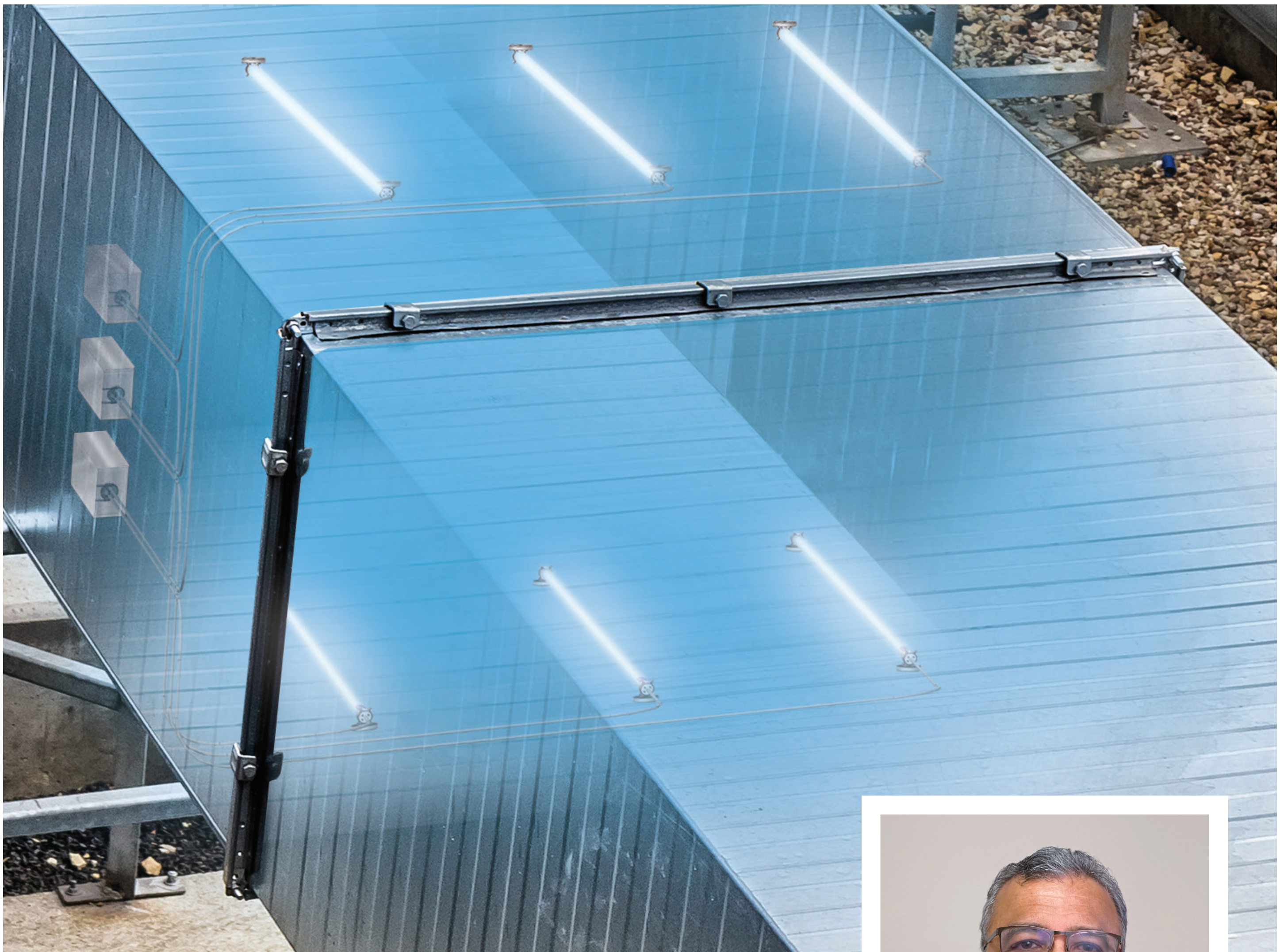
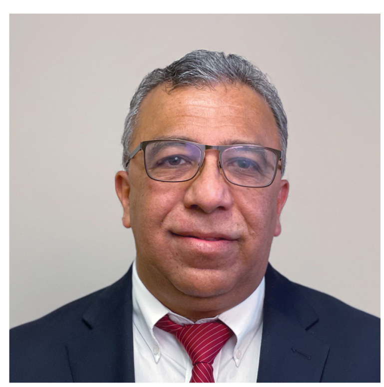
UV-C Disinfection in HVAC Systems: **Covid-19 and Beyond**





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Implementation Strategies for UV-C Disinfection in Commercial HVAC Systems: COVID-19 and Beyond

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1. Introduction

The current pandemic has led to an increased demand for germicidal ultraviolet disinfection technology to help control the spread of the SARS-CoV-2 virus in buildings. The World Health Organization has warned that Covid-19 "will not be the last pandemic."[1] There is now sufficient evidence pointing towards the airborne mode of transmission of the SARS-CoV-2 in addition to the droplet transmission, similar to the SARS outbreak of 2003 and the MERS outbreak in 2012.[2] A recently published study has presented data demonstrating the presence of SARS-CoV-2 at several locations along mechanical ventilation air return and supply pathways, including multiple locations in air handling units (AHU).[3]

As we move towards a post-pandemic world, we should not overlook other serious airborne infections such as seasonal flu and tuberculosis, which continue to cause widespread illness and deaths annually. In addition, the quality of building ventilation directly affects the relationship between airborne transmission of respiratory infections and the health and productivity of workers. According to the World Health Organization, approximately 30% of all commercial buildings have significant IAQ problems; in particular, ventilation systems have been implicated in the spread of infections and pollutants. The moist conditions found inside the typical AHU are breeding grounds for several types of microorganisms to thrive, including fungi and yeasts. High bacterial and fungal concentrations have been documented within HVAC systems, specifically on cooling coil surfaces and drain pans[4] which leads to fouling of the coil, resulting in an increase in energy consumption. High concentrations of these microorganisms on heat exchangers have the potential to be resuspended into the airstream, possibly introducing allergens or toxins into the indoor environment. Recent outbreaks of Legionnaires' disease have been associated with the airborne transmission of *Legionella* found in the building cooling towers.[5]

Historically, UV-C technology has been primarily used for cooling coil disinfection inside AHU with only limited applications for airstream disinfection primarily in healthcare settings. The value proposition of installing UV-C systems has primarily been to lower energy consumption due to coil cleaning, rather than improvement in indoor air quality. The current pandemic has changed this perspective with an increased interest in deploying UV-C technology for airstream disinfection and improving the indoor air quality. Various government and industry organizations, such as CDC, GSA, ASHRAE and IUVA, include UV-C as a recommended mitigation step to reduce airborne transmission and to improve the indoor air quality in commercial buildings. However, the lack of proper understanding of UV-C technology has also led to multiple challenges regarding product efficacy, safety and implementation for existing and new HVAC systems. This whitepaper will discuss key considerations to successfully implement UV-C solutions for enhanced protection and value during this pandemic and beyond.

2. UV Design Basics

In-duct UV-C systems are either installed inside the air handling unit (AHU) or inside the ventilation ductwork. The most effective UV-C system solutions for large commercial buildings generate both airstream and coil disinfection. The goal of coil disinfection is to reduce microbial growth on the coil and the goal of air disinfection is continuous in-use inactivation of the microbes transmitted in the airstream through the AHU or duct.

There are some important design criteria to be considered to size a UV-C system correctly for coil or airstream disinfection.

Applied Dose

The required UV-C dose to inactivate a pathogen forms the basis of design and application for all UV-C systems. The UV-C dose delivered at a target surface or object is the product of UV-C irradiance (intensity) at that target and exposure time, meaning that a higher UV-C dose can be delivered by increasing the intensity of UV-C light and the exposure time. This formula is extremely important when sizing a UV-C system for coil or airstream disinfection. A large dose can be delivered to a coil surface with a low UV-C irradiance because of the essentially infinite exposure time, making it relatively easy to disinfect the coil cost-effectively. On the other hand, for airstream disinfection, where the air velocity is typically 500 feet per minute inside the AHU (or even higher in the supply ducts), the UV-C exposure time for a microbe is a fraction of as second and would therefore require a much higher UV-C irradiance to achieve a high level of disinfection.

UV Susceptibility of Microorganisms

Different microorganisms exhibit varying susceptibility to UV-C light, with vegetative bacteria and viruses typically easier to inactivate than spores or fungi.[6] The susceptibility of a specific micro-organism to UV is generally expressed in terms of the "k-value", the UV-C inactivation rate constant for the specific microorganism. The k-value is then used to determine the D90 dose, i.e. the dose required to inactive 90% of the microorganism in a single pass, and calculated from the formula:

$$D90 = 2.303/k \qquad (1)$$

D99 dose, i.e. the dose required for 99% disinfection is twice the D90 dose; D99.9% dose is three times the D90 dose and so on.

Although the k-values or D90 values for different microorganisms are available in published literature[6], reported values for some microorganisms may differ widely. In such cases, it is prudent to adopt a conservative approach by using an average or worst-case value depending on the disinfection goals.

Intensity Versus Distance

The intensity of UV-C irradiance is inversely proportional to the square of the distance between the lamp and the exposed surface, based on the "inverse square law". Therefore, the UV-C intensity received by a surface decreases exponentially the further the surface is from the lamp. This information is relevant when deciding lamp placement for a coil disinfection application.

Wind Chill Effect
The output of UV-C lamps is dependent on the ambient temperature and air flow speeds. The lamp output can vary up to 60% across a range of temperatures and air flow speeds in typical HVAC systems.[7]

Duct Reflectivity
UV-C reflective duct and plenum materials are an economical way to enhance the overall irradiance in the duct. Galvanized aluminum ducts are good reflectors of UV-C and can enhance the overall UV-C irradiance by approximately 55%. However, it should be noted that materials that are reflective to visible light may be as reflective to UV-C light and therefore UV-C system designers should be consulted to select the appropriate duct material.

Other Design Considerations
In addition, the lamp configuration in the system, orientation (e.g. perpendicular or parallel to airflow), number of lamps, lamp outputs and lamp location inside the AHU or duct are important factors governing the overall performance of the UV system.

The use of an independently validated modeling software is recommended to correctly size a UV-C system by incorporating all the above factors that affect the overall applied dose for the application. In addition, the manufacturer should be able to provide independent performance validation of system performance through accredited third-party testing.

Safety and Materials Compatibility
UV-C over-exposure can cause damage to the eyes and skin, based on intensity, proximity to the source, and time of exposure. In-duct systems should be fully enclosed and sealed to prevent leakage of UV-C radiation to unprotected persons or materials outside of the HVAC equipment. It is recommended that lamp sections in the plenum should have door safety interlock switches, electrical disconnect devices and viewports to allow safe viewing of the UV-C system in operation from outside of the HVAC equipment. Facility owners should verify that UV-C systems comply with relevant UL standards for personnel and electrical safety and that adequate PPE is provided to service personnel to protect them from accidental exposure.

Long term UV-C exposure can also cause some degradation of organic materials used in internal AHU components, filters, duct materials. UV-C's short wavelength only penetrates a few micrometers into a material and may not cause failure of the product. However, adequate precautions should be taken to prevent any reduced performance or long-term safety concerns. Any potential degradation of critical components can be addressed by careful selection of the UVC-resistant material or by metallic shielding of components.

3. Current Practices and Challenges

As indicated earlier, with the exception of healthcare facilities and select government buildings, UV-C application pre-pandemic has primarily focused on coil disinfection. The high demand of

UV-C systems during this pandemic has spawned many UV-C companies that are providing unvalidated UV systems that are either undersized or oversized for the application, which can result in systems that are either too expensive or ineffective for the application. Building owners and design engineers have also been challenged with retrofitting UV-C systems into their existing HVAC system where there may be limitations of space, power requirements, electrical wiring and other key performance factors, all of which has also resulted in misapplication of the UV-C technology.

4. Sustainable UV-C Design for the Future

Coil Disinfection
Current practice for effective coil disinfection is to mount the UV-C lamps in near to the coil (12-24" distance, spacing the lamp rows to provide an even distribution of UV-C energy across the coil face. Lamps are either mounted upstream or downstream of the coil surface, although locating the lamps downstream allows disinfection of the drain pain as well. ASHRAE has recommended minimum irradiation levels of 50-100 microwatts/cm² to be applied to the coil surface.[8] Continuous exposure allows for a cumulative dose effective at preventing microbial growth on coil surfaces at relatively low irradiation levels. A 100 microwatts/cm² irradiance will apply a dose of 8,640,000 microwatts.sec/cm² in a 24-hour period. For example, this translates to a dose corresponding to greater than 99% inactivation of *Aspergillus Niger* fungal spores, which has very low susceptibility to UV with a D90 dose of ~ 390,000 microwatts.sec/cm². Some manufacturers recommend applying of irradiance values higher than ASHRAE minimum recommendations and mounting lamps on both sides of the coil. While oversizing may be conservative, this may lead to unnecessary increased equipment costs and energy consumption.

Air Disinfection
The irradiance levels applied for coil disinfection are inadequate for in-use airstream disinfection of microorganisms due to the the short exposure times for this application. As a rule of thumb, in-duct systems should be installed in a location that can provide a minimum of 0.25 s of UV-C exposure. For example, the SARS-CoV-2 virus, which has a reported D90 dose of 611 microwatts.s/cm² [9], the minimum coil irradiance level of 100 microwatts/cm² would translate to an applied dose of 25 microwatts.sec/cm², which, in turn, would only provide less than 10% inactivation of the virus. Therefore, airstream disinfection systems require much higher levels of UV-C irradiance compared to coil disinfection systems. In-duct air disinfection systems should be designed to have the desired single-pass inactivation level under worst-case conditions of air temperature and velocity in the irradiated zone.

As building owners and design engineers prepare for post-pandemic, they need to consider implementing robust UV-C solutions to meet current IAQ challenges and to prepare for future pandemics. Most of the UV-C installations during the pandemic were designed to prevent the transmission of the SARS-CoV-2 virus. In comparison, a UV-C system sized for Influenza A, the pathogen causing the seasonal flu, will require a much higher dose (more than threefold), with a D90 dose of 1940 microwatts.sec/cm² compared to 611 microwatts.sec/cm² for the SARS-CoV-2 virus. Therefore, a system that is designed for 90% inactivation of Influenza A virus will be capable of achieving almost 99.9% inactivation of the SARS-CoV-2 virus. ASHRAE has recently updated their guidance and recommended a minimum dose of 1500 microwatts.sec/cm² for airstream disinfection.[10]

The increased focus on dual deployment of UV-C systems to both prevent airborne transmission and to improve poor IAQ in ventilation systems warrants a fresh look at the most cost-effective approach to meet both objectives. Although the UV-C lamps may be installed anywhere in the HVAC system, the lowest air velocity occurs inside the AHU and provides the maximum efficiency and cost benefit. Locating the UV-C system near to and downstream of the cooling coils provides the dual benefit of disinfecting the air being transported into and from many spaces in the building and simultaneously irradiating the cooling coils and drain pans. As an example, a system which is sized for a 90% inactivation of Influenza A would provide enough UV-C energy to achieve greater than 99% inactivation of SARS-CoV-2 and more than sufficient energy to disinfect the cooling coil and drain pan, implying that the coil disinfection would come for free! Sizing and locating the UV-C system this way not only provides the maximum and sustained IAQ benefits, but also provides upfront and life-cycle cost benefits from reduced double-installation costs as well as the lower energy consumption and maintenance costs resulting from a clean coil.

Like most tools when used properly and limitations understood, a UV-C system which has been deployed following proper vetting criteria for performance, functionality, and safety will go a long way in improving the indoor air quality and health of the building occupants.

5. Summary

The long-term impact of the COVID-19 pandemic has transformed future building design practices to prioritize public health and mitigate the risk of spreading infection. The use of UV-C technology to improve indoor air quality, biofilm control and savings in energy consumption and maintenance costs is now well recognized. Facility professionals can utilize UV-C to greatly reduce the transmission of airborne pathogens in a reliable and cost-effective manner. A properly designed UV-C system can inactivate 99% or more of most microorganisms present in the HVAC ducts and cooling coils. Proper sizing and installation of a UV-C system in proximity to the cooling coil serves the dual benefit of coil cleaning and a high-level airstream disinfection, providing the building owner both maximum performance and life cycle cost benefit that is sustainable and applicable for future pandemics.

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