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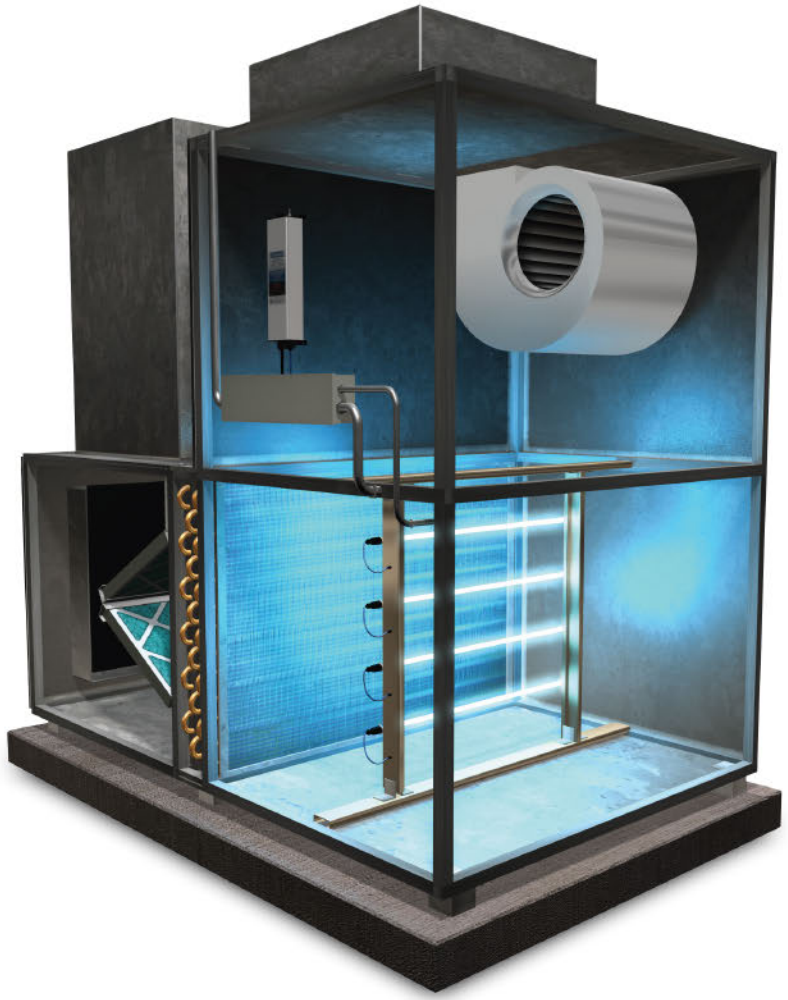
Ultraviolet Germicidal Disinfection for Commercial HVAC



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IAQ – The Reasons Why

- Tight Buildings designed to conserve energy
- Not bringing in enough outside air
- Concentration of contaminants 5-100X more polluted than outside
- Insulating ourselves like never before

“Ultraviolet germicidal irradiation (UVGI) uses short-wave ultraviolet (UVC) energy to inactivate viral, bacterial, and fungal organisms so they are unable to replicate and potentially cause disease. UVC energy disrupts the deoxyribonucleic acid (DNA) of a wide range of microorganisms, rendering them harmless.

UVC lamp devices and systems are placed in air-handling systems and in room settings for the purpose of air and surface disinfection (Figure 1). Control of bioaerosols using UVC can improve indoor air quality (IAQ) and thus enhance occupant health, comfort, and productivity.

Keeping the coils free of biofilm buildup can help reduce pressure drop across the coils and improve heat exchanger efficiency (therefore lowering the energy required to move and condition the air), and eliminates one potential air contamination source that could degrade indoor air quality. UVC is typically combined with conventional air quality control methods, including dilution ventilation and particulate filtration, to optimize cost and energy use.” - 2019 ASHRAE Handbook

“UVC applications can be used to reduce the spread of airborne infectious diseases such as tuberculosis, influenza virus, measles, SARS, and, presumably, SARS-CoV-2 (responsible for COVID-19).” - Published in a study by The IES Photobiology Committee on May 05, 2020

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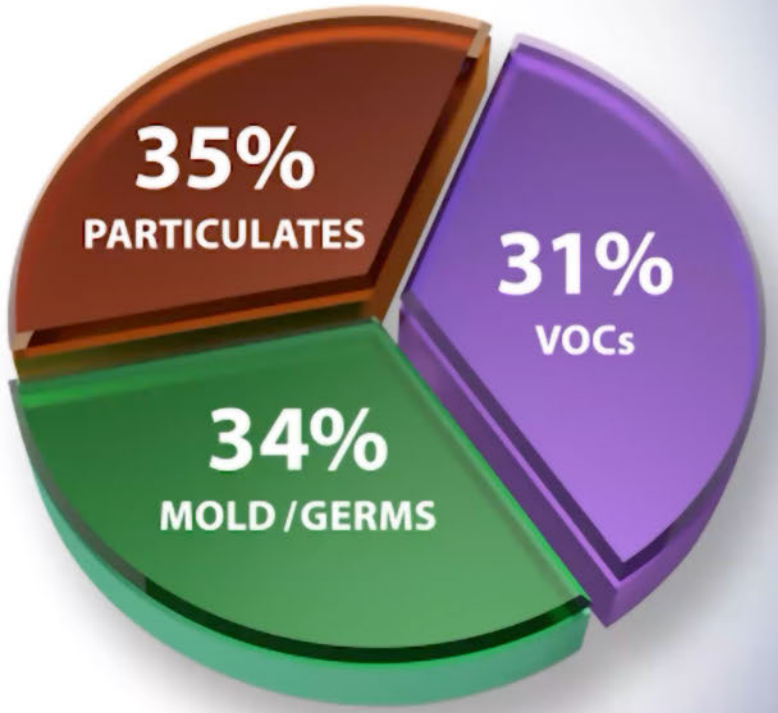
IAQ – What's in the air?

UV Addresses the "Other 2/3rds".

- Particulates (35%)
- Bacteria & Viruses (34%)
- Volatile Organic Compounds (31%)



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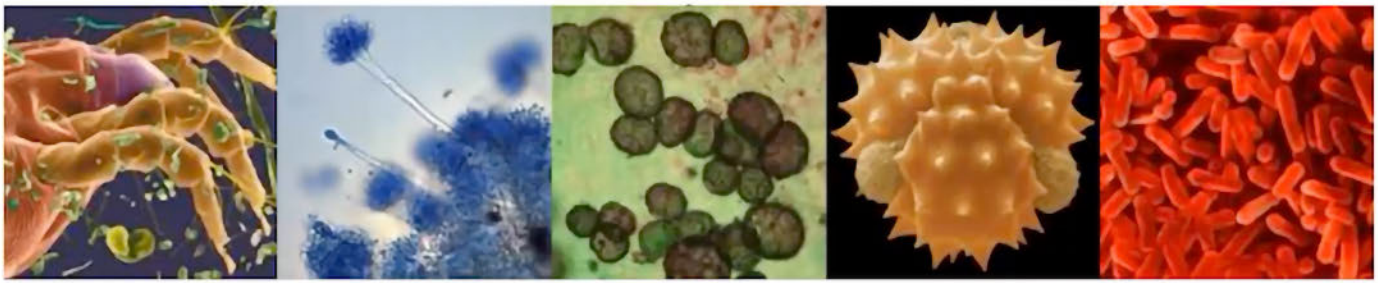

- Microbes (Molds, Bacteria, Viruses, Fungi) - **UV Light**
- Gases (Odors, Chemical VOC's) – **PCO**
- Particulates (Dust, Dander, Pollen) – **Filtration**

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BLUECALC™ UVGI DESIGN

Examples of target

Aspergillus niger

Fungus

Aspergillus niger is a fungus and one of the most common species of the genus Aspergillus. It causes a disease called "black mold" on certain fruits and vegetables such as grapes, apricots, onions, and peanuts, and is a common contaminant of food. Wikipedia

Kingdom: Fungi

Order: Eurotiales

Class: Eurotiomycetes

Family: Trichocomaceae

Scientific name: Aspergillus niger

Rank: Species

Botrytis cinerea

Fungus

Botrytis cinerea is a necrotrophic fungus that affects many plant species, although its most notable hosts may be wine grapes. In viticulture, it is commonly known as "botrytis bunch rot"; in horticulture, it is usually called "grey mould" or "gray mold". Wikipedia

Scientific name: Botrytis cinerea

Family: Sclerotiniaceae

Class: Leotiomycetes

Higher classification: Botrytis

Rank: Species

Organism Chart
UV-C Energy needed to Kill

MOLD	90%	99.9%
Aspergillus niger	132,000*	330,000*
ORGANISM		
Bacillus subtilis	5,800	11,000
Mycobacterium tuberculosis	6,200	10,000
Staphyllococcus aureus	2,600	6,600
VIRUS		
Influenza	3,400	6,600

* Microwatt-sec per cm^2

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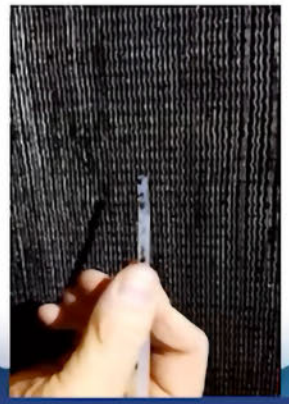
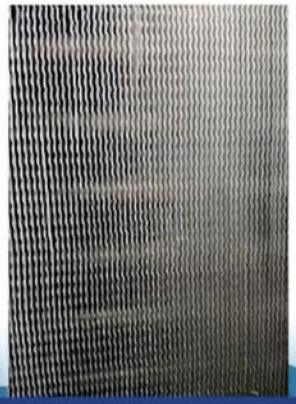
Leach, T., Taylor, G., Restoring Acceptable HVAC Performance with Ultraviolet Germicidal Irradiation (UVGI) Coil Treatment. ASHRAE, Winter Conference. January 2017.

AHU 9-1	Average CFU/In.²/Coil Surface Bacteria	Average CFU/In.²/Coil Surface Fungi	Average CFU/In.²/Coil Surface Total Microbes
Pre UVGI Installation	300,000	27,285	327,285
Post UVGI Installation	2	0	2
Microbial Log Reduction	5 Log	5 Log	5 Log

Pre UVGI Installation



Post UV-C Installation



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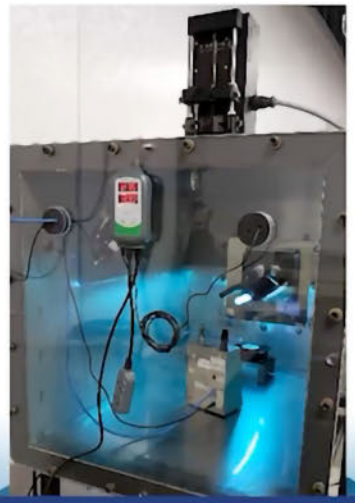
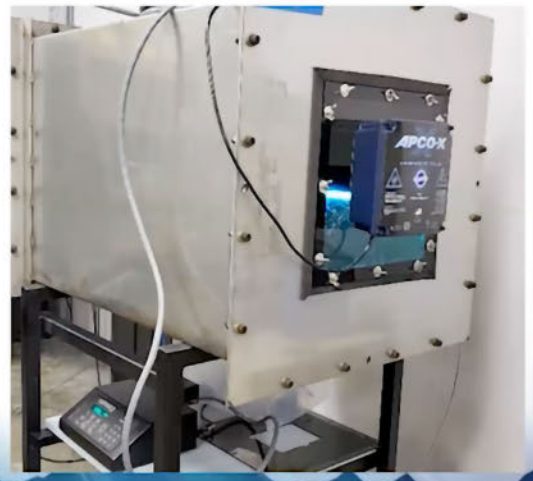
APCO®

Testing performed on an ASHRAE Standard 52.2 test duct system.

<u>APCO Achieved</u>:

Bacteria (S.epidermidis) – 98.85%
Virus (MS2 coliphage) – 99.03%
Mold (A.niger) – 78.8%
Odors (VOCs) – 99.9%





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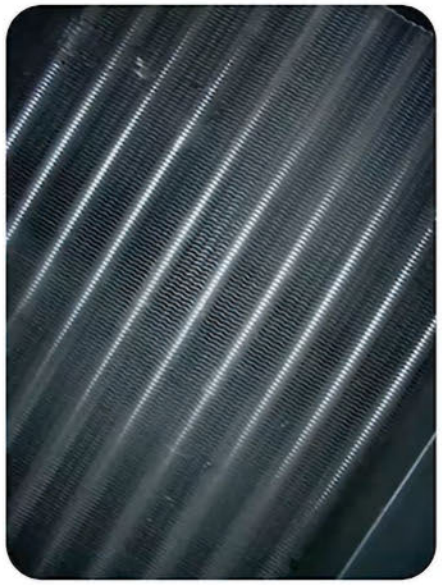
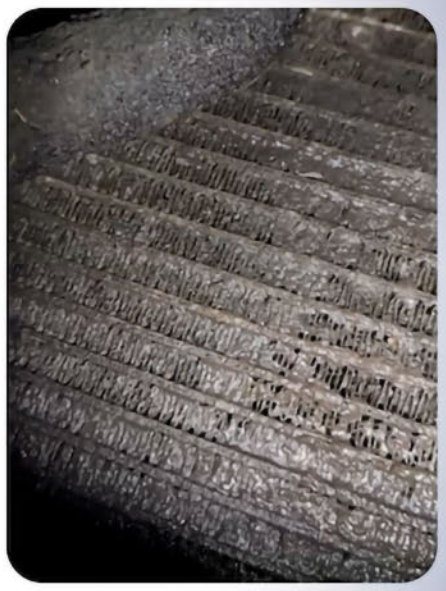
The EVAPORATOR COIL ISSUES

- The dark, damp, cool environment is ideal for propagating mold & biofilm
- Bio-Film coats and insulates coil fins acting as an adhesive attracting dirt
- "Dirty Sock Syndrome" that musty, foul odor that is pushed into the living area when the blower starts

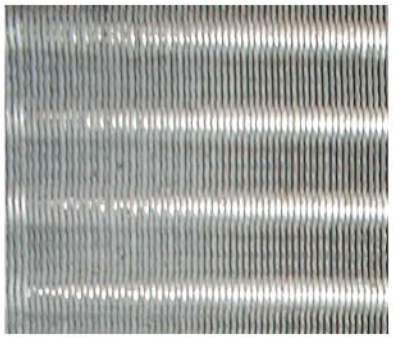




So What Happens?

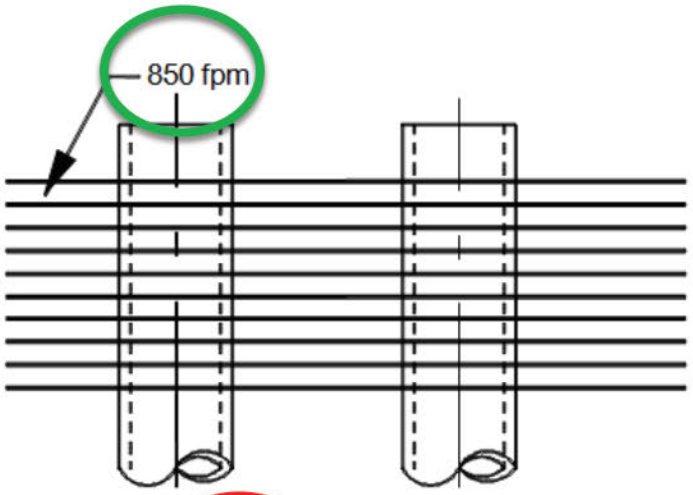
Organic Matter Lowers Coil Eff. & CFM / Increases Coil ΔP

New Clean Coil:



500 fpm

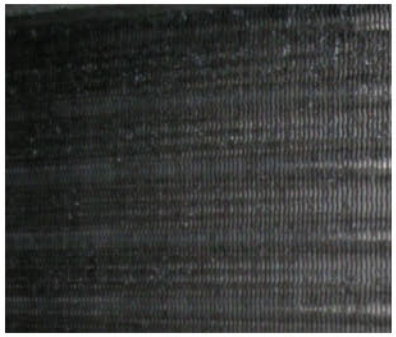
APPROACH



60% OPEN = **Optimum cooling / Design**

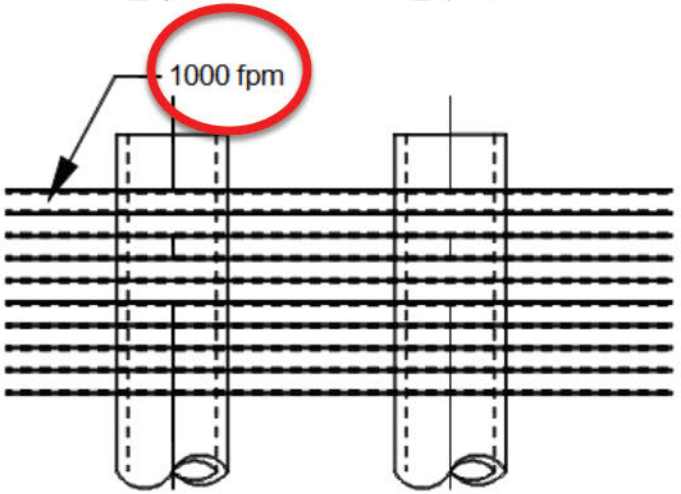
~54° WB

Add only .006" of bio film:



500 fpm

APPROACH

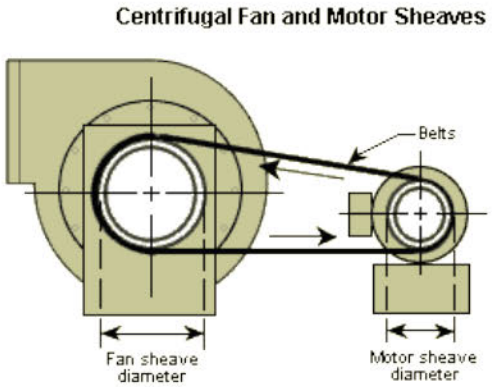


51% OPEN = **Decreased efficiency**

~58° WB

Typical Responses To The Problem

Speed up Fan



Pump More Chilled Water

Lower Coil Water Temp

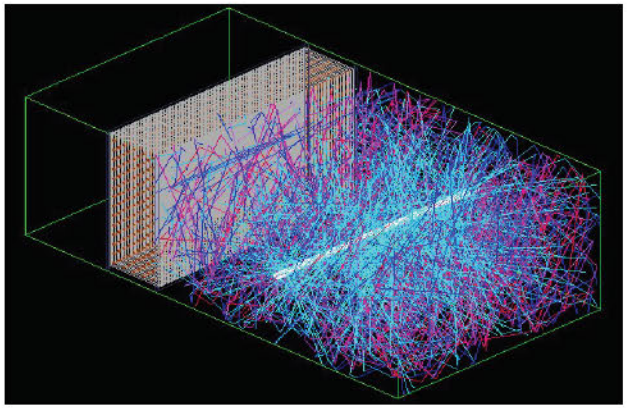
= Increased kWh Usage on Fan Motors **= Increased kWh Usage on Pump Motors** **= Significantly Increases kWh Usage on Chiller**

INCREASED ENERGY COSTS

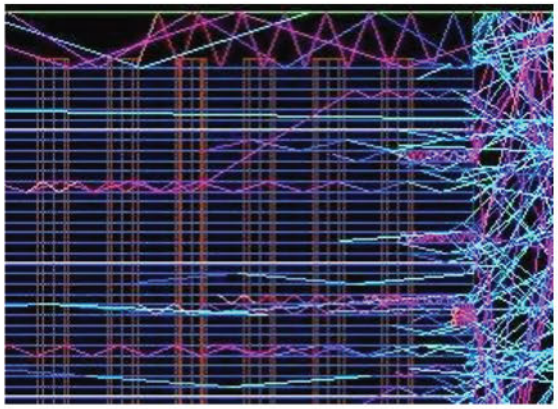
Restoring Coil Efficiency

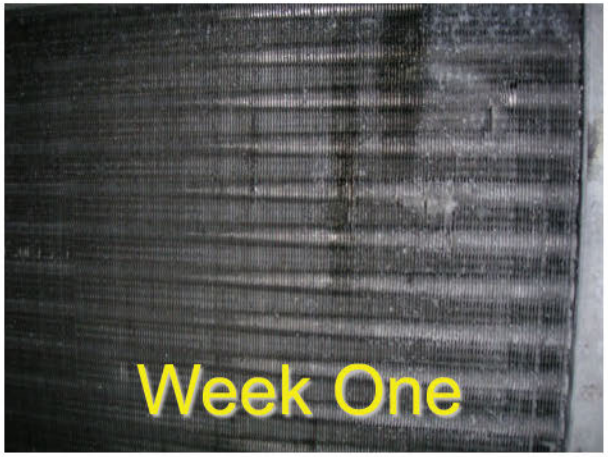
UV-C on the coil

UV-C energy degrades organic matter



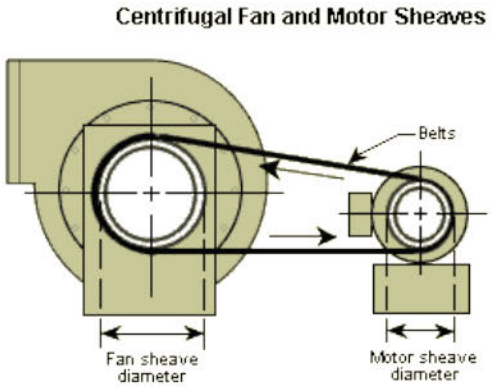
Energy is reflected through the coil





Harvesting Energy Savings From A Restored Cooling Coil

Slow Down Fan



Pump Less Chilled Water

Raise Coil Water Temp

= **Restored kWh Usage** = **Restored kWh Usage** = **Restores Significant kWh Usage**

SUSTAINABLE ENERGY SAVINGS

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How UV light works

Penetrates the cell walls of microorganisms

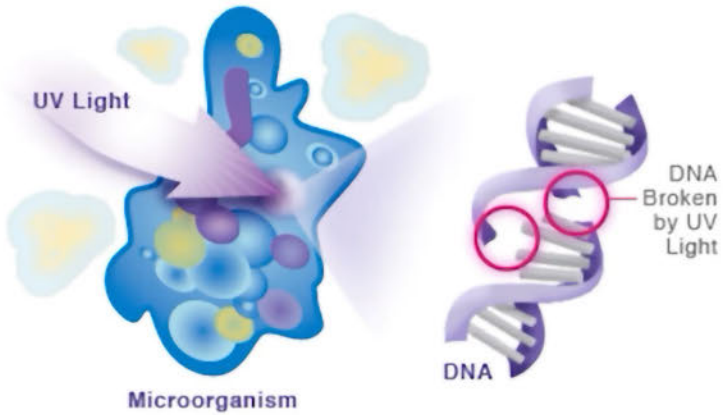
- Kills them / prevents reproduction

Airborne Disinfection

- High concentration UVC required

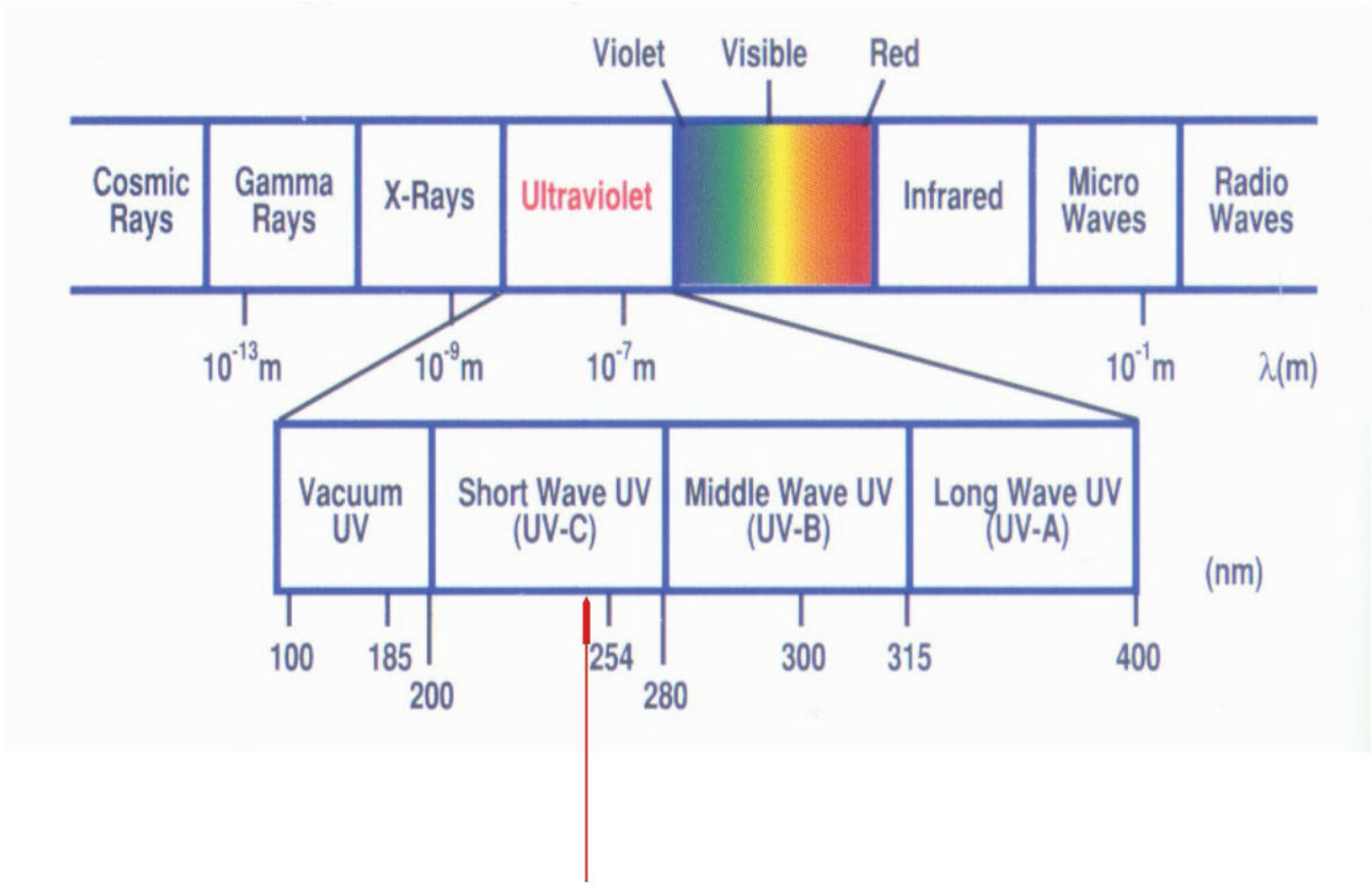
Surface Disinfection

- Contaminates are in constant contact with UV rays
- Prevents growth from occurring



UltraViolet C (UVC) light shatters microbes at the genetic level. It breaks DNA strands, disarming and destroying microorganism in just moments.

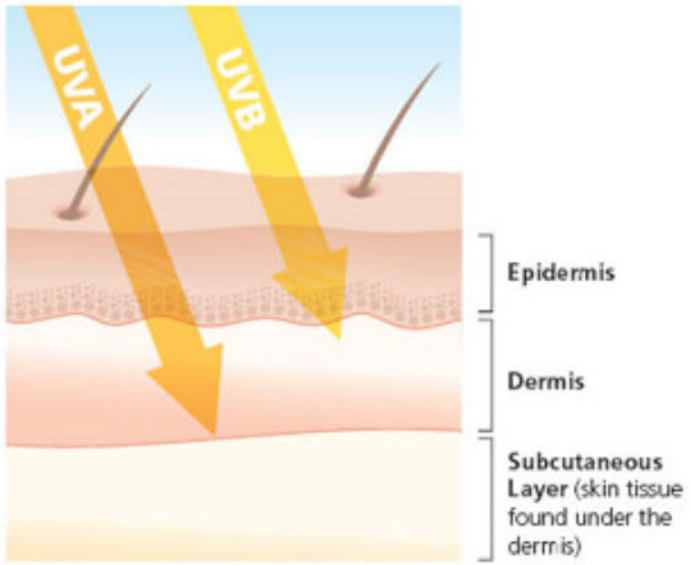
Light Spectrum



Ultraviolet Light Spectrum

- 1nm = 1/1000 micron
- UV-A (315nm - 400nm) - Includes black lights, sun tanning lamps and it is harmful to eyes
- UV-B (280nm - 315nm) - Causes sunburn and Skin cancer
- UV-C (200nm - 280nm) - Is naturally germicidal, damages the DNA of microbes and more
- UV-V (100nm – 200nm)- At 185nm Ozone is formed

- The Sun produces all 4; UV-A, UV-B and some Ozone (UV-V) make it through the Earth's atmosphere. UV-C is mostly filtered out



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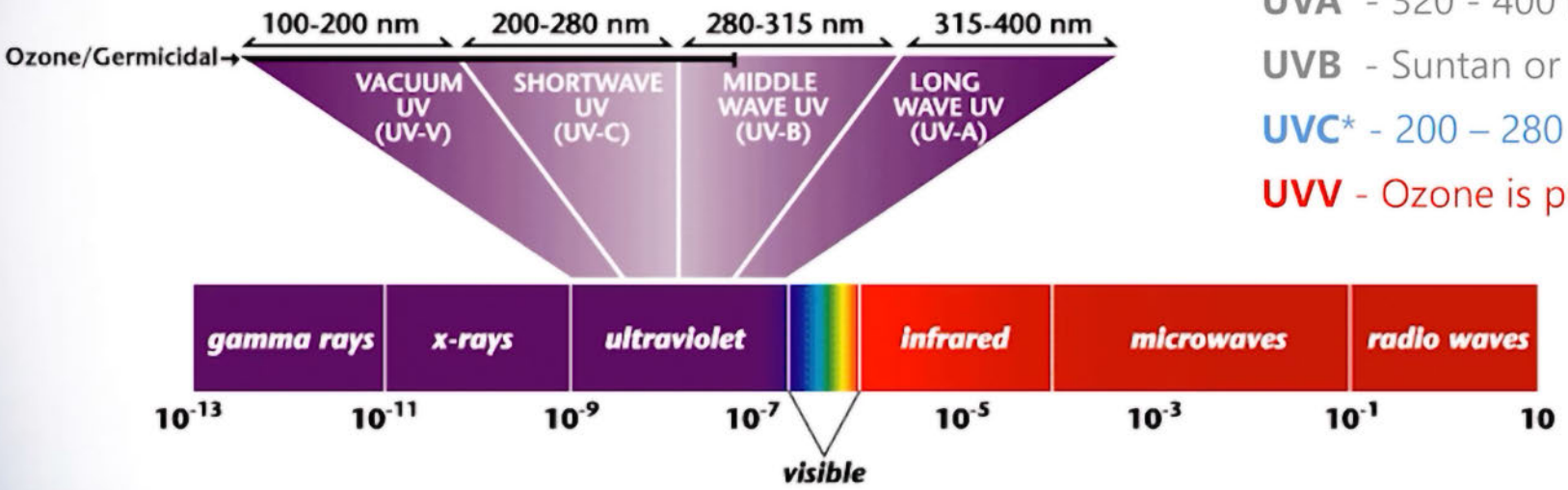
Ultraviolet Light Wavelengths



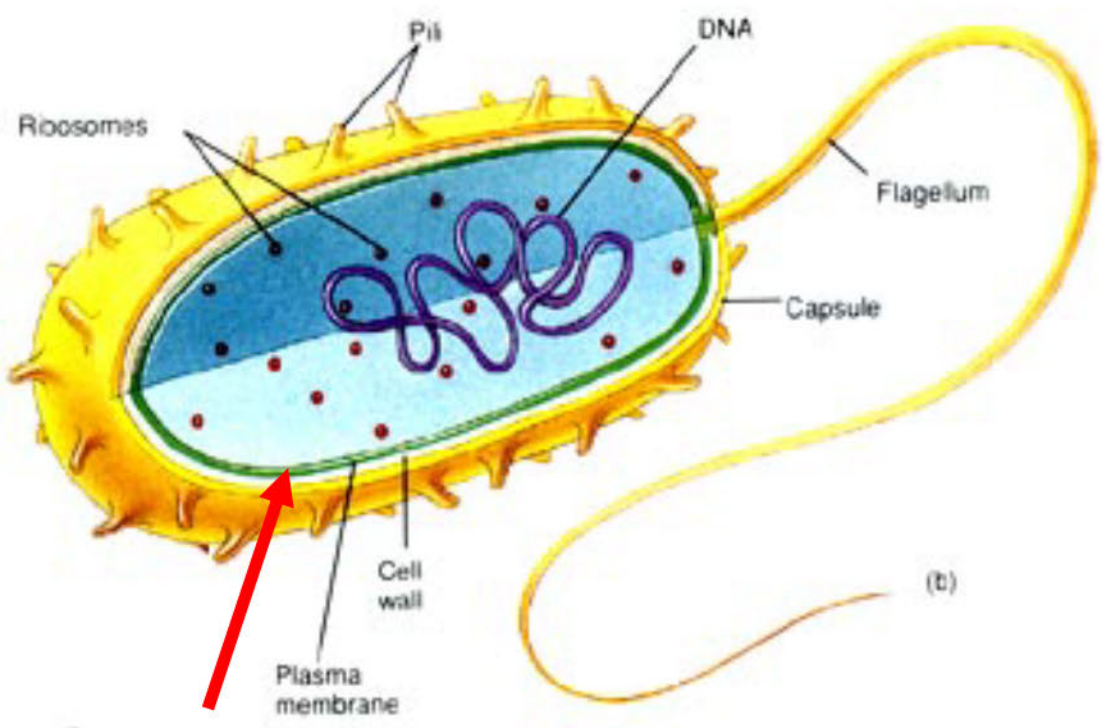
UVA - 320 - 400 nm

UVB - Suntan or Sunburn 280-320 nm

UVC* - 200 – 280 nm (ideal 254 nm)

UVV - Ozone is produced at185 nm

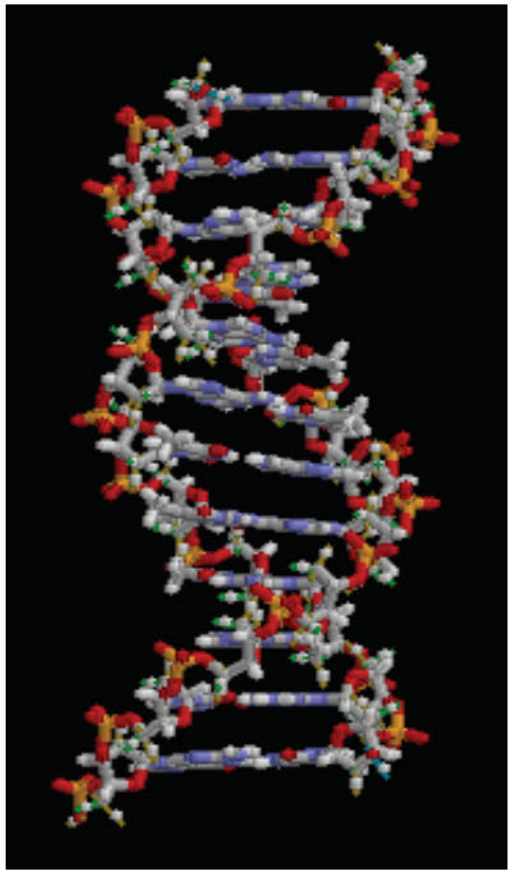
Cell Destruction

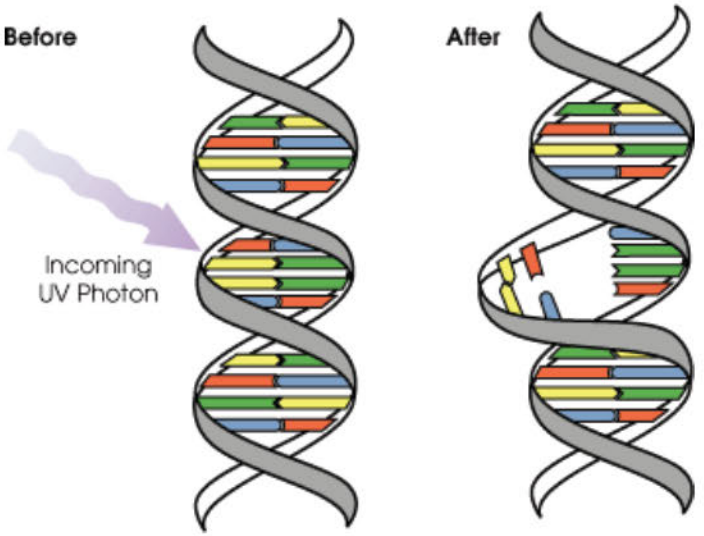


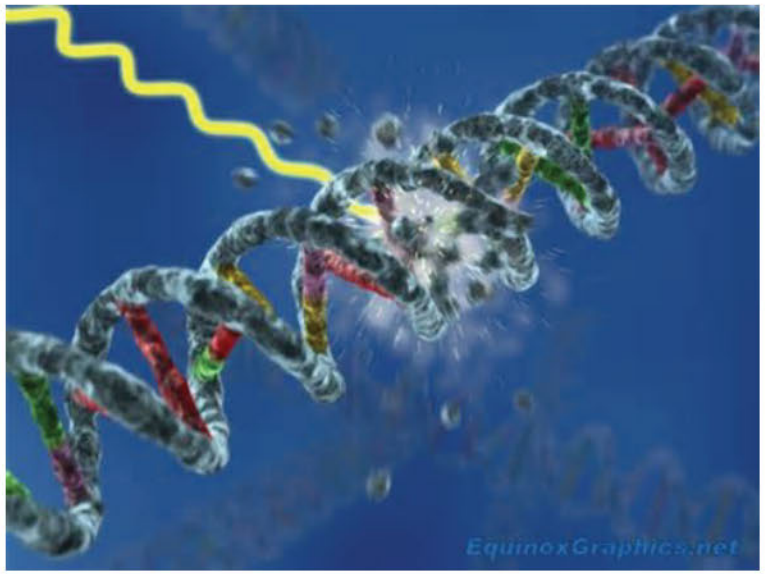
UV-C energy enters the cell

- Electromagnetic energy breaks through cell wall
- Damages DNA
- Cannot reproduce or feed
- Cell “Dies”

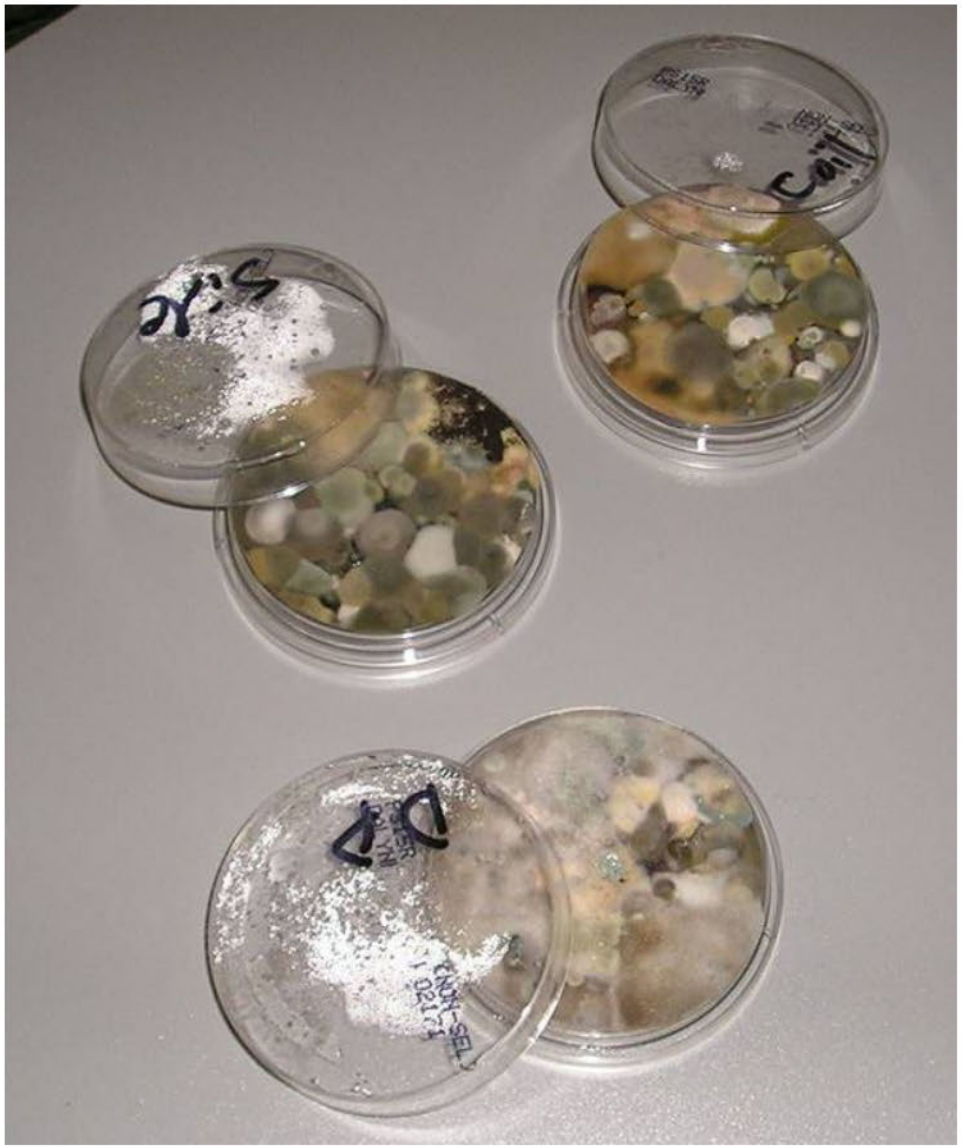
DNA Damage







Coil Surface Samples



Before UV

After UV

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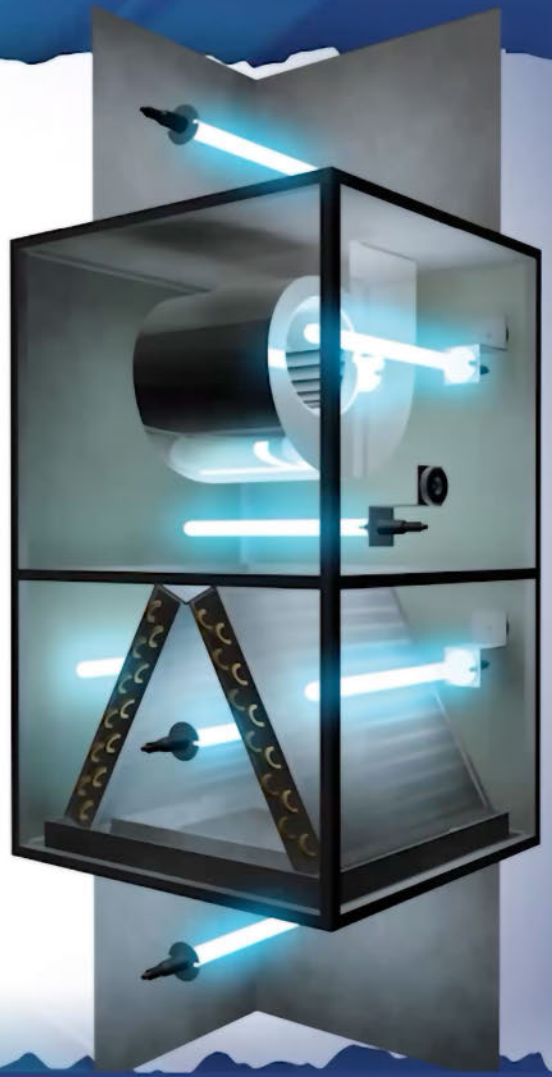
BLUE-TUBE UV®

- 24V / 110V models
- 1 and 2 year UV lamps
- Lifetime warranty
- Magnetic Bracket
- IP68 rated lamp plug



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(Time) x (Intensity) = Kill Rate

TIME: The longer the EXPOSURE TIME the more UV energy can be delivered resulting in a greater "Kill Rate".

INTENSITY: The stronger the UV source the more UV energy can be delivered to the contaminant resulting in a greater Kill Rate.

Dosage of UV-C for complete destruction (uW-sec/cm^2)

BACTERIA			
Agrobacterium Lumefaciens^	8,500	Streptococcus Lactis*	8,800
Bacillus Anthracis*(**Anthrax**)	8,700	Streptococcus Pyrogenes^	4,200
Bacillus Anthracis ***Spores***^(**Anthrax**)	46,200	Streptococcus Salivarius^	4,200
BaciHus Megatherium Sp. (Veg)*	2,500	Streptococcus Viridans*	3,800
Bacillus Megatherium Sp. (Spores)*	5,200	Typhoid Fever^	4,100
Bacillus Paratyphosus*	6,100	Vibrio Comma (Cholera)^	6,500
Bacillus Subtilis*	11,000	Vibrio Cholerae^	6,500
Bacillus Subtilis Spores*	22,000	**MOLDS**	
Clostridium Tetani^	23,100	Aspergillus Amstelodami^	77,000
Clostridium Botulinum^	11,200	Aspergillus Flavus*	99,000
Corynebacterium Diphtheriae*	6,500	Aspergillus Glaucus*	88,000
Dysentery Bacilli*	4,200	Aspergillus Niger (bread mold)*	330,000
Eberthella Typhosa*	4,100	Mucor Mucedo^	77,000
Escerichia Coli*	8,600	Mucor Racemosus (A & B)*	35,200
Legionella Bozemanii^	3,500	Oospora Lactis*	11,000
Legionella Dumoffiil^	5,500	Penicillium Chrysogenum^	56,000
Legionella Gormanil^	4,900	Penicillium Digitatum*	88,000
Legionella Micdadei^	3,100	Penicillium Expansum*	22,000
LegioneHa Longbeachae^	2,900	Penicillium Roqueforti*	26,400
Leglonella Pneumophfla		Rhizopus Nigricans (cheese mold)*	220,000
(Legionnaire's Disease)	2,760	**VIRUS**	
Leptospiracanicola-		Adeno Virus Type III^	4,500
Infectious Jaundice^	6,000	Bacterlophage (E.Coli)*	6,600
Leptospira Interrogans^	8,000	Coxsackie A2^	6,300
Micrococcus Candidus*	12,300	Infectious Hepatitis^	8,000
Micrococcus Sphaeroides*	15,400	Influenza*	3,400
Mycobacterlum Tuberculosis^	10,000	Rotavirus^	24,000
Neisseria Catarrhalis*	8,500	Poliovirus^	21,000
Phytomonas Tumefaciens*	10,500	Variola** (**Smallpox**)	24,000

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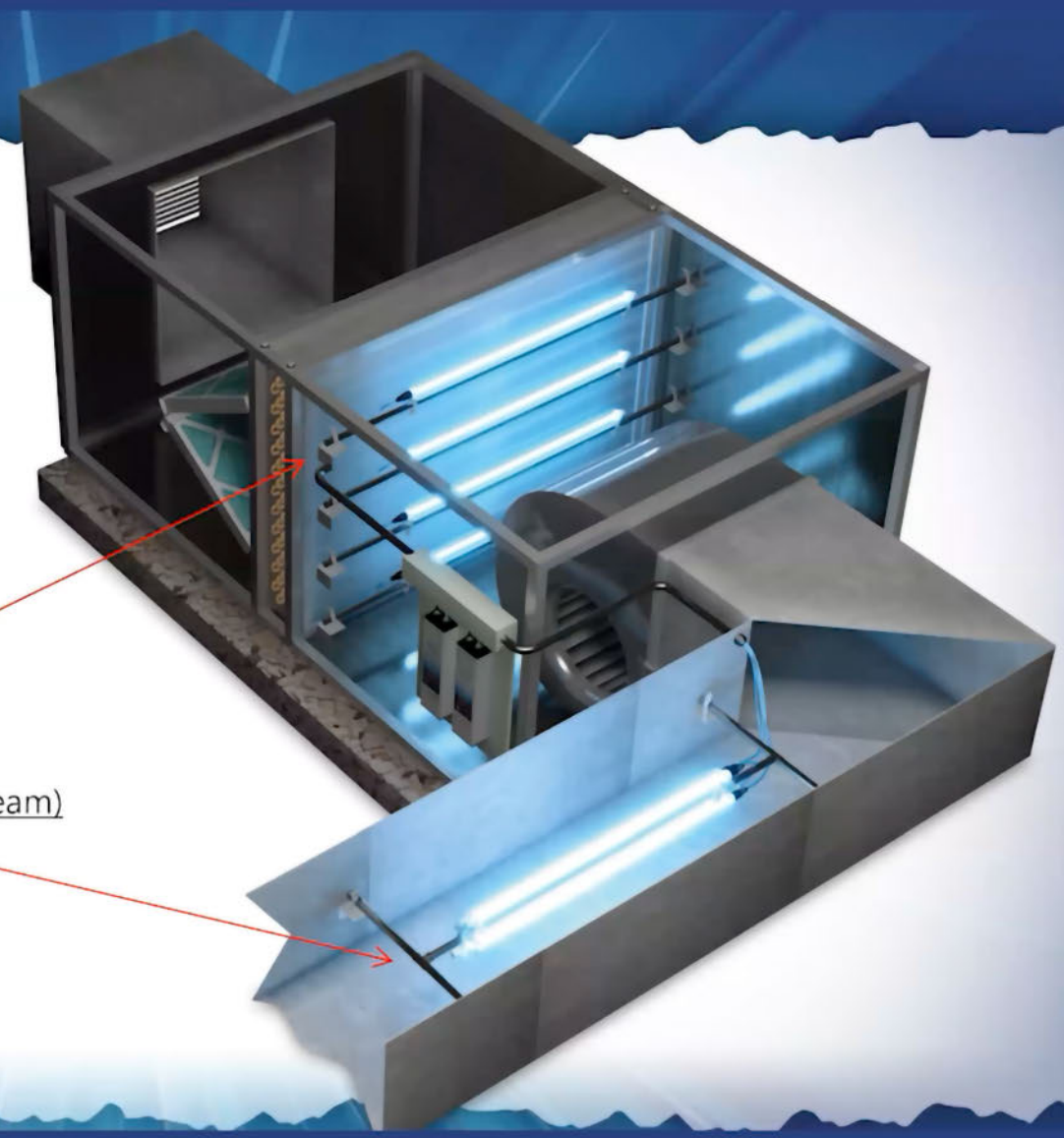
Commercial Systems



Surface disinfection (coils)
& Air Disinfection (>10 air changes per hour)

Airborne disinfection (airstream)
For low recirculation rates

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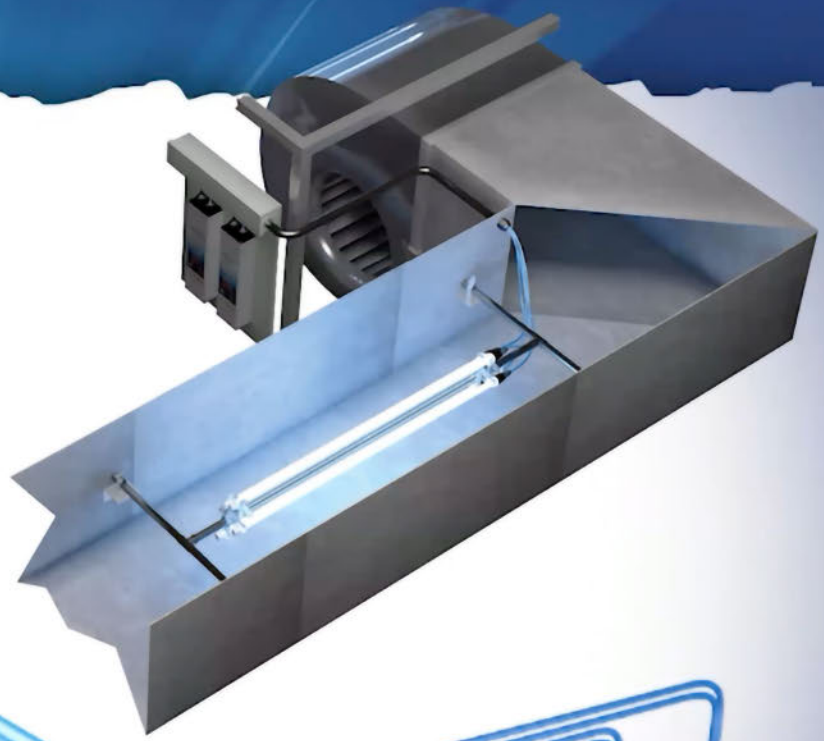
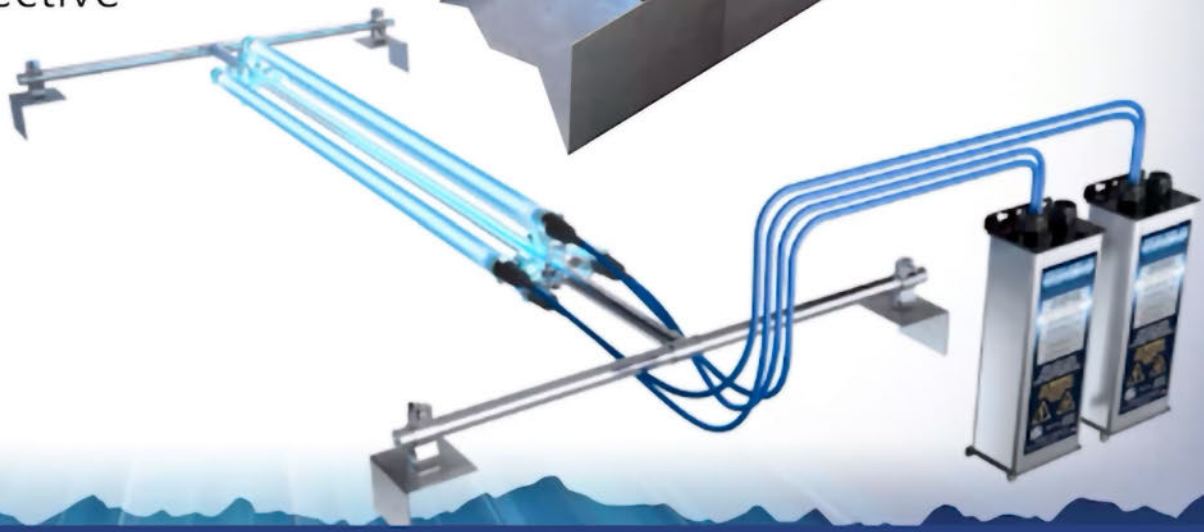
Airborne Disinfection

- Available from 18"- 60" HO UVC lamp lengths
- Modular design allows from 2-6 lamps per unit
- Flexible installation & cost effective
- Creates an intense UV field





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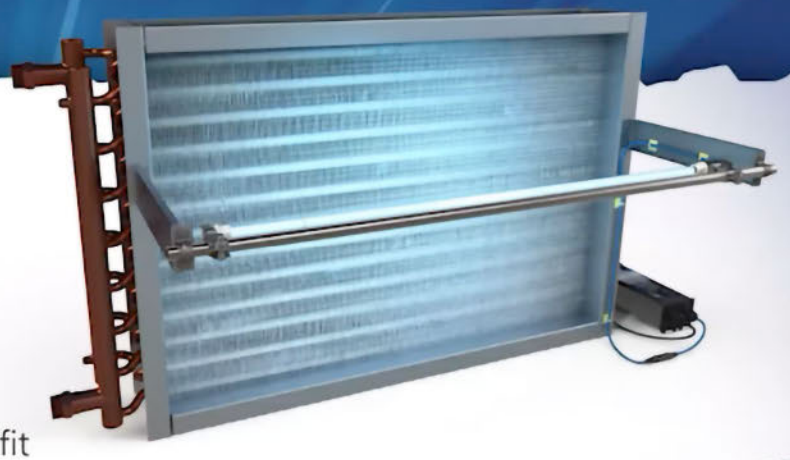
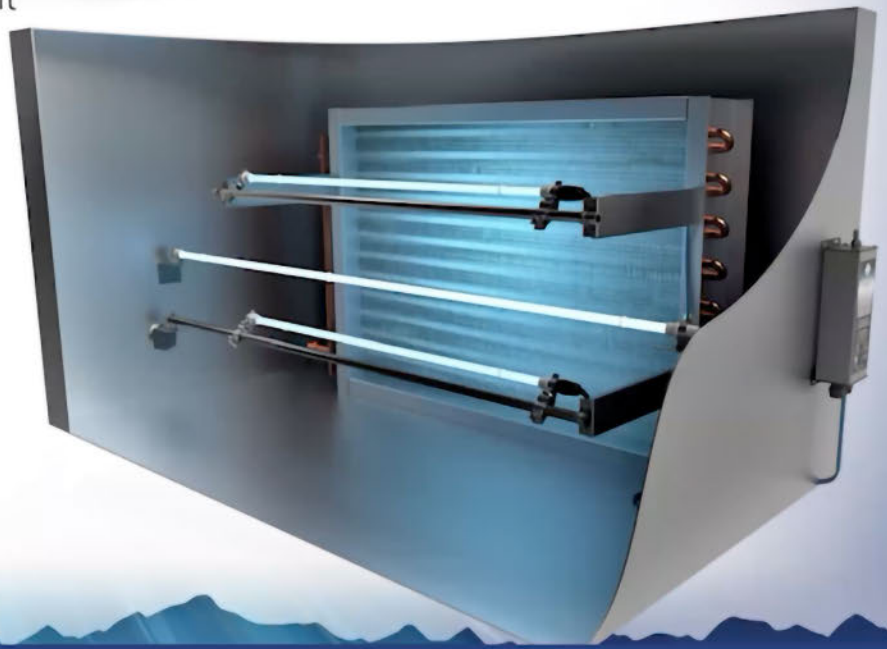
Coil Disinfection - Cleaning





- Allows for UVC light to be radiated throughout the entire AHU
- Designed to be built onsite for endless size combinations for exact fit
- High quality water-resistant lamps
- Water-resistant power supply, normal or high output
- Triatomic lifetime power supply warranty
- Includes all necessary mounting hardware except 0.5" EMT conduit
- Optional stainless steel tubing available

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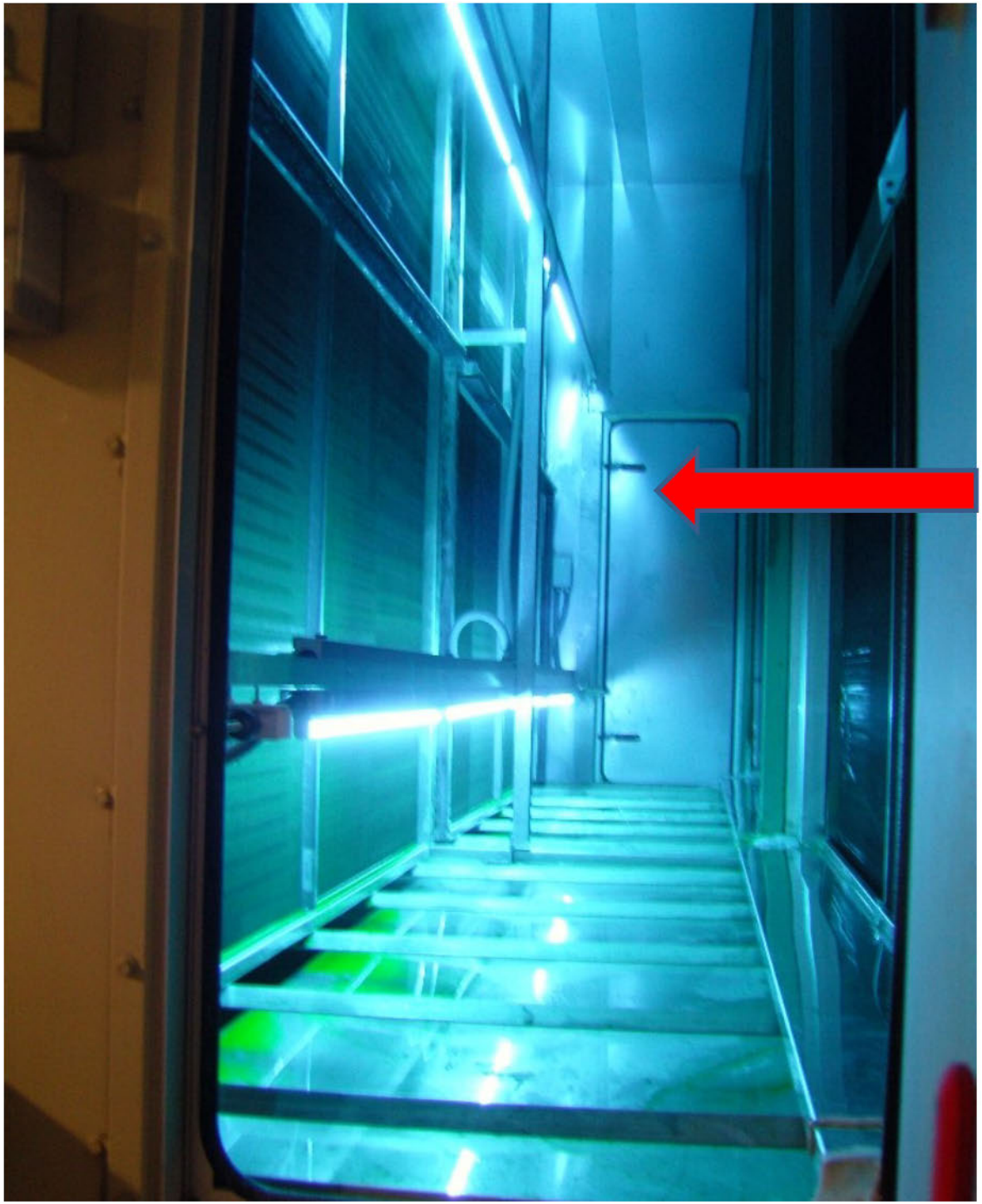
Tubular Rack System

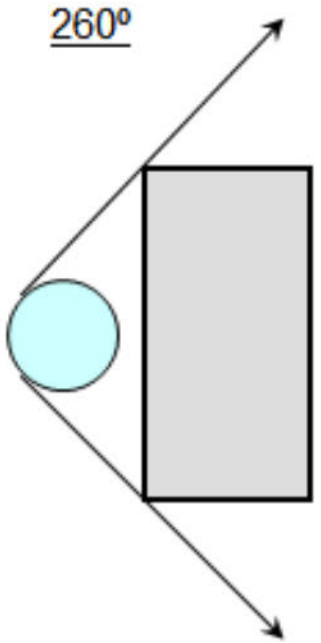
- Allows for UVC light to be radiated throughout the entire AHU
- Designed to be built onsite for endless size combinations for exact fit
- High quality water-resistant lamps & plugs
- Water-resistant power supply, normal or high output
- Lifetime power supply warranty
- Includes all necessary mounting hardware
  ½" EMT conduit field supplied
- Optional stainless-steel tubing available

360° UV-C Distribution

360° UV-C Distribution

- Provides best energy distribution
- Easier fit-up with fewest lamp lengths
- Remote ballasts
- Highest efficacy
- Lowest possible cost of ownership





Notice the light distribution.

Controls

- Toggle switch or Lock Out/Tag Out
  - Eliminates accidental operation
- Door interlocks (UL 1995)
  - Turns lights off when doors open
- Lamp/ Ballast Monitoring
  - Signals lamps on/off to BMS
- Radiometer
  - Usually seen for infection control or security applications

Surface Irradiation

95-98% of **ALL** UV-C applied in HVAC Systems is for Coil Irradiance and System Maintenance

- ☑ Coils, drain pans, fans, filters, plenum box, etc.
- ☑ Continuous & restorative cleaning
- ☑ Maintains as-built performance
- ☑ Energy savings, improved IAQ, & comfort benefits

UV-C Lamps

- 9,000 -18,000 hrs of useful life (ASHRAE recommends 9,000 hrs)
- Similar to fluorescent lamps
  - < 5.5 mg of mercury
  - Made on same machines
- Blue hue is only visible light
  - ~ 5% of lamp output is visible light (blue)
  - Blue light is not an indicator of the invisible UV-C wavelength!

The Value of Ultraviolet Disinfection Technology for Commercial HVAC

Germicidal Ultraviolet (GUV) lighting is a technology that harnesses the biological power of Ultraviolet Germicidal Irradiation (UVGI) — particularly short-wave UV-C in the 200 to 280 nanometer range on the UV spectral band — which has been proven to kill airborne & surface bacteria, mold spores, fungi and deactivate viruses, as validated by organizations including ASHRAE, CDC, GSA and the US Green Building Council who offer LEED green building credits for use of the technology.

When installed and configured by skilled technicians not only can UV-C lighting technology make our spaces healthier environments but also allow our HVAC and other mechanical systems to remain clean and run with greater efficiency, thus extending system life resulting in considerable cost savings over time.

In mechanical facility operations alone the applications are numerous, all resulting in reduced maintenance costs, liability risks and considerable ROI, including surface disinfection of air handler coils, airborne disinfection in ducts, and even disinfection of commercial ice machines. Surface disinfection, which is proven efficient and 99.9% effective, is the most common HVAC application, killing nearly all surface microbes in minutes.

Dirty coils waste money on energy with as little as .002" thickness of biofilm reducing HVAC systems efficiency by as much as 30% resulting in increased pressure drop, decreased air handler speeds and higher temperatures. An additional benefit includes reduced liability, particularly in healthcare facilities, where hospital acquired infections (HAIs) account for 1/20 of all patients with a cost of $30,000 per incident.

In a 2004 case study where a 27 year old 6,000 cfm air handler unit at Florida Hospital's (now AdventHealth) main campus in Orlando, Florida was suffering from a 50% blockage, within weeks after installing a UV-C system, static pressure over the coil decreased from 1.8"wg to 0.7"wg while air velocity over the coil more than doubled, from 230 fpm to 520 fpm. Visible evidence of mold and organic buildup had vanished and the air exiting wetbulb temperature decreased significantly from 57°F to 53°F. All of these factors contributed to a conservative estimate of 15% savings in HVAC system energy costs and once the UV-C systems were installed in the AHUs at all of Florida Hospital's facilities the energy savings totalled well into the six figures annually.

According to the EPA indoor air pollution is one of the top 5 health risks today. The indoor air we breath is often 5 times more polluted than the air outside and in some cases up to 100 times. As modern energy efficient buildings are increasingly engineered to prevent the escape of air, biological and chemical contaminants also remain trapped inside.

Indoor air pollution can be divided into thirds; particulates, mold/germs and odor causing volatile organic compounds (VOCs). While standard filtration is effective against particulates it has no effect on the other two thirds. These remaining biological contaminants and VOCs can be neutralized by supplementing HVAC filtration systems with UV-C technology.

A 2003 study conducted by The Lancet, one of the oldest and most highly respected medical journals, concluded that the utilization of GUV technology in three Montreal offices had a significant impact in reducing work-related illnesses; with a 20% overall decrease of all symptoms, a 40% decrease in respiratory symptoms and a 30% decrease in mucosal symptoms.

Ultimately, it was estimated that the installation of GUV technology in most North American offices could resolve common work-related symptoms caused by microbial contamination of HVAC systems in nearly 4 million employees resulting in increased productivity and additional ROI.

UV-C light works by breaking down the DNA & RNA of viruses, bacteria and other micro-organisms preventing them from replicating. The UV is absorbed by a chromophore, which creates intracellular reactive oxygen molecules, like hydrogen peroxide, that react with life-sustaining molecules.

In a very recent 2020 report by The Illuminating Engineering Society (IES) Photobiology Committee summarizes that "GUV applications can be used to reduce the spread of airborne infectious diseases such as tuberculosis, influenza virus, measles, SARS, and, presumably, SARS-CoV-2 (responsible for COVID-19)."

While the eradication of germs with beams of light can often sound like science fiction — germ killing UV robots roaming Pittsburgh International Airport for instance — the history of UVGI dates back to 1801 when German physicist Johann Ritter discovered the ultraviolet region of the spectrum. In 1903, Neils Finsen pioneered the use of UV-C therapy for the treatment of tuberculosis for which he was awarded the Nobel Prize.

UVC-HVACairhandlerThe earliest known applications of UV-C use in HVAC systems occurred in the mid-1900s. In the late 1950s, innovation into HVAC applications diminished as anti-biotics stole the stage in the battle against infection. Finally in 1995 the UV-C HVAC revival occurred when HVAC and UV treatment pioneer Forrest Fencl, co-founder of UV Resources, optimized the effectiveness of UV-C in the hostile air streams of HVAC systems.

Interest in the technology increased further following the 2014 Ebola virus outbreak in West Africa and today UV light disinfection is used widely in numerous applications for water treatment, agriculture, food processing, manufacturing, health care, construction and engineering for surface & airborne disinfection.

The many benefits of germicidal UV-C technology are clear, from considerable cost savings & decreased liability to employee health, welfare and productivity. To find out more about how you can increase your facility's efficiency and safety contact the experts here at Standard Plumbing & Heating. As always we will be happy to assist you promptly and professionally.

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ganisms that can be disseminated by infectious aerosols necessitate good design, construction, commissioning, maintenance, advanced planning, and emergency drills to facilitate fast action to mitigate exposure. In many countries, common strategies include naturally ventilated buildings and isolation. Control banding is a risk management strategy that should be considered for applying the hierarchy of controls to emerging pathogens, based on the likelihood and duration of exposure and the infectivity and virulence of the pathogen (Sietsema 2019) (Evidence Level B). Biological agents that may be used in terrorist attacks are addressed elsewhere (USDHHS 2002, 2003).

4. CONCLUSIONS AND RECOMMENDATIONS

Infectious aerosols can be disseminated through buildings by pathways that include air distribution systems and interzone airflows. Various strategies have been found to be effective at controlling transmission, including optimized airflow patterns, directional airflow, zone pressurization, dilution ventilation, in-room air-cleaning systems, general exhaust ventilation, personalized ventilation, local exhaust ventilation at the source, central system filtration, UVGI, and controlling indoor temperature and relative humidity. Design engineers can make an essential contribution to reducing infectious aerosol transmission through the application of these strategies. Research on the role of airborne dissemination and resuspension from surfaces in pathogen transmission is rapidly evolving. Managing indoor air to control distribution of infectious aerosols is an effective intervention which adds another strategy to medical treatments and behavioral interventions in disease prevention.

4.1 ASHRAE's Positions

- HVAC design teams for facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice. Based on risk assessments or owner project requirements, designers of new and existing facilities could go beyond the minimum requirements of these standards, using techniques covered in various ASHRAE publications, including the ASHRAE Handbook volumes, Research Project final reports, papers and articles, and design guides, to be even better prepared to control the dissemination of infectious aerosols.
- Mitigation of infectious aerosol dissemination should be a consideration in the design of all facilities, and in those identified as high-risk facilities the appropriate mitigation design should be incorporated.
- The design and construction team, including HVAC designers, should engage in an integrated design process in order to incorporate the appropriate infection control bundle in the early stages of design.
- Based on risk assessments, buildings and transportation vehicles should consider designs that promote cleaner airflow patterns for providing effective flow paths for airborne particulates to exit spaces to less clean zones and use appropriate air-cleaning systems. (Evidence Level A)
- Where a significant risk of transmission of aerosols has been identified by infection control risk assessments, design of AIIRs should include anterooms. (Evidence Level A)

- Based on risk assessments, the use of specific HVAC strategies supported by the evidence-based literature should be considered, including the following:
  - Enhanced filtration (higher minimum efficiency reporting value [MERV] filters over code minimums in occupant-dense and/or higher-risk spaces) (Evidence Level A)
  - Upper-room UVGI (with possible in-room fans) as a supplement to supply airflow (Evidence Level A)
  - Local exhaust ventilation for source control (Evidence Level A)
  - Personalized ventilation systems for certain high-risk tasks (Evidence Level B)
  - Portable, free-standing high-efficiency particulate air (HEPA) filters (Evidence Level B)
  - Temperature and humidity control (Evidence Level B)
- Healthcare buildings[8] should consider design and operation to do the following:
  - Capture expiratory aerosols with headwall exhaust, tent or snorkel with exhaust, floor-to-ceiling partitions with door supply and patient exhaust, local air HEPA-grade filtration.
  - Exhaust toilets and bed pans (a must).
  - Maintain temperature and humidity as applicable to the infectious aerosol of concern.
  - Deliver clean air to caregivers.
  - Maintain negatively pressurized intensive care units (ICUs) where infectious aerosols may be present.
  - Maintain rooms with infectious aerosol concerns at negative pressure.
  - Provide 100% exhaust of patient rooms.
  - Use UVGI.
  - Increase the outdoor air change rate (e.g., increase patient rooms from 2 to 6 ach).
  - Establish HVAC contributions to a patient room turnover plan before reoccupancy.
- Non-healthcare buildings should have a plan for an emergency response. The following modifications to building HVAC system operation should be considered:
  - Increase outdoor air ventilation (disable demand-controlled ventilation and open outdoor air dampers to 100% as indoor and outdoor conditions permit).
  - Improve central air and other HVAC filtration to MERV-13 (ASHRAE 2017b) or the highest level achievable.
  - Keep systems running longer hours (24/7 if possible).
  - Add portable room air cleaners with HEPA or high-MERV filters with due consideration to the clean air delivery rate (AHAM 2015).
  - Add duct- or air-handling-unit-mounted, upper room, and/or portable UVGI devices in connection to in-room fans in high-density spaces such as waiting rooms, prisons, and shelters.
  - Maintain temperature and humidity as applicable to the infectious aerosol of concern.
  - Bypass energy recovery ventilation systems that leak potentially contaminated exhaust air back into the outdoor air supply.
- Design and build inherent capabilities to respond to emerging threats and plan and practice for them. (Evidence Level B)

[8] It is assumed that healthcare facilities already have emergency response plans.

CHAPTER 62

ULTRAVIOLET AIR AND SURFACE TREATMENT

ULTRAVIOLET germicidal irradiation (UVGI) uses short-wave ultraviolet (UVC) energy to inactivate viral, bacterial, and fungal organisms so they are unable to replicate and potentially cause disease. UVC energy disrupts the deoxyribonucleic acid (DNA) of a wide range of microorganisms, rendering them harmless (Brickner et al. 2003; CIE 2003). Early work established that the most effective UV wavelength range for inactivation of microorganisms is between 220 and 280 nm, with peak effectiveness near 265 nm. The standard source of UVC in commercial systems is low-pressure mercury vapor lamps, which emit mainly near-optimal 253.7 nm UVC. Use of germicidal ultraviolet (UV) lamps and lamp systems to disinfect room air and air streams dates to about 1900 (Reed 2010). Riley (1988) and Shechmeister (1991) wrote extensive reviews of UVC disinfection. Application of UVC is becoming increasingly frequent as concerns about indoor air quality increase. UVC is now used as an engineering control to interrupt the transmission of pathogenic organisms, such as *Mycobacterium tuberculosis* (TB), influenza viruses, mold, and potential bioterrorism agents (Brickner et al. 2003; CDC 2002, 2005; GSA 2010; McDeVitt et al. 2008; Rudnick et al. 2009).

UVC lamp devices and systems are placed in air-handling systems and in room settings for the purpose of air and surface disinfection (Figure 1). Control of bioaerosols using UVC can improve indoor air quality (IAQ) and thus enhance occupant health, comfort, and productivity (ASHRAE 2009; Menzies et al. 2003). Detailed descriptions of UVGI components and systems are given in Chapter 17 of the 2016 *ASHRAE Handbook—HVAC Systems and Equipment*. Upper-air (also commonly called upper-room) devices are installed in occupied spaces to control bioaerosols (e.g., suspended viruses, bacteria, fungi contained in droplet nuclei) in the space. In-duct systems are installed in air-handling units to control bioaerosols in recirculated air that may be collected from many spaces, and to control microbial growth on cooling coils and other surfaces. Keeping the coils free of biofilm buildup can help reduce pressure drop across the coils and improve heat exchanger efficiency (therefore lowering the energy required to move and condition the air), and eliminates one potential air contamination source that could degrade indoor air quality. UVC is typically combined with conventional air quality control methods, including dilution ventilation and particulate filtration, to optimize cost and energy use (Ko et al. 2001).

This chapter discusses these common approaches to the application of UVC products. It also surveys the most recent UVC design guidelines, standards, and practices and discusses energy use and economic considerations for the application of UVC systems. Photocatalytic oxidations (PCOs), another UV-based HVAC application, are not discussed in this chapter, but are addressed in Chapter 47 of this volume.

The preparation of this chapter is assigned to TC 2.9, Ultraviolet Air and Surface Treatment.

1. FUNDAMENTALS

Ultraviolet energy is electromagnetic radiation with a wavelength shorter than that of visible light and longer than x-rays (Figure 2). The International Commission on Illumination (CIE 2003) defines the UV portion of the electromagnetic spectrum as radiation having wavelengths between 100 and 400 nm. The UV spectrum is further divided into UVA (wavelengths of 400 to 315 nm), UVB (315 to 280 nm), UVC (280 to 200 nm), and vacuum UV (VUV; 200 to 100 nm) (IESNA 2000). The optimal wavelength for inactivating microorganisms is 265 nm (Figure 3), and the germicidal effect decreases rapidly if the wavelength is not optimal.

UV Dose and Microbial Response

This section is based on Martin et al. (2008).

UVGI inactivates microorganisms by damaging the structure of nucleic acids and proteins at the molecular level, making them incapable of reproducing. The most important of these is DNA, which is responsible for cell replication (Harm 1980). The nucleotide bases (pyrimidine derivatives thymine and cytosine, and purine derivatives guanine and adenine) absorb most of the UV energy responsible for cell inactivation (Diffey 1991; Setlow 1966). Absorbed UV photons can damage DNA in a variety of ways, but the most significant damage event is the creation of pyrimidine dimers, where two adjacent thymine or cytosine bases bond with each other, instead of across the double helix as usual (Diffey 1991). In general, the DNA molecule with pyrimidine dimers is unable to function properly, resulting in the organism's inability to replicate or even its death (Diffey 1991; Miller et al. 1999; Setlow 1997; Setlow and Setlow 1962). An organism that cannot reproduce is no longer capable of causing disease.

UVGI effectiveness depends primarily on the UV dose (D_{UV}, $\mu J/cm^2$) delivered to the microorganisms:

$$D_{UV} = It \tag{1}$$

where I is the average irradiance in $\mu W/cm^2$, and t is the exposure time in seconds (note that 1 J = 1 W/s). Although Equation (1) appears quite simple, its application can be complex (e.g., when calculating the dose received by a microorganism following a tortuous path through a device with spatial variability in irradiance). The dose is generally interpreted as that occurring on a single pass through the device or system. Although the effect of repeated UV exposure on microorganisms entrained in recirculated air may be cumulative, this effect has not been quantified, and it is conservative to neglect it.

The survival fraction S of a microbial population exposed to UVC energy is an exponential function of dose:

$$S = e^{-kD_{UV}} \tag{2}$$

where k is a species-dependent inactivation rate constant, in $cm^2/\mu J$. The resulting single-pass inactivation rate η is the complement of S:

$$\eta = 1 - S \tag{3}$$

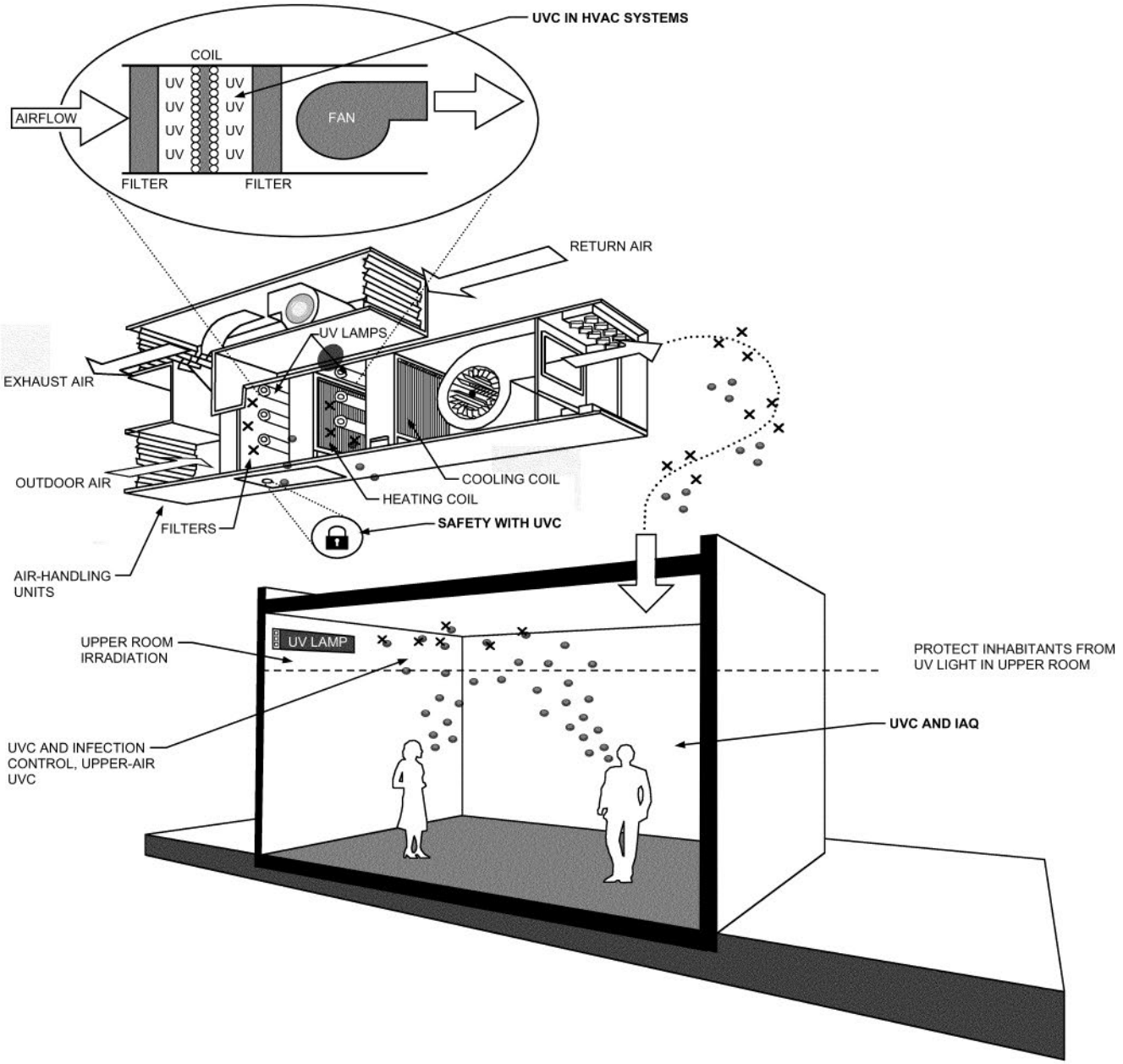

Fig. 1 Potential Applications of UVC to Control Microorganisms in Air and on Surfaces
(ASHRAE 2009)

and is a commonly used indicator of overall UVC effectiveness, representing the percentage of the microbial population inactivated after one pass through the irradiance field(s).

Inactivation rate constants (k-values) are species-dependent and relate the susceptibility of a given microorganism population to UV radiation (Hollaender 1943; Jensen 1964; Sharp 1939, 1940). Measured k-values for many species of viruses, bacteria, and fungi have been published in the scientific literature and previously summarized (Brickner et al. 2003; Kowalski 2009; Philips 2006). As shown in Figure 4, bacteria are generally more susceptible to UVC energy than fungi, but this is not always the case (see Chapter 17 of the 2016 *ASHRAE Handbook—HVAC Systems and Equipment*). It is more difficult to generalize when it comes to viruses. Reported k-values for different species of microorganisms vary over several orders of magnitude. Consequently, choosing which k-value to use for UVC system design is often difficult and confusing. The variation in reported k-values makes generalizing the use of Equation (2) particularly complicated for heterogeneous microbial populations. Even accurately determining S for one specific microorganism can be difficult, because the reported k-values for the same species sometimes differ significantly.

Variations in published k-values may relate to differences in conditions under which the UV irradiance of the microbial population was conducted (in air, in water, or on surfaces), the methods used to measure the irradiance level, and errors related to the microbiological culture-based measurements of microbial survival (Martin et al. 2008). Because no standard methods are currently available for the determination of inactivation rate constants, care is necessary when applying values reported in the literature to applications under different environmental conditions.

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Brief Report

Susceptibility of SARS-CoV-2 to UV Irradiation

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Highlights

- SARS-CoV-2 is highly susceptible to irradiation with ultraviolet light
- High viral loads of 5 *10^6 $TCID_{50}$/ml SARS-CoV-2 can be inactivated in 9 minutes by UVC irradiation
- UVC irradiation represents a suitable disinfection method for SARS-CoV-2

Abstract

The coronavirus SARS-CoV-2 pandemic became a global health burden. We determined the susceptibility of SARS-CoV-2 to irradiation with ultraviolet light. The virus was highly susceptible to ultraviolet light. A viral stock with a high infectious titer of 5×10^6 $TCID_{50}$/ml was completely inactivated by UVC irradiation after nine minutes of exposure. The UVC dose required for complete inactivation was 1048 mJ/cm^2. UVA exposure demonstrated only a weak effect on virus inactivation over 15 minutes. Hence, inactivation of SARS-CoV-2 by UVC irradiation constitutes a reliable method for disinfection purposes in health care facilities and for preparing SARS-CoV-2 material for research purpose.

Background

In December 2019, a novel coronavirus causing severe acute respiratory disease (SARS-CoV-2) was newly identified in the Hubei province, PR China, before becoming a global pandemic and causing tremendous health and socio-economic burdens[1]. At the time of writing, more than 14.9 million cases and >618,000 deaths were reported worldwide (2020.07.23). The actual number of people infected with SARS-CoV-2 is most likely to be much higher since numerous infections, especially in younger people, are asymptomatic and frequently not captured by routine diagnostic methods[2]. The symptoms of COVID-19 range from mild respiratory illness accompanied by cough, fever, myalgia, and fatigue, to severe, life-threatening pneumonia and acute respiratory distress syndrome (ARDS)[3]. Clearly, the prevention of the transmission of respiratory infections especially within hospitals or other institutions is of central importance. The disinfection of objects using UV-irradiation is an environmentally friendly method of killing bacteria, fungi and viruses without the use of harmful chemicals or heat. Consequently, UV light disinfection is becoming increasingly applied in healthcare facilities for disinfecting healthcare equipment, surfaces and operating rooms [4]. However, the efficacy of UV irradiation on the inactivation of SARS-CoV-2 in fluids has not been described thus far. In the present study, we investigated the susceptibility of high titer viral stocks of SARS-CoV-2 to combined or separate UVA and/or UVC irradiation.

Material and Methods

Isolation of SARS-CoV-2 from a nasopharyngeal swab

A clinical isolate of SARS-CoV-2 was isolated from a nasopharyngeal swab of a patient suffering from COVID-19 disease. The patient was hospitalized at the Department of Infectious Diseases of the University Hospital Essen. The swab was taken using a Virocult® vial (Sigma, Germany). The Virocult® medium was then incubated on Vero E6 cells cultured in DMEM containing 10% (v/v) fetal calf serum and supplemented with Penicillin (100 IU/ml), Streptomycin (100 µg/ml), Ciprofloxacin (10 µg/ml) and Amphotericin B (2.5 µg/ml). After five days of incubation, the supernatant was harvested and cell debris was removed by centrifugation. Afterwards, 100 µl of the clear supernatant was used for subsequent infection of a new Vero E6 cell culture flask. After five days of incubation, supernatants were found to be positive for SARS-CoV-2 by a conventional qualitative PCR. The virus suspension was harvested and cleared from cellular debris by centrifugation and stored at -80°C. Viral titers were determined by endpoint dilution assay and the 50% tissue culture infective dose ($TCID_{50}$) was calculated.

Inactivation of SARS-CoV-2 by UV-irradiation

To determine the susceptibility of SARS-CoV-2 to UVA and/or UVC irradiation, a viral stock at a concentration of 5×10^6 $TCID_{50}$/ml was irradiated with UV light for up to 30 minutes. UV exposure was performed by separate or combined irradiation with UVC (254 nm) and/or UVA (365 nm) of 600 µl virus stock in 24-well plates. The UV light source (UV-4 S/L, order no. 2950440, Herolab, Wiesloch, Germany) was placed at a distance of 3 cm above the bottom of the plate. The emitted light intensity was UVC (254 nm)=1940 $\mu W/cm^2$ and UVA (365 nm)=540 $\mu W/cm^2$ at a distance of 3 cm, as measured by radiometric analysis. This corresponds to an applied light dose of 1.94 mJ/cm^2 per second for UVC and 0.54 mJ/cm^2 per second for UVA, while $\mu W=10^{-6}$ J/s. The samples were taken after 0, 3, 6, 9, 12, 15, 18, 21, 24, 27 and 30 minutes of combined UVA and UVC irradiation. Samples irradiated with UVA were taken after 0, 3, 6, 9, 12, 15 minutes, and after UVC-irradiation after 0, 1, 2, 3, 6, 9 and 15 minutes. The $TCID_{50}$/ml concentration of each sample was determined by endpoint dilution, respectively.

Results

SARS-CoV-2 showed high susceptibility to UV irradiation. Total inactivation of SARS-CoV-2 at a concentration of 5×10^6 $TCID_{50}$/ml was achieved after 9 minutes of combined UVA and UVC exposure (Figure 1A). As calculated by nonlinear regression, 50% of the virus could be inactivated after 1.4 minutes of UV-treatment (Figure 1B). UVA exposure alone was less effective on virus inactivation. After 9 minutes of irradiation and an emitted dose of 292 mJ/cm^2, one log reduction of the viral load was observed. In contrast, complete virus inactivation was achieved after a 9 minute exposure to UVC and an emitted UVC dose of 1048 mJ/cm^2. These data confirm former findings that UVC is more effective in inactivating viruses, and highlight UVC irradiation as an effective method for the inactivation of SARS-CoV-2.

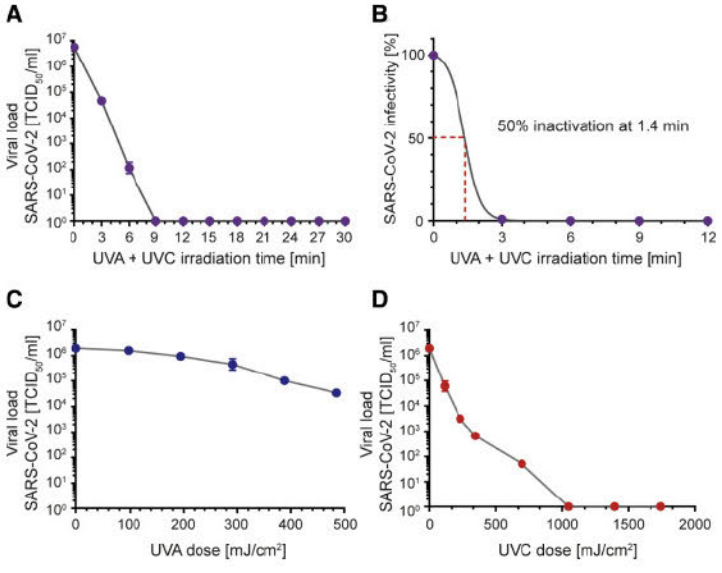

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Figure 1. **Inactivation of SARS-CoV-2 by UV irradiation.** SARS-CoV-2 at a starting concentration of 5×10^6 $TCID_{50}$/ml was irradiated with ultraviolet light (UV). UV treatment was performed by irradiation with UVC (254 nm) and/or UVA (365 nm) on 600 µl aliquots of virus in 24-well plates. The UV light source was placed at a distance of 3 cm above the bottom of the plate. Viral loads were determined by end point dilution after **(A)** combined UVA/UVC exposure at the indicated time points or separate exposure to **(C)** UVA light after 0, 3, 6, 9, 12 and 15 minutes or **(D)** UVC light after 0, 1, 2, 3, 6, 9, 12 and 15 minutes. **(B)** Non-linear regression was conducted to calculate the duration of combined UVA and UVC irradiation sufficient to inactivate the virus by 50%. The emitted light dose was measured with=1940 µW/cm^2 for UVC (254 nm) and 540 µW/cm^2 for UVA (365 nm) at a distance of 3 cm. This corresponds to an applied light dose of 1.94 mJ/cm^2 per second for UVC and 0.54 mJ/cm^2 per second for UVA (µW=10^{-6} J/s). The experiments were performed in triplicates. Error bars represent the standard deviation of the mean.

Discussion

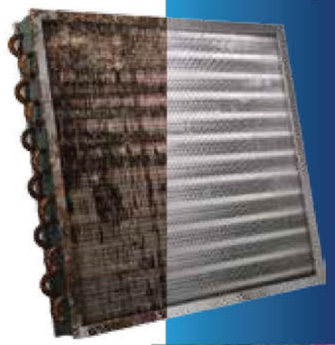
In the present study, we demonstrated that SARS-CoV-2 could effectively be inactivated by UVC irradiation, even at high viral titers, whereas UVA-irradiation was much less effective. These data are in line with previous reports where other coronaviruses e.g. SARS-CoV-1 were shown to be susceptible to UVC irradiation [5], [6], [7]. Viral stocks with titers of 1×10^6 $TCID_{50}$/ml of SARS-CoV-1 could be almost completely inactivated after 6 minutes of UVC-irradiation, corresponding to a UVC dose of 1446 mJ/cm^2 [5]. In our study, the emitted dose required for a complete inactivation of SARS-CoV-2 was 1048 mJ/cm^2 after 9 minutes of exposure. A similar dose of 1 J/cm^2 was also required to inactivate a viral load of $1 * 10^6$ $TCID_{50}$ H1N1 influenza virus [7]. UV light disinfection is chemical free and thus a suitable method for applying in healthcare facilities to disinfect healthcare equipment [4]. Most recently, a protocol for the disinfection of personal protective equipment (PPE) including filtering face pieces from health care workers described the potential use of ultraviolet light to inactivate SARS-CoV-2 [6]. Taken together, we demonstrated that UV irradiation is a highly effective method to inactivate the new corona virus SARS-CoV-2, even at the higher viral load levels that are found in research laboratories e.g. in cell-culture supernatants or in diagnostic material taken from the respiratory tract of COVID-19 patients.

Conclusion

We demonstrated that SARS-CoV-2, even at high viral titers, could be inactivated rapidly by UVC irradiation, revealing that this method is reliable not only for disinfection purposes in health care facilities but also for preparing inactivated SARS-CoV-2 material for research.

Coils with Mold

Coils with UV Light



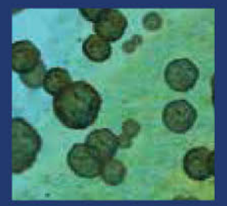
CLEAN COILS

UV light inhibits mold growth in the AC system which saves energy & maintenance costs.

FIGHT GERMS

UV light kills germs making indoor air healthier for everyone in the home.


Bacteria


Mold


Viruses


Allergens