MODULE 137

HVAC&R SKILLS WORKSHOP

ULTRAVIOLET GERMICIDAL IRRADIATION

Skills summary

What?

An introduction to ultraviolet germicidal irradiation (UVGI) as a disinfection or sterilisation method.

Who?

Relevant for HVAC&R system designers, installers, operators, and maintainers.

Ultraviolet germicidal irradiation (UVGI) is a disinfection or sterilisation method that uses ultraviolet (UV-c) light at sufficiently short wavelength to break down or degrade organic material and inactivate microorganisms. It is used in a variety of applications including food, air and water purification.

UVGI utilises the short wavelength of UV that is harmful to forms of life at the microorganic level. It is effective in destroying the nucleic acids in these microorganisms, so that their DNA is disrupted by the UV radiation. This removes their reproductive capabilities and kills them. The wavelength of UV that causes this effect is rare on Earth because the atmosphere effectively blocks it.

PULLOUT

Introduction

Using a UVGI device in air systems creates a deadly effect on any microorganisms such as pathogens, viruses and moulds that are in these environments. The system is not a filter; inactive particles remain in the airstream and, in the case of dead fungal spores, may still cause a negative human response due to their integral mycotoxins.

Coupled with an air-filtration system, UVGI can remove harmful microorganisms from these environments. UVGI is best applied in conjunction with pre-filtration to protect lamps and filtration downstream of the system to remove the inactivated microbes.

UVGI theory

Ultraviolet light is electromagnetic radiation with wavelengths shorter than visible light.

UV can be separated into various ranges, with short-range UV-c considered "germicidal UV". At certain wavelengths UV is mutagenic to bacteria, viruses and other microorganisms. At a wavelength of 2,537 Angstroms (254nm), see Figure 1, UV will break the molecular bonds within microorganismal

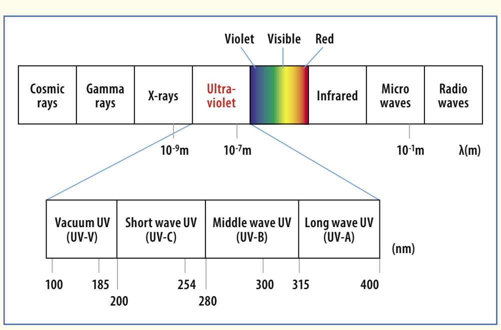


Figure 1: UV inactivates microorganisms at a wavelength of 2,537 Angstroms (254nm).

DNA, producing thymine dimers in their DNA thereby destroying them, rendering them harmless or prohibiting growth and reproduction. Ultraviolet radiation in the range of 2250 to 3020 angstroms is used in a variety of UVGI disinfection applications.

It is a process similar to the UV effect of longer wavelengths (UV-b) on humans, such as sunburn or sun glare. Microorganisms have less protection from UV-c, which does not occur naturally on Earth, and they cannot survive prolonged exposure to it.

An HVAC UVGI system is designed to expose the air stream (or surface) to germicidal UV-c shortwave radiation. Exposure comes from germicidal lamps, which emit germicidal UV-c electromagnetic radiation at the correct wavelength, irradiating the passing air or the protected surface. Lamps use a gas-filled tube with no phosphor coating and composed of fused quartz because ordinary glass absorbs UV-c. The typical source of UV-c in commercial HVAC systems is low-pressure mercury vapour lamps, which emit near optimal wavelength, see Figure 2. The lamps are designed to specifically emit 254nm ultraviolet radiation.

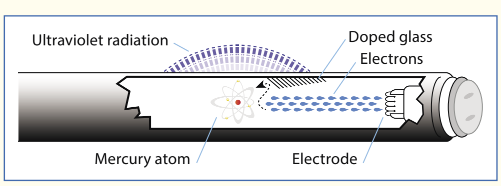


Figure 2: UV-c Lamp.

Usual UVGI lamps produce most of their output at a 254nm peak wavelength, when the optimum bacterial 'kill' is at about 265 nm (it varies with species). The optimal kill wavelength at 265nm is about 15% better than at 254nm, so the usual 254nm lamp kills with a high efficiency.

The effectiveness of germicidal UV-c in an HVAC environment depends on a number of factors including the:

- Length of time a microorganism is exposed to UV-c (exposure/dwell time)
- Presence of particles that can protect the microorganisms from UV-c
- Type of microbial contaminant (specific species) and the microorganism's inherent ability to withstand UV-c exposure
- Lamp distance and placement, air movement and patterns, temperature; relative humidity and air mixing
- Power fluctuations to the UV-c source that may impact the electromagnetic wavelength produced
- Lamp life cycle and cleanliness.

Contaminants targeted by UVGI

Given enough intensity and exposure duration UV-c kills or deactivates bacteria (including spores), fungi, DNA viruses and RNA viruses. It damages prions, but it is not proven that it permanently disables them. DNA and RNA are helical arrangements of various sequences of 4 amino acids – adenine, thymine, guanine and cytosine in the case of DNA. In RNA uracil replaces thiamine.

UV affects DNA mainly by breaking it, causing adjacent thymine amino acids to join together forming thymine dimers. DNA may self-repair after this process, so enough UV-c must be used to overwhelm any repair process. RNA is similarly affected but UV-c mainly acts on the uracil amino acid.

UVGI can control microbial growth on surfaces that are subject to moisture or high humidity; coils, ducts, filters, humidifiers. Microbial growth that can be controlled include fungi, bacteria, or even algae, but not viruses. The variety of microbes encountered by a given UVGI system is unpredictable and depends on the application (type of facility) and geographical location.

Spores, which are larger and more resistant to UVGI than most bacteria, can be controlled effectively through the use of high-efficiency filters. The coupling of filters with UVGI is the recommended practice in UVGI applications in general.

While the sterilisation of medical equipment using UVGI is a common and reliable practice, the disinfection of airstreams using UVGI has a history of varying success and unpredictable performance. A distinction exists between the terms "disinfection" and "sterilisation." Sterilisation is defined as the complete destruction of all microbial species. Disinfection is merely the reduction of microbial population. HVAC airstreams are generally disinfected, not sterilised.

Health effects of UVGI

UV radiation kills microorganisms. UV radiation damages people – for example it can cause skin cancer and damage the eyes (photokeratitis). Also, it helps vitamin D generation in the body and has minor medical uses. Disinfection is a major use.

There is limited evidence on the direct effects of UV-c on health, particularly when applied outside of healthcare settings. UVGI has been shown to be effective in reduction of microbial and endotoxin agents, which can breed and accumulate in HVAC systems, especially where condensation of water vapour occurs; however, no direct evidence of health benefits exists. UVGI for in-duct and in-room systems was named by ASHRAE as among the two highest research priorities for developing engineering controls to reduce infectious disease transmission.

Fungal contamination found in ventilation systems may contribute to fungal infections in individuals. A UVGI system is not a filter; inactive particles remain in the airstream and may still cause a negative human response. Using particulate filters in association with UVGI improves the potential health benefits.

Types of UVGI systems

The UV light germicidal effect is used in assorted medical applications (e.g. UV sterilisers). It is also used to treat potable water supplies. The types of UVGI systems developed for building and air-handling-unit (AHU) applications include:

- In-duct systems
- Microbial growth control (surface.disinfection systems)
- Room recirculation systems
- Upper-air systems.

Direct UVGI exposure can sterilise any surface if given enough time.

Use of UV in for treating air in ducts or rooms (outside of the medical context) does not seem to be common in Australia, but appears to have a wider use in the USA.

The use of UVGI as a HVAC surface-disinfection system is not uncommon in Australia.

The first step in the design of an airstream – or surface-disinfection – UVGI system is to characterise the application. This includes describing the airstream (air volume, velocity, temperature and humidity), identifying the specific surfaces to be treated, and possibly targeting specific microbes (the likely air contaminants).

Performance of UVGI lamps

UVGI for HVAC application is usually generated by shortwave UV-c lamps, which use a lamp tube with no phosphor coating and composed of fused quartz. These lamps emit ultraviolet light with two peaks in the UVC band at 253.7nm and 18 5nm due to the mercury within the lamp – as well as some visible light. One type of quartz glass allows only the nominal 254nm wavelength light to pass, another allows both to pass.

254nm lamps are primarily used for germicidal use. Because this usage may be near people these lamps should not emit ozone.

ASHRAE Standard 185 establishes a test method for evaluating the efficacy of UV-c lights for their ability to inactivate airborne microorganisms. Part one covers duct or airflow irradiation and part 2 covers surface irradiation. The results of these tests can be used to directly compare UVGI equipment on a standardised basis, irrespective of their application. Results from these tests give the design engineer a basis for specifying UV devices or estimating the relative performance of UVGI for a given application.

- ASHRAE 185.1 provides a method for testing UV-c lights for use in air handling units or air ducts to inactivate airborne microorganisms
- ASHRAE 185.2 provides a method of testing ultraviolet lamps for use in HVAC units or air ducts to inactivate microorganisms on irradiated surfaces.

Applying UVGI

Chemical and mechanical cleaning of HVAC systems to control microbial growth can be costly, difficult to perform, and dangerous to maintenance staff and building occupants. System performance can begin to degrade again shortly after cleaning as organic and microbial deposits begin to reappear or reactivate.

UVGI is a way to prevent or reduce the growth of bacteria and mould on system components and keep surfaces clean continuously, rather than periodically restoring fouled surfaces. This can mean reduced maintenance cost and improved HVAC system performance.

Removing and suppressing the formation of biofilms and organic growth on coils should reduce air-side pressure drop, increase heat transfer coefficient, and reduce fan and refrigeration system energy consumption.

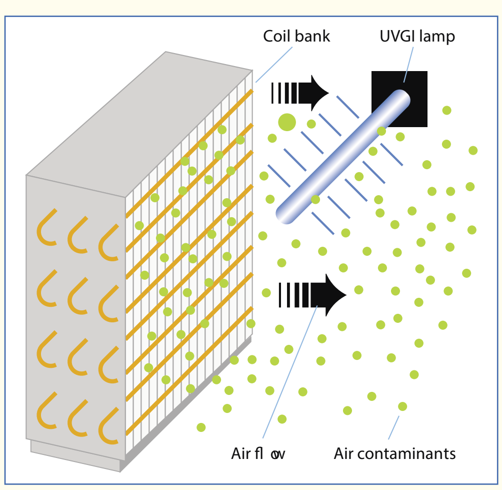


Figure 3: Coil irradiance in HVAC.

Most UVGI applied in HVAC systems is for coil irradiance to assist system maintenance and provide continuous cleaning to surfaces of coils, drain pans, filters and mixing boxes, see Figure 3. The UV light must reach the actual contamination (direct line of sight) and any light blockage by filter material or coil fins must be avoided. UV light may not adequately penetrate stagnant condensate or biofilms in corners of trays, etc.

Correctly applied UVGI coil irradiance can help maintain as-built performance and generate energy savings, improved IAQ, and comfort benefits for existing systems. In new constructions it is applied as a preventative measure to help maintain as-built conditions, in retrofit projects it is often used as a problem-solving measure.

UVGI eliminates or reduces the build-up of organic material on surfaces. This:

- Improves or maintains airflow
- Returns and/or retains design heat-transfer levels
- Reduces maintenance cleaning (inspection is still required).

The system tends to be gentler on coils than mechanical cleaning alternatives and can prolong system life.

Clean coils and HVAC surfaces will help improve indoor air quality (IAQ) by reducing mould products, pathogens and odours, which can improve comfort levels and improve productivity.

UVGI system design parameters

A number of parameters must be considered when considering UVGI products for HVAC designs. The most crucial factors are the:

- Air-flow or HVAC equipment that will be disinfected
- Lamp wattage and distance
- Ventilation system design.

The characteristics of an airstream that impact UVGI design are relative humidity (RH), temperature, and air velocity.

Increased RH is believed to decrease decay rates under ultraviolet (UV) exposure.

Air temperature has a negligible impact on microbial susceptibility to UVGI, but it can impact the power output of UVGI lamps, particularly where manufacturer design values are exceeded. Excessive lamp operating temperature can significantly degrade system performance.

Operating a UVGI system at air velocities above manufacturers' design limits can also degrade the system performance. The cooling effect of the higher air velocity on the lamp surface will cool the plasma inside of the lamp and reduce UV-c output.

Designing UVGI systems

UVGI units are commonly located in an AHU, downstream from the mixing box, typically downstream from the filter bank and upstream from the cooling coils.

UV-c output is a function of plasma temperature when power input is constant.

Data from the manufacturer should be consulted to determine the cooling effects or the limiting design air velocities and temperatures within which the lamps can be operated efficiently.

Doses are determined by the time of exposure and UVGI intensity, both of which are dependent on the velocity profile and the degree of air mixing and turbulence in the airstream.

The design velocity of a typical UVGI unit is similar to that for a filter bank.

Survival predictions for mixed- and unmixed-flow conditions differ in systems in which the lamps do not span the duct's entire width or length.

Dust, dirt or any other films coating the UV lamp surface can lower UV output. Therefore, lamps require scheduled inspection and cleaning as well as periodic replacement to ensure continued effectiveness. The lifetime of UVGI lamps varies depending on design and manufacture.

UVGI for airstream disinfection

The effectiveness of this form of disinfection is dependent on line-of-sight exposure of the microorganisms to the UV light. Environments where designs have created obstacles that block the UV light are not as effective. The placement of the UVGI lamps must achieve line of sight for disinfection to be achieved.

Removal rates depend on filtration rates, outdoor air rates, and the level of microbial contaminants in the untreated airstream (the contaminant challenge). The following design parameters must be considered when sizing a UVGI system for airstream disinfection:

- Duct height, width and length where air is exposed to UV-c
- Air velocity and temperature/humidity range
- Lamp de-rating due to cooling and fouling
- Air contaminant challenge, microorganism types and their sensitivity to UV
- Disinfection performance required
- Type and power of UV-c lamp(s)
- Reflectivity of duct materials, liner, surfaces.

Where the enclosing surfaces are highly reflective, reflectivity, can be an economical way of intensifying the UVGI field in an enclosed duct or chamber. Inter-reflected light, specular and diffuse reflection, contributes to the initial direct intensity. Note that some materials reflect visible light but not UV light. Polished aluminium for example is highly UV reflective, while copper is not.

Operating a UVGI system to disinfect a moving airstream may not provide adequate killing rates because of the short dwell time. Under ideal conditions, inactivation and/or killing rates of 90% or higher can be achieved, but performance depends on the following:

- Specific species of microbial contaminant in the air
- Air exposure/dwell time
- UV-c lamp intensity
- Lamp distance and placement
- Lamp life cycle and cleanliness
- Air movement patterns
- Temperature, relative humidity, and air mixing.

Recirculation systems deliver multiple UV-c doses to airborne microorganisms representing an effective increase in deactivation rate in comparison with the single-pass system. Redundancy in exposing microorganisms to UV is achieved by circulating the air repeatedly. Multiple passes ensures that the UV is effective against the highest number of microorganisms and will irradiate resistant microorganisms more than once, to break them down.

Airborne disinfection is best applied in conjunction with particle filtration; with pre-filtration applied in order to protect the lamps from surface contamination and downstream filtration applied to remove the inactivated microbial particles.

UVGI for coil cleaning

The effectiveness of UVGI to inactivate microorganisms on surfaces has been demonstrated. The long-term irradiation of cooling coil and other wet surfaces to avoid fungal amplification can also be applied as an effective microbial control strategy.

UVGI is commonly used in HVAC applications to help keep cooling coils clean, see Figure 4. Cooling coils have a high risk of microbiological contamination due to the presence of both moisture and nutrients. The benefits of UVGI coil cleaning can include:

- Deactivated mould, microbial growth (bio-films) and biological odours on the cooling coil
- Potential energy savings (5–30%) from a clean coil, due to improved heat-transfer efficiency
- Improved off-coil air quality
- Reduced coil maintenance tasks such as inspection and mechanical cleaning, which can damage the coil fins and impact debris into the centre of the coil
- Reduced static pressure through the coil, reducing fan energy use or increasing airflow
- Extended working life for the coil, by eliminating corrosive biofilms and reducing mechanical cleaning.

Surface irradiance levels in the order of 1μW/cm² can be effective although 50–100μW/cm² is more typical. These are minimum clean-surface values.

For practical HVAC UVGI cooling coil applications higher levels are required. An initial irradiance level of 1225μW/cm² (measured on the coil face in 2.5m/s airflow and 13°C) is recommended,

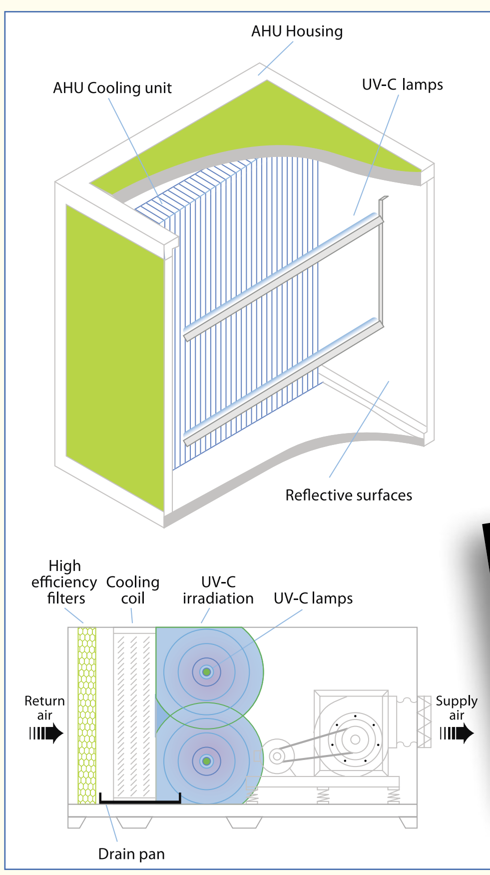


Figure 4: UVGI for AHU cooling coil cleaning.

with a minimum of 750μW/cm², after which the lamps would need replacing. This should provide the necessary penetration and ongoing coverage of microorganisms and their associated biofilms.

The use of reflectors to focus lamp output on surfaces can reduce the power required for surface treatment, but at the expense of reducing air treatment effectiveness. The UV light must have direct line of sight to the actual contamination and be assisted by reflective internal surfaces.

UVGI systems can be applied before or after the cooling coil (or both), see Figure 5, there are advantages and disadvantages to each position, see Table 1. Combining upstream and downstream irradiation provides the most comprehensive coverage.

Table 1 – Locating UVGI coil cleaning systems

UV Lamp Location	Advantages	Disadvantages
Downstream	More space to install equipment. Better irradiation of surfaces where condensation is highest. Irradiation of most contaminated part of coil and drain is achieved.	Lamp and fixtures must be rated for moist environment. Cooling effect on lamp may reduce UV output and system, performance or require additional lamps and power.
Upstream	Lamp and fixtures may be subjected to less moisture. Fewer lamps or less power may be needed.	May be space constrained for the installation. May take longer to clean coil. May not disinfect drain pan.

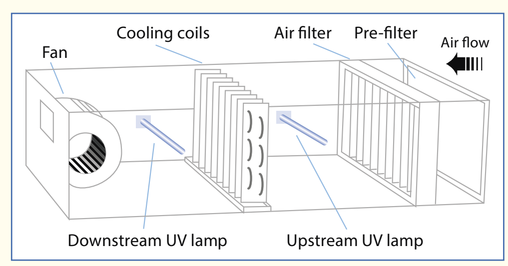
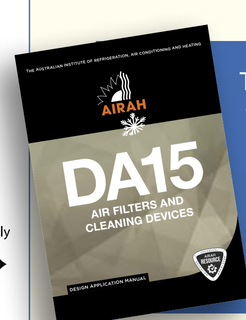


Figure 5: UVGI coil cleaning – upstream and/or downstream.



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