UV RESOURCES

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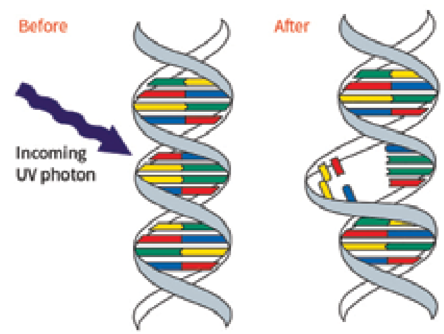
BASICS AND BENEFITS OF UV-C SYSTEMS FOR COMMERCIAL HVAC/R APPLICATIONS

Learn how UV-C light is applied in HVAC/R systems for continuously cleaning surfaces of cooling coils and drain pans for maintaining as-built energy, IAQ, and comfort performance.

By Daniel Jones

As air-conditioning / refrigeration equipment ages, its ability to maintain temperatures and humidity levels declines. Most often, the culprit is reduced coil heat-transfer effectiveness, or the ability of air-handling-units' (AHU) cooling coils to remove heat and moisture from the air.

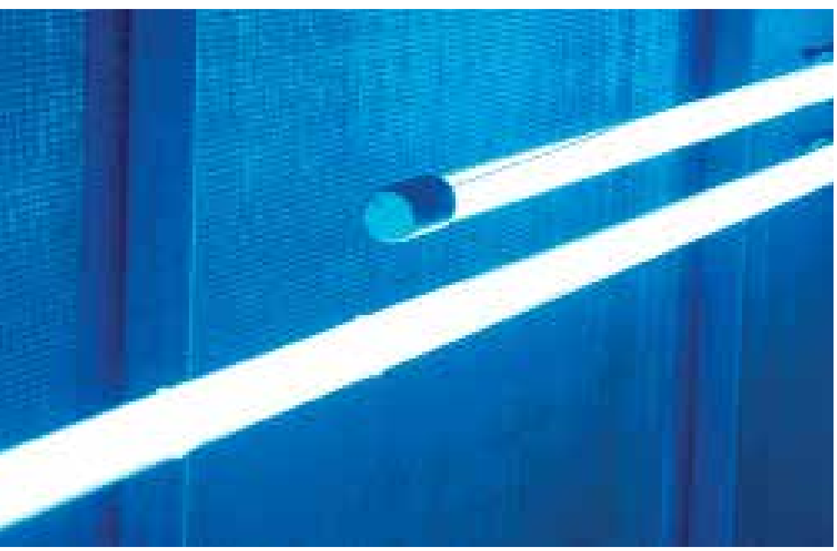
These inefficient heat-transfer rates derive primarily from the buildup of organic contaminants on, and through, the coil's fin areas. Such buildup is eliminated through the use of ultraviolet germicidal energy or light energy in the UV-C wavelength (253.7nm). UV-C works by disassociating molecular bonds, which in turn disinfects and disintegrates organic materials.



RIGHT: The 253.7 nm germicidal C-band wavelength inactivates virtually all microorganisms living on HVAC/R surfaces with a kill ratio of 90 percent or higher, depending on UV-C intensity, length of exposure, lamp placement and lamp life cycle.

RESTORING COOLING CAPACITY

UV-C lighting systems are not an exotic, new technology. They have been used extensively since the mid-1990s to significantly improve HVAC/R airflow and heat-exchange efficiency, which can reduce energy use by up to 25 percent. Although UV-C by itself doesn't save energy, it restores cooling capacity and airflow to increase the potential for energy savings.



In fact, researchers have found that exposing a fouled cooling coil to UV-C resulted in a 10 percent decrease in pressure drop and a 14.55 percent increase in heat transfer coefficient levels at reference conditions.[1]

In new/OEM equipment, UV-C keeps cooling coil surfaces, drain pans, air filters, and ducts free from organic buildup for the purpose of maintaining "as-built" cooling capacity, airflow conditions, and IAQ. In retrofit applications, UV-C eradicates organic matter that has accumulated and grown over time, and then prevents it from returning.

Although UV-C is a relatively simple technology, i.e., shining lamps onto surfaces and adding simple on/off controls to facilitate maintenance, many professionals are mystified about how UV-C works and how to apply it cost effectively. This article addresses these aspects of UV-C technology and the applications that seem the most awkward. It references ASHRAE guidelines found in Chapter 60.8: Ultraviolet Air and Surface Treatment in the 2015 ASHRAE Handbook – Applications.[2]

UV-C BASICS

We all are familiar with the harmful effects of UV from sunlight in the UV-A and UV-B wavelengths, giving rise to sunburn and the need for UV inhibitors, or blocking agents, which are found in such things as glasses and lotions.

However, unlike UV-A and UV-B radiation, the UV-C wavelength has more electron volt energy and is well absorbed (not reflected) by all organic substances, increasing its destructiveness. Given these properties, why don't we hear more about protecting ourselves from UV-C exposure outdoors? The reason is that UV-C is absorbed by the ozone layer and much of the atmosphere, and does not reach the Earth's surface.

So how much UV-C is needed to destroy organic matter? A 2010 study commissioned by ASHRAE and the Air Conditioning, Heating, and Refrigeration Institute (AHRI) found that even the most sophisticated organic compounds suffer from exposure to HVAC/R dosages of UV-C energy. Because UV-C lamp installations in HVAC/R applications operate continuously 24/7/365, a well-distributed dose similar to visible light is all that's needed.

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UV-C LAMPS AND LAMP REPLACEMENTS

Modern UV-C lamps are very similar to fluorescent lamps typically found in ceiling fixtures. Both types of lamps operate using identical electrochemical processes: i.e. an electric discharge through argon gas striking mercury vapor to generate a photon with a wavelength of 253.7 nm (typically called UV-C), which, in and of itself, is invisible.

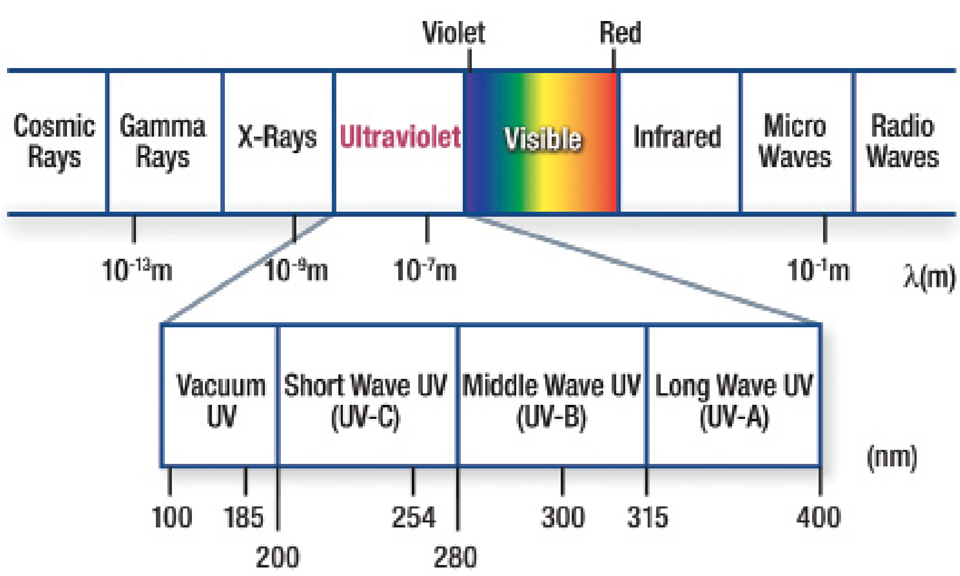

FIGURE 1: The electromagnetic spectrum, with a breakout of visible light segments – colors. The UV spectrum ranges from 100 nm to 400 nm and is invisible.

UV-C lamps differ slightly from their fluorescent counterparts in that the UV-C lamp's glass envelope must be a highly engineered, UV-C transparent shell. This allows the 253.7 nm wavelength to escape through the lamp envelope unfiltered. Fluorescent lamps, however, use ordinary glass which blocks the UV-C wavelength. The glass is also internally coated with phosphors. The UV-C energy is "contained" to excite the phosphors to glow (fluoresce) in the visible light range.

A typical UV-C lamp produces about 90 percent of its energy in the UV-C wavelength. About 4 percent of its energy is given up as heat, and the rest (~5 percent) is in the visible light range that is medium blue in color (Figure 1). This blue color, shown in Figure 2, results from the argon gas in the lamp envelope.

CHANGE ANNUALLY

UV-C lamps typically provide more than 80 percent of their initial output over a 9,000-hour period. Because UV-C lamps should be operated continuously, the corresponding 8,760 hours of a 24/7 schedule also fits conveniently into annual re-lamping schedules of lighting lamps.

Attempting to run UV-C lamps longer than 9,000 hours will produce individual lamp outages, requiring maintenance staff to monitor them routinely to know what to replace. This individual swapping out of lamps requires a larger inventory of replacements for when the lamps begin to fail in larger numbers.

FIGURE 2: UV-C's blue color results from the argon gas in the lamp envelope.

Like fluorescent lamps, UV-C lamps come in a variety of types and sizes, including single-ended and double-ended. The single-ended lamps are used in several lamp systems, some of which allow the lamps to be inserted through a plenum or duct into the air stream, typically downstream of the cooling coil (Figure 3). Double-ended lamps have pins at both ends, and are installed into specific length fixtures usually containing the ballast like a fluorescent fixture. Typically, all types are available in standard output (SO) and high output (HO). The difference between the two is their Watt and ballast rating. HO lamps are usually recommended because they are less expensive on a per-lamp-Watt basis.

FIGURE 3: Lamp installed through a plenum

Another consideration for contractors is opting for encapsulated lamps, which have a transparent Fluorinated Ethylene Propylene (FEP) coating over the glass envelope. Encapsulated lamps hermetically seal UV-C lamps in case of breakage. Should an accident occur, broken glass and mercury will remain within the lamp.

UV-C BENEFITS

UV-C systems provide several benefits when applied to HVAC/R systems: Efficiency; occupant comfort/indoor air quality, environmental impacts, and economic impacts.

> HVAC/R system efficiency: UV-C eliminates and/or prevents the buildup of organic material on the surfaces of coiling coils, drain pans, and interior air-handler surfaces. This improves airflow and returns/maintains heat-transfer levels of cooling coils to "as-built" capacity. As a result, the HVAC/R system does not use more energy to provide the desired amount of cooling effect and ventilation

capacity, which maintains system energy efficiency. On average, UV-C coil installations on existing systems reduce energy use by between 10 and 25 percent.

Comfort and IAQ: Clean coils and drain pans do not contribute foul odors, allergens, or pathogens to air streams and help the HVAC/R system sustain design temperatures and airflow rates. All of these factors translate into meeting the functional and performance requirements communicated by codes, standards and the owner's project requirements. In doing so, it can be said that UV-C systems help HVAC/R systems deliver quality comfort and IAQ and, by extension, occupant productivity, lower incidences of sick days, and reduced hot/cold calls and other service requests.[3]

Environmental impacts: UV-C systems have several characteristics that are consistent with green/clean technologies: they eliminate the need for chemical and mechanical (water) cleaning, which also reduces waste disposal issues. With a more efficient AHU, a UV-C system will save energy and reduce carbon footprints. Furthermore, UV-C lamps can be recycled with fluorescent lamps and be integrated with a facility's annual re-lamping program.

Economic impact: Reducing energy costs, sick calls, service calls, and system downtime for maintenance translate into significant cost savings for applying UV-C in commercial HVAC/R systems. It can also be inferred that buildings with highly functioning HVAC/R systems that deliver the benefits described above will increase the value of building tenant leases because they will have lower HVAC/R-related overhead and lower occupant turnover.

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UV-C LIFECYCLE

To realize the benefits described above, a UV-C system needs to be engineered, installed, operated and maintained – just like any other system. However, all of these life cycle steps are fairly simple to perform, as described below.

SIZING, SELECTION, AND SPECIFICATION

For a complete design solution, practitioners need to determine:

1. How much UV-C energy is needed to "do the job"
2. The lamp/ballast characteristics required to meet operating conditions
3. The required quantity and configuration of lamps needed.

In its 2015 ASHRAE Handbook – HVAC Applications, Chapter 60.8, ASHRAE Technical Committee, TC2.9, established minimum irradiation levels of 50-100 µW/cm^2 (microwatts per square centimeter) for cooling coil applications. This requirement must be met as a "minimum" threshold across the entire coil surface, including plenum ends and corners.

These engineering units, however, are unfamiliar to most practitioners. In lighting applications, sizing will generally use lamp Watts. One accurate way to convert microwatts to lamp Watts is to use a form-factor translation consisting of a 1-square meter surface with a 1-meter-long lamp located midway up the surface on a horizontal plane. The average lamp Watts and output of lamp manufacturers' published data shows that a 1-meter, 36-inch high-output (HO) lamp is rated at 80 lamp Watts with an output of 245 µW/cm^2, at 1-meter distance (i.e., distance of lamp surface to coil surface). UV-C lamps are usually installed at 12 inches from the coil surface, so the irradiance needs to be interpolated for that distance. Using the industry-accepted "cylindrical view factor model,"[4] the resulting irradiance is 1375 µW/cm^2 at 12 inches.

While this number seems to be more than enough to meet the 100 µW/cm^2 recommended by ASHRAE, all operating conditions must first be considered. Some conditions effectively decrease or "de-rate" the lamps' performance, such as air temperature and velocity. Yet other changes can positively increase design yield. In typical conditions of 500 fpm velocity and 55 F air temperatures, lamps are de-rated by about 50 percent. Hence, the 1375 µW/cm^2 generated from a conventional high-output 80-Watt lamp would now yield an irradiance of closer to 688 µW/cm^2—at 12 inches from the coil surface.

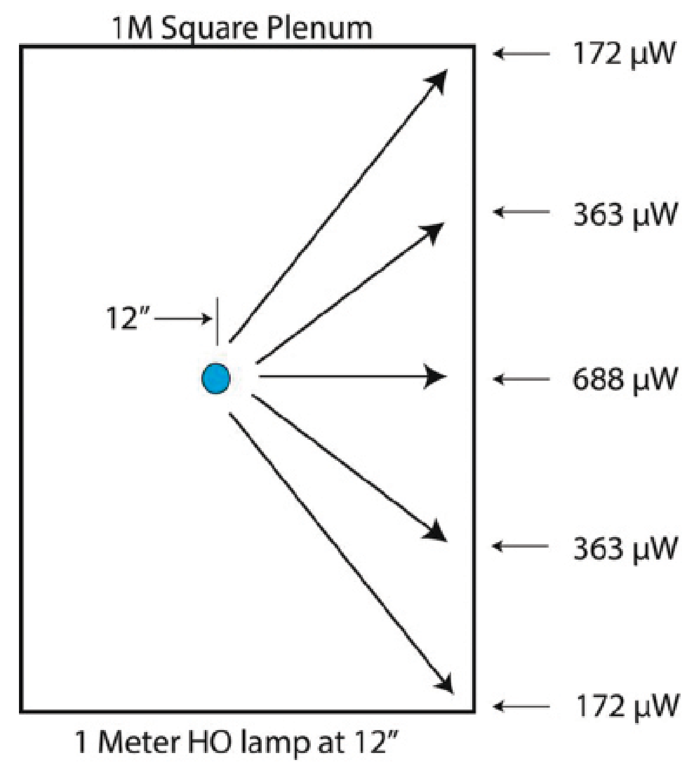

FIGURE 4 (above): Consider distance of UV-C lamp to the plenum corners.

Metal	UV-C Multiplier
Stainless Steel	1.40
Galvanized steel	1.50
Aluminum	1.75

TABLE 1: Reflectance multipliers for different surfaces.

The next factor to consider is distance of the UV-C lamp to the plenum corners. The Kowalski view factor on the 1-meter example (Figure 4) shows this to be 25 percent of the highest mean value. Following through our earlier example, 688 µW/cm^2 is multiplied by 0.25, which results in 172 µW/cm^2 at the farthest points, or corners of the plenum.

The positive effects? UV-C dosage is increased based on reflectivity from the plenum's surface, or the amount of UV-C energy bouncing off of the top, bottom and sides of a plenum toward the coil and elsewhere. Reflectivity sends UV-C energy everywhere to assure "all" surfaces are clean and disinfected. Different materials have different reflectance multipliers, as shown in Table 1. Using a galvanized steel plenum as an example, the multiplier is 1.50 (a 50 percent increase in UV-C energy); hence 172 µW/cm^2 x 1.50 = 258 µW/cm^2.

Even without considering reflectivity, the ASHRAE minimum UV-C dosage levels would be achieved at the farthest distance from the lamp to the coil. So, should less light be used? Because more light positively affects airborne microbial kill levels and because there is no significant cost savings for trying to use fewer or less-intense UV-C lamps, the 80-Watt HO lamp, or HO lamps are highly recommended.

By working through the 1-meter example, the results can be used for future UV-C lamp installations as follows. The lamp was a ~1-meter-long, 80-Watt HO lamp, irradiating a 1-square-meter surface, or 10.76 square feet. If the lamp wattage is divided by the square footage of the surface, it becomes (80/10.76) = 7.43 Watts per square-foot of coil surface area. This simpler <7.5 Watts per square-foot method exceeds ASHRAE's recommendations and therefore can be used as a guideline on most any size coil.

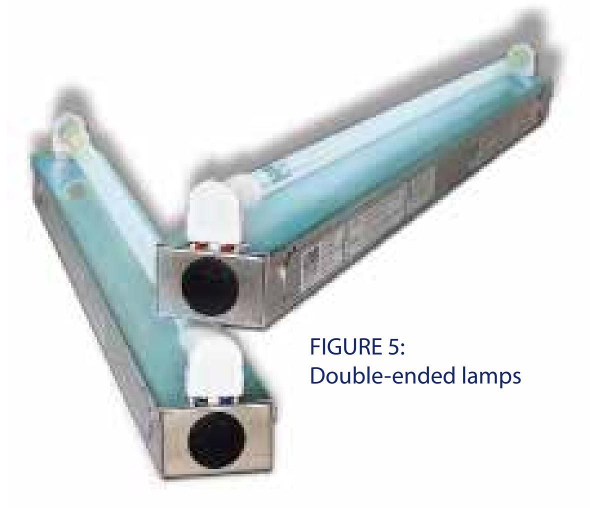

FIGURE 5:
Double-ended lamps

After determining how much UV-C energy is needed, engineers need to select the types of lamps that will provide the necessary light energy. Among the considerations are single-ended (Figure 3) and double-ended lamps (Figure 5). Double-ended lamps are used in specific length configurations and may confine the design in certain AHUs. Single-ended lamps provide flexibility relative to a given plenum's width because they can be easily overlapped (Figure 6). They also can be used in hard-to-access plenums and smaller rooftop units, as they are installed and serviced from outside the plenum (Figure 7).

When using single-ended lamps, lamps of a single length can often be selected for the entire facility. This minimizes the number of spare lamps that must be kept on site, and it increases the purchasing power for buying in bulk when re-lamping on an annual schedule. As mentioned, this approach simply overlaps lamps and eliminates the need for various combinations of sizes to get a perfect fit from one end of the coil bank to the other.

INSTALLATION DESIGN

For a complete UV-C installation design, practitioners may want to specify certain other aspects. This could include the 7.5 Watts per square-foot, a distance of 12 inches from the coil, and a lamp holder that will assure that the lamps are properly held and easily serviced. The design should also specify the electrical power. Ballasts today are typically offered in 120-277Vac designs for flexibility.

CONTROLS

UV-C systems have relatively simple controls, most of which pertain to safety. A typical control package includes a cutoff switch located just outside the plenum door. Also included in that control circuit are the

FIGURE 6 (top): Overlapping single-ended lamps.
FIGURE 7 (bottom left): Lamp being serviced from outside the plenum.

FIGURE 8: Multiple lamp sensors can be fed into a replicator so that one signal is relayed to building management, representing up to eight lamps.

door interlock switches that turn off the lights when an access door is opened. Access doors can also be equipped with a UV-C blocking view port to facilitate lamp inspections.

Simple, self-powered current sensors that show whether a particular lamp/ballast combination is on or off are in greater demand today. Multiple lamp/ballast sensors can be fed into a replicator that allows one signal to be relayed to the building management system (BMS) to represent up to eight lamp/ballast combinations (Figure 8). They also can be chained together to represent an infinite number of lamp/ballast combinations with one signal. Additional programming can be added to alert operators if a lamp or ballast is out, which eliminates the need to visit each AHU to check for failures, especially as the 9,000-hour useful life expectancy window approaches.

SAFETY

Facility staff need to be trained to wear proper eye protection when inspecting UV-C lamps, and to ensure they are turned off during replacement. While controls are designed into the UV-C system, commissioning providers need to check that they are documented appropriately and functioning properly.

SUMMARY

UV-C light is an incredibly effective and affordable technology for keeping critical components of commercial HVAC systems clean and operating to "as-built" specifications. Benefits of applying UV-C lamps in HVAC systems include greater energy efficiency, lower operating expenses, fewer occupant complaints, and better IAQ. For all these benefits, UV-C is relatively easy to apply – it's basically installing a bank of UV-C lamps in an air handler, or in a rooftop packaged system, and then replacing the lamps once per year. ■

The president and co-founder of UV Resources, a provider of UV solutions and replacement lamps for HVAC systems, Daniel Jones is an ASHRAE Member and a corresponding member of the ASHRAE Technical Committee 2.9 and ASHRAE SPC-185.2, devoted to Ultraviolet Air and Surface Treatment. He may be reached at dan.jones@uvresources.com.

[1] (Firrantello 2016). Firrantello, J.T., Bahnfleth, W. P., Montgomery, R., Kremer, P. K., "Field Study of Energy Use-Related Effects of Ultraviolet Germicidal Irradiation of a Cooling Coil," 12th REHVA World Congress CLIMA 2016, May 22-25, 2016, Aalborg, Denmark.

[2] 2015 ASHRAE Handbook—HVAC Applications -HVAC Systems and Equipment. ASHRAE. Chapter 60: "Ultraviolet Air and Surface Treatment."

[3] Menzies D, Popa J, Hanley J, Rand T, Milton D. Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double-blind multiple crossover trial. THE LANCET 2003; 362:pp1785-1791.

[4] Kowalski WJ, Bahnfleth WP, Witham DL, Severin BF, Whittam TS. 2000. Mathematical modeling of UVGI for air disinfection. Quantitative Microbiology 2(3):249–270.