

IUVA Draft Guideline IUVA-G02A-2005 International Ultraviolet Association

Guideline for Design and Installation of UVGI Air Disinfection
Systems in New Building Construction

Copyright 2005 International Ultraviolet Association

Prepared by the UV Air Treatment Steering Committee
A Subcommittee of the Topical Group of the International Ultraviolet Association
P.O. Box 1110, Ayr ON, Canada N0B 1E0
Tel: 619-632-8190, Fax: 519-632-9827

UV Air Treatment Steering Committee

Wladyslaw J. Kowalski Subcommittee Chair, The Pennsylvania State University
William Bahnfleth, The Pennsylvania State University
Charley Dunn, Lumalier
Brad Hollander, UVCM
Dave Witham, Ultraviolet Devices, Inc.
Sam Speer, Catalyx Technologies
Steve Guzorek, Field Controls Co.
Mary E. Clancy, Environmental Dynamics Inc.
Bob Levin, OSRAM Sylvania

International Ultraviolet Association

UV Air Treatment Board and Officers

Ed Nardell, Harvard School of Public Health, Chair

Louise Fletcher, University of Leeds, Vice-Chair

John M. Putnam, Vice-Chair

Bob Scheir, Steril-Aire, USA Inc.

Mary E. Clancy, Environmental Dynamics Inc.

Marc A. Deshusses, University of California

Charley Dunn, Lumalier

Scott Faland, Johnson Controls

Bill Fowler, Ultravation, Inc.

Henk Giller, Philips Lighting

Steve Guzorek, Field Controls Co.

Brad Hollander, UVCN

Timothy J. Leach, FP Technologies, Inc.

Sam Speer, Catalyx Technologies

Nick Velandar, Peterson Air Purifiers LLC

Dave Witham, Ultraviolet Devices, Inc.

Wladyslaw J. Kowalski, The Pennsylvania State University

Ex Officio

Jim Bolton, IUVA Executive Director

NOTE: The International Ultraviolet Association (IUVA) Draft Guidelines for UVGI Air Treatment Systems are international voluntary consensus guidelines developed under the auspices of the IUVA. This consensus represents a substantial agreement reached by parties in Academia and Industry with direct or indirect interests in air treatment with UVGI and related technologies. This consensus signifies concurrence of the majority of the individuals, organizations, and businesses involved in the drafting of this guideline but does not necessarily represent a unanimous opinion and the contents are subject to continual review, expansion, and revision. Compliance with this guideline is voluntary. Consensus is obtained by review of IUVA members and input from various agencies, professional societies, and the public.

This guideline does not supersede nor invalidate any local or governmental standards or the requirements of responsible authorities and the applicable documents should be consulted and adhered to where applicable. Relevant federal and professional guidelines and standards have been identified in the Bibliography and these should be consulted for further information.

The IUVA Chair should be contacted for participation in the development and review process of subsequent revisions, or in regards to interpretation, constructive criticism, and permission to reprint portions of the guideline. This document is being released to the public in the current draft form for review and comment for a period of approximately one year. Comments may be sent to drkowalski@psu.edu.

IUVA does not advocate the use of any particular manufacturer's equipment or services and the use of specific equipment in the tables and figures should not be construed as such. It is impermissible for vendors to use any part of this document to imply product preferences.

DISCLAIMER: The International Ultraviolet Association has developed and promulgated this guideline for the benefit of the public and private sectors based on the best available information and technology and accepted industry practices. IUVA cannot guarantee that installation, operation, maintenance, or testing of the systems specified herein will be nonhazardous or without risk.

TABLE OF CONTENTS

1.0 Introduction.....	4
1.1 Purpose and Scope	4
2.0 Guidelines for New Building Construction	5
2.1 Outside Air Flowrates	5
2.2 Air Filtration	6
2.3 In-Duct UVGI Air Treatment	8
2.4 Recirculation Air Treatment	9
2.5 Cooling Coil Disinfection Systems	10
2.6 Buffer Zones	11
2.7 Aerobiological Performance Indices	13
2.8 Summary of New Building Construction Guidelines	15
3.0 References & Bibliography.....	16
Appendix A: Checklist for Air Treatment Systems.....	19

1.0 Introduction

Ultraviolet germicidal irradiation (UVGI) systems are used for air and surface disinfection. This document is one of a series of guidelines and standards issued by IUVA to foster the development of effective and reliable air treatment systems intended to control or improve the aerobiological quality of indoor environments.

1.1 Purpose & Scope

This guideline has been developed in response to industry-wide need and is written to assist the installation and testing of in-duct air treatment systems, specifically those based on ultraviolet disinfection technologies, in new building construction projects. This subject, new building construction, is treated separately due to the fact that it is simpler and more cost-effective to design air treatment systems for new buildings than to retrofit them in existing buildings. For information on retrofitting existing buildings see IUVA-G03A-2006, "Guideline for Design and Installation of UVGI In-Duct Air Disinfection Systems."

The primary purpose of air treatment systems for buildings is to reduce the incidence of respiratory and other diseases. These include epidemic contagious airborne diseases (i.e. influenza, SARS virus, etc.), non-contagious infectious diseases (i.e. fungal infections), allergens (i.e. pollen and fungal spores), and respiratory irritants. A secondary purpose of air treatment systems is the protection of occupants against potential bioterrorism. Because the risk of a bioterrorist attack is almost infinitesimal in comparison with the risks of naturally occurring epidemics, biodefense is not the focus of this document. However, any systems designed to protect against naturally occurring biological agents will also be effective against intentional releases and therefore this document can be considered to implicitly encompass hypothetical bioterrorism threats as well as the real and daily hazards of airborne pathogens and allergens.

This document is intended for typical commercial office buildings and other multi-story facilities. It is not intended to apply to single-unit residential housing and does not necessarily apply to health care facilities, for which other guidelines will be issued at a later date.

NOTE: This draft guideline is issued to IUVA members and associates for comments as of March 24, 2006. The current contents are incomplete and do not necessarily represent any consensus viewpoints and it is not to be released to non-members without IUVA permission. Upon completion of the review and comment process the subcommittee will issue a draft of this guideline for public comment. Comments are due by 5-10-2006 and should be sent to drkowalski@psu.edu.

2.0 Guidelines for New Building Construction

It is the recommendation of this standard that all new building construction make allowances for the inclusion of air treatment systems, either by designing in an air treatment system or by designing in the option of adding an air treatment system later. The performance of air treatment systems is so critically linked to the whole building ventilation system that the most ideal systems are those that are integrated into the design prior to construction. To this end, the following section describes principles and practices that can enhance the ability of a building to cleanse itself of biocontaminants more efficiently than can a system retrofitted to existing buildings.

2.1 Outside Air Flowrates

The quantity of outside air in any building ventilation system plays a major role in the purging of indoor airborne microbes. Typically, outside air comprises between 15-25% of the total airflow through modern building ventilation systems. Increasing outside air flowrates where climate permits is one approach to improving indoor microbial IAQ. In cold or hot climates, increased outside air in combination with economizer cycles and heat recovery can also be used to reduce the energy costs.

In accordance with ASHRAE Standard 62-2001, "Ventilation for Acceptable indoor Air Quality," it is recommended that indoor environments provide 20 cfm of fresh air per occupant and a minimum of 15% outside air overall or otherwise conform to ASHRAE recommendations (ASHRAE 1999 & 2001). Outside air flowrates above the 15% minimum will improve building aerobiological performance albeit at some energy cost.

2.2 Air Filtration

New buildings should include high-efficiency filtration for the purposes of air treatment. Allowance should be made in the design such that the fan can accept the pressure loss associated with a high efficiency filter.

The outdoor air should be filtered to remove environmental fungal spores, environmental bacteria, pollen, and dust. It is somewhat less critical to irradiate outside air with UV since UV is more effective against microbes that hail from human sources indoors. It is therefore recommended that outside air be filtered with at least a MERV 6-8 filter to remove pollen, spores, and environmental bacteria.

For recirculated or return air, it is recommended that a filter in the range of MERV 11-15 be included in the design of every recirculating system for new building construction. The preferred location is inside the air handling units, but filters may also be located in the return or supply air ductwork. If a UVGI system is present, filters should be located upstream of the UV lamps in order to keep them free of dust accumulation and thereby maintain high output. Figure 2.1 illustrates the recommended locations and sizes of the air filters to be used in new building projects.

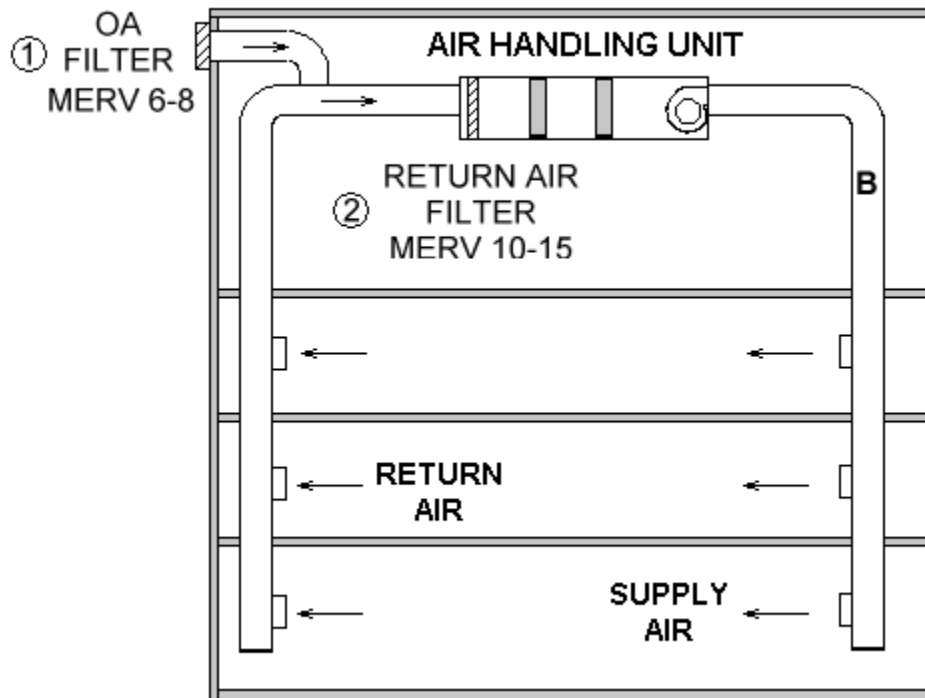


Figure 2.1: Recommended locations and sizes of outside air (1) and return air filters (2).

Space must be provided for filter banks (typically for 4-12 in thick filters) in the air handling units if such is not already provided by the equipment manufacturer. Alternatively, filters may be installed in the duct upstream of downstream of the

air handling units. Air handling units or ductwork should be provided with sufficient space to accept filter frames for filters of at least 2-4" thickness. Frames need to be of a type that can provide good seals such that filter bypass is minimized or eliminated.

Filter air velocity should be a maximum of 500 fpm to assure design performance. Filters operating above this velocity should correct any performance predictions for the reduced filter efficiency at above design velocities (Kowalski et al 1999, Kowalski and Bahnfleth 2002, Kowalski 2003).

Figure 2.2 shows examples of the predicted performance of MERV rated filters. These are nominal performance curves and manufacturers should be consulted for performance data on specific filter models, regardless of the stated MERV rating.

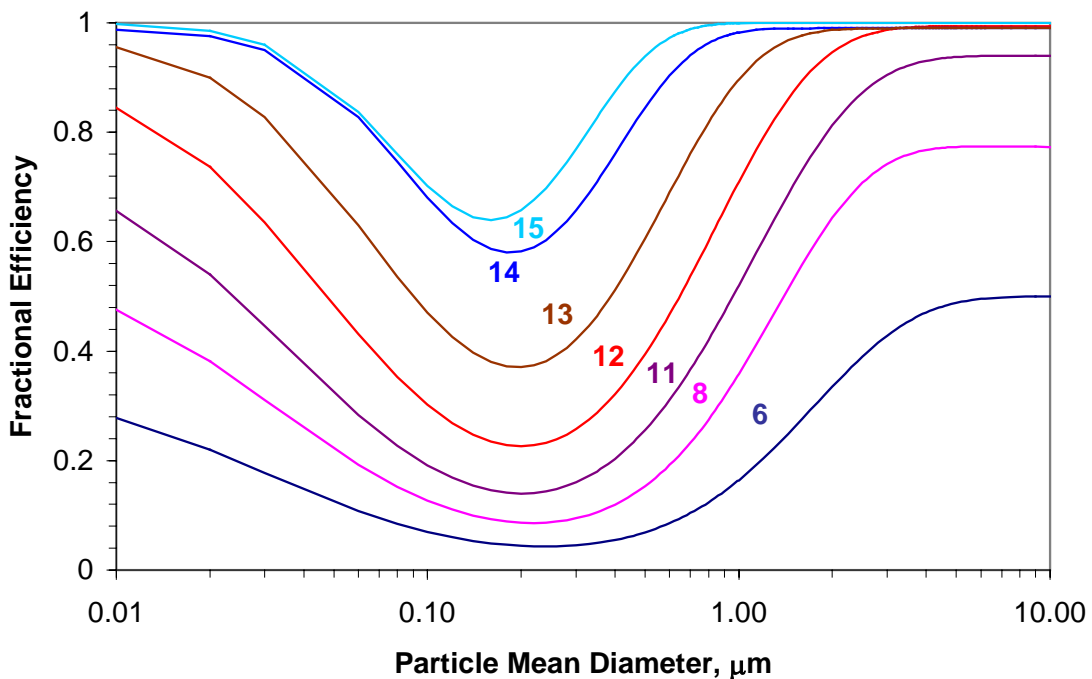


Figure 2.2: Predicted performance curves for a range of MERV rated filters.

During construction many contaminants are produced and aerosolized and these may include dust, allergens, and fungal spores. As a result it is prudent to change out any installed filters immediately after construction is completed and before the building is occupied.

2.3 In-duct UVGI Air Treatment

It is recommended that all new building construction either include some form of air treatment, or make allowance in the design for later additions of air treatment systems. Space should be provided in each and every air handling unit such that an effective UVGI system can be installed or retrofitted. It is recommended that at least 2 feet, and preferable 4 feet, of space be provided either downstream of the filters, or upstream and downstream of the cooling coils (but avoiding the downstream heating coil area). Furthermore, it is necessary that the design air velocity inside the air handling unit be maintained within the limits 400-500 fpm or as close to these limits as is feasible. It is also essential that filters be provided upstream of the UVGI lamps, as discussed in the previous section. Figure 2.3 illustrates the space that should be provided around the cooling coils in an air handling unit and the preferred locations of a UVGI system and air filters. Alternate locations for UVGI systems may exist in the supply or return ductwork or in air mixing plenums.

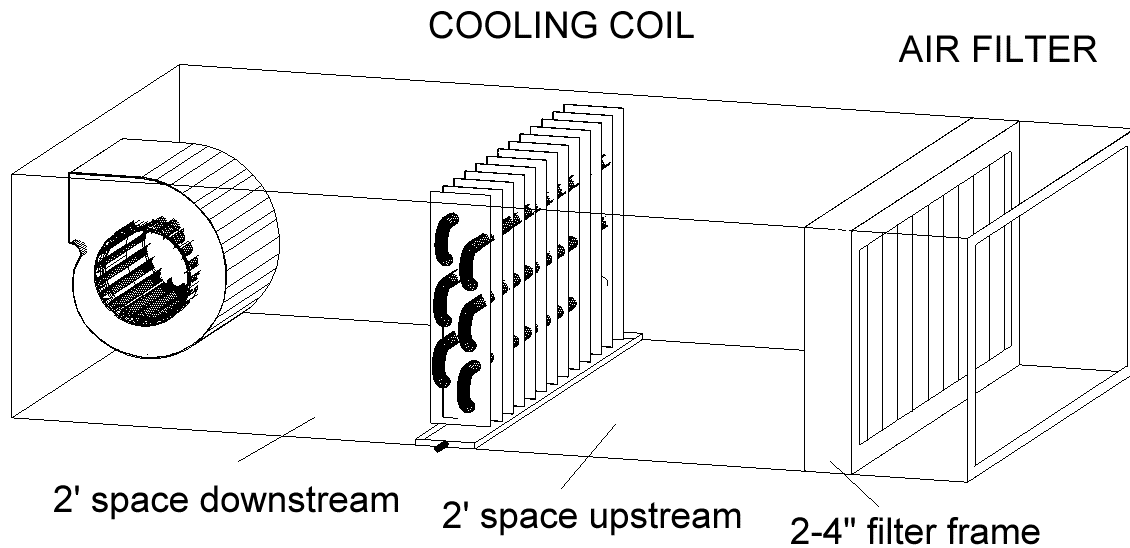


Figure 2.3: Air handling units should provide for a minimum of 2 feet of space upstream and downstream of the cooling coils for UVGI placement. Air filter frames should allow for 2-4" filters upstream of the UVGI location.

It is recommended that UVGI air treatment systems be designed in the URV 11-15 range. For an explanation of URV ratings see IUVA-G01A-2005, "General Guideline for UVGI Air and Surface Disinfection Systems." For further details on UVGI system design and installation, refer to IUVA-G03A-2005, "Guideline for Design and Installation of UVGI In-Duct Air Disinfection Systems." For details on testing and commissioning, refer to IUVA-S01A-2005, "Standard for the Testing and Commissioning of UVGI In-Duct Air Treatment Systems."

A checklist for air treatment systems has been provided in Appendix A.

2.4 Recirculation Air Treatment

In areas of new buildings that cannot be served by the central air handling unit (and any integral air treatment system), it is suggested that local recirculation UVGI systems be installed. For new building construction in which recirculation UVGI units are being installed, it is recommended that the units have between 1-6 ACH. The unit airflow, therefore, will dictate the size (volume) of the room to which it can be added. Otherwise the manufacturer should be consulted for sizing assistance. For details on designing and installing recirculation air treatment systems see IUVA-G05A-2005, "Guideline for the Design and Installation of UVGI Unitary Recirculation Air Disinfection Systems." For details on testing and commissioning, refer to IUVA-S03A-2005, "Standard for the Testing and Commissioning of UVGI Unitary Recirculation Unit Systems."

2.5 Cooling Coil Disinfection Systems

Cooling coil disinfection systems are recommended in new buildings due to both the cost savings that accrue from maintaining design performance, reduced maintenance, and the potential health benefits to occupants from the reduction of microbial loading on cooling coils and other air handling unit surfaces. For new building construction it is recommended that corrugated coil fins not be used as these tend to inhibit penetration of UV rays. Similarly, the closer the fin spacing, the less penetration will occur and it is suggested that cooling coil fins be limited to 8-12 fins per inch. In addition, space should be provided both upstream and downstream of the cooling coils if possible, so as to facilitate irradiation of the coils from both sides. Cooling coil disinfection systems can be combined with air disinfection systems.

For performance requirements of cooling coil disinfection systems see IUVA-G04A-2005, "Guideline for the Design and Installation of UVGI Cooling Coil Surface Disinfection Systems." For testing requirements see IUVA-S02A-2005, "Standard for the Testing and Commissioning of UVGI Cooling Coil Disinfection Systems."

2.6 Buffer Zones

One approach to enhancing protection of building occupants against outside air contaminants that does not necessarily entail considerable expenditure is to isolate the first floor or lobby of a commercial building by placing it on a separate ventilation system with air treatment. Isolation or pressurization of the lobby creates a barrier or buffer zone between the building and the outside air, and between the lobby and the upper floors, which will both protect occupants in the event of a release and facilitate evacuation. The buffer zone ventilation system should incorporate high airflow and a high air exchange rate coupled with an effective air treatment system such that even a release within the buffer zone will be rapidly purged and disinfected. In addition to biodefense, such designs will aid in minimizing the entry of common environmental biocontaminants. Many buildings today either place the lobby on a separate ventilation system or pressurize the lobby to prevent influx of outdoor air. It is suggested, but not required by this document, that new building construction consider implementing buffer zones since they can be designed in with little additional cost. Figure 2.4 illustrates the concept of a buffer zone in a commercial office building.

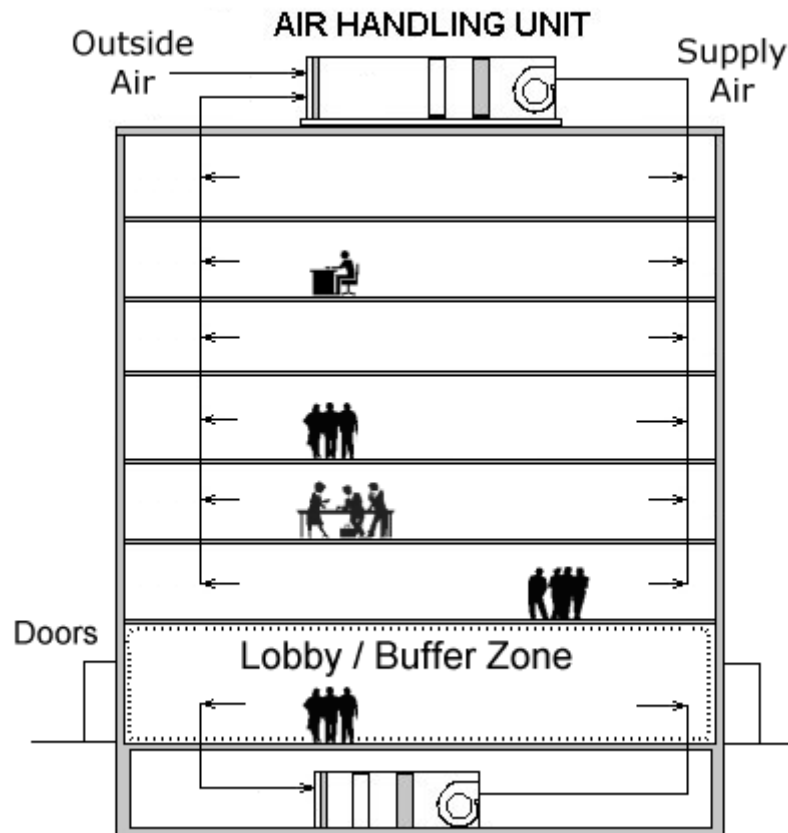


Figure 2.4: A lobby with a separate ventilation system and air treatment can be used as a buffer zone, a sheltering zone, and a safe evacuation route.

The basic attributes of a buffer zone include a first floor with reasonably airtight barriers with respect to all surrounding zones and to the outdoors. The ventilation system should be sized to deliver at least 2-4 times the airflow and so approach about 6 ACH. This flowrate, coupled with an integral UVGI/filtration air treatment systems, will provide high rates of air disinfection. It is recommended that the UVGI system be rated URV 13-15 and that the filters be rated MERV 13-15.

This document does not specifically require the incorporation of a buffer zone in new building construction but provides this information as an option for enhancing the protection of building occupants against biocontaminants that may enter through the lobby, including pollen, spores, and pollutants.

2.7 Aerobiological Performance Indices

Ideally, new buildings will be designed to provide the cleanest air possible with the minimal add-on cost of construction. The airborne levels of bioaerosols would be sufficiently low that atopic individuals and asthmatics would not experience undue respiratory distress during pollen season or any other time of the year, and that the incidence of airborne infections due to colds, flus, and other airborne diseases would be lower than the average for similar older buildings. The exact levels of airborne bacteria, fungal spores, and pollen that would achieve such results are not certain, but some proposed limits have been summarized by researchers in various publications and numerous studies have evaluated “normal” levels of bioaerosols (ACGIH 1973, 1989 & 1991, EPD 1999, Bourdillon et al 1948, AIHA 1989, CEC 1994, CMHC 1991, IAQA 1995, EPA 1995, Reynolds et al 2001, Gallup et al 1993, Rao and Burge 1996, Kowalski 2006). The proposed limits in these referenced documents are summarized in Table 2.1 as proposed targets for new building construction air quality. These limits do not represent criteria for health hazards nor should they be considered to apply in general to any other types of buildings. They merely represent an appropriate target for designers since some air treatment design goal must be defined. It remains to be seen whether these design goals are feasible and whether or not they will produce the desired result – reduction of respiratory symptoms and infections. Table 2.1 should in no way be construed to represent indoor limits for bioaerosols, the responsibility for which belongs to the various agencies and organizations involved in assessing such risks (i.e. EPA, OSHA, ACGIH, AIHA, etc.) and these organizations should be consulted for more specific information on indoor limits of airborne bioaerosols.

Table 2.1: Suggested Indoor Performance Goals for New Buildings

Airborne Bacteria	cfu/m ³	500
Airborne Fungal Spores	cfu/m ³	150
Indoor/Outdoor (I/O) Ratio	subject to above levels	0.1
Airborne Pollen	gr/m ³	10

Note: These recommendations do not supersede those for any specific applications.

For further information on measuring indoor bioaerosol levels and evaluating in-duct air treatment system performance refer to IUVA-S01A-2005, “Guideline for the Testing and Commissioning of UVGI In-Duct Air Treatment Systems.”

The Building Protection Factor (BPF) is an index that estimates the percentage of occupants protected against any biological agents whether they are naturally occurring or otherwise. It is suggested that new buildings be designed to provide a minimum 50% BPF and that they preferably provide a BPF in the range 80-95%. For information on estimating the BPF of any building, and for information on other aerobiological performance indices, refer to IUVA-S07A-

2005, "Standard for the Evaluation and Testing of Building Aerobiological Performance Indices." Detailed methods for evaluating and testing for BPFs are also provided in this standard.

2.8 Summary of New Building Construction Air Treatment Guidelines

Table 2.2 provides a summary of the previous recommendations for new building construction. Most of these criteria are amenable to absolute determination through field testing or otherwise. Verification of the URV may depend primarily on analysis, or on lab testing of components. The BPF can only be established through analysis based on design parameters or via analysis based on testing results. The guidelines are subject to change as new information and operational experience develops. A checklist of items has been provided in Appendix A to assist designers in addressing critical points of new building construction that relate to air treatment systems.

Table 2.2: Guidelines for New Building Construction

Outside Air	should meet ASHRAE 62.1 minimum standards
	minimum 15% outside air
	20 cfm outside air per person
OA Filtration	1st filter: dust filter or coarse prefilter
	2nd filter: MERV 6-8 for pollen and spore control
Return Air Filtration	1st filter optional if OA filtered
	final filter: MERV 10-15 for pathogen control
	use UV-proof filters if exposed to UVGI
	face velocity 500 fpm
	filter frame must be airtight to prevent bypass
	filter frames should provide 2-4" for filters
UV Air Treatment	inclusion or allowance provided
	provide URV 10-15 system
	provide 2 feet space minimum both sides of coils
	provide minimum 4 feet total travel distance
	air velocity 600 fpm max
provide MERV 8-15 filters upstream of UV	
UV Coil Treatment	inclusion recommended
	aluminum fins recommended
Materials	materials used in vicinity of UV systems should be UV-proof or UV-resistant, including wiring, gaskets, grommets, insulation, etc.
Building Protection Factor	minimum 50% BPF

3.0 References & Bibliography

- ACGIH (1973). *Threshold Limit Values of Physical Agents*. The American Conference of Government Industrial Hygienists, Cincinnati.
- ACGIH (1989). *Guidelines for the Assessment of Bioaerosols in the Indoor Environment*. American Conference of Government Industrial Hygienists, Cincinnati.
- ACGIH (1991). "Threshold Limit Values and Biological Exposure Indices for 1991-1992." American Conference of Governmental Industrial Hygienists. Cincinnati, OH.
- AIHA (1989). "The Practitioner's Approach to Indoor Air Quality Investigations." *Indoor Air Quality International Symposium*, Fairfax, VA 43-66.
- ASHRAE (1992). *Chapter 25: Air Cleaners for Particulate Contaminants*. HVAC Systems and Equipment, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.
- ASHRAE (1999). "Standard 62-1999: Ventilation for acceptable indoor air quality." American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, GA.
- ASHRAE (1999). "Standard 90.1-1999: Energy Standard for Building Except Low-Rise Residential Building." American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta.
- ASHRAE (1999a). "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.
- ASHRAE (2001). "Standard 62-2001: Ventilation for acceptable indoor air quality." American Society of Heating Refrigerating and Air-Conditioning Engineers. Atlanta, GA.
- ASHRAE (2003). *HVAC Design Manual for Hospitals and Clinics*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.
- Bourdillon, R. B., Lidwell, O. M., Lovelock, J. E., and Raymond, W. F. (1948). "Airborne bacteria found in factories and other places: Suggested limits of bacterial contamination." *Special Report Series No. 262* Medical Research Council. London.
- Burroughs, H. E. (1997). "Filtration: An investment in IAQ." *HPAC* 69(8):55-65.
- Burroughs, H. E. B. (1998). "Improved filtration in residential environments." *ASHRAE J* 40(6):47-51.
- CEC (1994). "Biological Particles in Indoor Environments." 12 Commission of the European Communities. Luxembourg.
- CMHC (1991). *Testing of Older Houses for Microbiological Pollutants*. I. Bowser Technical Canadian Mortgage and Housing Corp., Ottawa, Canada.
- EPA (1995). "Inside IAQ: EPA's Indoor Air Quality Research Update." *EPA/600/N-95/007* Environmental Protection Agency <http://www.epa.gov/appcdwww/iemb/insideiaq/fw95.pdf>.
- EPD (1999). "Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places." Indoor Air Quality Management Group, The Hong Kong Government of Special Administrative Region, Environmental Protection Department. Hong Kong.
- FEMA (2003). "Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings." *FEMA 426* Federal Emergency Management Agency <http://www.fema.gov/fima/rmsp426.shtm>.
- FEMA (2003). "Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks." *FEMA 427* Federal Emergency Management Agency <http://www.fema.gov/fima/rmsp427.shtm>.
- FEMA (2003). "Primer to Design Safe School Projects in Case of Terrorist Attacks." *FEMA 428* Federal Emergency Management Agency <http://www.fema.gov/fima/rmsp428.shtm>.
- FEMA (2003). "Insurance, Finance, and Regulation Primer for Terrorism Risk Management in Buildings." *FEMA 429* Federal Emergency Management Agency <http://www.fema.gov/fima/rmsp429.shtm>.
- First, M. W., Nardell, E. A., Chaisson, W., and Riley, R. (1999). "CH-99-12-1: Guidelines for the application of upper-room ultraviolet germicidal irradiation for preventing transmission of airborne contagion." *ASHRAE Trans* 105(Pt.1)
- Gallup, J. M., Zanolli, J., and Olson, L. (1993). "Airborne bacterial exposure: Preliminary results of

- volumetric studies performed in office buildings, schools, and homes in California." *Indoor Air: Proceedings of the 6th International Conference on Indoor Air Quality and Climate*, Helsinki, Finland 167-170.
- GSA (2003). *The Facilities Standards for the Public Buildings Service*. Public Buildings Service of the General Services Administration, Washington. <http://hydra.gsa.gov/pbs/p100/>.
- IAQA (1995). *Indoor Air Quality Standard #95-1 recommended for Florida*. Indoor Air Quality Association, Inc., Longwood, FL.
- IUVA (2005). "General Guideline for UVGI Air and Surface Disinfection Systems." *IUVA-G01A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Guideline for Design and Installation of UVGI Air Disinfection Systems in New Building Construction." *IUVA-G02A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Guideline for the Design and Installation of UVGI Unitary Recirculation Air Disinfection Systems." *IUVA-G05A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for the Testing and Commissioning of UVGI In-Duct Air Treatment Systems." *IUVA-S01A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for the Testing and Commissioning of UVGI Cooling Coil Disinfection Systems." *IUVA-S02A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for the Testing and Commissioning of Upper Room UVGI Systems." *IUVA-S04A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for the Testing of UVGI Surface Disinfection Systems." *IUVA-S05A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for Laboratory Testing of UVGI Air and Surface Rate Constants." *IUVA-S06A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for Epidemiological Testing of Air Treatment Systems." *IUVA-S08A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for the Testing and Commissioning of UVGI In-Duct Air Treatment Systems." *IUVA-S01A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005). "Standard for the Evaluation and Testing of Building Aerobiological Indices." *IUVA-S07A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005a). "Guideline for Design and Installation of UVGI In-Duct Air Disinfection Systems." *IUVA-G03A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- IUVA (2005b). "Standard for the Evaluation and Testing of Building Aerobiological Indices." *IUVA-S07A-2005* International Ultraviolet Association. Ayr, Ontario, Canada. www.iuva.org.
- Kowalski, W. J., Bahnfleth, W. P., and Whittam, T. S. (1999). "Filtration of Airborne Microorganisms: Modeling and prediction." *ASHRAE Transactions* 105(2):4-17. <http://www.engr.psu.edu/ae/wjk/fom.html>.
- Kowalski, W. J., and Bahnfleth, W. P. (2000). "Effective UVGI system design through improved modeling." *ASHRAE Transactions* 106(2):4-15. <http://www.engr.psu.edu/ae/wjk/uvmodel.html>.
- Kowalski, W. J., and Bahnfleth, W. P. (2000). "UVGI Design Basics for Air and Surface Disinfection." *HPAC* 72(1):100-110. <http://www.engr.psu.edu/ae/wjk/uvhpac.html>.
- Kowalski, W. J., Bahnfleth, W. P., Witham, D. L., Severin, B. F., and Whittam, T. S. (2000). "Mathematical modeling of UVGI for air disinfection." *Quantitative Microbiology* 2(3):249-270. http://www.engr.psu.edu/ae/iec/abe/publications/math_modeling.pdf.
- Kowalski, W. J., and Bahnfleth, W. P. (2002). "MERV filter models for aerobiological applications." *Air Media* Summer:13-17.
- Kowalski, W. J., and Bahnfleth, W. P. (2003). "Immune-Building Technology and Bioterrorism Defense." *HPAC Engineering* 75 (Jan.)(1):57-62.
- Kowalski, W. J. (2003). *Immune Building Systems Technology*. McGraw-Hill, New York.

- Kowalski, W. J., and Bahnfleth, W. P. (2004). "Proposed standards and guidelines for UVGI air disinfection." *IUVA News* 6(1):20-25.
- Kowalski, W. J. (2006). *Aerobiological Engineering Handbook: Airborne Disease and Control Technologies*. McGraw-Hill, New York.
- Levetin, E., Shaughnessy, R., Rogers, C. A., and Scheir, R. (2001). "Effectiveness of germicidal UV radiation for reducing fungal contamination within air-handling units." *Applied & Environ Microbiol* 67(8):3712-3715. <http://aem.asm.org/cgi/content/full/67/8/3712>.
- Nardell, E. A. (1988). *Chapter 12: Ultraviolet air disinfection to control tuberculosis*. Architectural Design and Indoor Microbial Pollution, R. B. Kundsinn, ed., Oxford University Press, New York. 296-308.
- Nardell, E. A., Keegan, J., Cheney, S. A., and Etkind, S. C. (1991). "Airborne infection: Theoretical limits of protection achievable by building ventilation." *Am Rev Resp Dis* 144:302-306.
- NIOSH (2002). "Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks." *DHHS (NIOSH) Pub. No. 2002-139* Dept. of Health and Human Services, CDC, National Institute for Occupational Safety and Health. Cincinnati, OH.
- NIOSH (2003). "Guidance for Filtration and Air-cleaning Systems to Protect Building Environments." *DHHS (NIOSH) Pub. No. 2003-136* Dept. of Health and Human Services, CDC, National Institute for Occupational Safety and Health. Cincinnati, OH.
- Philips (1985). *UVGI Catalog and Design Guide*. Catalog No. U.D.C. 628.9, Netherlands.
- Rao, C. Y., and Burge, H. A. (1996). "Review of quantitative standards and guidelines for fungi in indoor air." *J Air & Waste Mgt Assoc* 46(Sep):899-908.
- Reynolds, S. J., Black, D. W., Borin, S. S., Breuer, G., Burmeister, L. F., Fuortes, L. J., Smith, T. F., Stein, M. A., Subramanian, P., Thorne, P. S., and Whitten, P. (2001). "Indoor environmental quality in six commercial office buildings in the midwest United States." *Appl Occup Environ Hyg* 16(11):1065-1077.
- Riley, R. L. (1980). *The role of ventilation in the spread of measles in an elementary school*. Airborne Contagion, Annals of the New York Academy of Sciences, R. B. Kundsinn, ed., NYAS, New York. 25-34.
- Riley, R. L., and Nardell, E. A. (1989). "Clearing the air: The theory and application of ultraviolet disinfection." *Am Rev Resp Dis* 139:1286-1294.
- Scheir, R., and Fencl, F. B. (1996). "Using UVC Technology to Enhance IAQ." *HPAC* 68(2)
- VanOsdell, D., and Foarde, K. (2002). "Defining the Effectiveness of UV Lamps Installed in Circulating Air Ductwork." *ARTI-21CR/610-40030-01* ARTI. Arlington, VA.

Appendix A: Checklist for UVGI System Design and Installation

Project		
Input Data	Design Parameters	Enter values
	UVGI Classification Code	
	Airflow, cfm	
	Air Velocity, fpm	
	Duct Width, cm	
	Duct Height, cm	
	Duct Length, cm	
	Travel Time, seconds	
	Air Temperature, Minimum/Maximum, C(F)	
	Relative Humidity, Minimum/Maximum, %	
	Total UV wattage, W	
	Is lamp burned in?	Y or N
	Lamp burn-in time, hours	
	Enter IESNA Lamp rating, $\mu\text{W}/\text{cm}^2$ at 1 meter	
	Are Filters included?	Y or N
	Enter Filter rating (MERV)	
	Enter lamp minimum & maximum operating temperatures.	
Enter ballast maximum operating temperature		
Are ballasts certified by UL, ETL or other lab?	Y or N	
Analytical	Estimated URV of UVGI System (if applicable)	
	Was a zone model used to evaluate performance?	Y or N
	If so, provide the BPF for Scenario A	
	BPF for Scenario B	
	BPF for Scenario C	
	Were lamps corrected for cooling effects?	Y or N
	Enter cooling effect correction factor	
	Were lamps corrected for end-of-life decrease?	Y or N
Enter correction factor for end-of-life decrease.		
Installation	Installation Parameters	
	Lamp location (see Section 6.1)	
	Is lamp downstream of heating coils	Y or N
	Distance downstream of heating coils	
	Thermal cutout switches included	Y or N
	Access door or manual switches included	Y or N
	Warning signs placed locally?	Y or N
	Training for maintenance personnel	Y or N
	Any UV leakage observed in vicinity of AHU?	Y or N
	Any UV leakage in nearest supply registers?	Y or N
	Is ballast located inside or outside air handling unit?	Y or N
	Is wiring, if any, inside the air handling unit?	Y or N
	If wiring is internal, is it routed through conduit per UL?	Y or N
	Do UV lamps disengage on fan shutdown?	Y or N
	Has area been inspected for possible photodegradation of materials?	Y or N
Maintenance	Maintenance Parameters	
	Inspection frequency	
	Filter replacement frequency	
	UV Lamp life or replacement frequency	
	Lamp irradiance testing frequency, if any.	