Upper-Room UVGI:

An Infectious Disease Control Strategy Whose Time Has Come

By David Skelton

The SARS-CoV-2 (COVID-19) pandemic has created an unprecedented demand for germicidal ultraviolet (UV) light irradiation equipment, marking a turning point for what may well be the world's most underutilized technology for infectious disease control in buildings.

For nearly a century, ultraviolet germicidal technology has been effectively used to destroy surface and airborne microbes such as tuberculosis, measles, and more. But for reasons that are difficult to pinpoint, its applications have mostly been limited to such high-risk locations as emergency rooms and surgical suites. That changed in the months following the COVID-19 outbreak. Suddenly, a variety of facilities from churches to hair salons were feverishly looking for ways to safely return to normal. Not surprisingly, their search led many to ultraviolet germicidal irradiation (UVGI), and specifically to *upper-room* (UVGI), as a way to mitigate the risk of infection. This paper will explain in a manner that is accessible to all building owners and managers what upper-room UVGI is, how upper-room UVGI differs from other UV strategies and what makes it a particularly relevant solution for a wide range of mainstream applications today.

For those that may be unaware, it should be emphasized that UVGI is neither new nor unproven. Its effectiveness at microbial inactivation has been studied and well-documented since the 1930s. It has been successfully used to control the spread of pocketed outbreaks of measles and tuberculosis[1] and it also has been used to destroy additional air and surface microbes including chickenpox, mumps, and cold viruses.[2] Furthermore, the Center for Disease Control (CDC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have all recognized UVGI as effective at controlling the spread of viral and bacterial microbes.

All this being the case, why hasn't germicidal ultraviolet (UV-C) light been applied with greater regularity in buildings? And why haven't we heard more about the technology?

There is no single answer except perhaps to say that historically pharmacology and vaccines have taken center stage when it comes to eradicating infectious diseases. As a society, we have transitioned over time from a culture of prevention to one of after-the-fact treatment and vaccines. But if the severity of the COVID-19 pandemic has taught us anything, it is that the wait for a vaccine can be excruciating — not to mention economically devastating.

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[1] Reed, Nicholas G. "The History of Ultraviolet Germicidal Irradiation for Air Disinfection." *Public Health Reports* 125, no. 1 (January 2010): 15–27. https://doi.org/10.1177/003335491012500105

[2] Jones, Daniel, and Michael Ivanovich. "UV-C for HVAC Air and Surface Disinfection." *AMCA Inmotion* (2020): 2–10 https://www.researchgate.net/publication/344633657

What Is UVGI and How Does It Work?

UV light, an electromagnetic radiation, is classified into four wavelength ranges, referred to in nanometers (nm): vacuum UV (100 to 200 nm), UV-C (200 to 280 nm), UV-B (280 to 315 nm), and UV-A (315 to 400 nm). Of these, UV-C light is most useful as a means of disinfection. At this particular range UV light is absorbed by the DNA, RNA, and proteins of biological organisms. When this absorption occurs, the organism is no longer able to replicate or infect other organisms, including people. The duration and level of UV-C exposure required for deactivation varies slightly from microbe to microbe, but generally deactivation is within seconds. Most importantly, there are no known pathogens that are resistant to some level of dosage of UV-C energy,[3] *including* SARS-CoV-2, the causative agent of COVID-19. (See Table 1 for a listing of well-known pathogens that have been deactivated by UV-C light as of the writing of this article.)

There also have been a limited number of cases when, applied or used improperly, temporary injuries have occurred. However, given proper application and basic safety measures, UVGI is quite safe and is not associated with any long-term health effects. Education is key for this technology to assume its rightful place in healthy building strategy and pandemic preparedness. That begins with a brief explanation of UV irradiation and how it can be manipulated to inactivate disease causing microbes.

In UVGI applications, UV-C at wavelengths close to 254 nm is delivered through low-pressure mercury vapor lamps that can be applied in several ways to disinfect air, surface and even drinking water.

UV-C lamps for surface applications can either be fixed or portable and are intended for use in spaces that are presently unoccupied. UV-C lamps for air disinfection

Table 1

Well-Known Pathogens Deactivated Through UVC

Common Name	Pathogenic Name	Pathogen Type
Pneumonia	Pseudomonas aeruginosa	Bacteria
TB/Tuberculosis	Mycobacterium tuberculosis	Bacteria
Coronavirus	Coronavirus	Virus
Legionella	Legionella pneumophila	Bacteria
Acinetobacter	Acinetobacter baumannii	Bacteria
Flu	Influenza A & B	Virus
Staph/MRSA	Staphylococcus aureus	Bacteria
Avian Flu	Avian Influenza Virus	Virus
Measles	Measles	Virus
Chicken Pox	Varicella Zoster	Virus
Strep	Streptococcus pyogenes	Bacteria
E. Coli	Escherichia coli	Bacteria
Typhoid Fever	Salmonella typhi	Virus
Salmonella	Salmonella enteritidis	Bacteria
Black Mold	Aspergillus Niger	Mold
C. diff	Clostridium difficile	Bacteria

There are no known pathogens that are resistant to some level of dosage of UV-C energy,[3] *including* SARS-CoV-2, the causative agent of COVID-19.

[3]"UV-Disinfection," Philips, accessed January 5, 2021, https://www.usa.lighting.philips.com/products/uv-disinfection

are typically applied in one of two ways: They can be installed within the mechanical air handling system of a building (a method known as "in-duct" UVGI) to disinfect building supply air; or they can be included as part of specially designed fixtures that are installed on walls and/or ceilings to disinfect the air within a space. The latter method, commonly referred to as "upper air" or "upper-room" UVGI, specifically targets contaminants within an *occupied space*, while in-duct UV-C treats supply or recirculated air prior to its delivery to the space. As such, upper-room UVGI treats air close to the contaminant source (people), making it particularly effective at preventing person-to-person spread.

Upper-room UVGI fixtures can be either wall-mounted, suspended from the ceiling, or both, depending on the size and geometry of the room. The fixtures may be open or louvered depending on the ceiling height. Louvered fixtures can be safely installed in rooms that are 8 to 9 ft high as long as the bottom of the fixture is at least 7 ft from the floor. The louvers direct and confine the irradiation from the UV-C lamps to the germicidal field which is usually no greater than 6 inches from the ceiling. Open or non-louvered fixtures direct germicidal energy into the entire upper-room area and can be safely used in rooms with ceilings that are over 9 ft high.

Air movement (created by the natural rise and fall of convection, existing HVAC, or in some cases paddle fans) helps to "herd" exhaled viruses and other room contaminants into the irradiation zone. Eradication is fast, typically within seconds depending on the dose of UV-C irradiance energy and the particular virus or bacteria.

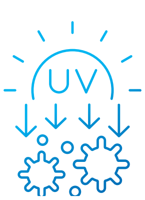
Visual Sense of Security

What makes upper-room UVGI particularly appealing in the age of COVID-19 is that it can be easily and affordably applied to existing buildings. Unlike in-duct systems, it doesn't require HVAC expertise to apply or install. Some applications may require hidden wiring, in which case an electrician may be needed, but in many cases the lights can be installed by properly trained facility maintenance personnel. UVGI manufacturers and their representing agents can access the particular application and help select appropriate equipment.

According to Mike Shea, president of the Tom Barrow Company, one of the largest commercial HVAC manufacturers' representatives in the United States, it is the literal and psychological accessibility of upper-room UVGI that makes it especially relevant given the hardships of the COVID-19 pandemic. Shea has supplied UV-C products along with the many airside HVAC products that his company has sold for many years. However, it wasn't until the recent pandemic that he was confronted with such a high demand specifically for *upper-room* UVGI.

"Upper-room is much easier for the average business owner to understand. For one thing, it isn't hidden away in the mechanical system. People can see it working. And right now people really want that visual sense of security when they enter into a space," said Shea.

Since the start of the pandemic, upper-room UVGI fixtures have been used in dentist offices, gyms, K-12 classrooms, universities, office spaces, churches, and more. The demand was there even before scientists had a chance to test the effects of UV-C on the new virus. Since then, evidence has been mounting that UV-C is effective against SARS-CoV-2.



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Ultraviolet Light Vs. SARS-CoV-2

Long before COVID-19, a wealth of evidence had proven UV-C light as an effective intervention against the transmission of airborne diseases. More recently, the scientific community has published work that validates UV-C light as specifically effective against SARS-CoV-2.

In October 2020, the *American Journal of Infection Control* published a report, Susceptibility of Sars-CoV-2 to UV Irradiation, asserting the following:

- SARS-CoV-2 is highly susceptible to irradiation with ultraviolet light.
- High viral loads of 5 x 10^6 TCID50/ml SARS-CoV-2 can be inactivated in 9 minutes by UVC irradiation.
- UVC irradiation represents a suitable disinfection method for SARS-CoV-2.[4]

Data from the study "confirm former findings that UV-C is more effective in inactivating viruses and highlight UVC irradiation as an effective method for the inactivation of SARS-CoV-2."[5]

Results from another study conducted and drafted by scientists at Boston University show that "UV-C is a powerful tool that can be applied extensively in a wide range of public institutions including hospitals, nursing homes, workplaces, schools, airports, and shopping centers to disinfect contaminated equipment and surfaces to prevent and reduce SARS-CoV-2 contact transmission."[6] As of this writing a preliminary report from the study has been published online and awaits peer review.

Regarding upper-room UVGI specifically, results from a *peer-reviewed* feasibility study "strongly suggest that upper-room UVGI, if applied correctly, should be effective at disinfecting SARS-CoV-2 virions suspended in respiratory droplets in the air."[7]

Application and Education Is Key to Safety

Safety remains a concern in the minds of many, largely because many fail to recognize that neither in-duct nor upper-room UVGI equipment is designed or intended for *direct exposure* to human skin. However, as long as equipment is properly installed and safety protocols observed, upper-room UVGI can be safely installed in a variety of spaces.

Unlike solar UV exposures, UV-C radiation does not penetrate beyond the "dead" outer layer of the skin and therefore is not associated with the same long-term effects. That said, *direct exposure* of the skin or eyes to UV-C radiation can cause erythema ("sunburn") and photokeratitis ("welder's flash") to the eyes.[8] Even though upper-room UVGI may be operating while a room is occupied, that does not mean occupants are being directly exposed because non-reflective louvers channel radiation within a narrow field, well above the heads of occupants. Students in a classroom can lie flat on their backs and stare at the ceiling without incurring any harm. Direct exposure would be akin to someone climbing on a ladder and putting themselves within the irradiation field. Otherwise, normal room movement and occupation presents no danger.

What accidents have occurred have been attributed to improper installation and human error. This has been the conclusion of at least one double-blind, placebo-controlled field trial of upper-room UVGI at 14 homeless shelters in six U.S. cities from 1997 to 2004.

[4]Christiane Silke Heilingloh et al. "Susceptibility of SARS-CoV-2 to UV irradiation," *American Journal of Infection Control*, 48, no. 10, (2020): 1273-1275, https://bit.ly/2JNJkg2

[5]Heilingloh et al. "Susceptibility of SARS-CoV-2," https://bit.ly/2JNJkg2

[6]Storm, Nadia. "Rapid and Complete Inactivation of SARS-CoV-2 by Ultraviolet-C Irradiation." (September 21, 2020). https://www.researchsquare.com/article/rs-65742/v2

[7]Beggs C.B. and E.J. Avital. 2020. "Upper-room ultraviolet air disinfection might help to reduce COVID-19 transmission in buildings: a feasibility study." *PeerJ* 8: e10196. https://doi.org/10.7717/peerj.10196

[8]Reed, Nicholas G. "The History of Ultraviolet." https://doi.org/10.1177/003335491012500105

The study concluded:

> *"Upper-room UVGI has the potential to offer significant protection at relatively low cost and is especially well-suited for retrofitting older buildings. Based on the results reported here, concerns regarding safety — particularly the possibility of photokeratitis conjunctivitis and skin erythema from excessive UV-C exposure — should not deter application of carefully designed and maintained upper-room UVGI systems.*
>
> *[....] current upper-room UVGI technologies, with proper engineering, installation, and maintenance, can be placed safely in a wide range of indoor spaces, even in buildings as diverse as homeless shelters. [...] With a greater understanding of the application of UVGI, the full potential of this technology to improve control of person-to-person transmission of human airborne pathogens in buildings should be realized."*[9]

In addition to proper installation and maintenance, there are certain precautions and protocols that should be observed. These include, but may not be limited to, worker training, the posting of signage that informs occupants about the presence of the UVGI devices, safe maintenance procedural training, and in some cases the installation of sensors to detect any movement within the radiation field and associated alarms or shut-offs. The FDA also suggests (and the author of this article concurs) that anyone considering implementing the technology should ask the following questions of UV-C equipment manufacturers:

- What health or safety risks are associated with the equipment?
- What instructions for use or training are available or provided for the product?
- Does the product generate ozone? (Note: Ozone is only produced at wavelengths lower than 200nm, therefore germicidal UVGI lamps at 254 nm should be ozone free.)
- How should broken or damaged lamps be handled and disposed?[10]

To ensure uninterrupted service in the future, prospective buyers should also inquire about the availability of replacement lamps. Some manufacturers use proprietary lamps in their fixtures which can be very expensive and difficult to find, especially during high-demand periods. Non-proprietary lamps are generally widely available, much less expensive, and can even be ordered online.

Making Old Air New Again

Throughout the pandemic, we've all been coached on the value of ventilation, filtration, and dilution as a way to purge indoor air of disease-causing pathogens, but these are not stand-alone strategies.

Upper-room UVGI has the potential to offer significant protection at relatively low cost and is especially well-suited for retrofitting older buildings.

[9]Nardell, Edward, Scott Bucher, Philip Brickner, Charles Wang, Richard Vincent, Kathleen Becan-McBride, Mark James, Max Michael, and James Wright. (2008). "Safety of Upper-Room Ultraviolet Germicidal Air Disinfection for Room Occupants: Results from the Tuberculosis Ultraviolet Shelter Study." *Public Health Reports* (Washington, D.C.: 1974). 123. 52-60. 10.1177/003335490812300108. https://bit.ly/38hYLqw

[10]FDA. "UV Lights and Lamps: Ultraviolet-C Radiation, Disinfection, and Coronavirus." *US Food & Drug Administration.* (2020). https://bit.ly/3pS4Lfj

For example, to mitigate the risks of COVID-19, ASHRAE now recommends upgrading HVAC air filters to MERV-13 or higher if possible.[11] But doing so comes at a high cost because forcing air through a high-efficiency filter capable of removing infectious particles requires a *lot* of fan energy. Very often facility managers discover that existing fans simply don't have the muscle to overcome the resistance.

ASHRAE also recommends increasing ventilation and operating systems with 100% outdoor air whenever possible. Unfortunately, most buildings are designed to recirculate a certain amount of pre-conditioned return air. They do not have the capacity to fully condition (heat, cool, humidify *and* dehumidify) every bit of indoor supply air. And even if they do, this is highly cost-prohibitive to most owners.

"We've seen this a lot in the past year. One university decided to operate all their buildings at 100% outdoor air even though it was not designed to operate that way. It was done knowing that it could create many other problems, like mold," said Shea.

The application of upper-room UVGI can, to a degree, make old air fresh again by inactivating biological contaminants like mold, bacteria, germs, and viruses. This has been demonstrated in various studies using a commonly used metric for ventilation, air changes per hour (ACH).

ACH, quite simply, refers to how often the air in a space is completely replaced. The higher the ACH, the lower the risk of spreading airborne disease. For example, current CDC guidelines for health-care facilities require a minimum of 6 air changes for all rooms. Some spaces, like operating rooms, require 15 or more ACH. An ACH of 4 is the minimum recommended air change rate for most commercial buildings. Often, studies that measure the efficacy of UVGI to inactivate specific airborne pathogens are compared to the number of ACH that would be needed to eliminate the same pathogens using normal ventilation.

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Upper-room UVGI is not only less expensive than physically creating air changes using mechanical ventilation, but also more effective. In a study published in 2002, researchers at the Harvard School of Public Health found that when it came to reducing the concentration of two common bacterium, one causing tuberculosis and the other associated with a number of hospital-acquired infections, upper-room UVGI produced equivalent ventilation ranging from 6.4 ACH to 28.5 ACH using ceiling and wall-mounted [UVGI] fixtures.[12]

Another study, which focused on the virus that causes smallpox, yielded even more impressive data with regard to equivalent air changes using upper-room UVGI.

[11]ASHRAE. *ASHRAE position document on infectious aerosols*, (2020). https://bit.ly/2LslF5a

[12]Ko, Gwangpyo, Melvin W. First, and Harriet A. Burge. "The characterization of upper-room ultraviolet germicidal irradiation in inactivating airborne microorganisms." *Environmental Health Perspectives* (2002) 110:95-101. https://dash.harvard.edu/handle/1/4515099

> *"Using vaccinia virus aerosols as a surrogate for smallpox we report on the effectiveness of air disinfection, via upper-room UVC light, under simulated real world conditions including the effects of convection, mechanical mixing, temperature and relative humidity. In decay experiments, upper-room UVC fixtures used with mixing by a conventional ceiling fan produced decreases in airborne virus concentrations that would require additional ventilation of more than 87 air changes per hour. Under steady state conditions the effective air changes per hour associated with upper-room UVC ranged from 18 to 1000."* [13]

But what about SARS-CoV-2? Can similarly high ACH rates be attained using upper-room UVGI to remove the virus that causes COVID-19? Per the same peer reviewed feasibility study referenced earlier in this paper, it is expected that it can:

> *"Through analysis of expected and worst-case scenarios, the efficacy of the upper-room UV-C approach for reducing COVID-19 transmission in confined spaces (with moderate but sufficient ceiling height) is demonstrated. Furthermore, it is shown that with SARS-CoV-2, it should be possible to achieve high equivalent air change rates using upper-room UV air disinfection, suggesting that the technology might be particularly applicable to poorly ventilated spaces."* [14]

Although direct evidence is lacking due to the novelty of the COVID-19 virus, Table 2 summarizes the equivalent ACH rates for reduction of airborne contaminants.

"There is no overstating the significance of this to building owners. Upper-room UVGI provides a level of airborne germicidal treatment that, practically and affordably speaking, neither filtration nor ventilation

Table 2

Ventilation and Dilution

ACH reduction of airborne-contaminants

ACH	Minutes required for removal efficiency of:		
	90%	99%	99.9%
1	138	276	414
2	69	138	207
3	46	92	138
4	35	69	104
5	28	55	83
6	23	46	69
7	20	39	59
8	17	35	52
9	15	31	46
10	14	28	41
11	13	25	38
12	12	23	35
13	11	21	32
14	10	20	30
15	9	18	28
16	9	17	26
17	8	16	24
18	8	15	23
19	7	15	22
20	7	14	21
25	6	11	17
30	5	9	14
35	4	8	12
40	3	7	10
45	3	6	9
50	3	6	8

Source: CDC Guidelines for:

American Conference of Governmental Hygienists
US Department of Health Education and Welfare
Public Health Service, DHS publication (NIOSH) 74-117

can. And it's accessible – both to sprawling universities as well as bars and restaurants," said Shea.

Shea also added that without some sort of supplementary strategy like UVGI, building owners that seek to meet the latest ASHRAE 90.1 energy guidelines ultimately will be spinning their wheels while also trying to mitigate the spread of COVID-19 with filtration and ventilation alone. Even ASHRAE in its 2020 Position Document on Infectious Aerosols acknowledges that the design and operation of HVAC systems are only "one part of an infection control bundle" while calling out UVGI as a "well researched and validated" strategy.[15]

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[13]McDevitt J.J., D.K. Milton, S.N. Rudnick, M.W. First "Inactivation of Poxviruses by Upper-Room UVC Light in a Simulated Hospital Room Environment." *PLOS ONE* 3(9) (2008) e3186. https://doi.org/10.1371/journal.pone.0003186

[14]Beggs C.B. et al. "Upper-Room Ultraviolet Air." https://doi.org/10.7717/peerj.10196

[15]ASHRAE. ASHRAE position document on infectious aerosols, (2020). https://bit.ly/2LslF5a

Conclusion

As the world waits for widespread immunity to the COVID-19 virus, each of us is confronted with the same two questions almost daily: What can we do to stay safe (and solvent) in the meantime? And what can we do to lessen the impact of future infectious outbreaks? Upper-room UVGI is a potential antidote to the helplessness that many feel, particularly business owners and institutions whose activity and livelihoods have been upended in the last year. The solution is easily retrofitted and a visual reminder to building occupants that the air within a given space is continuously being cleaned of harmful pathogens.

The technology is well researched with a long track record of success against some of the most contagious diseases known to man. It has earned the right to a prominent position in the fight against COVID-19, as well as a preparedness strategy for future health crises.

About the Author

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David Skelton is a recognized specialist in specifying, design/build, and installation of Ultraviolet Germicidal Irradiation (UVGI) products and turnkey environmental disinfection services, with a focus on improved Indoor Air Quality (IAQ), environmental disinfection, energy efficiency/cost savings, and maintenance reduction. David has over 35 years of experience in the engineering and manufacturing of HVAC-related products and is an accomplished speaker for ASHRAE and PDS (Professional Development Series) conferences, leading engineering seminars with his overview of UVC technology for air and surface disinfection.

David's past and current roles include: past Chairman of ASHRAE TC-2.09, UV Air and Surface Disinfection; ASHRAE Subject Matter Expert (SME) and published-data peer-reviewer; Voting Member, ASHRAE GPC-37, Upper-Air UVC Disinfection; Voting Member, ASHRAE SPC-185.1, and 185.2, test standards for air and surface treatment; Voting Member, Underwriters Laboratory UL, STP 60335-2-40 Standards Committee; Advisory Panel, US TAG for ISO/TC-142, technical panel committee for cleaning equipment for air and other gases; NIST Work Group: US Dept of Commerce UVC Healthcare Standards; and International Ultraviolet Association (IUVA) Member.

About Lumalier

Lumalier was founded in 1963 to develop advanced Ultraviolet Germicidal Irradiation (UVGI) technology, products, innovations, and engineering controls. Lumalier's advanced UV germicidal disinfection products are specifically engineered to benefit the healthcare, educational, office, institutional, commercial, retail, and residential markets.

In 1980, Lumalier partnered with Dr. Paul Jenson from the CDC to work on improving the original upper air designs from the 1930's to help control tuberculous around the world. By working with the CDC, the design was not patented so it could be used globally.

In 2020, Lumalier became part of the United Enertech family of companies, and today is a leading manufacturer of UVGI products. The company offers a complete selection of UVGI air and surface disinfection products including upper-air disinfection products designed to target air contamination in high-risk areas; in-duct disinfection products which are installed inside ventilation systems to provide high-level disinfection of airborne infectious pathogens throughout the entire building; and surface disinfection UV fixtures engineered for high-level disinfection of contaminated surfaces that can spread infection.

Lumalier remains an active member of the International Ultraviolet Association (IUVA), and an active member and participant of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), and its UV Technical Committee TC2.9, and UV Standards Committee SPL-185.