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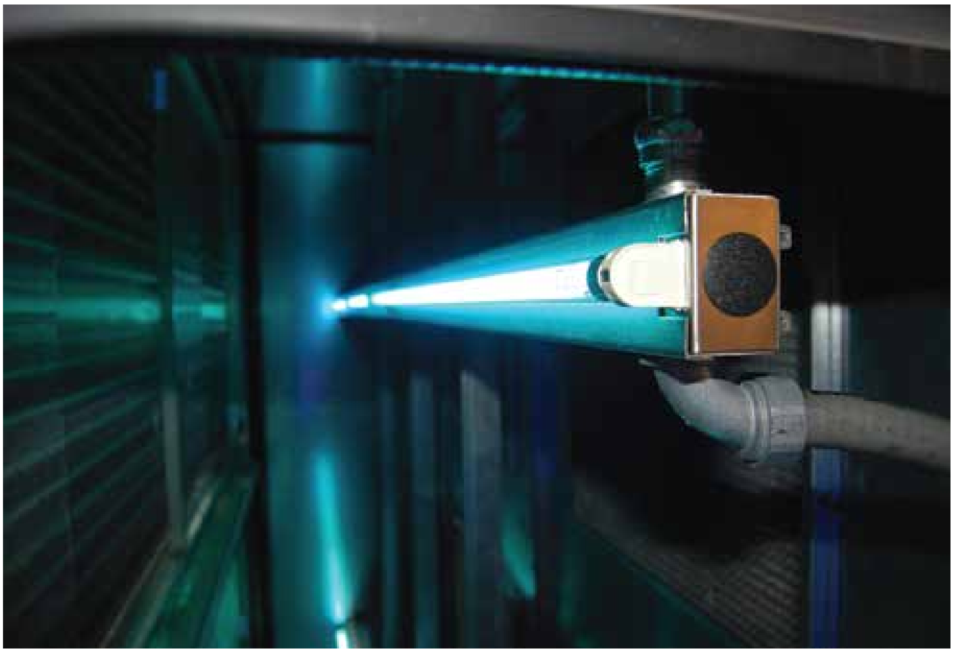
Ultraviolet filtration

Maintaining energy efficiency with UV

Ultraviolet-C energy (UV-C) in HVAC equipment is applied in surface irradiation of cooling coils, drain pans, and other interior surfaces of air handler plenums. This represents over 95% of the UV-C installations in US HVAC equipment. Here, Forrest Fencl, President, UV Resources looks at commercial HVAC UV-C applications, and how the technology can be a cost-effective supplement to air filtration.

There are two distinctly separate methods of applying ultraviolet-C energy (UV-C) in HVAC equipment. The first is surface irradiation of cooling coils, drain pans, and other interior surfaces of air handler plenums designed to maintain their cleanliness and operational efficiencies. This is the most common UV-C application method, and represents well over 95% of the UV-C installations in North American HVAC equipment.

The second type of UV-C application is airstream disinfection, which is designed to kill airborne microorganisms 'on the fly' as supply air moves past the irradiation source.



The High-Output DEF ultraviolet lamp series from UV Resources is designed to provide up to twice the ultraviolet irradiation energy to kill and/or degrade the toughest microorganisms and organic matter at less than half the cost of similar products.

This type of system requires a more technical approach to the amount (dosage) and location of UV-C equipment within an HVAC system.

Airstream disinfection applications include counter-bio-terrorism systems (Kowalski 2003) and controls for infectious diseases in high-risk facilities, such as embassies, pharmaceutical manufacturing, and infection-control regions in hospitals and prisons. Discussion of these specialized applications is best left for a future article; however, it is worth noting that the surface applications mentioned above can provide a fair amount of airstream disinfection. For example, a single-pass airborne kill ratio of up to 35% is not uncommon under typical HVAC conditions, meaning that each time the air passes the UV-C irradiation field, more than one-third of all the airborne microbes are inactivated.

Some interesting research has been done that compares the effectiveness of UV systems with exposure rates of 0.5 seconds versus MERV 13-15 air filters. Findings indicate that for some pathogens, such as smallpox, UV can provide higher-kill-rates than the capture rates of air filters; whereas filtration has a greater effectiveness toward other, larger pathogens, such as anthrax (Kowalski 2003).

Because surface irradiation methods account for a much greater proportion of the UV-C market, this article covers commercial HVAC UV-C applications, and how the technology can be a cost-effective supplement to air filtration.

UV-C for surface disinfection

The benefits of UV-C surface irradiation systems include maintaining indoor air quality and comfort levels commensurate with the owner's performance requirements of the HVAC system, and doing so with minimal wasted energy. The section below: 'Benefits of UV-C for HVAC,' describes four categories of benefits.

For new construction, UV-C systems maintain as-built coil performance continuously from start-up. For retrofit applications, UV-C systems remove organic growth on the inner and outer coil surfaces, and similarly, clean drain pans and other interior plenum surfaces. Following the UV-C application, these surfaces remain clean, maintaining as-built capacity and cleanliness thereafter.

For surface disinfection systems, the goals of a successful UV-C system are:

- Achieve minimum levels of surface irradiation (dose) per 2011 ASHRAE Handbook – HVAC Applications, Chapter 60 (ASHRAE 2011)
- Utilize the fewest number of same-size lamps (lowest first cost)
- Assure easily inspected and serviced lamps (lowest operating cost)
- Properly controlled for safety (a basic requirement for any system)

As air-conditioning equipment ages, its ability to maintain adequate space temperatures and humidity levels decline. Predominantly, the culprit is reduced coil-heat-transfer effectiveness, or the ability of air-handling-unit's (AHU) cooling coil to efficiently remove heat from the air. Evidence shows this drop in performance can occur within five years of startup due to the buildup of contaminants on coil surfaces. This accumulation of organic material causes higher leaving-air wet-bulb temperatures, meaning an AHU is removing less total heat (sensible and latent) from the air and, as a result, the space temperature and humidity is elevated. Additionally, coil pressure drop levels become higher and, especially with constant-volume fans, airflow levels will be reduced.

Of course, there are energy and other cost penalties associated with coil fouling, such as chilled water systems consuming more energy to compensate for lost coil capacity. There are also a higher number of hot/cold calls and their associated maintenance actions.

When airflow and coil temperature differentials decrease, there is a corresponding decline in HVAC system capacity -- even small changes can have a dramatic effect on cooling capacity and occupant comfort. Therefore, both must remain at as-built conditions for a system to perform as designed.

The economical, X-Plus extended UV-C Lamp-base fixture from UV Resources can be easily mounted from the exterior of any HVAC system, making it ideal for hard-to-access outdoor and indoor equipment up to 30 tons.

Coil cleaning

Equipment manufacturers usually recommend coil cleaning twice a year, and no less than annually to not only prevent mold growth and capacity loss, but to keep contaminants from compacting deep within the coil. With staffs and budgets shrinking, however, time and money for in-house or contracted coil cleaning is becoming scarce. In fact, some building operators report they have not cleaned their AHU's coils in three or four years.
If coil cleaning is not performed regularly, contaminant buildup deep inside internal surfaces can become so difficult to remove that expensive coil replacement becomes the only option. UV-C has been shown to clean even compacted contaminant from a coil.

Performance losses from contaminant buildup have led many building operators to retrofit their air-conditioning systems with UV-C light systems as a trial. According to Chapter 60.8 in the 2011 ASHRAE Handbook—HVAC Applications (ASHRAE 2011), UV-C technology can reduce mold and biofilm, coil pressure drop, and coil-cleaning needs. Further, it states that the use of UV-C can increase airflow and heat-transfer coefficient levels and reduce both fan- and refrigeration-system energy uses. Clearly, there are many advantages offered by UV-C, making

The RLM Xtreme fixtureless UV-C lamp system from UV Resources creates a more energy-efficient HVAC system that doesn't have to waste energy to move air.

the technology sometimes seem almost too good to be true.

ASHRAE's *Handbook* also recommends that the UV-C irradiance levels should strike coil surfaces at 50-100 microwatts per square centimeter (μW/cm²). A more understandable and convenient way to achieve the recommended dosage of UV is to use lamp watts, which is printed directly onto all major suppliers' lamps. ASHRAE's recommendation of 100 μW/cm² works out to be slightly under 7.5 lamp watts per square foot of coil surface area, which equates to <0.015 watts per cfm.

Costs and payback

Many users report that their cost for an installed system featuring high output lamps was about $0.10 per cfm (US). For a 27,000 cfm system, this amounts to an investment less than $3,000. The operating cost for a system that is on year-round (24/7/365) is then easy to estimate: Annual energy cost = Installed Wattage (kW) x Utility Rate ($/kWh) x 8760 hours. A 27,000 cfm system at $0.10/kWh rate comes out to (0.580 x 0.10 x 8760) about $508/year, or less than 1 percent of the power to operate that air conditioning system.

Field reports indicate that the first-cost of a UV-C system (initial investment) is approximately the same(or less) as a single, properly performed coil-cleaning procedure, especially when system shutdowns, off-hours work, associated overtime, and/or contractor labor costs, are considered.

Sizing for proper dosage for surface irradiation

UV-C lamps are sized to deliver a particular amount of light (irradiation) on a surface i.e., a dosage. Dosage for surface irradiation is the amount of energy striking the coil specifically and all other surfaces, in microwatts per square centimeter (μW/cm²).

Ideally, this would be simple; however, in practice, air temperature and surface reflectivity change the dosage level, thus requiring users to adjust for these factors in order to appropriately size applications. For example, cooler temperatures and moving air will lower a lamp's output, requiring the system designer to de-rate or reduce a lamp's effective UV-C dosage level; while reflective surfaces tend to amplify or increase the dosage. According to ASHRAE, the recommendation is 50-100 μW/cm² striking all areas of a coils' surface, including its far corners.

These terms, however, are unfamiliar to most practitioners. A simpler way is to resolve them to lamp Watts. Using a form-factor translation consisting of a 1 m² surface and a 1 m lamp located midway up the surface on a horizontal plane, works best. Using lamp manufacturers' data, a high-output (HO) 80 Watt lamp is rated at 245 μW/cm² at 1 meter (i.e., lamp surface to coil surface). Because UV-C lamps are usually installed 12 in. from the coil's surface, the irradiance is interpolated for that distance. Using the industry-accepted 'cylindrical view factor model,' the resulting irradiance at 12 in. is 1375 μW/cm².

De-rating a lamp's UV-C output results from the typical conditions of 500 fpm velocity and 55 F air temperatures, for which the output level is decreased by about 50%. Hence, the 1375 μW/cm² generated in the example above, would now be rated as 688 μW/cm². The next consideration is the UV-C irradiance (dosage) at the farthest corners. The view factor model shows that the irradiance there is 25% of the highest mean value. Therefore, the 688 μW/cm² is multiplied by 0.25, which results in 172 μW/cm². Next, the irradiance (dosage) is increased based on reflectivity from all the plenum's surfaces. Reflectivity sends UV energy everywhere and assures 'all' surfaces are clean and disinfected. Different materials have different reflectance multipliers (table 1). Using galvanized steel as an example, the multiplier is 1.50 (a 50% increase in dose); hence 172 μW/cm² x 1.50 = 258 μW/cm².

That said, we see that the 80 Watt, 36-in. HO lamp met all of the ASHRAE criteria under typical conditions on a coil that was 1 m², or 10.76 ft² of surface area. If the lamp wattage is divided by the square footage of the coil (80/10.76) = 7.43, we see that about 7.5 HO lamp watts per square foot of coil surface area exceeds ASHRAE's recommendations. This procedure provides a simplified means for practitioners to properly size UV installs for most any coil, large or small. This also takes much of the misunderstood nomenclature out when verifying effective dosage designs.

A greater dosage is desirable because 'too much' does not adversely impact system components and it will result in higher UV-C irradiation at the center of the coil. Since a larger percentage of the air goes through the center of the coil, the airborne kill ratios of infectious microbes is also higher.

UV-C system into an HVAC system

UV-C lamps are not replacements for HVAC air filters; instead, they supplement them with air and surface disinfection. One benefit of UV-C lamps of possible interest to Filtration and Separation readers is that UV-C irradiation deactivates pathogens and degrades surface organic materials.

UV-C lamps are typically installed horizontally 12 in away from the coil's surface; however, 15 years of experience has verified that distances ranging from 3 - 30 in. will work fine and will not hamper the results obtained from the algorithm under 'Sizing for proper dosage for surface irradiation' above.

The lamp's proximity to the airstream, within the 3 in. to 30 in. range distance, is only minutely different in terms of airborne kill ratio effectiveness.

UV-C systems are typically installed downstream of the cooling coil in the direction of airflow. This is favored because the air downstream approaches saturation, meaning that within this plenum, there could be raw water, damp insulation, and other conditions that are known contributors to the

Metal	UV-C multiplier
Stainless steel	1.40
Galvanized steel	1.50
Aluminum	1.75

Table 1. Approximate UV-C dosage multipliers for different materials typically used in HVAC equipment. Courtesy: UV Resources

Handbook of HVAC Applications

All of the system enhancing efficiencies of UV-C technology is discussed in greater depth in ASHRAE's 2011 Handbook of HVAC Applications, Chapter 60, a link to which may be found here https://www.ashrae.org/resources--publications/Description-of-the-2011-ASHRAE-Handbook-HVAC-Applications.

growth of mold and some forms of bacteria. Also, coil drain pans are often extended in this location to catch raw water carry-over from the cooling coil.

UV lamps are available in multiple lengths ranging from 24 - 60 in. (60-145 W) and more. Lamps should be overlapped in the plenum to reduce the number of sizes used. Through this procedure, the designer can often use a single lamp length, which will minimize both first, and replacement, costs. A 27,000 cfm system, for example, could have a coil size of about 6 ft H x 9 ft W that might use four 60 in., 145 W lamps, or, in this example, 10.7 lamp watts per square foot (higher airborne kill).

As for power and control, a connection to power between 120-277 Vac fed through a toggle switch outside of the plenum and door interlock cut-off switches are the basic installation criteria. Check manufacturer's IOM details for how to secure the lamps in place for easy lamp installation and subsequent replacement.

UV-C systems should be designed with door interlocks such that when air handlers are opened, the UV-C lights are automatically switched off. Warning labels are to be placed on air-handler doors. Additional controls can include lamp/ballast monitors and alarms to a BMS. These types of controls are inexpensive today and provide monitoring on a continuous basis.

Lamp replacement

Most all lamp manufacturers list a UV-C lamp's 'useful life' as 9,000 hours, which is conveniently close to the 8,760 hours in a year.

At 9,000 hours, lamp output begins to fall to 85% or less of the original output in a quality lamp. Because the blue hue produced by the lamp is not indicative of the invisible UV-C energy output, lamp manufacturers are not willing to guarantee useful UV-C output for longer than 9,000 hours even though they may be lit. Also, running lamps longer will produce lamp outages usually one at a time, causing service personnel to inspect them routinely to know what to replace. This is inefficientand expensive. Replacing lamps only as they burn out also requires added inventory.

Most users and management groups report that they prefer to set up an annual schedule for lamp replacement. An annual lamp schedule has the following benefits:

- It provides time to get a full replacement competitively quoted and fulfilled.
- The inventory or replacement lamps are reduced to a recommended quantity of 5% of the installed lamp quantity to hedge against breakage or premature failure.
- It eliminates the time, labor, and cost of trying to monitor the lights on a more frequent basis, especially toward the 9,000-hour lifespan.
- It minimizes system down-time and provides maximum UV-C output to keep the kill ratio of airborne microorganisms as high as possible.

Another consideration is whether to use lamps encapsulated with PTFE for safety. Encapsulated lamps trap the glass and mercury within a protective envelope should the lamp be broken. In most all applications there is a risk of lamp breakage. Encapsulation is recommended because the lamp clean-up procedures can be extensive and therefore expensive. Otherwise, guidelines for handling broken lamps can also be found in the 2011 Handbook, Chapter 60. Generally, UV-C lamps are recycled in the same manner as fluorescent lamps.

Benefits of UV-C for HVAC

UV-C systems provide four types of benefits when applied to HVAC systems: HVAC system efficiency, comfort and indoor air quality, environmental impacts, and economic impacts.

HVAC system efficiency UV-C eliminates and/or prevents the buildup of organic material on the surfaces of cooling coils, drain pans, and interior air-handler surfaces. This improves airflow and returns/maintains heat-transfer levels of cooling coils to 'as-built' capacity. This means the HVAC system does not use more energy than necessary to provide the desired amount of ventilation and cooling capacity, which maintains system energy efficiency. On average, UV-C coil installations on existing systems can reduce energy use by 10% to 25%, and more.

Comfort and IAQ: Clean coils and drain pans do not contribute to foul odors, allergens, or pathogens to airstreams, but do help the HVAC 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 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.

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. They also help save energy to reduce carbon footprints and UV-C lamps can be recycled with fluorescent lamps; and, in fact,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can 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 from applying UV-C systems in commercial HVAC systems. It can also be inferred that buildings with highly functioning HVAC systems that deliver the benefits described above will increase the value of building tenant leases because they will have lower HVAC-related overhead and lower occupant turnover.

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 to applying UV-C lamps in HVAC systems range from: energy efficiency, lower operating expenses and fewer occupant complaints, to better and healthier indoor air.

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About the author

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