North Carolina DOT HVAC Technology Reference Document

The COVID-19 pandemic has prompted a flood of products into the marketplace that claim to make the air safe to breathe. Some of these products may be helpful while others may pose unintended health risks to employees and customers. This document was created to help transit agency managers take the guesswork out of considering HVAC upgrades. North Carolina DOT commissioned the development of this document by one of the nation's leading Hospital HVAC engineering firms, and had it reviewed and endorsed by faculty at the University of North Carolina Gillings School of Public Health. This document reviews broad categories of technology; not individual products. None of these technologies serve as a replacement for mask usage and physical distancing during the COVID-19 pandemic, but targeted investments may be incrementally helpful in critical facilities and vehicles.

Indoor Air Management Technology	Application	How it Works	Important Considerations	Potential Funding Sources/ROM Cost
TECHNOLOGIES TO CONSIDER FOR REDUCING THE RISK OF AIRBORNE DISEASES LIKE COVID-19				
HEPA Filters (Portable) 	**Personal Air Filtration** (Facilities Only)	Portable HEPA filters mechanically remove potentially harmful particles from the air within a small radius of the device.	* ASHRAE states here that "Research has shown that the particle size of the SARS-CoV-2 virus is around 0.1 µm (micrometer). However, the virus does not travel through the air by itself. Since it is human generated, the virus is trapped in respiratory droplets and droplet nuclei (dried respiratory droplets) that are predominantly 1.0 µm in size and larger." * According to ASHRAE standard 52.2, MERV-13 and better filters can remove more than 98% of particles between 0.3 µm and 1.0 µm on the first pass; HEPA filters (MERV-17 and better) can remove virtually all infectious respiratory droplets on the first pass. * The manufacturer should state the maximum spatial coverage provided by their portable HEPA filtration devices. * The placement of portable HEPA filters in a room is critical to minimize how air currents might draw "dirty" air across the faces of other building occupants. * **Portable HEPA filters, if properly sized to the space to be treated, can be very effective at removing potentially harmful particles from the air. NCDOT endorses their use at workstations in critical spaces.**	Operating Dollars $100 - $2500 each

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TECHNOLOGIES TO CONSIDER FOR REDUCING THE RISK OF AIRBORNE DISEASES LIKE COVID-19				
Higher MERV rated or HEPA filters (In-line) 	**Filtration Efficiency** (Facilities and Vehicles)	MERV-13 and higher rated filters, including HEPA filters (MERV-17 and 18), mechanically remove a vast majority of potentially harmful particles from the air.	* Higher MERV rated filters are a reliable way of removing potentially infectious particles from the air. Any upgrade – even from a MERV-6 to a MERV-7 filter – can be beneficial. * ASHRAE states here that "Research has shown that the particle size of the SARS-CoV-2 virus is around 0.1 µm (micrometer). However, the virus does not travel through the air by itself. Since it is human generated, the virus is trapped in respiratory droplets and droplet nuclei (dried respiratory droplets) that are predominantly 1.0 µm in size and larger." * According to ASHRAE standard 52.2, MERV-13 and better filters can remove more than 98% of particles between 0.3 µm and 1.0 µm on the first pass; HEPA filters (MERV-17 and better) can remove more than 99.97% of particles 0.3 µm in size on the first pass. * According to ASHRAE, "HEPA filters may not be an appropriate option for some into HVAC systems due to high pressure drops and the likelihood that systems will need new filter racks to allow sufficient sealing to prevent filter bypass"- check with your HVAC provider to evaluate feasibility, airflow reductions due to pressure drops, and potential noise concerns. *** In-Line HEPA filters, if properly sized to the HVAC system, can be very effective at removing potentially harmful particles from the air. NCDOT endorses their use in critical facility spaces and vehicles. NCDOT recommends working with your HVAC contractor and/or vehicle manufacturer to determine the highest MERV rated filter than can be used without putting unacceptable strain on your HVAC equipment and/or voiding its warranty.**	Operating/Capital $30 - $400 each

Indoor Air Management Technology	Application	How it Works	Important Considerations	Potential Funding Sources/ROM Cost
TECHNOLOGIES TO CONSIDER FOR REDUCING THE RISK OF AIRBORNE DISEASES LIKE COVID-19				
Ionization Devices (In-line and UL 2998 certified) 	**Filtration Efficiency** (Facilities Only)	In-line ionizing devices use static electricity to get smaller particles (like a respiratory droplet) to stick to larger particles (like a piece of dust) so they can be more easily captured in filter material.	* Because ionization devices incrementally improve filtration efficiency, they are most useful in facilities where MERV-13 (or better) filters are not feasible. Transit vehicle air change rates are likely high enough to negate benefits provided by an ionization device. * The highest-rated MERV filter practicable should be used in conjunction with this technology to maximize its health benefits and serve as a fail-safe (to the degree possible). Filters used in conjunction with ionizing devices should be sealed at the edges so no air can bypass the filter media. * According to ASHRAE, there are many variations of this technology, and "studies of ionizers have shown results ranging from no benefit to some benefit for acute health symptoms." * Claims that these devices can safely kill microbes (bacteria, fungus, and virus) require further study. * Some of these devices can generate ozone as a byproduct of operations. ASHRAE has taken a position that devices that generate any level of ozone should be avoided: "Studies of ionizers have shown results ranging from no benefit to some benefit for acute health symptoms… Negative health effects arise from exposure to ozone and its reaction products. Consequently, devices that use the reactivity of ozone for cleaning the air should not be used in occupied spaces. Extreme caution is warranted when using devices in which ozone is not used for the purpose of air cleaning but is emitted unintentionally during the air-cleaning process as a by-product of their operation." * Devices with UL 2998 certification were evaluated according to industry standards and determined to produce virtually zero ozone during their operation. * According the CDC, the "needlepoint bi-polar ionization [variant] has a less-documented track record in regards to cleaning/disinfecting large and fast volumes of moving air within heating, ventilation, and air conditioning (HVAC) systems. [This technology] is still considered by many to be an 'emerging technology.'" ASHRAE also states "Convincing scientifically-rigorous, peer-reviewed studies do not currently exist on this emerging technology; manufacturer data should be carefully considered." *** NCDOT supports the use of ionization devices only with UL 2998 certification and where MERV-13 and higher rated filters are not possible, though the highest practical MERV filters should be used in conjunction with this technology.**	Capital $250 - $1200 each

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TECHNOLOGIES TO CONSIDER FOR REDUCING THE RISK OF AIRBORNE DISEASES LIKE COVID-19				
Upper Room Ultraviolet Germicidal Irradiation (UVGI)  	**Air Cleaning (Disinfection)** (Facilities Only)	Upper room UVGI devices create an irradiation zone with UV-C light (200 to 280 nm) in high-ceiling areas that can slowly disinfect air as it is naturally cycled to/from the ceiling area via convection.	* The CDC recommends upper room UVGI "as a supplement to help inactivate SARS-CoV-2, especially if options for increasing room ventilation are limited." * The CDC stated in their 2009 publication, Environmental Control for Tuberculosis, "when mechanical ventilation is increased in a room where an upper-room UVGI system has been deployed, the effectiveness of the UVGI system may be reduced because the residence time of the [pathogen] in the irradiated zone decreases." * UV-C light is harmful to human tissues; therefore, upper room UVGI devices must be installed at the proper height within a room, as mentioned in this NIH Journal. * *Upper room UVGI should not be confused with other UV light technologies described in this document.* * **Based on ASHRAE's advice, NCDOT suggests this technology will only add significant value in facility spaces where mechanical ventilation and filtration is limited, and should only be used in spaces where walls and ceilings have low UV reflectivity. NCDOT does not recommend upper room UVGI in vehicles where significant air changes occur.**	Capital $1000 - $2000 each

Indoor Air Management Technology	Application	How it Works	Important Considerations	
TECHNOLOGIES THAT ARE HELPFUL FOR OVERALL AIR QUALITY, BUT NOT REDUCING THE RISK OF AIRBORNE DISEASES LIKE COVID-19				
Humidification and Dehumidification Devices (Portable and HVAC In-line) 	**Humidity Regulation** (Facilities Only)	Humidification devices add water vapor or steam into the air to increase its relative humidity. Dehumidification devices remove water vapor from the air to decrease its relative humidity.	* There is no specific humidity target for indoor spaces during the COVID-19 pandemic. * According to the CDC, SARS-CoV-2 "is more stable at low-temperature and low-humidity conditions, whereas warmer temperature and higher humidity shortened half-life." * However, ASHRAE' Position Document on Infectious Aerosols states that for an indoor space, "scientific literature generally reflects the most unfavorable survival for microorganisms when the RH [Relative Humidity] is between 40% and 60%...studies showed that RH below 40% is associated with three factors that increase infections." This ASHRAE document further illustrates the optimum RH zone and a variety of health considerations including the risk of mold or fungal growth above 60% RH. * Building envelope construction is critical. Analysis of the building envelope is recommended prior to implementing added humidification to avoid mold growth. *** Targeting the proper humidity range for a space will be beneficial for general indoor air quality, however, airborne disease transmission can occur regardless of humidity levels. Therefore, NCDOT does not support the adjustment of humidity in a space as a means of reducing transmission of airborne diseases like COVID-19.**	
HVAC In-Line Ultraviolet Germicidal Irradiation (UVGI) Devices 	**Surface Disinfection** (Facilities Only)	HVAC in-line UVGI devices are used to continuously shine UV-C light (200 to 280 nm) onto ductwork, coil, or filter media surfaces to irradiate and disinfect those surfaces over time.	* In-line UVGI devices are primarily used to control the growth of mold and bacteria on surfaces inside an HVAC system; not to disinfect the air. ASHRAE's Position Document on Filtration and Air Cleaning states "experience suggests that control of a moving airstream does not provide favorable killing rates because of the short dwell time [of the air in range of the UV light]." * UV lights can be located at a final filter position which will slow air velocities and increase effectiveness; however, filter material must be safe for UV light exposure. * ASHRAE recommends that in-line UV-C devices "should always be coupled with mechanical filtration; MERV-8 filter for dust control [or the] highest practical MERV filter recommended". *** UVGI devices are effective at inhibiting mold and bacterial growth in damp areas within the HVAC system, resulting in better general indoor air quality. However, NCDOT does not recommend this technology for reducing transmission of airborne diseases like COVID-19.**	

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TECHNOLOGIES THAT ARE HELPFUL FOR OVERALL AIR QUALITY, BUT NOT REDUCING THE RISK OF AIRBORNE DISEASES LIKE COVID-19				
Sorbent Air Cleaners 	**Air Cleaning (Removal of VOCs)** (Facilities Only)	Sorbent air cleaners remove contaminants from the airstream via physical adsorption and chemisorption onto a sorbent surface.	* Most sorbent air cleaners are effective at removing gaseous contaminants from the air, but as stated by ASHRAE: "While there may be exceptions, most sorbent beds alone are not generally efficient at removing viruses from airstreams." * In EPA's 2018 Residential Air Cleaners Technical Summary document, "regular replacement is required because its adsorption capacity is exhausted and physical adsorption is a reversible process, meaning pollutants may not be permanently captured." Therefore, this technology is not economically feasible for large scale HVAC integration. *** This technology, while effective at removing VOCs from the air, is not well known nor studied on its abilities to remove pathogens from airstreams. Accordingly, NCDOT does not recommend this technology for reducing transmission of airborne diseases like COVID-19.**	
Demand Control Ventilation (DCV) 	**Outdoor Air Ventilation** (Facilities Only)	DCV devices use a computer and an array of CO_2 sensors to dynamically adjust for more or less outdoor air ventilation based on occupancy (i.e. more humans in the space generate greater quantities of exhaled CO_2); this helps balance indoor air quality and energy efficiency.	* The CDC recommends increased outdoor ventilation as a helpful COVID-19 mitigation strategy, however, the CDC released a statement in October of 2020 for building or HVAC operators to "Disable Demand-Control Ventilation (DCV) controls that reduce air supply based on temperature or occupancy." *** DCV systems can be valuable tools to balance HVAC performance and energy efficiency under normal circumstances. However, because they can restrict outdoor air ventilation, NCDOT does not endorse the use of this technology during the COVID-19 pandemic or a future health emergency involving an airborne disease.**	

Indoor Air Management Technology	Application	How it Works	Important Considerations	
TECHNOLOGIES TO AVOID				
Photocatalytic Oxidization (PCO) and Dry Hydrogen-Peroxide Devices 	**Air Cleaning (Disinfection)**	PCO devices use UV light and a catalyst (usually titanium dioxide) to cause a "redox" chemical reaction in which oxidative gases can break- down pathogens. Some of these devices generate gaseous hydrogen peroxide as a byproduct of the redox process.	* According to ASHRAE, some PCO devices are effective and "remove harmful contaminants". However, "some are ineffective in reducing concentrations significantly; manufacturer data should be considered carefully." * According to ASHRAE, "Nearly all organic, gaseous indoor air contaminants and microbes are subject to PCO decomposition… [however, there exists] potential of an incomplete oxidizing process, which produces by-products of reaction that can be more toxic or harmful than the original constituents (e.g., formaldehyde)." * EPA's 2018 Residential Air Cleaners Technical Summary document corroborates that PCO devices "can generate harmful byproduct such as formaldehyde, and acetaldehyde, and ozone". *** Due to the wide range of PCO and Dry Hydrogen-Peroxide Devices on the market and their varying degrees of effectiveness and risk, including the generation of harmful byproducts, NCDOT does not recommend the use of these devices in facilities or vehicles.**	
Vaporized Hydrogen Peroxide (VHP) 	**Air Cleaning (Disinfection)**	Liquid Hydrogen-Peroxide is diffused into the space via a nebulizing device to disinfect the air.	* There has been limited research on the effectiveness and safety of VHP when generated inside active HVAC ducts and occupied spaces. * OSHA's permissible exposure limit (PEL) for hydrogen peroxide is "1 part per million (ppm) as an 8-hr Time Weighted Average (TWA)," which is what most VHP device manufacturers cite as a basis for safety of their product. However, those devices typically aim to maintain a constant 1ppm ambient concentration of VHP. And according to OSHA, "TWA is the employee's average airborne exposure in any 8-hour work shift of a 40-hour work week which shall not be exceeded." Pending any credible, peer-reviewed, and published scientific studies to the contrary, the concentration of VHP required to inactivate airborne viruses will likely be unsafe for workers to inhale. * ASHRAE mentions that for VHP treatment to be safe, "the space MUST be unoccupied during VHP treatment. Requires spaces to be sealed, including all doorways, plumbing/electrical penetrations and HVAC supply and return vents, to prevent vapor from escaping. After prescribed exposure times, remaining H_2O_2 vapor is scrubbed from the space." *** Due to the hazards associated with breathing hydrogen peroxide and the lack of research on VHP treatment for safely disinfecting the air in occupied spaces, NCDOT recommends against the use of these devices in facilities or vehicles.**	

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TECHNOLOGIES TO AVOID				
Intentional Ozone Generation  	**Air Cleaning (Disinfection)**	Intentional generation of ozone using corona discharge, UV, or other methods to oxidize odorous compounds, gases, and microbes.	* According to ASHRAE, "Ozone is harmful for health and exposure to ozone creates risk for a variety of symptoms and diseases associated with the respiratory tract… [and] should only be considered for disinfection on unoccupied spaces." * The EPA also states "If used at concentrations that do not exceed public health standards, ozone applied to indoor air does not effectively remove viruses, bacteria, mold, or other biological pollutants." *** Due to the hazards associated with the use of ozone in occupied spaces, NCDOT does not recommend the use of these devices in facilities or vehicles.**	
Chemical Air Treatment *Photo not available*	**Air Cleaning (Disinfection)**	A proprietary chemical solution is diffused into occupied spaces via a mister or nebulizing device to disinfect the air.	* New products are coming into the marketplace at the time of this writing, including one that is "an airborne virucide used with water-based haze and fog machines" that claim to kill SARS-CoV-2 in the air. * Despite claims of key ingredients being non-toxic, further study is needed to determine if chronic exposure to the fog might perform and/or cause unintended health effects in a field environment. Such studies would include peer-reviewed analysis of virucidal activity in field conditions, impacts of air change rate on effectiveness, and unintentional generation of irritants when the chemical is heated. *** Further research is needed before NCDOT can consider endorsing this technology; until that research is performed and evaluated by NCDOT and its partners, NCODT does not recommend the adoption of such technology.**	
Plasma Devices 	**Air Cleaning (Disinfection)**	An electric arc is created which ionizes incoming gases and molecular bonds are broken down to transform pollutants	* In EPA's 2018 Residential Air Cleaners Technical Summary document, "[A] wide variety of plasma generation types yields confusion on how a product actually works. Byproducts are formed from many plasma technologies, including particles, ozone, formaldehyde, carbon monoxide, chloroform, nitrogen oxides, and a large number of other organic gases. Most studies have investigated gaseous removal while fewer have evaluated particle removal." *** Due to the harmful byproducts that can be generated by Plasma devices, NCDOT does not recommend the use of these devices in facilities or vehicles.**	

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TECHNOLOGIES TO AVOID				
Ionization Devices (Portable and/or Not UL 2998 Certified) 	**Air Cleaning**	Portable ionizing devices use static electricity to get smaller particles (like a respiratory droplet) to stick to larger particles (like a piece of dust) so they respond quicker to gravity and fall to the floor.	* Portable ionizing devices may cause particles to fall more quickly to the ground but not at a rate that has any appreciable reduction in risk for airborne disease transmission. * Ionization devices without a UL 867 or UL 2998 certification have not been evaluated by a credible organization for ozone production at levels considered safe for public health. * ASHRAE states "Studies of ionizers have shown results ranging from no benefit to some benefit for acute health symptoms… Negative health effects arise from exposure to ozone and its reaction products. Consequently, devices that use the reactivity of ozone for cleaning the air should not be used in occupied spaces. Extreme caution is warranted when using devices in which ozone is not used for the purpose of air cleaning but is emitted unintentionally during the air-cleaning process as a by-product of their operation." * Devices with UL 2998 certification were evaluated according to industry standards and were determined to produce virtually zero ozone during their operation. *** Due to few perceived health benefits as well as ozone hazards associated with portable ionizers and ionizers without UL 2998 certification, NCDOT recommends against the use of these devices in facilities or vehicles.**	
UV-C Portable Room Decontamination 	**Surface Disinfection**	Portable UV-C (200 nm to 280 nm) lamps are placed in a space for a period of time to irradiate and disinfect surfaces within the effective range of the device.	* The FDA states that "Direct exposure of skin and eyes to UV-C radiation from some UV-C lamps may cause painful eye injury and burn-like skin reactions… Some UV-C lamps generate ozone... [and] UV-C can degrade certain materials, such as plastic, polymers, and dyed textile." Thus, these portable UVGI devices are designed for surface disinfection in unoccupied spaces, not disinfecting the air in occupied spaces. *** Because portable UVGI products are designed only for surface disinfection in unoccupied spaces, NCDOT does not recommend the use of these devices for air treatment.**	

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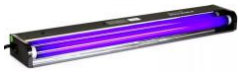
TECHNOLOGIES TO AVOID				
Black Lights and "Near UV" Light 	**Surface Disinfection and Air Cleaning (Disinfection)**	Black Lights or Near UV lights (405 nm) use a different mechanism to kill microbes; they excite naturally-occurring molecules inside organisms, creating reactive oxygen species similar to bleach.	* According to ASHRAE, the "effectiveness [of Near UV] at killing viruses, including SARS-CoV-2, is not as well documented." Additionally, some studies suggest it is "approximately 1000 times less [effective] than UV-C and the effective doses are not practical in an occupied environment." *** Due to perceived effectiveness issues when compared to UV-C technology, NCDOT does not recommend the use of Black Lights and Near UV devices for air treatment.**	
"Far UV-C" Ultraviolet Germicidal Irradiation (UVGI) Devices 	**Surface Disinfection and Air Cleaning (Disinfection)**	Far UV-C (205 nm to 230 nm) UVGI devices are used to slowly disinfect air and surfaces using a spectrum of light that may be safe for human tissues.	* Far UV-C light is an emerging technology that has been proven to kill airborne SARS-CoV-2 in a laboratory, but it still requires significant field testing for safety and efficacy. * As stated in ASHRAE's Filtration/Disinfection Technical Resource, Far UV-C devices are "Unable to fully penetrate larger microorganisms. The UV dose required to inactivate microorganisms is significantly higher at these wavelengths than in the UV-C range [typically used for UVGI]. While safety concerns are reduced, [Far UV-C light] can still cause damage to eyes and skin." *** Further research is needed before NCDOT can consider endorsing this technology; until that research is performed and evaluated by NCDOT and its partners, NCODT does not recommend the adoption of such technology.**	