Seeking New Weapons Against Microbial Foes

The world seems *small* lately, and not just because the walls are closing in during COVID lockdown. In the year since SARS-CoV-2 encircled the globe, we have all been learning about microscopic pathogens, searching for ways we can contribute to the battle of the mega against the micro. Literature from decades past demonstrate the fundamentals of how ultraviolet (UV) irradiation can be used to disinfect our interior spaces. While decades of research have shown the effectiveness of conventional, low pressure discharge lamps that generate UV-C, what about other wavelengths, or some of the new technologies?

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Last summer, the Lighting Research Center collected feedback about UV disinfection technologies from over 200 lighting specifiers, manufacturers and others from the lighting industry. Primary concerns for most respondents were safety hazards of UV, confirming whether UV is an effective disinfection strategy and verifying that disinfection has been achieved at a site. Also of concern was damage to room materials and a lack of building codes. Energy, cost and maintenance of UV disinfection systems were of some concern as well.

Using those questionnaire results, we developed a report at the end of 2020, *Lighting Answers: UV Disinfection Products*. Available for free download, the publication addresses three key aspects of UV disinfection: product effectiveness; radiation safety; and energy use in buildings.

When deciding what approach to take for UV disinfection in commercial buildings, specifiers should evaluate many needs such as: what organisms are being targeted, whether they are airborne vs. surface-dwellers, what UV "dose" is required to disable those organisms, what percentage of inactivation is needed ("log kill"), and whether the space needs continuous disinfection while humans are present.

As shown in **Figure 1**, various pathogens require different doses of UV to be inactivated. Larger organisms such as fungi generally require more UV than smaller ones. Small bacteria and viruses can be 1,000 times more susceptible to UV than larger fungi. Fortunately, the virus that causes COVID-19 is expected to be very susceptible to UV-C. But even when COVID-19 recedes someday, healthcare environments will increasingly be called to battle antibiotic-resistant bacterial infections such as C. *diff* and MRSA. UV disinfection technology will continue to be useful in our microbial battles of the future.

Measurement Questions. Measurements and amounts matter with UV disinfection. UV "dose" is measured in Joules per sq meter and is a product of irradiance (or "fluence" for airborne pathogens) and time; to achieve disinfection, one can apply a low irradiance over a long time, or if rapid disinfection is needed (such as air in a fast-moving HVAC duct), one will need a high irradiance to achieve the desired UV dose.

When determining what percentage of inactivation is necessary, a space with higher levels of infection will need to target higher inactivation rates [from 90% ("1 log kill") up to 99.9999% ("6 log kill")] to achieve comparable disinfection. Higher log kill targets necessitate greater UV doses.

UV wavelength impacts how well a technology will disinfect. The wavelength of peak susceptibility for disinfection differs between microorganisms. The efficiency of different wavelengths is called an action spectrum; though action spectra of most organisms are similar in the traditional germicidal spectral region (250 to 300 nm) due to a common mechanism based on DNA and RNA damage, action spectra based on other mechanisms vary widely. As shown in the sidebar, UV wavelengths are broken down into wavebands that roughly correspond to different disinfection mechanisms and effectiveness for different uses.

UV source types are growing more diverse. Low pressure discharge mercury lamps (LPD Hg) have a long and proven history of achieving disinfection in air and water treatment; however, human occupants must be shielded from exposure. Other technologies emit UV-C at other wavelengths, with a range of products and target applications. Pulse xenon products emit a broad distribution of wavelengths, rather than strategically targeting one pathogen's weakest point. Krypton chlorine excimer lamps generate very short UV-C wavelengths, particularly 222 nm, and are typically filtered to prevent dangerous occupant exposure at 254 nm. New UV LEDs offer promising options for very focused spectral output and distributions; however, it may take a few years for quantum efficiencies, cost and life of UV-C LEDs to be competitive with these other technologies.

LED products that emit UV-A or short-wavelength visible (violet) light are now available; while these products do not directly disinfect most viruses in the air, they have been shown to be effective with surface disinfection of bacteria and fungi. UV-A and short visible wavelengths disinfect using a different mechanism than UV-C, by indirectly creating reactive oxygen species with other materials in the environment. UV-A and visible wavelengths are naturally-occurring in our environment, so humans and pets can safely be exposed to amounts below the threshold limit values established by the American Conference of Industrial Hygienists. Since they can be used while occupied,

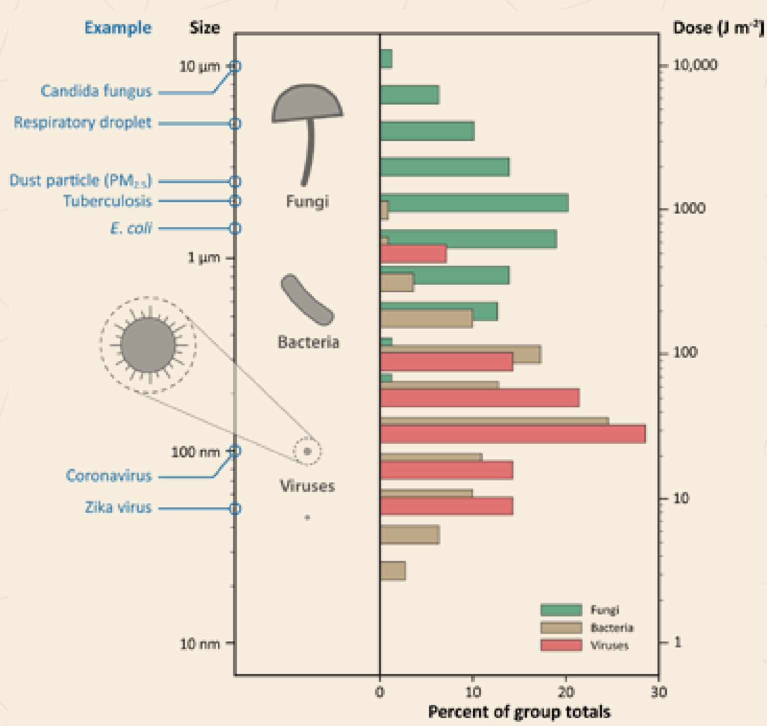

Figure 1.
UV-C disinfection dose varies depending on type of organism.

ABC's of UV

As shown below, ultraviolet wavelength bands include UV-C, UV-B, and UV-A, as well as visible light. The wavelength bands correspond to source types, uses, surfaces vs. air, and viruses vs. bacteria/fungi. Extensive discussion of advantages, drawbacks and safety considerations of each of these are shown in the 2020 publication: *Lighting Answers: UV Disinfection Products*.

	UV-C (10 – 280 nm)		UV-B (280 – 315 nm)	UV-A (315 – 400 nm)	Visible Light (>380 nm)
	Far UV-C (200 – 230 nm)	*Traditional germicidal (254 nm)*		*Antibacterial products (350 – 405 nm)*	
Sources	Krypton chlorine excimer, Xenon	Medium and low pressure discharge Hg, LED, Xenon	Sunlight, Hg, LED, Xenon	Sunlight, LED, Xenon	Sunlight, LED, Xenon
Typical uses	Germicidal (viruses, bacteria, and fungi)	Germicidal (viruses, bacteria, and fungi)	Tanning booth, Vitamin D production, material curing, psoriasis treatment	Bactericidal, blacklight theatrical effects, material curing	Bactericidal, material curing
Disinfection of surfaces	Yes	Yes	N/A	Primarily, and if other adjuncts present	Primarily, and if other adjuncts present
Disinfection of air	Yes	Yes	N/A	May depend on an adjunct (e.g., TiO_2) to be effective	Possibly, if adjunct present
Effective against viruses	Yes	Yes	N/A	Not primarily*	Not primarily*
Effective against bacteria/fungi	Yes	Yes	N/A	Yes	Yes

** Some evidence of effectiveness against non-enveloped viruses (e.g. norovirus), by means of secondary reactive oxygen species.*

these technologies may become increasingly useful as antibiotic-resistant pathogens continue to proliferate. A trade-off, however, is that the irradiance needed to achieve the required dose necessitates high output, which does have energy implications.

Drawbacks. One drawback of UV disinfection technologies is that materials in the built environment may not be designed to withstand UV exposure; material may fade, turn yellow or become brittle. Another drawback is that some UV disinfection products generate ozone, which is another health hazard to occupants. Ozone can also destroy elastic materials such as rubber bands and face mask ear loops.

UV-C is a line of sight technology; it will not penetrate deep into crevices or layered surfaces. Workarounds for surface disinfection could include moving the UV source to avoid shadowing, unfolding portable reflectors, or installation of multiple sources. In commercial buildings, UV-C has been used successfully for decades to disinfect moving air, both in HVAC ducts and in upper room applications.

In 2020 the Lighting Research Center tested 12 disinfection products with a wide range of technologies and intended applications (**Figure 2**). These included hybrid UV and visible light products, ceiling-mounted products, portable sterilizers, a portable air purifier and hand-held wands. Some of these products were found to be more practical than others at disinfection capability; hand-held UV wand required several minutes or even hours to disinfect common surfaces. One product claimed to emit UV-C but in fact emitted UV-A. Two commercially-available products were not designed with reflectors.

When safely measuring UV-C in the lab or in the field, personal protective equipment for eyes and skin is paramount. The UV-A and visible disinfection products the LRC tested did not require protective equipment.

Most people lack access to calibrated UV meters. For that reason, the LRC also evaluated UV-sensitive test cards; while not especially precise, test cards were shown to be sensitive to UV-C, so could be used as part of a maintenance program to confirm that UV-C products are still working.

In the years to come, we expect our battle against microbial pathogens will take advantage of diverse lighting and photonic technologies with spectral outputs that strategically target disinfection. ◎

Figure 2. Laboratory testing of UV products in 2020.

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