STANDARD AND GUIDELINE REQUIREMENTS FOR UVGI AIR TREATMENT SYSTEMS

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ABSTRACT

Ultraviolet Germicidal Irradiation (UVGI) systems for air disinfection are coming into increasing use for indoor air quality, disease control, and biodefense applications. However, there are currently no consensus standards for the design, application, or testing of UVGI systems. Several agencies are currently investigating development of guidelines, including the U.S. National Institute of Occupational Safety and Health (NIOSH), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), American Refrigeration Institute (ARI), and the International Ultraviolet Association (IUVA). Such documents will ultimately provide a basis for the development of consensus standards that will support the rapid adoption and advancement of UVGI technology. This paper reviews the requirements for guidelines and standards needed to ensure successful UVGI applications as proposed by IUVA.

INDEX TERMS

Ultraviolet germicidal irradiation, air disinfection, standards and guidelines

INTRODUCTION

The ability of germicidal ultraviolet radiation (225-302 nm) to disinfect air has been known for more than 60 years (Sharp 1939). Since that time, the use of ultraviolet germicidal irradiation (UVGI) for air treatment has experienced sporadic growth in use and limited acceptance. More recently, increased concern for the quality of indoor environments under a variety of circumstances has created renewed interest in UVGI, both as a research topic and as a technology for application in buildings. Possible applications of UVGI include medical facilities where transmission of contagious diseases between patients and staff is a constant concern; for defense against biological weapons attacks, and for general improvement of indoor air quality in all types of buildings.

The penetration of UVGI into these important application areas is currently impeded both by a lack of conclusive field data to demonstrate successful performance and by the lack of guidance and standards that designers can apply with confidence. In both areas, progress is being made, but much remains to be done. A recent study (Menzies, et al. 2003) reported a statistically significant reduction in microbial and endotoxin concentrations on irradiated surfaces of ventilation systems and reduction of respiratory and other symptoms in an office building. VanOsdell and Foarde (2002) demonstrated reproducible deactivation of airborne vegetative bacteria, bacteria spores, and fungal spores in laboratory tests under a variety of conditions. Their work also developed the only currently published protocol for testing UVGI lamp performance. Progress has also been made in the application of analytical methods to the design of ducted UVGI systems (Kowalski and Bahnfleth 2000a, 2000b, Kowalski, et al. 2000).

Despite these promising developments, there is no consensus guidance on the design, installation, commissioning and certification of UVGI systems. Those currently applying it rely on a variety of sources including manufacturers literature, peer reviewed publications, and handbooks. At present, the most well-developed areas of standards related to the application of UVGI are the rating of lamps (IESNA 2000; CIE 2003), electrical safety (certifiable by any of several laboratories), and safe human exposure limits (NIOSH 1972; ACGIH 1991; AIHA 2001; IRPA 1985; NEHC 1992). Lack of widely accepted standards based on credible scientific evidence and practical experience remains one of the most significant barriers to increased use of UVGI in applications for which it is appropriate.

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This paper outlines the content of a group of draft guidelines and standards under development by the International Ultraviolet Association (IUVA), an organization comprised of manufacturers, researchers, designers, and others interested in all aspects of the application of ultraviolet radiation. Thirteen separate, but related documents are proposed, of which six have been issued as internal drafts. Together, these documents comprehensively cover performance data and procedures required for design, installation, testing, and commissioning of UVGI systems, drawing on existing knowledge. The currently planned list of guidelines and standards and their status as of May 30, 2005 is as follows:

- IUVA-G01A: General Guideline for UVGI Air and Surface Disinfection Systems (draft under internal IUVA review)
- IUVA-G02A: Guideline for Design and Installation of UVGI Air Disinfection Systems in New Building Construction (draft under internal IUVA review)
- IUVA-G03A: Guideline for Design and Installation of UVGI In-Duct Air Disinfection Systems (draft under internal IUVA review)
- IUVA-G04A: Guideline for the Design and Installation of UVGI Cooling Coil Surface Disinfection Systems (first draft pending)
- IUVA-G05A: Guideline for the Design and Installation of UVGI Unitary Recirculation Air Disinfection Systems (first draft pending)
- IUVA-S01A: Standard for the Testing and Commissioning of UVGI In-Duct Air Treatment Systems (draft under internal IUVA review)
- IUVA-S02A: Standard for the Testing and Commissioning of UVGI Cooling Coil Disinfection Systems (first draft pending)
- IUVA-S03A: Standard for the Testing and Commissioning of UVGI Unitary Recirculation Unit Systems (first draft pending)
- IUVA-S04A: Standard for the Testing and Commissioning of Upper Room UVGI Systems (first draft pending)
- IUVA-S05A: Standard for the Testing of UVGI Surface Disinfection Systems (first draft pending)
- IUVA-S06A: Standard for Laboratory Testing of UVGI Air and Surface Rate Constants (draft under internal IUVA review)
- IUVA-S07A: Standard for the Evaluation and Testing of Building Protection Factors (draft under internal IUVA review)
- IUVA-S08A: Standard for Epidemiological Testing of Air Treatment Systems (first draft pending)

The final form and use of these documents remains to be determined, but the process of development, itself, should contribute to the formulation of consensus and the identification of areas in which more research is needed. It is expected that all will exist as first drafts by the end of 2005 and issued for first public review during 2005 and 2006. The purpose of this paper is primarily to indicate important issues that are being, or need to be addressed in the IUVA drafts rather than to summarize specific recommendations, which may be modified prior to issuance of final forms of these documents.

CLASSIFICATION OF SYSTEMS

Although it is common to refer to UVGI without qualification as to system type, there are several unique types that need to be considered in standards. The draft IUVA documents identify eleven distinct system types ranging from in-duct air disinfection for HVAC application, to upper air single-room systems, to surgical site surface disinfection. While there are certain common issues in the application of such systems, such as lamp performance and safety, the information and methods needed to design each type will be quite different. The most common types of systems (in no particular order) are in-duct and cooling coil disinfection systems in HVAC applications, standalone recirculating units such as may be found in hospital isolation rooms, and upper air systems. For both in-duct and coil disinfection systems, one of the key needs is an accurate calculation of UV dose, which depends mainly on the radiation field in the device. For both standalone recirculating and upper air systems, the air flow patterns in the space served are also critical, as they determine how effectively contaminated air is brought into the zone of action of the device. The IUVA guidelines will address systems other than upper air systems, which are

covered by guidance under development by the U.S. National Institutes of Occupational Safety and Health, but IUVA intends to develop a standard for testing and commissioning such systems.

DESIGN AND INSTALLATION

Any design procedure requires the definition of a performance goal and the calculation of the component capacities and system parameter values required to meet it. In the case of a UVGI system, the goal will most likely be measured as a fractional reduction in surface or airborne microbial contamination, or reduction to a specific level, or perhaps in terms of infections. In order to conduct this analysis, a significant amount of data must be available, the specific items varying with the type of system.

Lamp rating data is fundamental and should include the effects of temperature, air speed, and aging. Lamp output derates significantly (typically by 10 – 20 percent relative to initial output) over time, and output may vary by a factor of two as a result of thermal effects. The testing of the lamps themselves is the subject of an ASHRAE proposed standard that has just begun development. In systems of all types, the irradiance field produced by a lamp of known characteristics must also be determined. Simple point and line source models have seen widespread use, but view factor methods may be a more powerful and accurate approach, particularly for systems with diffusely reflective surfaces. In-duct, coil irradiation, and standalone recirculating device performance may be strongly enhanced by reflectivity, so the ability to account for enclosure reflectivity is also needed.

Once the UV radiation field has been established a variety of application-specific considerations must be addressed. For in-duct and other HVAC applications, the placement of the unit in the system as a whole will affect how well it can function. Thus, multizone airflow and contaminant dispersion modeling or an equivalent analysis is required. Such modeling is currently rare in the design process, so guidance on the development of models and design scenarios is a key need. In order to design a system properly, the designer must employ assumptions and scenarios that are relevant to the application, both in terms of the characteristics of the treated microbe(s) and their sources (e.g., localized, distributed, short term, indigenous).

Two types of dose response information are needed for design and the body of reliable data for neither is in great supply. The first is the dose response of the microorganisms of concern to UV radiation under the conditions of exposure. The second is the inhalation dose response. The human dose response is needed to determine acceptable levels of the microorganism and the microorganism dose response is needed in order to determine the capacity of the UVGI system required to meet that target.

A further factor that should be considered in design of all UVGI systems is air filtration. Filtration can serve two distinct and essential functions. One is to maintain lamp cleanliness to reduction of effectiveness over time due to fouling. The other is the use of filtration to complement UVGI performance. The microorganisms most effectively treatable by UVGI tend to be of a size that requires high-efficiency filtration while many microorganisms that are resistant to UVGI are of a size that can be filtered with relative ease. Therefore, guidance for selecting UVGI and filtration as a system to maximize performance across a wider spectrum of microorganism size is incorporated in the draft standard.

A rating method for both components and systems that could be useful for design is also proposed in the draft standards. At the level of components, a UVGI rating value (URV) is proposed in terms of levels of dose delivered by a device. This concept is intended to be analogous to the MERV filter performance metric defined by ASHRAE Standard 52.2 (ASHRAE 1999). At the system level, a building protection factor (BPF) is proposed to characterize the performance of the air treatment system in each particular building. Both concepts are new and their definitions are likely to be the subject of discussion and revision for some time.

TESTING AND COMMISSIONING

The draft IUVA testing and commissioning standards define requirements for rating systems and verifying performance.

Measurement if irradiance can be used to verify installed lamp ratings or performance, check for UV leakage at the time of manufacture and as-installed, verify irradiance levels on cooling coil surfaces, and verify the safety of upper room UVGI systems. Broad range UV photosensors are needed instead of narrow band UVC sensors since most lamps are of the broad range type.

Surface sampling of cooling coils is required to demonstrate the efficacy of cooling coil irradiation systems. Air sampling is advisable for buildings in which air treatment systems are retrofit. Air should be sampled before the system is placed in operation and again about two weeks after the system has begun operation.

Criteria for acceptable reductions in airborne levels of bacteria and fungi after the retrofit of an air cleaning system in a building have been suggested but are a matter for which the accumulation of field data will be helpful. It is expected that achievable reductions in airborne levels may vary from 50-90%. Absolute criteria for acceptable levels of indoor bacteria and fungi have not been established but various sources have suggested indoor fungi levels should not exceed about 100-500 cfu/m^3. For bacteria, indoor limits of about 500-1000 cfu/m^3 in occupied buildings have been suggested. The ratio of indoor fungi to outdoor fungi is also a potential criterion and typical values for healthy buildings are about 10-15%.

Epidemiological studies on the health benefits of air treatment are few in number and limited in quality. Institutional buildings such as schools and hospitals maintain records of before and after respiratory illnesses and absences in order to accumulate data on the potential effects of air treatment on the spread of diseases and occurrence of allergies. Such data would be useful both for establishing the capacity of air treatment to prevent epidemics and to save lost work time due to illness. One of the draft IUVA standards will address collection of such data.

CONCLUSIONS

Decades of research and application have shown that UVGI systems can reduce the risk of infection by airborne microorganisms in a variety of applications including room air cleaning, cooling coil and condensate pan protection, and surgical site disinfection. Slow market penetration of UVGI is due in part to the lack of consensus standards for design and testing. The former is needed in order to optimize performance so that UVGI systems are as economical as possible and complement other modes of air treatment. The latter is required in order to prove performance and ensure reliability. The effort undertaken by IUVA to develop draft guidance may result in documents issued by that organization or contribute to standards writing efforts by other organizations such as ASHRAE. Although it is possible to outline the guidance needed for UVGI application, the level of knowledge is not satisfactory in all areas. In particular, additional experimental research to confirm the validity of analytically based design methods and epidemiological studies to validate expected effects on health are needed.

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