UV-C Lights—Do They Improve Indoor Air Quality?

WHITE PAPER

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The recent COVID-19 pandemic has made clear the link between Americans' health and the quality of the air they breathe indoors. As a building's indoor air quality (IAQ) comes under increased scrutiny, so do the performance standards of each facility's heating, ventilation and air conditioning (HVAC) system. Safe IAQ is no longer an abstract goal; it's an expectation.

One increasingly popular means of improving commercial IAQ is the use of ultraviolet-C (UV-C) technology. UV disinfection is one of the most-researched, scientifically proven and extremely effective means of destroying harmful airborne and surface pathogens. UV-C installations are a simple, effective, and relatively inexpensive means of inactivating viruses and bacteria. This, in turn, makes air cleaner and healthier, in addition to boosting HVAC capacity, energy savings and operational efficacy.

POOR INDOOR AIR QUALITY

Most people know that outdoor air pollution can impact their health, but too many people ignore the fact that indoor air pollution can also have significant and harmful health effects. Studies conducted by the U.S. Environmental Protection Agency (EPA) and others show that indoor air pollutant levels can be two to five times–and occasionally more than 100 times–higher than outdoor levels.[1,2] (See Figure 1). These levels are concerning because most Americans spend up to 90% of their time indoors.

Said differently, by the time a person is 50 years old, 45 of those years will be spent indoors.

In addition to harmful health effects, poor air quality can cause or aggravate existing illnesses, as well as spread communicable diseases. In fact, according to the EPA, poor indoor air quality can irritate the eyes, nose, and throat; contribute to headaches, dizziness, fatigue, respiratory diseases, heart disease, and cancer.[3]

An article in Science magazine noted (emphasis added):

> "The COVID-19 pandemic has revealed how unprepared the world was to respond to it, despite the knowledge gained from past pandemics. **A paradigm shift is needed** on the scale that occurred when Chadwick's Sanitary Report in 1842 led the British government to encourage cities to organize clean water supplies and centralized sewage systems. In the 21st century, we need to… ensure that the air in our buildings is clean with a substantially reduced pathogen count, contributing to the building occupants' health, just as we expect for the water coming out of our taps." [4]

Fortunately, the paradigm is already starting to shift. In March 2022, the federal government launched the Clean Air in Buildings Challenge, which calls on all building owners and operators, schools, colleges and universities, and organizations of all kinds to adopt key strategies to improve the indoor air quality in their buildings. The goal of the program is to make ventilation and air filtration enhancements to help keep occupants safe.

More recently, the EPA proposed strengthening the national ambient air quality standards (NAAQS) for fine particle pollution, also known as fine particulate matter, or $PM_{2.5}$.[5] The proposed EPA rulemaking is based on scientific evidence that shows the current standard does not protect public health with an adequate margin of safety, as required by the Clean Air Act. As such, the agency recommends lowering the primary (health-based) annual $PM_{2.5}$ standard from 12 micrograms per cubic meter (μg/m3) to a level within the range of 9 to 10 μg/m3.

The public health agency estimates that if NAAQS standards are strengthened, it will prevent up to 4,200 premature deaths per year and 270,000 lost workdays per year.[6]

At the same time, the Centers for Disease Control & Prevention (CDC) is advocating a system of layered safeguards to reduce exposure to the virus that causes COVID-19. Public health experts recommend using multiple mitigation strategies, including improvements to building ventilation, to reduce the spread of disease and lower the risk of exposure. In addition to ventilation upgrades, the layered approach includes physical distancing, wearing face masks, hand hygiene and vaccination, strategies we're all familiar with by now.

THE ABCS OF IAQ.

But what exactly is substandard indoor air quality, anyway?

Poor indoor air quality (IAQ) is a condition of unacceptable levels of contaminants in the air serving and surrounding occupants in a closed and mechanically conditioned space. Three culprits drive poor IAQ: suspended particles, gas phase compounds and bioaerosols.

Bioaerosols are extremely small living organisms or fragments of living things suspended in the air: dust mites, molds, fungi, spores, pollen, bacteria, viruses, amoebas, remnants of plant materials, and human and pet dander.

According to the EPA, fine particles ($PM_{2.5}$) are of greatest concern because they can enter the respiratory tract and reach the lower parts of the lungs.

For perspective, a single hair from your head is about 70 micrometers in diameter. That is 30 times larger than the biggest fine particle (see Figure 2).

As mentioned above, exposure to PM2.5 can exacerbate pre-existing health conditions and lead to the development of some diseases (e.g., respiratory and cardiovascular) and premature mortality[7] (see Figure 3).

FIGURE 1: Various components that comprise the quality of our air.

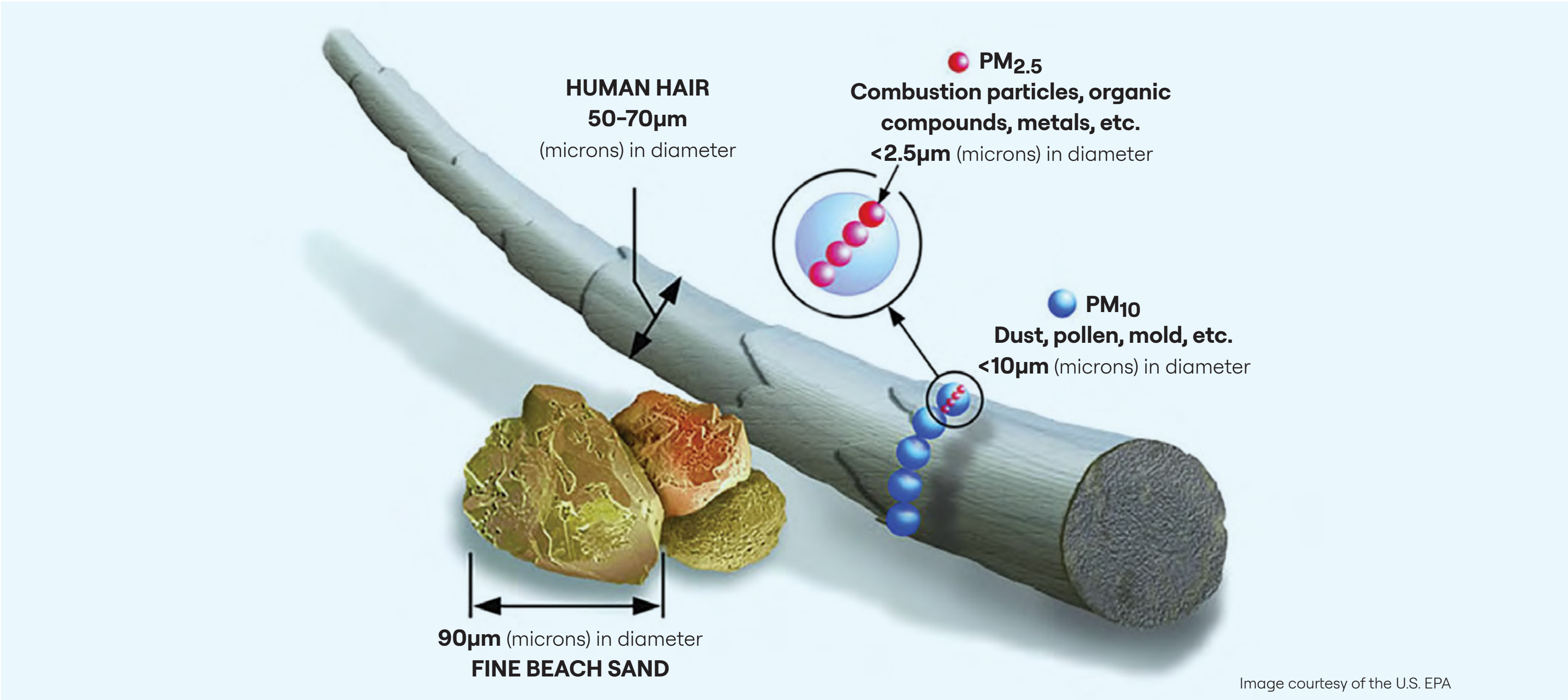


FIGURE 2: PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope, according to the U.S. EPA.

HVAC SYSTEMS IMPROVE OR EXACERBATE IAQ

HVAC systems cool spaces by removing heat and humidity from the air. They do this by passing the air through a "cold coil." The condensation produced from this process offers a perfect breeding ground for biofilm, and act as a sort of "glue" for dust and other airborne particulates to build up on the coil.

These captured particulates provide a great food source for microbial proliferation, as do the moist and dark conditions inside an HVAC air handler. In addition, mold and bacteria that often grow on cooling coils and drain pans can shed contaminants into the occupied space, posing infectious and non-infectious disease risks.

Once present, biological contaminants are difficult to control in an HVAC system and are rarely abated. Coil and duct cleaning followed by biocidal treatments have proven somewhat helpful but are costly, labor intensive and, like a snapshotin- time, temporary.

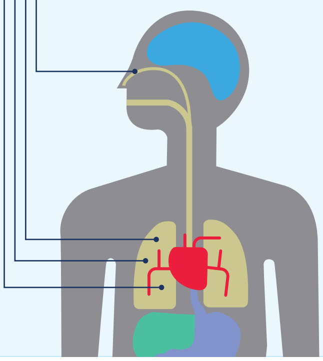
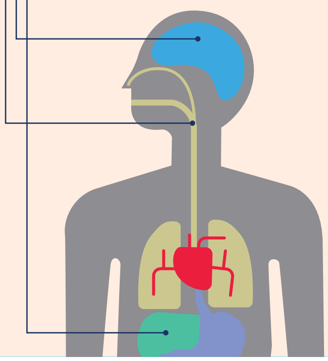
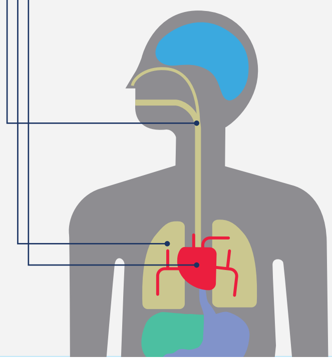
Some HVAC manufacturers apply microbial inhibitor coatings to air handler surfaces; however, biological activity is relentless and will eventually gain a foothold. The use of coil cleaning chemicals is another potential tool, yet facility managers are understandably reluctant to introduce these due to the detrimental effects on the indoor environment and the equipment.

A RAY OF SUNSHINE

Is there any light at the end of this vexing tunnel? There is. Ultraviolet light within the "C" band wavelengths (200-280 nanometers) has been used since the late 1800s to destroy microorganisms, biofilms and pathogens in water and on surfaces. And over the last two decades, it has been used successfully in HVAC equipment to improve system efficiency, reduce maintenance, increase cost savings–and, most importantly, reduce or eliminate occupant discomfort caused by bioaerosol contamination.

In fact, infectious disease researchers contend that UV-C is an essential mitigation control. "It is not an exaggeration to claim that the most effective, evidence-based, costeffective, safe and available engineering intervention to disinfect air is... germicidal ultraviolet air disinfection."[8,9]

Common Indoor Air Pollutants

Category	Bioaerosols	Volatile Organic Compounds	Particulates
Size range	0.007 – 50 µm	Vapors	0.001 – 50 µm
Some sources	• Bacteria • Mold • Viruses • Fungi • Pollens	• Paints, solvents • Office equipment • Cleaning supplies • Aerosol sprays • Wood preservatives • Carpet emissions • Chemicals	• Dust • Pollen • Exhaust • Smoke/combustion • Plant matter • Pet dander • Cleaning solutions
Health effects	• Some types of asthma • Respiratory infections • Hypersensitivity pneumonitis • Allergic rhinitis 	• Eye, nose and throat irritation • Headaches, loss of coordination and nausea • Damage to liver, kidney and central nervous system 	• Eye, nose and throat irritation • Aggravation of coronary and respiratory disease symptoms • Premature death in people with heart or lung disease 

Sources: www.epa.gov/indoor-air-quality-iaq/indoor-pollutants-and-sources www.ncbi.nlm.nih.gov/pmc/articles/PMC7215772

FIGURE 3: Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems, according to the U.S. EPA.

The UV-C electromagnetic wavelength is well-absorbed by microbial DNA and RNA, which damages the genetic material in viruses, bacteria, mold, and other organisms, rendering them unable to reproduce and non-infectious (see Figure 4). Moreover, there are no chemicals, VOCs or dangerous byproducts produced by UV-C energy, so it is eco-friendly and safe to use around food, plants, furniture and electronics.

A Harvard study of more than 3,000 workers showed that sick leave doubled among employees in poorly ventilated areas.[10] Poor air quality has also been shown to decrease office workers' cognitive function and decision making ability,[11] lower student reading and math achievement, damage teacher retention and worsen morale.[12]

Public health officials and professional building engineers know the fundamentals for improving indoor air quality: 1) ventilation or dilution, 2) mechanical filtration, and 3) germicidal UV-C energy, often in a layered or multifaceted approach (see Figure 5).

These engineering controls are endorsed by the CDC and recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).[13]

For example, ventilation can dilute pathogen concentrations, while filters capture airborne containments and UV-C energy inactivates pathogens so they are no longer harmful.

Increased ventilation, high-efficiency MERV filters, and UV-C systems help to provide a more comfortable indoor environment, while reducing pathogen transmission, preventing mold and bacterial growth within the HVAC system.

Many existing HVAC systems were originally designed to operate with MERV 8 filters or less, but since the pandemic, ASHRAE–and, by extension–the CDC, recommend facility managers upgrade HVAC filters to the equivalent of a MERV 13.

But there's a hitch: high-efficiency filters can have unintended consequences. A high-efficiency MERV 13 filter, used in an older HVAC system that was not designed for the associated increase in static pressure, can reduce airflow levels, increase energy consumption, and decrease the number

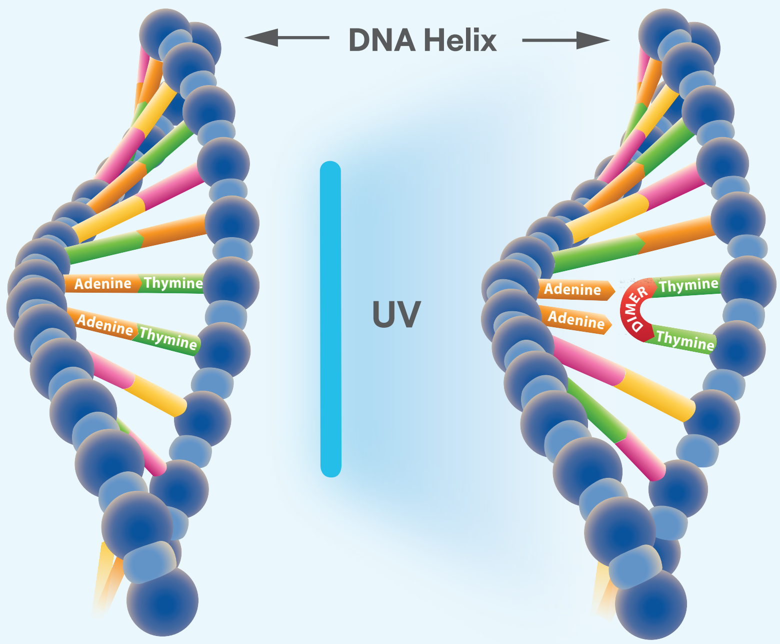


FIGURE 4: Through a process known as photodimerization, UV-C energy damages a cell's nucleic acids and protein structure, causing two consecutive bases (Thymine shown) to bind together. This genetic damage prevents microorganisms from infecting and replicating, ultimately leading to cell inactivation.

of air changes in the space. These performance issues can dissuade or prevent building managers from implementing the use of MERV 13 filters.

For example, after examining the HVAC systems at 17 federal buildings, the inspector general's office at the General Services Administration found that nearly half of them could not accommodate high-efficiency air filters. It was reported that trying to use them "would reduce airflow and potentially cause the systems to fail."[14]

Fortunately, there's a simple, cost-efficient alternative allowing the millions of legacy HVAC systems that were never intended to perform with MERV 13 or higher filters to still achieve CDC and ASHRAE recommendations.

Third-party research has shown that facility engineers can combine germicidal UV-C with medium-efficiency MERV 8 air filters in a layered approach to meet or exceed MERV 13 level performance without sacrificing airflow or compromising cooling capacity[15] (see Figure 6). The MERV 8 filters capture the larger particles, while UV-C inactivates the smaller, more susceptible pathogens.

This strategy delivers the best of both worlds. A germicidal UV-C system can reduce airborne pathogens on each pass, potentially disinfecting a room's total air volume multiple times each hour.

MORE PERFORMANCE. LESS COST.

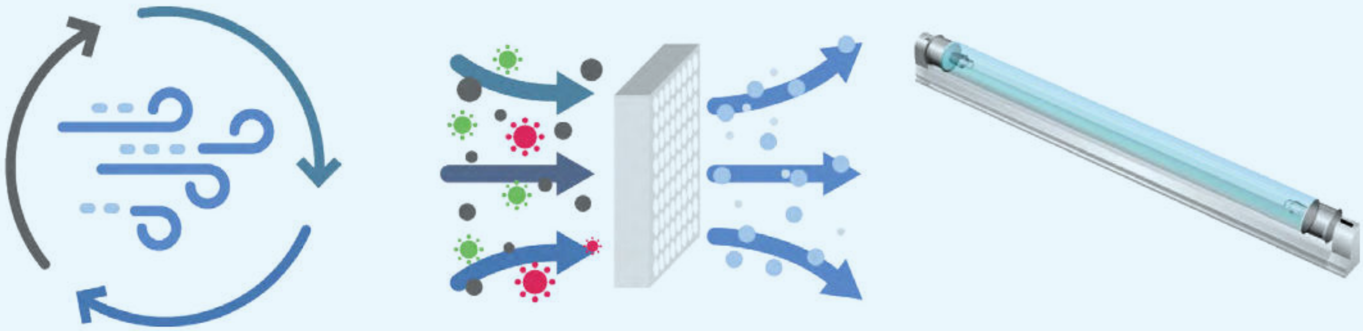
Besides the energy savings from the lower resistance and fan operation linked with MERV 8 filters, building owners can save on their their annual filter costs. MERV 8 filters cost significantly less than than their MERV 13 counterparts.

UV-C can slash HVAC energy consumption by up to 20% by restoring coil and airflow performance to near-original design capacity. As equipment ages, microbial fouling or contaminant buildup on evaporator coils increase pressure drop and lowers heat transfer efficiency, degrading the air handler's ability to remove heat and water from the air. As coil efficiency degrades, space humidity increases, leading

" It is not an exaggeration to claim that the most effective, evidence-based, cost-effective, safe and available engineering intervention to disinfect air is...germicidal ultraviolet air disinfection."

–Infectious Disease Researchers

Proven Engineering Controls Recommended by ASHRAE to Reduce Infectious Aerosols*



Ventilation and Dilution | **Mechanical Filtration** | **Germicidal UV-C Energy**

*ASHRAE (2022). ASHRAE positions on Infectious Aerosols. Retrieved from https://www.ashrae.org/File Library/About/Position Documents/PD_-Infectious-Aerosols-2022_edited-January-2023.pdf

FIGURE 5: ASHRAE identifies ventilation, mechanical filtration and UV-C energy as effective controls against infectious aerosols. The underlying strategy is to dilute (ventilation), remove (filter) or inactivate (UV-C) pathogen concentrations.

to poor IAQ levels and uncomfortable occupants. This forces operators to pull other, more energy-intense levers, such as increasing fan speeds and decreasing chilled water temperatures.

UV-C resolves the coil fouling issue. Once installed, a UV-C system breaks down organic buildup and biofilms on the coil, heat transfer efficiency improves, pressure drop falls, and energy and monetary savings significantly increase. In fact, ASHRAE commissioned independent research that found UV-C yielded an average pressure drop reduction of 21% and an increase in heat transfer coefficient of 14%.[16] By returning systems to virtually "as new" condition, most UV-C installations designed for coil cleaning pay for themselves in less than six months.

According to the U.S. Energy Information Administration, in March 2022, average U.S. commercial electricity prices were up 5% over the same period in 2021.[17] In addition, hotter and more humid summer temperatures and higher energy costs mean facility engineers must squeeze as much cooling and dehumidification as possible from their HVAC systems.

DOLLARS AND SENSE.

With HVAC operating budgets under pressure, UV-C can lower energy consumption, and restore cooling capacity while reducing occupant complaints by dramatically improving air quality. Besides substantial operational savings, UV-C fixtures installed in air handlers or HVAC ducts make workplaces safer, healthier and more productive.

Nationwide, the potential annual savings and productivity gains from improved IAQ are $14 billion from reduced respiratory disease, $4 billion from reduced allergies and asthma, $30 billion from reduced sick building syndrome, and $160 billion from direct improvements in worker performance.[18]

Further, the EPA estimates that if finalized, a strengthened primary annual $PM_{2.5}$ standard at a level of 9 micrograms per cubic meter – the lower end of the proposed range – could yield $43 billion in net health benefits by 2032.[19]

Decades of peer-reviewed science validating UV-C disinfection efficacy and endorsements by the CDC and

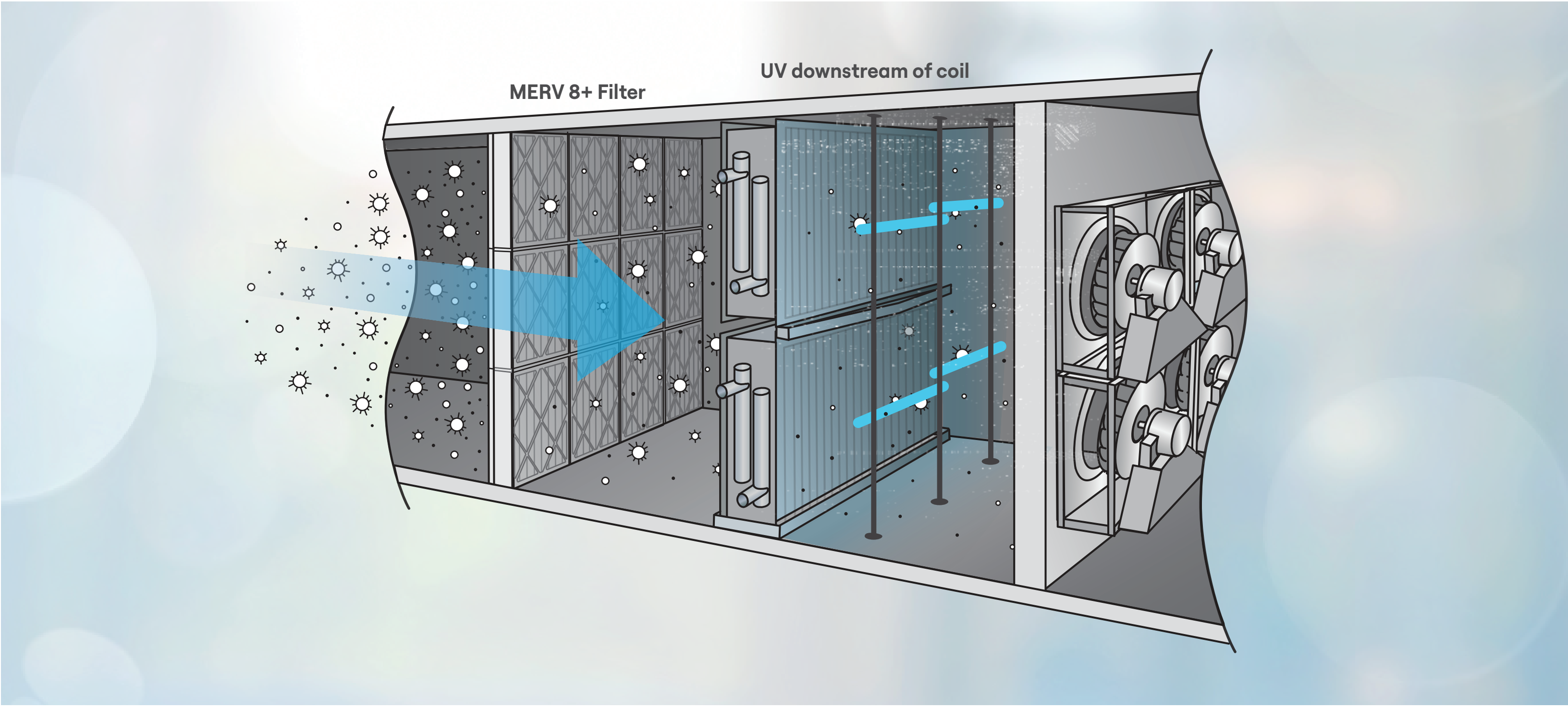


FIGURE 6: Facility engineers can combine medium efficiency (MERV 8) with UV-C to meet or exceed MERV 13-level efficiency rates without sacrificing airflow or compromising cooling capacity.

ASHRAE have convinced many property managers to embrace this germicidal technology over unproven non-peer-reviewed methods.

LAX, DFW and Syracuse Airports, Loyola University Medical Center, the College of American Pathologists and Schenectady County Community College are just a few of the hundreds of companies and organizations across America benefitting from this time-tested and proven infection mitigation methodology.

CASE IN POINT

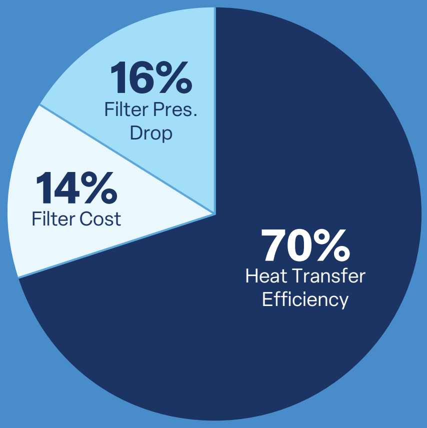


CHART 1: UV-C + MERV 8 Cost Savings

The combining or layering of air cleaning technologies has an exponential effect on an air handling unit's (AHU's) overall pathogen removal performance since the MERV 8 filter captures the larger pathogens, and the UV-C inactivates the smaller, more susceptible pathogens.

Moreover, from a budgetary perspective, as noted below, the MERV 8 filter costs roughly half its more efficient MERV 13 counterpart. As a result, it eliminates energy-intense adjustments typically used to compensate for reduced airflows, such as increasing fan speed. See Chart 1 for the various savings available by combining air cleaning technologies.

A large southeastern university recently calculated the difference between utilizing MERV 13 HVAC filters alone and combining UV-C and MERV 8 filters, as shown in Table 1. For example, at one campus building served by 20 AHUs, each with ten 16x20x2-inch pleated filters that were changed quarterly, the combination of UV-C and MERV 8 saved approximately 30% in annual filter costs alone ($16,960 vs. $12,976).[20] A key driver for these savings was the cost premium for the MERV 13 filters over the MERV 8 equivalents ($21.20/ea. vs. $8.72/ea.).

In the University's case, the energy savings derived from the less-restrictive MERV 8 HVAC filter (compared to a MERV 13 filter) nearly paid for the UV-C fixtures during the project's first year ($2,587 savings toward the $2,860 installed cost of the UV system).

With the reduced static pressure and cleaner cooling coils, university facility staff expects to spend 20% less energy using the less-restrictive filters in addition to the air filter cost savings.

Filtration Costs for a 10,000CFM University AHU	MERV 8 Filter	MERV 13 Filter	Difference
Cost of Individual Filter/Lamp (A, B)	$8.72	$21.20	$12.48
Cost of 10 Filters per AHU	$87	$212	$125
Cost of 4 filter changes per year (labor, disposal, etc. not included)	$349	$848	$499
Initial Filter Pressure Drop	0.25	0.40	
Energy Cost to Run Filters (at initial only) (10 filters) .13kwh (8760)	$1,000	$1,601	$601
Additional Cost to Run MERV 13 (filter cost and pressure drop)			$1,100
UV installation cost (onetime includes lamps, Electrical and labor)	$2,860		
Energy Savings from UV on coils (c)	$2,587		-$273
First Year NET Savings per AHU			**$827**

Estimated Annual Cost Savings	Replacement Cost per AHU	20 AHU's
MERV 8 pleats filter plus replacement UV lamps	$649	$12,976
MERV 13 pleats filter	$848	$16,960
Annual Filter Savings Alone	$199	**$3,984**
Continued Energy Savings with UV	$2,587	$51,740
Annual Savings with UV + MERV 8 vs. MERV 13	**$2,786**	**$55,724**

(A) Filter prices provided by the university

(B) Example does not include expected filter and lamp increases for year two and beyond

(C) Application based on a 10,000CFM (25 ton) AHU operating 5,860 hours of cooling at $0.13 kwh; coil pressure drop reduction of .10" wg, 56F to 55F LWB change

ENDNOTES

1 Wallace, LA, et al. Total Exposure Assessment Methodology (team) Study: Personal exposures, indoor-outdoor relationships, and breath levels of volatile organic compounds in New Jersey. Environ. Int. 1986. Retrieved from https://www.sciencedirect.com/science/article/pii/0160412086900516

2 US Environmental Protection Agency. Why Indoor Air Quality is Important to Schools. 2022. Retrieved from https://www.epa.gov/iaq-schools/whyindoor-air-quality-important-schools

3 U.S. Environmental Protection Agency. Indoor Air Quality: What are the trends in indoor air quality and their effects on human health? September 2021. Retrieved from https://www.epa.gov/report-environment/indoor-air-quality

4 Science Magazine. Ventilation in buildings: where water sanitation was in the 1800s. 2021. Retrieved from https://scienmag.com/ventilation-inbuildings-where-water-sanitation-was-in-the-1800s/

5 US Environmental Protection Agency EPA Proposes to Strengthen Air Quality Standards to Protect the Public from Harmful Effects of Soot. January 2023. Retrieved from https://www.epa.gov/newsreleases/epa-proposes-strengthen-air-quality-standards-protect-public-harmful-effects-soot

6 IBID. 5.

7 US Environmental Protection Agency. Presentation. Proposed Revisions to National Ambient Air Quality Standards for Particulate Matter. 2023. Retrieved from https://www.epa.gov/system/files/documents/2023-01/PM%20NAAQS%20Reconsideration%20Proposal%20-%20Overview%20Presentation_0.pdf

8 Nardell EA. Air Disinfection for Airborne Infection Control with a Focus on COVID-19: Why Germicidal UV is Essential. Photochem Photobiol. 2021 May. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8251047/

9 Mphaphlele M, Dharmadhikari AS & Jensen PA, et al. Institutional Tuberculosis Transmission. Controlled Trial of Upper Room Ultraviolet Air Disinfection: A Basis for New Dosing Guidelines. American Journal of Respiratory and Critical Care Medicine. 2015 Aug. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4595666/

10 Corsi R, Miller SL, VanRy M, et al. Designing infectious disease resilience into school buildings through improvements to ventilation and air cleaning. The Lancet Covid-19 Commission, Task Force on Safe Work, Safe Schools, Safe Travel, 2021. Retrieved from https://covid19commission.org/safe-work-travel

11 MacNaughton A.J, Satish P, U, et al. Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments. 2016. Retrieved from https://ehp.niehs.nih.gov/action/showCitFormats?doi=10.1289%2Fehp.1510037

12 IBID. 10.

13 ASHRAE Positions on Infectious Aerosols. Oct. 13 2022. Retrieved from https://www.ashrae.org/File%20Library/About/Position%20Documents/PD_-Infectious-Aerosols-2022_edited-January-2023.pdf

14 FEDWeek. IG Voices Unfiltered Concerns about Federal Building Air Quality. October 11, 2022. Retrieved from https://www.fedweek.com/fedweek/ig-voices-unfiltered-concerns-about-federal-building-air-quality/

15 Saputa D & Jones D. Combining UV-C and MERV 8 Filters Exceed MERV 13 Pathogen Removal Performance. 2022. Retrieved from https://uvresources.com/uv-c-merv-8-hvac-filters-outperform-merv-13-pathogen-removal-performance/

16 Firrantello J, Bahnfleth W. Field measurement and modeling of UVC cooling coil irradiation for heating, ventilating, and air conditioning energy use reduction (RP-1738)—Part 1: Field measurements. Science and Technology for the Built Environment. 2018. Retrieved from https://www.tandfonline.com/doi/full/10.1080/23744731.2017.1402662

17 U.S. Energy Information Administration. Form EIA-861M (formerly EIA-826), Monthly Electric Power Industry Report. Average Price of Electricity to Ultimate Customers by End-Use Sector, by State, March 2022 and 2021. Retrieved from https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

18 Paragon Controls Incorporated. Cost of Poor Indoor Air Quality. 2010. Retrieved from https://cdn.thomasnet.com/ccp/01084552/44115.pdf

19 IBID. 5.

20 This figure includes the cost of the initial UV-C fixture installation and replacement lamps for the 20 AHUs.

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