Steril-Aire, Inc.
2840 N. Lima Street
Burbank, CA 91504

The Efficacy of UVC in Building Mechanical Systems

By Robert Scheir, Ph.D.

Why is Indoor Air Quality Important to your Business?

Facility owners and managers know all too well that poor indoor air quality can result in adverse health effects leading to lost productivity and revenue, not to mention possible litigation. Poor indoor air quality is especially of concern within a healthcare environment where there are a large number of immunocompromised, immuno-suppressed, elderly and infant patients. Considering the fact that in the U.S., one hospital patient out of 20 acquires an infection[1], healthcare management and infection control are faced with the serious issue of preventing hospital acquired infections (HAIs) to improve patient outcomes. Preventative efforts are also being ramped up due to the staggering costs of HAIs - $33 billion in excess costs every year[1] - and new government non-reimbursement policies for HAIs.

According to the EPA, "pollutants in our indoor environment can increase the risk of illness." There is growing scientific and anecdotal evidence that rank indoor air pollution as an important environmental health problem. Even well-run buildings can experience episodes of poor indoor air quality that can significantly influence rates of respiratory disease, allergy and asthma symptoms and sick building symptoms. The EPA also sites the heating, ventilating and air conditioning (HVAC) system as a pollutant source for the foul smells associated with Sick Building Syndrome (SBS). The cause of the problem is usually the growth of mold and bacteria on the coil of the system.

Indoor air quality is also a key component of the U.S. Green Building Council LEED-IEQ rating system. It includes the reduction of "the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants."

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Relationship of IAQ to Building Mechanical Systems

In all situations where IAQ is deemed a problem, three factors are present: a source of the contamination, susceptible occupants, and a mechanism to transport the contaminants. The sources of contamination come from the building, building furnishings, its occupants and the outdoors; the susceptible occupants are individuals occupying the building; and the HVAC system that circulates large volumes of air throughout the building is the primary transport mechanism. It may also be the source of contamination.

HVAC coils and drain pans present a viable environment for growth of bacteria and mold. The EPA and World Health Organization are just two organizations that have identified a building's mechanical system as a source of pollutants and microbial contamination. According to the World Health Organization, approximately 30% of all commercial buildings have significant IAQ problems, and ventilation systems are implicated in the spread of infection and pollutants.

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A report to the U.S. House of Representative's Subcommittee in 2002 clearly documented that mold can cause respiratory infections (including nosocomial infections) due to the inhalation of the fungus *Aspergillus.* It ties outbreaks of hypersensitivity pneumonitis directly to exposure from mold-contaminated ventilation systems.

The NIOSH study found that when "a building has poor drainage in the pans underneath the air conditioning coils, there is a 160% increase in the risk of multiple work-related respiratory symptoms." If there is debris in the air intake of the building, there is a 100% increase in risk for these multiple building-related respiratory symptoms that may also indicate serious respiratory disease or sensitization, such as asthma." The study also found that airborne fungi, volatile organic compounds (VOCs) and specific organic chemicals have been related to symptoms such as wheezing, shortness of breath, tight chest and cough.

The Microbiology of HVAC Biofilm

So what's going on in the HVAC system? Air conditioning coils are the source of accumulation of biofilm that adheres to the fins of the coil. Biofilms are composed of different microorganisms adhering to surfaces and producing polysaccharides, proteins and nucleic acids. This material allows the biofilm to stick together and develop attached communities. They are attached primarily to the coils and drain pans. Biofilms also provide protection to the microorganisms from penetration of outside agents such as the antimicrobial agents that facility managers may use to try to destroy them.

The biofilms themselves give off products of metabolism known as VOCs and microbial volatile organic compounds (MVOCs), which have been found to play a major role in Sick Building Syndrome, eliciting building occupant complaints that range from irritation, watery eyes and headaches, to more severe allergy and asthma responses. In addition, many of the biofilm organisms growing on the coil and in drain pans of HVAC systems are known opportunistic organisms causing infections.

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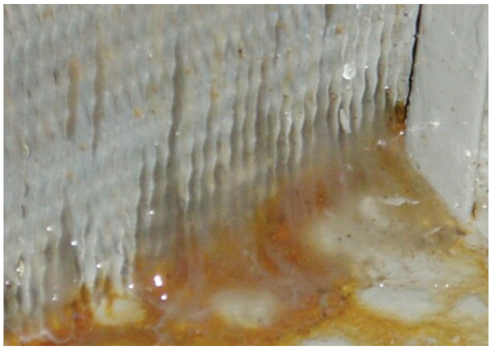
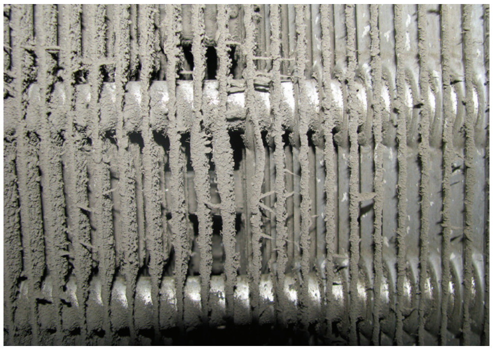


Biofilm on the coil and in the drain pan



A close-up look of fouled evaporator coil fins

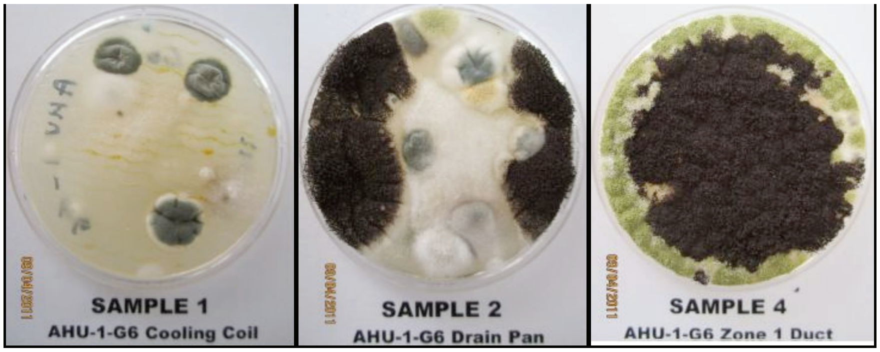
The list below identifies some of the many microorganisms found in HVAC biofilm within mechanical systems.

GRAM NEGATIVE BACTERIA	
Enteric Organisms	Pseudomonas-related Organisms
Serratia marcescens	*Pseudomonas aeruginosa*
Klebsiella pneumoniae	*Pseudomonas sp.*
Klebsiella sp.	*Flavobacterium sp.*
Enterobacter aerogenes	*Aeromonas*
Enterobacter sp.	*Acinetobacter*
Salmonella typhimurium	*Achromobacter sp.*

GRAM POSITIVE BACTERIA
Staphylococcus
Bacillus
Streptococcus

FUNGI
Aspergillus
Alternaria
Chaetonium
Cladosporium
Fusarium
Gliocladium
Memnoniella
Penicillium

Contact plates facilitate easy and reproducible surface microbial (bacteria, yeast/mold) testing. The plates are used for enumeration of microorganisms on environmental surfaces such as cooling coil fins, drain pans, ducts and registers. Typical mold results found within 5 days of incubation are demonstrated below.



The air can also play a major role in the transmission and dispersal of microorganisms, and building HVAC systems have been found to be a transport mechanism. One cough can produce over 3000 droplet nuclei, and sneezing generates tens of thousands droplet nuclei, which can spread to individuals up to 10 feet away[2]. These small, infectious droplets nuclei, generally less than 5 µm or less, can remain suspended in the air and disseminated by air currents to be inhaled by a susceptible host.

Bioaerosols have been revealed to cause certain human diseases, such as tuberculosis, Legionnaires' disease and different forms of bacterial pneumonia, coccidioidomycosis, influenza, measles, and gastrointestinal illness.[3][4] In fact, the WHO clearly states that *"Legionella pneumophilia,* the organism responsible for legionellosis (Legionnaires' disease; Pontiac fever), can become airborne during the evaporation of water droplets from air conditioning cooling towers and subsequently may be inhaled by building occupants. A case cited in a study from the Center for Health Design (CHD) traced an outbreak of Methicillin-resistant *Staphylococcus aureus* (MRSA) to a hospital ventilation system.[5]

The World Health Organization (WHO) further concurs with the idea that many infections are transmitted through the air saying, "Some nosocomial infections are due to airborne microorganisms" and there is increasing evidence that pathogenic aerosols propagate via airborne transmission.

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The Relationship of Energy Efficiency and Biofilm

Biofilms also have a detrimental effect on HVAC equipment. Its sticky surface enables dirt to adhere to the metal, insulating the metal from the air and reducing the coil's ability to cool the air passing over the fins.

The biofilm also blocks the spaces between the fins reducing the airflow, thus raising the static pressure. To maintain the building at the desired temperature, the fans have to work harder. The chilled water temperature may be lowered, making the chiller and compressor work more, resulting in increased energy costs.

Mechanical engineers know that HVAC systems account for an estimated of 40-60% of energy use in buildings. When you consider that fouled coils can add another 30% [6] to building energy costs, while producing 10% less cooling, performance and energy efficiency become key factors in the bottom line.[7]

The Efficacy of UVC in Eliminating HVAC Biofilm

History of UVC

Ultraviolet C band, also known as ultraviolet germicidal irradiation (UVGI), in the form of germicidal lamps has been in existence for over 100 years. In 1903, the Nobel Prize was awarded to Niels Ryberg Finsen for his work in the field, and over the last century, there has been a tremendous amount of research dedicated to the subject matter. [8-20] In the 1930s, research focused on controlling infectious pathogens in medical facilities. UVC was found to effectively kill *Mycobacterium tuberculosis,* the causative agent of tuberculosis as well as other microorganisms such as mycoplasma, viruses and fungi. Since the mid-20th century, UVC has been used for medical and food processing sanitizing applications as well as drinking and wastewater disinfection.

Surface Decontamination

The effectiveness of UVC for surface decontamination in HVAC systems was documented in a 2001 study titled, *"Effectiveness of Germicidal UV Irradiation for Reducing Fungal Contamination within Air-Handling Units,"* in the Journal of Applied and Environmental Microbiology.[20] The study, conducted in a 286,000 sq. ft. office building, found that UVC light fixtures were effective in reducing fungal contamination within air handling units.

With the proper intensity and exposure time, UVC is effective at destroying or inactivating many microorganisms.[21-31] Listed in Table 2.1 are the required doses to inactivate common surface microorganisms.[12] The higher the concentration of organisms, and/or the greater their tolerance to germicidal UVC energy, the higher the dose required to achieve inactivity.[32] Dose is defined as (μW·s/cm^2) = (intensity) x (exposure time). Intensity is defined as the power of electromagnetic radiation incident on a surface, typically reported in microwatts per square centimeter (μW/cm^2).

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To prevent the growth of microorganisms on the cooling coil, Steril-Aire recommends a minimum UVC intensity of 200 μW/cm^2 should be maintained on all portions of the evaporator coil at all times; which requires that the UVC lamps remain on 24/7. With sufficient intensity and exposure time, UVC will prevent the growth of any mold or biofilm on the cooling coil and drain pan of HVAC systems.

The table below provides a partial list of microorganisms found in cooling coils and drain pans and the irradiance of UVC energy (μW·s/cm^2) required to destroy 90.0% of the microorganisms.[12,32,33]

MICROORGANISM	D_{10} Dose (μW·s/cm^2)
Acinetobacter	5,500
Aspergillus flavus spores	60,000
Aspergillus glaucus spores	44,000
Aspergillus niger spores	132,000
B. subtilis	5,800
B. subtilis spores	11,600
Cladosporium	26,000
Escherichia coli	3,000
Fusarium spores	24,300
Mucor mucedo	33,800
Penicillium digitatum	44,000
Penicillium expansum	13,000
Penicillium roqueforti	13,000
Pseudomonas aeruginosa	5,500
Rhodotorula	48,600
Serratia marcescens	2,420

Airborne Contamination Control

According to a report issued June 24, 2009 by ASHRAE, airborne transmission of diseases through heating and air conditioning systems may be much more common than previously thought. ASHRAE cites UVC as one of the control strategies that may help avoid transmission.

"While the long-standing public health view is that transmission of influenza occurs through direct contact or large droplets, newer data suggests it also occurs through the airborne route." In a press release announcing the findings, ASHRAE president Gordon Holness announced, "HVAC systems may contribute far more to transmission of the disease." This press release can be seen online at http://www.ashrae.org/pressroom/detail/17266.[34] The full report, titled *Airborne Infectious Diseases,* can also be viewed online at www.ashrae.org/positiondocuments.[35]

In buildings requiring general air cleaning and where there are four to six air changes per hour, UVC lamp systems installed in the air handlers can reduce contaminant levels below that which affects most people. Where a high level of infection control is needed for hospital and medical environments, germicidal UVC can successfully deliver contaminant destruction rates of 99+ percent, properly applied in combination with high air exchange rates of typically 15-20 air changes per hour or more.[36,37]

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Airborne contamination comes from a variety of sources. Contaminants may be introduced to a building by an infected building occupant releasing viruses or bacteria which is recirculated through the building by the air handling system.[38] It may originate from an act of bioterrorism or from outside bacterial contamination (as occurs with Legionnaires' disease). It may also originate from the HVAC system itself from the biofilm on the cooling coil and in the drain pan. Excess bacteria and fungi in the air increases the likelihood of affecting building occupants and can also contaminate surfaces and products that reach the marketplace such as food and beverage products. Contaminated food and beverage products can lead to consumer illness, costly product recalls and reduced shelf life.[39]

Contaminants not Addressed by UVC

Non-organic contaminants that are not addressed by UVC include dust, lint, ash and other particulates. To eliminate these contaminants, particulate filters are required. UVC complements the use of particulate filters in HVAC systems and helps extend the service life of these filters if positioned downstream of the UVC. UVC does not take the place of particulate air cleaning devices.[40]

How UVC Works

Ultraviolet germicidal irradiation (UVGI) is a sterilization method that utilizes ultraviolet (UV) energy at a wave length of 253.7 nm to break down microorganisms or inactivate viral, bacterial, and fungal species.

UVC irradiation alters the molecular bonds within the ability of DNA of a microorganism, thereby destroying them, rendering them harmless or prohibiting growth and reproduction.

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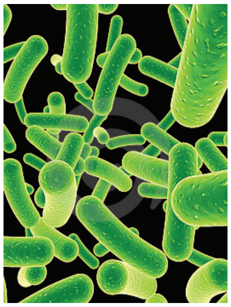
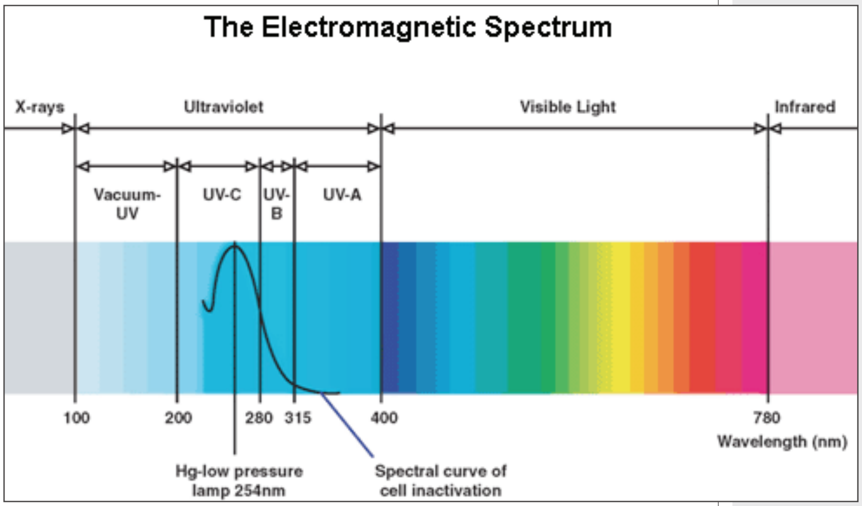


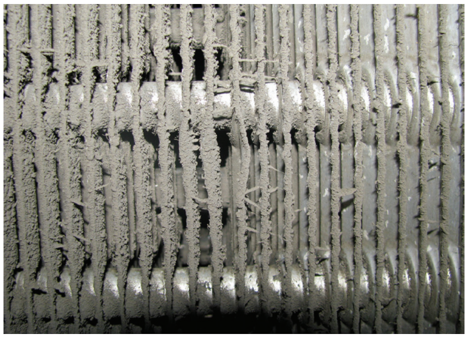


UVGI provides a highly effective method of destroying microorganisms. The recirculating air in HVAC systems creates redundancy in exposing microorganisms to UV ensuring multiple passes so that the light energy is effective against large quantities of pathogens.

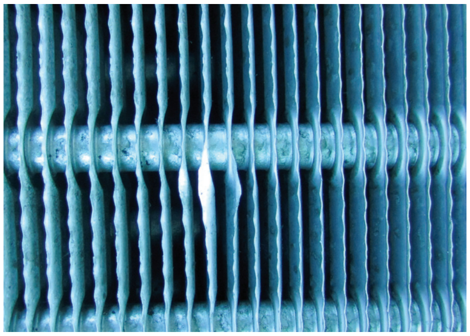
For optimum performance in the HVAC environment, Steril-Aire recommends the UVC device should be manufactured to deliver output of nine microwatts per linear inch of glass measured from a distance of one meter, tested at an air velocity of 400 fpm (feet per minute), and situated in a temperature of 50° F. This information is critical because UVC output declines over time, reaching a half-life after 9,000 operating hours or slightly over one year when running on a 24/7 basis. It is necessary to start at a high enough output, based on microwatts per linear inch of glass, to ensure adequate output will be maintained throughout the service life of the device. Otherwise, the device may not be able to maintain effective microbial control.

For the most effective microbial control, the UVC should be installed on the supply side of the system, downstream from the cooling coil and above the drain pan. This location provides more effective biofilm and microbial control than in-duct UVC installations because the UVC irradiates the contaminants at the source and delivers simultaneous cleaning of surface and airborne microorganisms.

The following photos clearly demonstrate the ability of high output germicidal UVC to remove biofilm deep in the coil fins and eliminate microbial activity. This type of successful microbial growth removal was achieved in a matter of days.



Cooling coil fins before UVC



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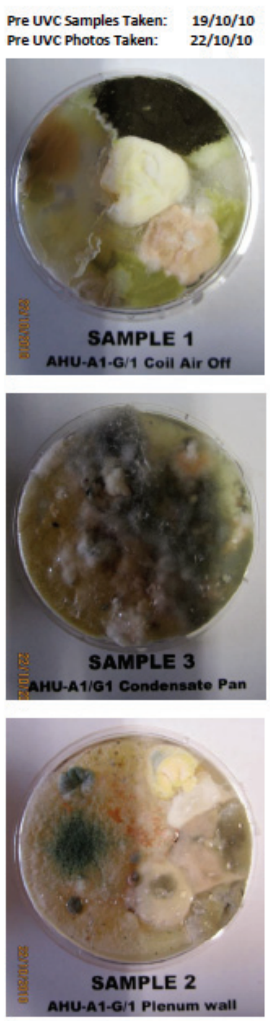
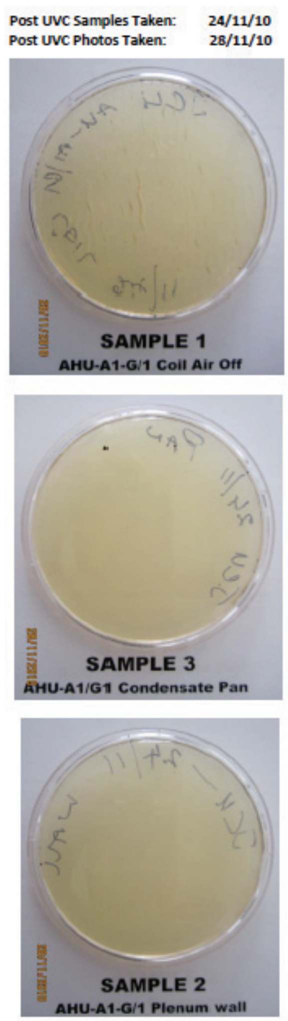


Contact plates before UVC



Contact plates after UVC

Case Studies and Peer-reviewed Data

The effectiveness of high output, systems-engineered UVC in HVAC systems to remove biofilm growth and reduce airborne pathogens has been documented with anecdotal and scientific evidence. Studies and research have been performed demonstrating the efficacy of actions of germicidal UVC and its applications.

Case study #1: Muskogee Community Hospital (OK) installed UVC in 77 air handling units that serve patient areas and in 7 ceiling-mounted devices specially designed for after-hours disinfection of the surgical and procedural areas. The Muskogee Community Hospital president states they have achieved a “zero” HAI rating.

Case study #2: The U.S. Environmental Protection Agency’s (EPA) National Homeland Security Research Center Technology and Testing Evaluation Program engaged RTI International to conduct an independent performance test to evaluate HVAC in-duct ultraviolet light systems and the “biological inactivation efficiency” of aerosol, bioaerosol and chemical challenges. The installation resulted in no viable *S. marcescens* bacteria or MS2 viruses downstream of the coils. The top UVC manufacturer outperformed every company tested in the irradiation of *B. atrophaeus* (an Anthrax spore surrogate) at 96.5% efficiency. The full study can be found on the EPA site at www.epa/gov/NHSRC/news100406a.html.

Case study #3: A California preschool documented a 50% decrease in teacher absenteeism, 25% decrease in student absenteeism and improved student performance. These results ultimately led to increased school funding.

Case study #4: The Florida Hospital system of Orlando, FL was able to eliminate more than 200 coil cleanings per year with tremendous labor and chemical cost savings with mold completely eliminated downstream of the HEPA filters. After the UVGI installation, worker complaints of coughing, sneezing and watery eyes abated.

Case study #5: A newly published peer-reviewed abstract[41] documents the effectiveness UVGI in reducing ventilator-associated pneumonia (VAP) in a neonatal intensive care unit (NICU).

The study was performed at the Buffalo Department of Pediatrics, Neonatology, Women and Children's Hospital of Buffalo (NY) over 2.5 years. The microorganisms found in the HVAC system included *Pseudomonas, Klebsiella, Serratia, Acinetobacter, Staphylococcus aureus* and *Coagulase-negative Staphlococcus* species. The study showed a greater than 5 Log (that's 99.999%) microbial load reduction per square centimeter of HVAC coil in just 6 days! The study finding also included a decrease in antibiotic use in NICU high-risk patients.

"The study showed a greater than 5 Log (that's 99.999%) microbial load reduction per square centimeter of HVAC coil in just 6 days!"

The Women and Children's Hospital of Buffalo has realized a significant reduction in direct costs and 3rd party charges.

Case study #6: The cleanliness of UVC-treated coils at Robbinsdale Area School District 281 with a K-12 student population of 13,000 was verified by petri dish testing of samples from coils surfaces. They state that "there has been a decline in respiratory illnesses since the renovation."

Case study #7: A 7 ½ year study conducted in the In Vitro Fertilization Cleanroom Laboratory of the Lehigh Valley Hospital and Health Network found that the use of ultraviolet C or "UVC" lights installed in the HVAC system had a clinically significant impact on clinical pregnancy rates (CPR). In presenting the findings at the annual meeting of the American Society for Reproductive Medicine (ASRM), Kathryn C. Worrilow, Ph.D. reported that the + beta and CPR increased by an average of 17.8% and 18.2%, respectively, following 10 of the 13 change-outs of the Steril-Aire UVC Emitters over the test period.

Case study #8: A recent study was published by the Laboratory of Biological Agents, Laboratory of Physical Agents – ISPESL Occupational Hygiene department of Italy outlining the efficacy of UVC Emitters in inactivating the spore of *Aspergillus fumigatus* in an experimental setting. This test indicated a 90% kill rate of this potentially harmful mold (occupational risk group 2, DLgs 626/94; European Directive 2000/S4/CE).

Case study #9: A double-blind multiple crossover study was performed in Montreal, Canada to assess the effect of UVGI installed in office ventilation system and the effect on workers' health and well-being. The use of UVGI resulted in 99% reduction of microbial and endotoxin concentrations on irradiated surfaces within the ventilation systems. Over a 12 week period, the 771 participants reported a reduction in overall sickness by 20% and a 40% drop in breathing problems.

The results, both scientific and anecdotal, provide powerful evidence about the causal role of biofilm in contributing to building occupant health and safety. Germicidal UVC is a reasonable control strategy.

ASHRAE Position

In the *2008 ASHRAE Handbook—HVAC Systems and Equipment,* ASHRAE published a Chapter (Chapter 16) on this topic titled *"Ultraviolet Lamp Systems."* [42] The publication of this UVC Chapter 16 in the ASHRAE handbook is significant because it reflects the growing acceptance among HVAC and facility professionals of the proven benefits of UVGI in HVAC systems. As summarized on the ASHRAE web site www.ashrae.org, the chapter "includes a review of the fundamentals of UVC germicidal energy's impact on microorganisms; how UVC lamp systems generate germicidal radiant energy; common approaches to the application of UVGI systems for upper-air room, in-duct, and surface cleansing; and a review of human safety and maintenance issues."

Summary

In summary, there is sufficient scientific and anecdotal evidence linking poor indoor air quality to biofilm commonly found in HVAC systems. This biofilm has adverse health effects on occupants and has contributed to escalating health care costs and lost productivity.

The most effective UVC systems work efficiently and produce Ultraviolet C Band in the cold (50° F) moving air (400 fpm air velocity) at the discharge side of air conditioning coils. The highest efficacy is achieved when the UVC produces high output at 9 µW/cm^2 at 1 meter per one inch arc length.

UVC use in HVAC systems is now recognized as an important contributor to improved indoor air quality, biofilm control, energy savings, and maintenance reductions in commercial, residential, health care and other environments.

"UVC use in HVAC systems is now recognized as an important contributor to improved indoor air quality, biofilm control, energy savings, and maintenance reductions..."

Robert Scheir, Ph.D.

Robert Scheir, Ph.D. is president and chairman of Steril-Aire, Inc., Burbank, Calif., a leading manufacturer of UVC devices for IAQ, mold, infection and contamination control applications in the HVAC and food processing industries.

Scheir has served as a senior executive with Steril-Aire since 1995. His varied responsibilities at the company have included research, sales, financial management, technical and application support, and frequent speaking engagements at industry conferences and forums. Scheir was a senior scientist at McDonald-Douglas Corporation specializing in biological warfare detection instrumentation, and he has had extensive experience in microbial air pollution, detection and remediation. He has more than 25 years' experience in the field of infectious disease detection and control in hospitals, medical laboratories and industry. He has served as a quality assurance manager for Abbott Labs and as a manufacturing officer for Health Valley Foods. He was president of two medical products manufacturing companies, Calscott, Inc. and Cal Labs.

Scheir obtained his Ph.D. in medical microbiology from the University of California, Los Angeles, performed graduate studies in immunochemistry at The Johns Hopkins University School of Hygiene and Public Health, and received his Bachelor of Science in microbiology from the University of Maryland. He is also registered as a Clinical Technologist in the State of California and has served as a consultant to industry.

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