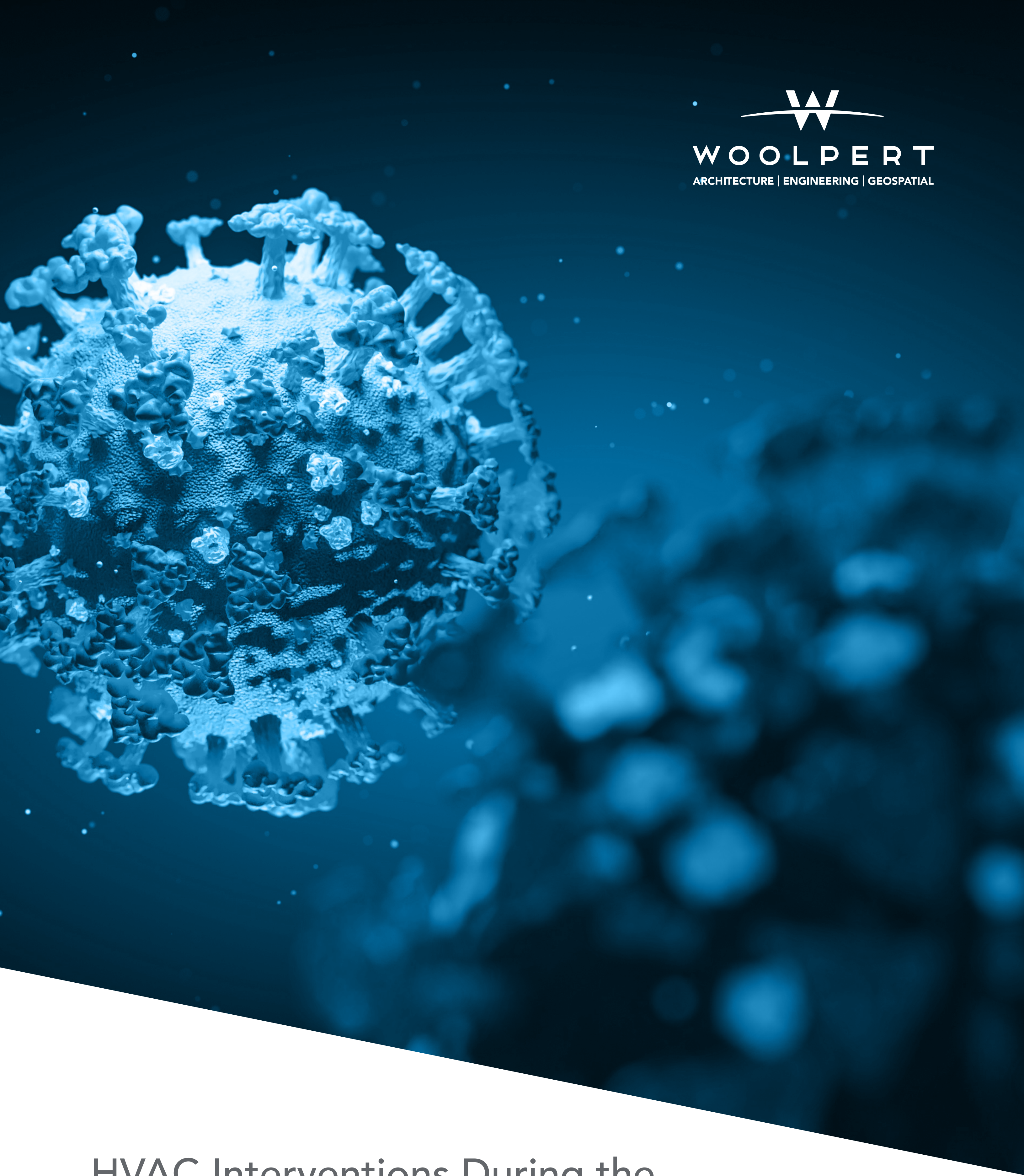

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# HVAC Interventions During the COVID-19 Pandemic: A Synthesis

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# *HVAC Interventions During the COVID-19 Pandemic: A Synthesis*

Since the outbreak of COVID-19, building operators have been working to find strategies that will help in reducing the spread of the virus while keeping occupants safe and comfortable. As options are analyzed, the role of heating, ventilation and air conditioning (HVAC) systems has become a common discussion point. Building operators and occupants have many questions regarding if and how they can utilize HVAC systems to prevent the spread of Coronavirus and other pathogens inside a building. One area of concern is the operation of HVAC equipment and if continuous system operation will enhance the spread of infectious diseases. This paper seeks to synthesize existing research and testing on various operational/equipment changes in order to assist building operators in responding to the COVID-19 pandemic.

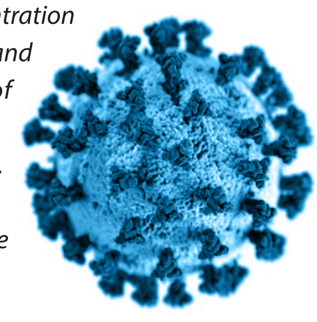
While there are specific HVAC operational strategies that can aid in reducing the movement of pathogens, it is important to note that there is no substitute for regular surface cleaning, disinfection, hand sanitation and social distancing; the HVAC system plays only a part in protecting occupants from pathogen transmission.

Exposure through the air occurs through droplets, which are released and fall to surfaces about 1 meter (3 feet) from the infected, and via small particles, called aerosols, which stay airborne for hours at a time and can be transported long distances (ASHRAE, 2020). The Coronavirus is approximately 0.16 micrometers (µm) and the invisible droplets carrying the virus are between 0.5 µm and 15 µm. These droplets can remain airborne in a droplet of water from 7 minutes to 1 1/2 hours (Camfil, 2020), depending on the size. Studies indicate that the smaller droplets (less than 10 µm) can stay airborne for long enough to potentially travel enough distance to cause secondary host infections. These smaller aerosol droplets have the ability to be picked up through the return air inlet of an HVAC system, but the extent to which they are recycled is dependent on return air source location, distribution of the released aerosol, droplet size, air distribution, temperature, relative humidity and filtration (ASHRAE, 2020).

There are many factors that need to be considered before investing in any upgrades to a building. Specific guidelines need to be in place in order to properly evaluate the system and determine the most cost-effective options. Strategies discussed herein will evaluate several proven methods and offer guidance based on known studies and past data to allow engineers and building owners to make informed decisions.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has issued a statement regarding the transmission of SARS-CoV-2, the Coronavirus that causes COVID-19, and the operation of HVAC systems:

*"Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures. Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause*



*thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus"* (ASHRAE, 2020).

In other words, HVAC systems should not be permanently disabled as this will do little to prevent the spread of the virus. Our team has reviewed the available literature to synthesize recommended strategies to reduce the likelihood of exposure to pathogens and bacteria through HVAC systems. ASHRAE has also created a document that evaluates some of these strategies in detail, "ASHRAE Position Document on Airborne Infectious Diseases." In the following pages, we further discuss strategies presented in the ASHRAE guidelines, including ventilation, exhaust, temperature, humidity, air filtration, ultraviolet (UV) lights, air purifiers and building controls.

# *Recommended Strategies to Reduce the Likelihood of Exposure through HVAC Systems*

## AIR PURIFIERS

Air purifiers, plasma fields and ion fields are systems used to clean air. Through the use of electronically created fields, these systems are effective at eliminating pathogens, volatile organic compounds (VOCs) and odors.

Many purification systems utilize third party testing to demonstrate substantial reductions of common pathogens and VOCs. Some of the pathogens and VOCs that have already been tested in systems include certain molds and allergens, Influenza strains, C-Diff, Staph, MRSA, E. Coli, Legionella and Coronaviruses, including COVID-19.

These systems can be used in all HVAC system applications. There are various models that can be used depending on where they are to be installed, including models best suited for residential equipment, recirculating fan coil units, large commercial air handlers or rooftop units. Along with fighting airborne pathogens and VOCs, the systems inherently improve indoor air quality and lower odors, which can contribute to higher productivity and happiness of occupants and an overall lower number of sick days. Many industries are already using this technology to improve their building indoor air quality, including Orlando International Airport, Mayo Clinic, Google, Boeing, Harvard University, Wells Fargo, the U.S. Army, Duke University Medical Center and Fulton County Schools in Atlanta, Georgia.

In addition to their availability for all systems, most models have cost-effective installation. Small-to-medium size devices are installed in HVAC equipment or within ductwork and are powered by low voltage wiring. Once installed, most models have self-cleaning capabilities, require no maintenance and can last 10-20 years depending on the manufacturer.

### Possible Negatives

*Ozone Emission:* Ozone creation is a possible side effect of air purifiers and varies by manufacturer and model type. Air purifiers should have a UL 867 rating to confirm the device meets minimum ozone creation standards. Furthermore, some air purifier models are UL 2998-rated, indicating they create 0.00 ppm ozone emissions. This rating system ensures air purifiers are able to function with little-to-no harmful side effects.

### Monitoring Options

The air purifier's operation can be monitored in a few ways through the Building's control systems. One process would include placing volatile organic compound (VOC) sensors in the affected rooms. The sensors would then monitor the room VOC levels and track if the system is functioning properly. If used in a widespread application, a more effective way to monitor the system operation may be to mount an ion detector downstream of any model (either in ductwork or within the spaces themselves) which would then report ion levels in real time to the building control systems.

### In Summary

Many purification systems have already been tested through third parties and proven to be effective against viruses similar to Coronavirus. The systems have wide application across all types of HVAC systems and have multiple model options that can be easily adapted to the users' needs. In addition, most models are cost-effective to install, operate and maintain, although they may require installation of additional sensors or building controls to be effectively monitored during use. Assuming the proper conditions are met and an appropriate model is selected for the building's HVAC system, we recommend third-party tested air purifiers as a risk-reduction strategy for Coronavirus.

## UV LIGHTS

Since being discovered as a disinfectant in 1878, UV light has been used in a broad range of commercial, industrial and medical applications including water treatment, hygiene and infection control. UV light is a form of electromagnetic radiation with a wavelength from 10-400 nanometers (nm) but the preferred sub-bands used for disinfecting are UVC (100-280 nm) and Far UVC (207–222 nm). Conventional UVC has been used for many decades for germicidal disinfecting while Far UVC is a relatively newer technology for sterilization and disinfecting. According to Ohio manufacturer Materion, "the market for UVC disinfection is blossoming, driven partly by recent outbreaks and fear of viruses and bacteria such as SARS, MERS, MRSA, Ebola, norovirus and C-DIFF. UV LEDs can play a useful role in preventing infectious disease" (Materion, 2020). Capable of killing germs exposed to the light, the myriad possible applications include killing airborne germs in air purifiers, sterilizing HVAC systems and disinfecting surfaces. Two primary types of UV sterilization are discussed in this section.

UVC light has been tested as an effective solution against a myriad of viruses. According to an article published in the Journal of Virological Methods, SARS caused by Coronavirus (SARS-CoV) is eliminated through exposure to UV light in the 254 nm range (Darnell, Subbarao, Feinstone, & Taylor, 2004). UV treatment has also been found to kill MERS or MERS-CoV, another type of corona virus that emerged in 2012. In a study published in the U.S. National Institutes of Health's National Library of Medicine (NIH/NLM), UVC light deactivated MERS-CoV within 5-10 minutes of exposure (Bedell, 2016). When it comes to the latest outbreak of Coronavirus, UV light has been confirmed to be effective in eliminating the virus as found in research by Juan Leon, an environmental health scientist at Emory University, and Dr. Lena Ciric, an associate professor at University College London (Larson, 2020).

In contrast to UVC, the Far UVC wavelength is around 207-222 nm and is superior to conventional UVC in multiple ways. It is currently thought to be safer and more effective than the conventional UVC products available. Far UVC physically destroys cells due to its shorter wavelength and higher photon energy when compared to traditional UVC, which chemically changes bonds and causes mutations that prevent cells from replicating but does not destroy them. Research is still emerging to determine the exposure time needed to effectively deactivate Covid-19.

A key advantage of Far UVC is that it cannot penetrate human skin or eyes. Far UVC's shorter wavelength renders it unable to pass through the barrier of non-living cells on skin or tears on the surface of the eye. At the same time, this shorter wavelength is what makes it superior in penetrating and inactivating bacteria and viruses. In fact, since Far UVC light is thought to be safer to use around humans than traditional UVC, it can be used to disinfect a room even when people are present. This makes it practical for daily disinfection tasks (Ponnaiya, 2018).

There is already significant use of Far UVC air disinfection in healthcare settings and cleanroom environments. Medical-grade High Efficiency Particulate Arrestor (HEPA) filters can trap at least 95% of particles 0.3 µm or larger (ISO 29463-1, 2011), catching most dust and spores, but they can let through smaller bacteria and viruses smaller than 0.3 µm. When Far UVC is combined with indoor HEPA air filtration, it virtually eliminates all airborne microbes, even antibacterial-resistant ones. Cleaning the air of pathogens can help minimize the chance of spreading a virus even if it mutates into something that may bypass the latest vaccines.

### Potential Negatives

*Unsafe Exposure to UVC Lights:* UV light within the UVC wavelength is harmful to skin and eyes and can increase the risk of cancer. This makes it impractical to use directly in occupied rooms and special care will need to be taken during the installation, use and maintenance of UVC systems. This does not apply to Far UVC as the wavelength of Far UVC is safe for human exposure and can be used in occupied rooms.

*Strict Temperature and Humidity Requirements for UVC Lights:* UVC bulb intensity diminishes with lower temperatures. If used inside an HVAC system, it is recommended to use UVC light only on the upstream side of the cooling coils (UV Resources, 2020). Relative humidity also plays a major role in the amount of time it takes UVC light to render a pathogen inactive. The higher the humidity, the lower the effectiveness of the UVC light (UV Resources, 2020).

*Impractical Exposure Requirements for UVC Lights:* Conventional UVC lights are ideal for the sterilization of stationary objects within the HVAC system such as cooling coils, condensate drain pans, plenum walls and filter banks. Once a particle lands on or is trapped by a part of the system treated with UV light, it should receive an ample dose of UV light to render it inactive. However, UVC lighting only works in line of sight. Reflective surfaces may extend the reach of the UVC light but cooling coils that are in deeply shadowed areas will not be sterilized.

*Far UVC Cost:* There are limited manufacturing sources for fixtures and lamps that utilize the Far UV spectrum and products are very expensive. Products that use the UVC spectrum are a bit more affordable, but still not cost-effective for use on a wide scale.

*Bulb Life Expectancy:* Whether utilizing conventional UVC or Far UVC lighting, the life expectancy of the bulbs is typically the same. The average bulb lasts around 9,000 hours, although the life-span can vary significantly depending on manufacturer and operating conditions. Some manufacturers claim the bulbs can last in excess of 20,000 hours.

*Germicidal Effectiveness Decreases Over Time:* Regardless of runtime hours, many manufacturers recommend replacement of the bulbs on a yearly basis because the bulbs can lose nearly half their germicidal effectiveness after one year. This is one of the problems in assuring continued irradiation effectiveness of the bulbs. Just because the bulbs are on, does not mean they are still disinfecting. The bulbs will need to be monitored regularly (every 6 months minimum) with a UV meter to ensure the appropriate intensity of UV light is being emitted (Safety, 2017).

### Monitoring Options

If the building already has a control system, a UV meter could be interfaced with the control system to alarm the operator when the UV light intensity is too low and the bulbs should be replaced. These routine replacement costs and monitoring strategies should be taken into consideration before adding UVC lights within an HVAC system or space.

### In Summary

Although UVC light may be applicable in certain situations, UVC light is not an overall effective or practical method of eliminating viruses moving through ductwork. There is some evidence UVC is effective on particles suspended in the air, given adequate residence time exposed to the UVC light. It is, on the other hand, very effective at killing molds and bacteria that may grow on damp surfaces within the HVAC system, thus playing an important role with respect to general indoor air quality, and could be considered as an addition to recommended strategies in contained environments.

Far UVC sterilization is a more effective, user-friendly option if UV sterilization is the desired strategy. It is more efficient at low dose rates, faster than traditional UVC as it kills pathogens in seconds vs. minutes, has a higher absorption rate in bacteria and viruses, and is safer for use around humans because it cannot penetrate skin or eyes. The use of Far UVC is a viable option assuming monitoring conditions are met and the operator is informed of the increased cost and maintenance.

## AIR FILTRATION

The Minimum Efficiency Reporting Value (MERV) is a measurement scale designed in 1987 by ASHRAE to report the effectiveness of air filters; the higher the MERV value the smaller the particle size that can be filtered effectively. Most filters designed for home HVAC fall in the range of MERV 7 or 8, which are approximately 90% effective at removing particles from 3 to 10 µm in size (ASHRAE, 2017). At the other end of the scale are HEPA filters, which fall in the range of MERV 17 to 20 and can remove 99.97% of 0.3 µm particles (ASHRAE, 2017).

Higher end HVAC systems, such as those in institutional buildings, sports arenas, large commercial office buildings and others, may have the capability of installing 2 sets of filters. The first filter would be a MERV 8 to prefilter the air, the second would be a MERV 15 filter to remove whatever the prefilter does not capture. This set up would still add the cost of the MERV 15 filters, but they would require less frequent changing. The cost and changeout interval of the prefilters would be the virtually the same as the filter change costs and intervals prior to the modification.

Another possible solution is the addition of self-contained air cleaning devices. These units contain prefilters, high efficiency filters and a fan to circulate the air. They can be floor-mounted, suspended from the ceiling or, if space is sufficient, mounted in parallel with the return air duct, which will allow it to filter the air before it returns to the unit without adding a burden to the current system.

### Potential Negatives

*Lower MERV Ratings are Not Effective:* As the Coronavirus is approximately 0.16 µm and the invisible droplets carrying the virus can be between 0.5 µm and 15 µm, a typical MERV-8 residential filter, which is efficient at removing particles from 3 to 10 µm, is not sufficient to prevent the spread of Coronavirus.

*HEPA Filters Require Specialized Housing:* HEPA filters require a suitable housing to maintain their efficiency rating and any leakage around the filter reduces the effectiveness of the filtration system. There is little to no value in attempting to install HEPA filters in a standard filter housing as most commercial HVAC systems are not designed to "push" air across such a fine filter (also called the "pressure drop" across the filter) and could not handle the addition of HEPA filters without affecting the system's capacity.

*High MERV Ratings are Unsuitable for Common Uses:* A MERV 15 rated filter or higher is required to trap a particle the size of the Coronavirus (Camfil, 2020). The pressure drop of a MERV 15 filter is twice that of a MERV 8 filter. Most HVAC systems for restaurants, bars, churches, schools, retail establishments, etc., are not capable of handling the increased filter pressure drop without drastically affecting system airflow, although increasing the fan horsepower or adjusting the drive belts may be possible to maintain the required system airflow in some cases. A MERV 15 filter is also 8 to 10 times the cost of a MERV 8 filter, which would cause building owners to spend more on filter replacements (Camfil, 2020). Ultimately, using a MERV 15 filter for filtering outdoor air would be very costly and require very frequent replacements. In addition, pollens and other contaminants in the outdoor air stream would quickly load the filter to its maximum holding capacity.

*High Cost for Self-Contained Air Cleaning Devices:* Air cleaning units have high upfront costs and regular filter replacement costs, making implementation of multiple units throughout an entire building cost prohibitive. The units would also increase the energy usage and utility costs of the building to a degree that would be unaffordable for business operating on a tight budget.

### Monitoring Options

Building operators will need to be aware of the capability of their filtration system, the cost of filter replacements and the frequency with which filters will need to be replaced. Operators will also need to check filters regularly to make sure they are not becoming filled with large particulates and are functioning properly. For buildings that utilize HEPA filters, the housing will need to be checked and maintained to ensure no leakage is occurring around the filter. It is recommended that the system be installed with a sensor that monitors pressure and alerts maintenance personnel if the filter is dirty.

### In Summary

Increasing filtration efficiency to MERV 15 is not always feasible but could be an option for some HVAC systems. It would add cost, affecting businesses operating on a tight operating budget. Filtration can reduce the recirculation of pathogens, but only once they enter the system. Most buildings do not have any means whatsoever to contain a pathogen once expelled and keep it from affecting nearby occupants. Filtration will help, but the vast majority of the contaminants will remain in the space on the various surfaces within the building. As a result, we recommend the use of filtration as the primary strategy only in specific cases where MERV 15, with pre-filtering if feasible, can be applied cost-effectively.

Self-contained air cleaning devices would be too costly to implement throughout an entire building but they could be utilized as a secondary risk-reduction strategy for Coronavirus, when cost-effective, in specific spaces where people gather and dwell, like conference rooms or waiting rooms.

# Additional Strategies: Thermal Comfort and Pathogens

The strategies discussed below provide additional considerations for thermal comfort and building operation in the long term. As strategies addressing the spread of Coronavirus are explored, it is important to keep in mind how these systems will function and be maintained throughout their lifecycle.

## ADJUSTING VENTILATION/ EXHAUST

The current ventilation and exhaust rates required for schools, offices, prisons and other public facilities address general indoor air quality but not the transmission of infectious diseases. With the appearance of Coronavirus, questions have arisen about the applicability of using additional methods, such as those used in the design of healthcare facilities, for other building types. Healthcare facilities have more complicated ventilation and increased HVAC design standards in order to reduce the transmission of infectious diseases. For example, HVAC systems in healthcare require use of 100% outside air in certain spaces (no recirculation of return air from the building spaces), utilize room pressurization plans to control the amount and direction of air flow between adjacent rooms, provide higher room air change rates, require specific room temperatures and humidity setpoints and utilize higher filtration methods.

One suggested strategy for non-healthcare buildings is to simply increase the ventilation rates, exhaust rates and room air change rates to levels that are closer to healthcare requirements. However, many HVAC systems may not be designed to handle the increased load and necessary fan power and will be unable to properly cool or heat the spaces to comfortable temperatures if this method is used. In addition, an imbalance of supply and exhaust rates could have an undesirable effect on the overall building pressure, causing unconditioned outside air to be drawn into the building. Both scenarios can cause an increase in humidity and energy usage in the building. As a result, this strategy should only be implemented as a temporary risk reduction strategy for Coronavirus and not utilized as a permanent solution.

## ALTERING ROOM PRESSURIZATION

Room pressure differentials are often used in hospitals and healthcare facilities to control airflow between specific areas in a building and, as recognized by ASHRAE, "Airborne infection isolation rooms are kept at negative pressure with respect to the surrounding areas to keep potential infectious agents in the rooms" (ASHRAE, 2020). Other hospital rooms with patients that have compromised immunities are kept at positive pressure to keep potential pathogens out. In commercial buildings, restrooms and janitor's closets are required to exhaust air and have slightly negative room pressures while the overall building pressure is kept positive.

Considering the spread of Coronavirus, it is possible that any space in a public building could contain airborne pathogens, which would make it impractical to select only specific parts of the building for negative/positive pressure as it would be nearly impossible to determine which rooms would need which level of pressure to prevent particle spread. Overall, altering specific room pressure differentials would not be practical for commercial buildings beyond what is typically required per code.

## NATURAL VENTILATION

Another strategy currently being evaluated addresses utilizing natural ventilation by opening windows directly in the rooms to reduce the transmission of diseases. The feasibility of this option is dependent on the climate zone, time of year and operable window availability. Many commercial buildings no longer have operable windows and very few studies are available to indicate how natural ventilation can reduce infection control (ASHRAE, 2020). Providing natural ventilation during unfavorable weather conditions will have a significant effect on thermal comfort and humidity control in a building and is not suggested until more studies can be conducted.

## DISABLING DEMAND-CONTROLLED VENTILATION FUNCTIONS

Disabling demand-controlled ventilation functions (if a building utilizes this feature) to allow more outside air into the building is another strategy currently being considered. Demand-controlled ventilation typically involves utilizing carbon dioxide sensors to monitor the carbon dioxide levels in a space and reduce the amount of outside air when spaces are not occupied.

Disabling the demand-control ventilation feature will increase outside air flow rates into the building but will also increase utility costs because of the extra energy it takes to condition outside air. Once again, this strategy may be used as a temporary risk-reduction strategy but is not viable as a permanent solution.

## ECONOMIZER FUNCTIONS

The economizer function in HVAC systems can provide 100% outside air through the HVAC system when weather conditions are favorable. This option not only offers better indoor air quality, but also provides significant energy savings. However, not all HVAC systems have the capabilities to utilize this function and it can only be used during favorable weather conditions. Dry and milder climates will be able to utilize this option more often than hot and humid climates, but this does not provide a permanent solution for all building types.

## ADJUSTING TEMPERATURE OR HUMIDITY

HVAC systems have the ability to control the indoor temperature and humidity, which may influence the transmission of pathogens. Recent studies have indicated humidity levels in the space influence the transmission of pathogens and affect a person's ability to fight infection. A study published in the Proceedings of the National Academy of Sciences concluded, "low ambient humidity impairs barrier function and innate resistance against influenza infection" (Taylor, 2019). Furthermore, a 2013-2014 study investigating the relationship between indoor humidity levels and healthcare-associated infections found "maintaining indoor humidity levels between 40%-60% decreased exposure to infectious particles and reduced viral illness transmission" (Taylor and Hugentobler, 2014).

The Department of Homeland Security (DHS) Science and Technology has performed initial testing on the stability of SARS-COV-2 virus on solid surfaces as a function of temperature, humidity and solar intensity. On indoor surfaces, they concluded that the "virus is most stable at low humidity (20%) and decays faster at relative humidity greater than 40%" (DHS, 2020). They also simulated sunlight indoors on surfaces and found, "sunlight reduced infectious virus to undetectable levels after just 3 minutes of exposure to the solar equivalent of midday sun on a sunny day in the middle latitudes of the U.S." (DHS, 2020). Although useful, these studies only make recommendations on minimum and maximum relative humidity levels (40%-60%), but do not give recommendations on optimal space temperature ranges.

Despite these findings, increasing space temperatures and humidity levels inside a building above ASHRAE occupant comfort guidelines is not recommended. Aside from affecting thermal comfort, higher space temperatures and humidity levels during warmer months can propagate mold growth and cause additional health concerns.

Most commercial buildings are designed to maintain relative humidity levels below 60% by utilizing the cooling systems. However, during the heating season, most systems do not have humidification capabilities to maintain a minimum of 40% relative humidity and commercial humidifiers add a significant first cost, energy usage and additional maintenance to function properly. If humidification is deemed to be a beneficial strategy for the building type/occupants, the cost implications of adding humidity to maintain 40% relative humidity levels should first be evaluated. The owner/operator of the building must then be made aware of the additional costs and risks associated with humidification.

Overall, temperature and humidity setpoints should be designed and maintained per ASHRAE occupant comfort guidelines. Increasing or lowering temperature and humidity levels beyond those guidelines could result in discomfort to the occupants and higher energy costs, along with increasing the potential for other airborne issues such as mold.

## Building Controls

The scope of work associated with building controls will vary based on other strategizes that are selected.

1. If existing Building Automation Systems (BAS) have all capabilities that are required, then it is possible that they will only need minor adjustments to effectively operate with the additional equipment.
2. If the existing BAS is not fully capable of supporting the planned strategies, modifications to the BAS will be required. This may include adding sensors, control modules and motorized dampers.
3. If there is no BAS currently in the building, or the existing BAS is not capable of being modified to operate planned strategizes, then a new BAS will need to be installed to handle all operations.

There is no catch-all solution that can be applied to every building as HVAC systems, controls and capabilities will vary depending on building type, size, occupancy and climate zone; however, based on the information and strategies presented above, we have listed some retrofit options in the following section that should be evaluated to reduce the spread of pathogens and improve ventilation and thermal comfort in buildings.

## Retrofit Options

Multiple retrofit options exist depending on the HVAC and controls systems that exists in the building. At a minimum, the following steps should be considered when evaluating the best options for the HVAC system:

1. Confirm ventilation and exhaust is being provided in the spaces to meet the minimum requirements by code.
    a. Confirm outside air dampers are operating as intended. Outside air dampers are often closed to save energy or resolve uncomfortable temperatures due to inadequate unit capacity.
    b. Enable or add airside economizer function if feasible.
2. Provide the highest-rated MERV filter that the HVAC equipment is capable of supporting. Most equipment fans should be able to handle MERV 8 rating at a minimum. If the system can employ higher than a MERV 8 rated filter, the owner should be made aware of the filtering capabilities and cost implications associated with the improved filters. Maintenance routines will also need to be implemented to change dirty filters on a regular basis.
3. Evaluate the need for a humidification system and asses the options and costs if a humidification is determined to be necessary.
4. Evaluate UV light applications, costs and benefits to the building systems or particular spaces. This can include UV applications to only specific areas, such as adding Far UVC lights to disinfect public restrooms.
5. Evaluate the cost and benefit of self-contained air cleaning for the building or particular space.
6. Assess what building system controls will need to be added or modified to support the chosen strategies. This includes analyzing the existing BAS or evaluating if there is a need for a BAS if one does not currently exist. Suggested controls include:

   a. Add filter pressure monitoring or implement maintenance routines;

   b. Add/modify temperature and humidity monitoring. An alarm should be incorporated to notify operators if the temperature or humidity is too low;

   c. Monitor outside air dampers to verify correct operation, including economizer function;

   d. If utilized, monitor UV light systems via UV meter; and

   e. If utilized, monitor air purifier systems via VOC sensors or ion detectors.

7. Perform a post-installation assessment to document compliance and results. This includes testing, adjusting and balancing the HVAC system, and commissioning HVAC system and controls.

In addition to these steps, building operators should engage qualified engineering firms to perform a Building Systems Assessment and determine the best retrofit solutions. The assessment should include such questions as: What type of HVAC systems are in the building? What is the occupancy of the space? What are the areas or spaces of concern? How sensitive are the functions of the building to disruptions like power outages? What type of system controls are in place?

## *In Conclusion*

Buildings that are occupied 24/7, such as prisons and nursing homes, will have different needs than offices or schools. The suggested retrofit options and costs should be evaluated and documented during the building assessment. The assessment, documentation and recommendations should be included in requests for specific CARES Act funding.

Faced with an evolving global pandemic, and challenged by the responsibility to do something for the occupants in their buildings, building owners and operators should allow themselves the grace to know there is no easy button. The best they can do is to take a step forward each day, and to remain curious and willing.

Building owners; operators; design engineers; Test, Adjust and Balance (TAB) contractors; and commissioning agents should work together to determine optimal and cost-effective strategies for public building needs in order to make the best use of funding. This is a chance to not only make our buildings safer from the spread of viruses and foster trust in people to return to work in public spaces, but also improve the long-term indoor air quality and the operational performance of these buildings. Overall, better indoor air quality will result in more productivity, less illnesses and happier occupants.

# References


ASHRAE. (2017). *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size: ANSI/ ASHRAE Standard 52.2-2017* (2nd ed., Vol. 52). Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2020). *Ashrae Position Document on Infectious Aerosols.* Retrieved from https://www.ashrae.org/file library/about/ position documents/pd_infectiousaerosols_2020.pdf

Bedell, K., Buchaklian, A., & Perlman, S. (2016). Efficacy of an Automated Multiple Emitter Whole-Room Ultraviolet-C Disinfection System Against Coronaviruses MHV and MERS-CoV. Infection Control & Hospital Epidemiology, 37(5), 598-599. doi:10.1017/ice.2015.348

Camfil Addresses the Coronavirus Pandemic-Infectious Respiratory Illnesses. (2020). *Camfil Addresses the Coronavirus Pandemic-Infectious Respiratory Illnesses.* Retrieved from https://www.camfil.com/damdocuments/43168/523332/flyer---Coronavirus-air-filtration-strategies-eng-us.pdf

Cohen, J., et. al, (2018, January 4). Could ultraviolet lamps slow the spread of flu? Retrieved from http://www.sciencemag.org/news/2018/01/could-ultraviolet-lamps-slow-spread-flu#

Columbia University Center for Radiological Research. (2020, March 26). Using the Power of Light: Preventing the Airborne Spread of Coronavirus and Influenza Virus. Retrieved from https://www.crr.columbia.edu/research/ using-power-light-preventing-airborne-spread-coronavirus-and-influenza-virus

Darnell, M. E., Subbarao, K., Feinstone, S. M., & Taylor, D. R. (2004). Inactivation of the coronavirus that induces severe acute respiratory syndrome, SARS-CoV. Journal of Virological Methods, 121(1), 85–91. doi: 10.1016/j.jviromet.2004.06.006

Department of Homeland Security (DHS). (2020). *S&T's Research, Development, Testing and Evaluation (Rdt&E) Efforts re Covid-19.* DHS Science and Technology. Retrieved from https://carnivalwarehouse.com/images/site/pageserver/file/ COVID19-dhs-study-4132020.pdf

Dietz, L., Horve, PF., Coil, DA., Fretz, M., Eisen, JA., Van Den Wymelenberg, K. (2020). 2019 novel coronavirus (COVID-19) pandemic: built environment considerations to reduce transmission. mSystems 5:e00245-20. https:// doi.org/10.1128/ mSystems.00245-20

Downes, A., & Blunt, M. A. (1878). *On the Influence of Light upon Protoplasm* (pp. 199–200). Royal Society Publishing.

Gavin, J., & DiLouie, C. (2019, May). Sanitizing Light: LEDs Become a Disinfectant Technology. Retrieved from http://www.ecmag.com/section/lighting/sanitizing-light-leds-become-disinfectant-technology

Gorvett, Z. (2020, April 24). There's only one type of UV that can reliably inactivate COVID-19-and it's extremely dangerous. British Broadcasting Company (BBC). Retrieved from https://www.bbc.com/future/ article/20200327-can-you-kill-Coronavirus-with-uv-light

Hepacart. (2019, October 24). Retrieved from https://www.hepacart.com/blog/ effective-uv-disinfection-lights-4-benefits-of-far-uv-sterilray

International Standard Organization (ISO). (2011). ISO 29463-1 High-efficiency filters and filter media for removing particles in air – Part 1: Classification, performance, testing and marking.

Jump, R. L., et. al, (2007). Vegetative Clostridium difficile Survives in Room Air on Moist Surfaces and in Gastric Contents with Reduced Acidity: a Potential Mechanism To Explain the Association between Proton Pump Inhibitors and C. difficile-Associated Diarrhea? A*ntimicrobial Agents and Chemotherapy*, 51(8), 2883–2887. doi: 10.1128/aac.01443-06

Lu, J., et. al, (2020). COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020. *Emerging Infectious Diseases,* 26(7). doi: 10.3201/eid2607.200764

Materion. Killing Germs with LEDs. Retrieved May 10, 2020, from http://www.materion.com/resource-center/newsletters/ materials-news-stats-and-chats/killing-germs-with-leds

Philips. NEW: UV LED. Retrieved May 12, 2020, from http://www.lighting.philips.com/main/products/special-lighting/uv-purification/uv-led

Ponnaiya, B., Buonanno, M., Welch, D., Shuryak, I., Randers-Pehrson, G., & Brenner, D. J. (2018). Far-UVC light prevents MRSA infection of superficial wounds in vivo. PloS one, 13(2), e0192053. https://doi.org/10.1371/journal.pone.0192053

Puro Lighting. Puro and COVID-19. Retrieved May 10, 2020, from http://www.purolighting.com/Coronavirus/

Rahmani, B., Bhosle, S., & Zissis, G. (2009). Dielectric-Barrier-Discharge Excilamp in Mixtures of Krypton and Molecular Chlorine. *IEEE Transactions on Plasma Science*, 37(4), 546–550. doi: 10.1109/tps.2009.2013864

Safety Tips for Using Germicidal Lamps, Safety Tips for Using Germicidal Lamps (2017). Retrieved from https://lessonslearned.lbl.gov/Docs/2650/Germicidal lamp safety tips.pdf

Schoen, L. Guidance for Building Operations During the COVID-19 Pandemic. *ASHRAE Journal*, 72–74. Retrieved from https://www.ashrae.org/file library/technical resources/ashrae journal/2020journaldocuments/72-74_ieq_schoen.pdf

Sosnin, E. A., Avdeev, S. M., Tarasenko, V. F., Skakun, V. S., & Schitz, D. V. (2015). KrCl barrier-discharge excilamps: Energy characteristics and applications (Review). *Instruments and Experimental Techniques,* 58(3), 309–318. doi: 10.1134/s0020441215030124

Taylor, S., & Hugentobler, W. (2014). International Society of Indoor Air Quality and Climate. Retrieved from https://www.isiaq.org/docs/Papers/Paper340.pdf

Taylor, S. (2019). *Optimize Occupant Health, Building Energy Performance and Your Revenue Through Indoor-Air Hydration.* The American Society of Heating, Refrigerating and Air-Conditioning Engineers. Retrieved from https://www.ashrae.org/file library/professional development/tech hour/tech-hour-ppt_stephanie-taylor_november-2019.pdf

Trevisan, A., Piovesan, S., Leonardi, A., Bertocco, M., Nicolosi, P., Pelizzo, M. G., & Angelini, A. (2006). Unusual High Exposure to Ultraviolet-C Radiation. *Photochemistry and Photobiology,* 82(4), 1077. doi: 10.1562/2005-10-27-ra-728

Underwriters Laboratory (UL). (2019). UL 2998: Environmental Claim Validation Procedure (Ecvp) for Zero Ozone Emissions from Air Cleaners.

Underwriters Laboratory (UL). (2011). UL 867: Standard for Electrostatic Air Cleaners. Retrieved from https://standardscatalog.ul.com/standards/en/standard_867

UV Resources. (2020, February 3). UV Resources Field News No. 2. *Powerful Upper-Room Germicidal UV-C Fixture Kills Airborne Viruses and Bacteria.* Retrieved from http://www.uvresources.com/news/press-releases/powerful-upper-room-germicidal-uv-c-fixture-kills-airborne-viruses-and-bacteria/