based on intensity readings

In the case of surface disinfection, it could be expected that all exposed surfaces would be sterilized after a few days or weeks of UV exposure, and therefore the criteria of acceptability is to have negligible or zero cfu per square inch of sampled surface area. It is often difficult to obtain a zero cfu surface sample, since even the act of sampling may introduce trace levels of bacteria or fungi, so the criteria of acceptability may have to be stated as "approximate sterility." Sterility is a technical term,

defined as six logs of reduction, which, depending on initial conditions, may or may not be possible to prove. That is, if the "before" condition shows 100,000 cfu/in^2. of surface and the "after" condition shows 1 cfu/in^2, this may not absolutely prove that sterility has been achieved but it certainly demonstrates that the system is working. Figure 4 shows one example of an air handling unit for which surface fungal spores had been measured before and after the installation of a UVGI system.

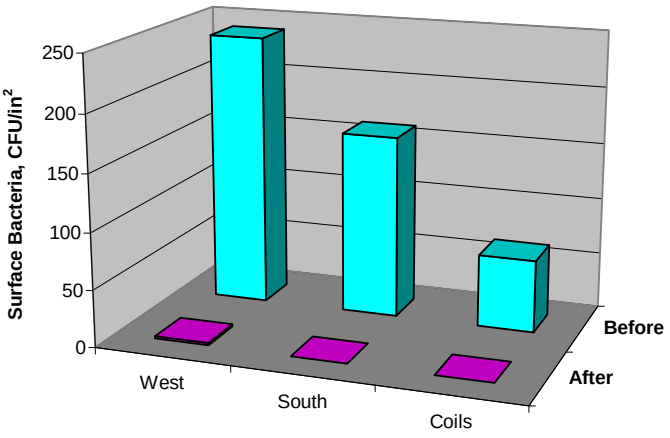

Figure 4: Results of one test on the surface disinfection of internal air handling unit wall surfaces, including the cooling coils. Virtual sterilization was achieved after less than two weeks of operation. Surface sampling results provided by Immune Building Systems, Inc.

BUILDING PROTECTION FACTOR

The effectiveness of any unit, whether in-duct or stand-alone, is limited by the application in which it is placed. The performance of any air treatment system is coupled with the building or facility in which it is placed. Building volume, airflow, building air quality criteria, etc., will define the operating requirements of any air cleaning system, and if the air treatment system is not precisely sized for the application, the performance will be affected by the building characteristics. Although an installed air treatment system may have high rates of microbial removal, its true effectiveness will depend on a combination of system airflow, building volume, degree of air mixing, and other factors. It may be necessary to define an additional rating system for buildings that quantifies the degree to which each building removes airborne pathogens and allergens. Currently, buildings can be classified as normal, healthy, sick, or immune, as shown in Figure 5. Such a classification system could be quantified further to create a "Building Rating Value" (or BRV) that could be used to define the effectiveness of air treatment in a retrofitted building. One such proposed method is the "Building Protection Factor" that is used to define the percentage of occupants protected from a biological agent release in a building (Kowalski, 2003).

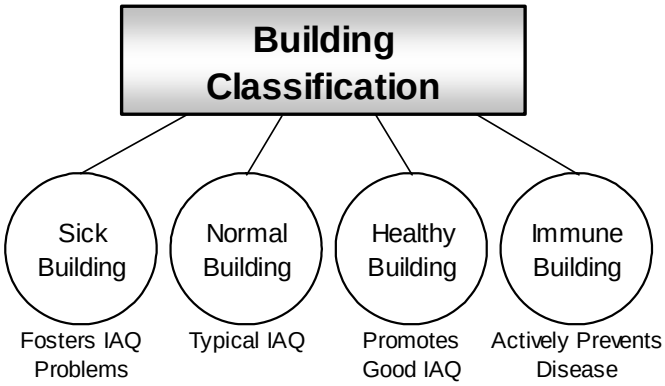

Figure 5: Current classifications often used to describe the degree to which a building protects occupants from airborne microbial hazards.

Defining the air cleaning ability of a whole building, however, may be beyond the intended scope of this proposed standard. At the same time, the in-place testing of an air treatment system may be unavoidable. This aspect of the proposed standard can be revisited once the fundamental components are complete.

SAFETY AND HEALTH REQUIREMENTS

Exposure to UV radiation is hazardous to humans as well as other animals and plants. Guidelines have been established for occupational exposure by NIOSH. Also of concern is the production of potentially hazardous contaminants, such as ozone, for which exposure limits also have been set. Ozone levels are often quite low and can be measured, monitored, or controlled if necessary. Other chemical byproducts due to UV exposure of airborne microbes are possible but this area has not received much conclusive study. Under normal conditions, the quantities of air borne microbes have such a vanishingly small mass that their potential byproducts are unlikely to produce levels that approach a TLV or PEL. This is an area, however, that may require further research.

UV lamps that are breakable may not be suitable for every application (i.e., the food industry). UV lamps that contain mercury may require special handling and disposal. Most of these subjects are adequately addressed in other guidelines and standards and these can be referenced for further information or reiterated in the current proposed standard.

CONCLUSIONS

The development of an international standard for the performance and testing of UVGI systems is a daunting challenge that encompasses many fields and has such a broad scope that it will require the cooperation of many academic and industrial leaders in the UVGI industry, microbiology, and other relevant fields. Since the demand for air treatment systems has outstripped the available knowledge base, it is essential that such a standard be developed as quickly as is practical, especially in light of recently accelerated concerns about bioterrorism. The Ultraviolet Air Treatment Topical Group of the International Ultraviolet Association has brought together many of the major players in academia and industry, and we hope that this will lead to a significant change in the current

philosophy of building science -- the widespread adoption of air treatment in building design. The corresponding reduction in the transmission of indoor airborne diseases that would surely result would be a major first step towards the possible future eradication of the many respiratory diseases that currently threaten mankind around the globe.

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