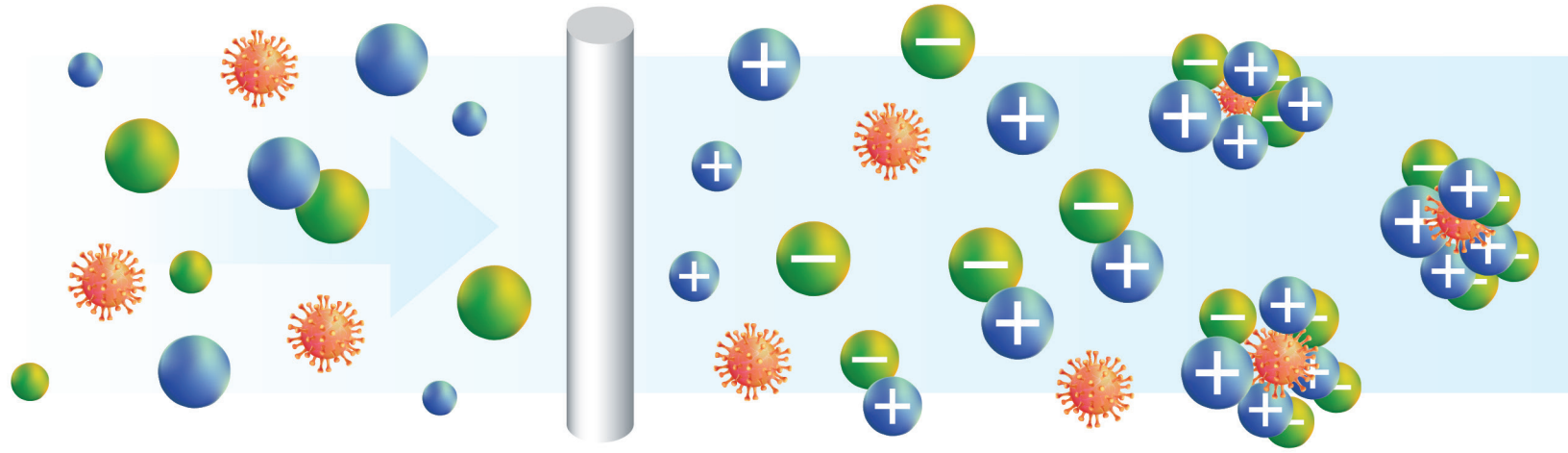
A Taxonomy of Air-Cleaning Technologies Featuring UL 867 Bipolar Ionization



Many infectious respiratory agents are transmitted through droplets and smaller aerosols emitted when a person breathes, talks, sings, coughs or sneezes. Larger droplets tend to remain airborne only briefly before settling out onto the ground or other surfaces due to gravity. Aerosols can remain airborne for longer periods. A person can become infected when they inhale droplets or aerosols containing infectious microorganisms emitted by an infectious person, or when they touch a contaminated surface (fomite) and then touch their face and expose the mucous membranes of their eyes, nose, or mouth. Other pathogens and bioaerosols that can be transmitted through the air include bacteria, such as Legionella, and fungal spores.

There are four major approaches to manage indoor air quality and reduce the potential growth and transmission of pathogens in an indoor environment:

- **DILUTE & EXHAUST.** These two approaches are typically used in combination to relocate pathogens gradually from the occupied space to the outside space. Increasing outdoor air ventilation, i.e., increasing the amount of fresh air (with an assumed lower concentration of pathogens) brought in from the outside, dilutes the concentration of pathogens in the indoor air. Increasing the amount of indoor air (along with the pathogens it carries) that is exhausted to the outside maintains building pressure and increases the rate at which pathogens are removed from the occupied space. This combined approach is effective for reducing the concentration of airborne pathogens, but it does not address contaminated surfaces and it may lead to increased energy consumption from the need to condition the outdoor air. In addition, uncontrolled ventilation can increase humidity levels in the room, which may contribute to the creation of mold and, under certain conditions, potentially facilitate the transmission of other pathogens. Furthermore, depending on the airflow within a room, vortices may be formed, and some pathogens may find refuge in areas of the room with reduced airflow and stagnant air.
- **CONTAIN.** The third element is to manage indoor humidity as it can support growth of surface-bound and airborne microbes like certain viruses, bacteria, and fungi. Keeping relative humidity levels within the ASHRAE®-recommended range of 40%-60% maximizes occupant comfort and can reduce the risk of microbial growth.
- **CLEAN.** The last and very important pillar includes either:
    - “Capturing” pathogens so that they cannot reach the occupants of the space. This is what filters do – as the air circulates through a filter, the filter retains a portion of the pathogens that reach the filter; the portion depends on the size of the bioaerosol particle and the efficiency of the filter. Like the dilute and exhaust approach, the detention approach does not address contaminated surfaces or pockets of stagnant air. With respect to energy, filters that remove substantial amounts of small microbe-containing particles (e.g., MERV 13 or HEPA filters) may have a higher pressure drop than lower efficiency filters and thus increase energy consumption; however, this energy increase is usually smaller than the one associated with increased outdoor air ventilation.
    - “Attacking/inactivating” the pathogen. Ultraviolet (UV) light or a chemically reactive antimicrobial substance can inactivate pathogens. There are two general ways of achieving inactivation:
        - **Bring the air to the inactivating agent.** Ultraviolet germicidal irradiation (UVGI), bipolar ionization (BPI) or photocatalytic oxidation (PCO) systems can be installed in an air handling unit to inactivate the pathogens as the air passes through the air handling unit. This approach does not address surface contamination or pockets of stagnant air.
        - **Bring the inactivating agent to the room.** The approach is similar to the previous one, but the inactivating agent (e.g., antimicrobial substance) is brought into the room. Some of these solutions allow the inactivation of pathogens on surfaces as well as in areas with reduced airflow.

With respect to bringing the inactivating agent to the room, potential solutions are dependent upon whether the spaces are occupied or unoccupied.

Unoccupied Spaces

Solutions for unoccupied rooms can use UV power levels and wavelengths or chemicals that are potentially harmful to humans. Because of the potential harm to humans, these solutions can be applied only on an episodic basis when the room is not occupied, so they cannot provide continuous protection.

Occupied Spaces

Solutions for occupied rooms can only use technologies that are within acceptable safety limits for humans. Examples of solutions2 that are safe for use in occupied spaces include in-room HEPA filters, upper room UV, dry hydrogen peroxide, and bipolar ionization.

Bipolar Ionization (BPI)

Ionization has been studied for almost a century, and air ionization products have been available in the market for decades, although the technology has evolved significantly over the years. Despite the length of time that ionization has been in the market, there is still limited understanding of some of the phenomena related to ionization. There are also divergent opinions about the efficacy of the technology. The underlying chemistry3 is complex to begin with, and this complexity is compounded by the existence of many variants of the technology (i) across manufacturers and (ii) across time, as the technology has evolved.

What is Bipolar Ionization? Bipolar ionization uses ions as antimicrobial agents. Ions are atoms or molecules that have gained or lost one or more electrons, so they are electrically charged. Ions form naturally in the environment from such energy sources as UV light, frictional charging by the wind, water droplet breakup (waterfalls, sea waves), electrical discharge from lightning, etc. Bipolar ionization (BPI) refers to technologies that use an artificial source of energy to produce both positively charged ions (cations) and negatively charged ions (anions). The ions are typically produced by applying voltage to electrodes to create an electric field; as the air passes through the electric field, some atoms or molecules in the air stream may lose or gain electrons and become ions. Different electrical arrangements give rise to different variations of BPI devices (e.g., corona discharge, dielectric barrier discharge, or needlepoint). There are BPI devices that can be installed in an air-handling unit or in a duct, as well as stand-alone BPI devices (usually portable) that operate in a room.

How Bipolar Ionization Reduces Contaminants. Bipolar ionization has been proven to be effective in removing particulates through a process called agglomeration. Ions attach to particles (e.g., dust, pollen, or dander) and the charged particles attract other particles of opposite polarity to form larger particles. The particles eventually become large enough to settle out due to gravity, be captured by a filter, or be attracted and attach to other surfaces.

When it comes to inactivating pathogens and reducing volatile organic compounds (VOCs), the processes are more complex and not fully understood. The amount of energy required to remove an electron from an atom or molecule is called ionization energy, or ionization potential. Different atoms and molecules have different ionization potentials. Thus, the types of ions produced by a BPI device depend on the composition of the air and on the amount of energy applied. At high energy levels, it is believed ionization generates, among other things, a complex mixture of reactive oxygen species (e.g., superoxides, peroxides, or hydroxyls).

The complication in the process described above is that, at high energy levels, ozone is also produced. Ozone was produced by some air cleaners in the past; however, it is now widely accepted that ozone is toxic and can cause harm to humans. Thus, ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality requires that air-cleaning devices comply with the UL 2998 standard, which validates ozone emissions to less than 5 parts per billion (ppb). Many BPI products, particularly older device models, do not meet the UL 2998 requirements; they may only meet the older and less stringent UL 867 standard, which allows ozone emissions up to 50 ppb. Some newer BPI products limit the input energy below the level at which ozone is produced, so these products comply with UL 2998. However, the resulting ion cloud may be composed of fewer or less reactive ions. Thus, it is important to verify the compliance of a

BPI product with UL 2998 and consider the test parameters under which any test results on efficacy were obtained.

Experimental results. To validate the efficacy of the BPI technology, Trane® conducted experiments in the fall of 2020 at an independent laboratory (LMS Technologies, Inc.). The experiments were conducted in a 1,007 cubic foot chamber, with both airborne and surface-bound microorganisms and under a variety of airflow conditions. The test was performed on a needlepoint bipolar ionization device4, a type of BPI technology, that met UL 867 standard, which was installed (per manufacturer's installation guidelines) in the ductwork of the HVAC system and was rated for airflows up to 6,000 cfm. It should be noted that the amount of ozone produced during the experiment was not significant, although our measurement was incidental and not in accordance with the procedure prescribed in UL 867.

The following graphs illustrate the results from a representative sample of tests conducted with the bacteriophage MS2 virus in the air and on surfaces. The BPI device demonstrated apparent efficacy for inactivating airborne viruses, but not for surfaces. It should be noted that the MS2 virus is a small, non-enveloped virus; as such, it is likely more difficult to inactivate than an enveloped virus5. In laboratory tests, the MS2 is often used as a surrogate for the SARS-CoV-2 due to its ease of handling without fear of infection and higher resistance to deactivation over SARS-COV-2. SARS-CoV-2 is an enveloped virus and is expected to be inactivated faster than MS2.

Airborne pathogens. **Figure 1** illustrates the reduction in culturable airborne MS2 concentrations for the BPI device with different filter options and for natural decay. The BPI device was turned on for one hour prior to time-zero, which includes the 14-minute virus injection period, and remained operational throughout the duration of the test. The horizontal axis shows the time elapsed since the end of the MS2 virus injection in the air of the test chamber; the vertical axis shows the reduction in the culturable virus concentration as a percentage of the initial concentration of the virus in the chamber at time zero. The graph shows three curves for BPI, one for each of three different filter arrangements: MERV 8 filter upstream of the device, MERV 8 filter downstream of the device, and no filter at all. Most BPI manufacturers recommend placing the filter upstream of the BPI device. For comparison purposes, the graph also shows the natural decay (percent reduction in culturable virus concentration without any technology applied). In this experiment, the airflow from the HVAC system was 101 cfm or 6 air changes per hour (ACH). Similar results (not shown in the graph) were obtained for Staphylococcus aureus, which was used as representative of bacteria.

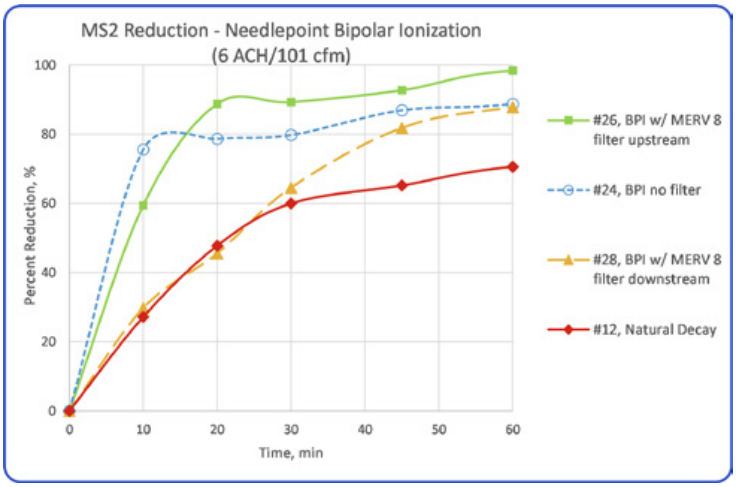


Figure 1: Reduction of MS2 virus in air by BPI device with airflow of 6 ACH.

Figure 2 illustrates the negative ion concentration in the chamber during the test mentioned above as measured by an AlphaLab Air Ion Counter Model AIC2. The device had been operating for an hour before the injection of the contaminant. The injection of the MS2 started at time -14 min and lasted until time zero. As shown on the graph, the concentration of negative ions was about 6,000 ions/cc before the start of the MS2 injection. In the experiment

where the filter was placed downstream of the device, the pre-injection ion concentration was much lower, which is expected since ions react to filters. Upon injection of the MS2, the concentration of ions in the chamber dropped quickly, which shows that ions were interacting with the contaminant.

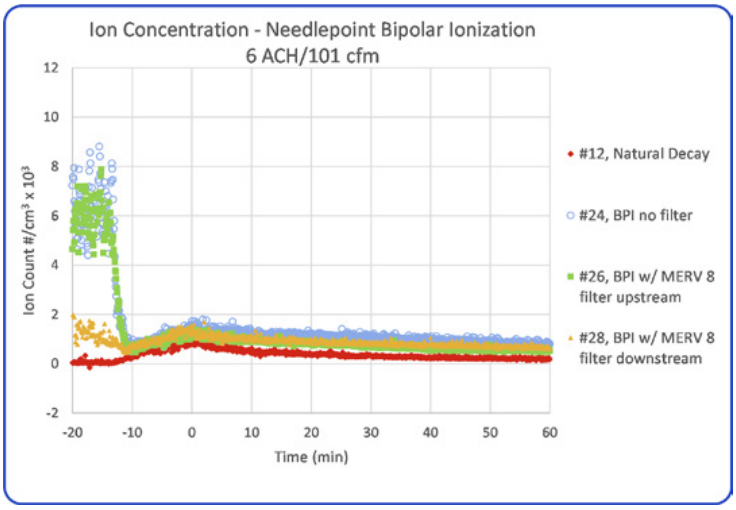


Figure 2: Negative ion concentration in the test chamber during MS2 in-air test at 6 ACH.

The left graph in **Figure 3** illustrates the reduction in culturable airborne MS2 concentrations that the BPI device achieved with an HVAC airflow of 336 cfm, or 20 ACH. The axes and the curves have the same interpretation as in the previous test (**Figure 1**). The concentration of ions in this experiment followed a pattern very similar to that shown in **Figure 2**, except that the pre-injection concentration of negative ions in the chamber was much higher (between 20,000 ions/ cc and 40,000 ions/cc). As in the first test, the ion concentration dropped significantly upon injection of MS2. The higher concentration of ions under the higher HVAC airflow could potentially be explained by the fact that the ions separate from one another more effectively as they are generated by the device, so the neutralizing recombination of positive and negative ions is reduced. The right graph in **Figure 3** shows a comparison of the reduction in culturable airborne MS2 concentrations achieved by the BPI device for different HVAC airflows. It was unexpected to see a similar rate of reduction of MS2 given the much higher number of ions that reached the chamber under the higher HVAC airflow.

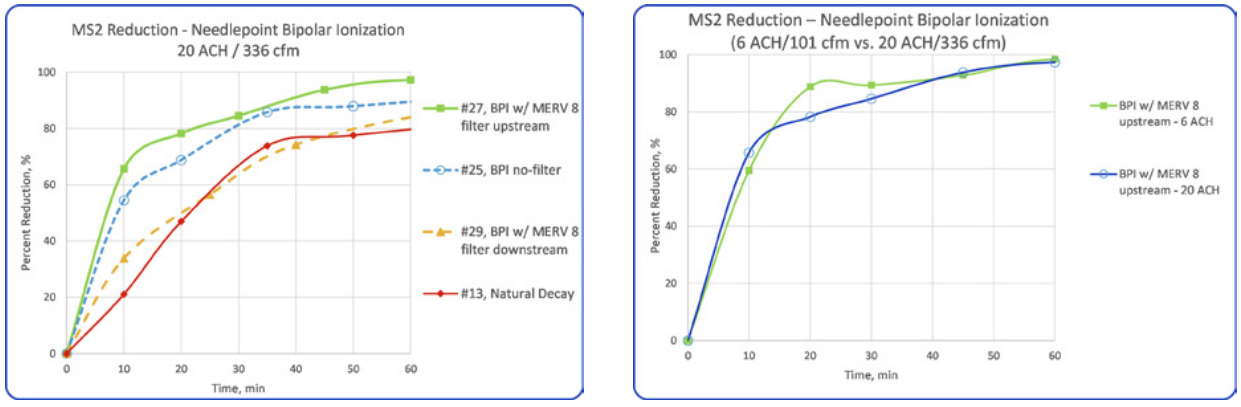


Figure 3: Reduction of MS2 virus in air by BPI device with airflow of 20 ACH (left); comparison of MS2 inactivation in air for different airflows (right).

Surface-bound microorganism. **Figure 4** illustrates the results of an experiment with MS2 on a polystyrene substrate surface. For these tests, inoculated coupons are placed in the chamber and exposed for the desired length of time. At the prescribed sample time, a pneumatic system is used to cover the coupons. The coupons are retrieved at the end of the test and analyzed. The horizontal axis shows time in hours. The vertical axis shows relative culturable MS2 concentration (i.e., the concentration of MS2 on the surface divided by the initial concentration of MS2 on the surface when the experiment started). The HVAC airflow during this experiment was 101 cfm, or 6 ACH. As can be seen in the graph, the reduction in culturable MS2 virus while the BPI device was on was essentially no different than that from natural decay. It should be noted that the concentration of ions in the chamber (approximately 6,000 ions/cc) remained stable throughout the test, which confirms that the device was operating properly. Thus, it appears that the BPI device was ineffective against MS2 on surfaces under these test conditions.

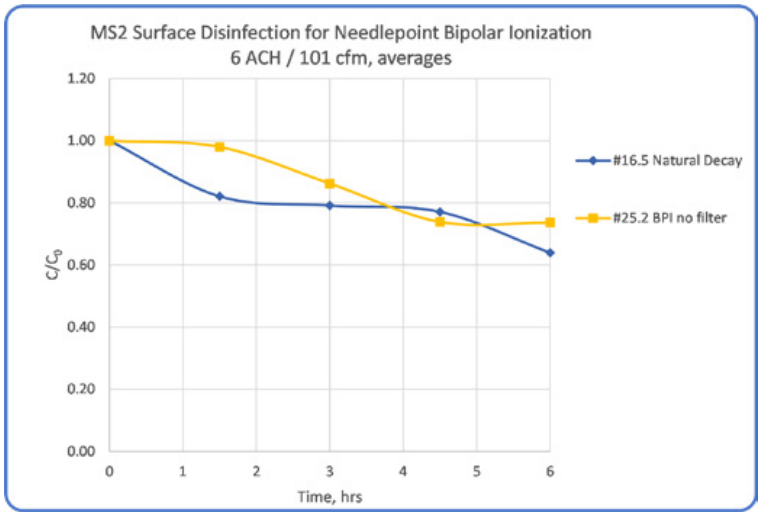


Figure 4: Surface culturable MS2 virus concentrations with and without BPI at 6 ACH.

We are aware of claims by BPI manufacturers that they have achieved reduction of SARS-CoV-2 on surfaces. At this time, Trane has not been provided enough information to reconcile the differences in results of the various tests. Numerous potential factors could explain the different outcomes. MS2 is a small non-enveloped virus, so it is harder to inactivate than SARS-CoV-2 (which is enveloped). The experimental setup may have been different – various parameters, such as the size of the chamber, distance from the device, airflow, sample preparation, collection, and analysis methods, etc., may have been different.

Volatile organic compounds (VOCs). **Figure 5** illustrates the results of an experiment with formaldehyde (CH2O) in the air. For these tests, formaldehyde concentration was determined and logged using a real-time analyzer, Aerodyne QC-TILDAS Formaldehyde Monitor. The horizontal axis shows time, and the vertical axis shows the formaldehyde concentration. The HVAC airflow during the test was at 6 ACH. The concentration of ions in the chamber remained stable during the entire test, even after the injection of formaldehyde, and at a level consistent with levels observed during previous tests with the same HVAC airflow (i.e., around 6,000 ions/cc). As can be seen in the graph, the decay of formaldehyde with the BPI device is practically indistinguishable from the natural decay. Very similar results were also obtained with toluene (C7H8), another VOC. The decay of toluene with the BPI device operating was indistinguishable from the natural decay, and the concentration of ions in the chamber remained stable during the entire test.

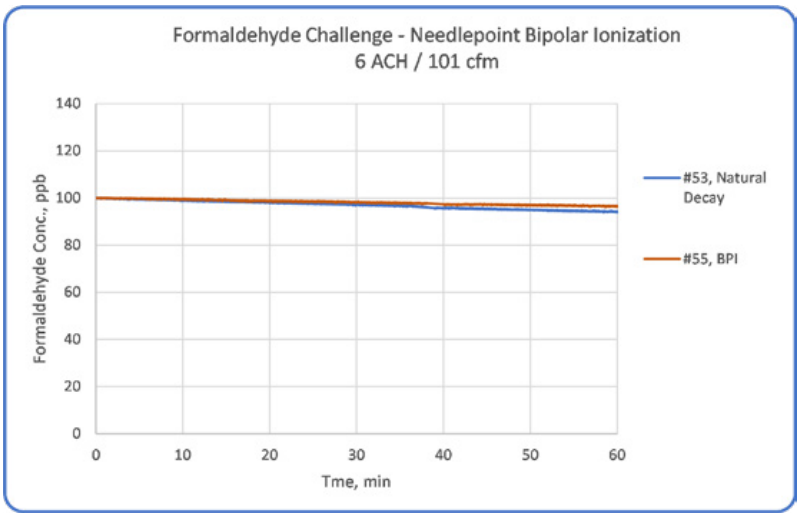


Figure 5: Airborne formaldehyde concentrations with and without BPI device at 6 ACH.

The inability of the needlepoint bipolar ionization device to reduce formaldehyde and toluene has serious ramifications for the applicability of the technology to the Indoor Air Quality Procedure (IAQP) in ASHRAE Standard 62.1. If the technology cannot reduce airborne VOCs, it cannot supplant outdoor air ventilation, so it cannot conserve energy.

Conclusions. In the tests that Trane Technologies™ conducted, the UL 867 BPI device demonstrated efficacy for in-air microorganisms, specifically MS2 (virus) and S. aureus (bacteria). In the tests conducted, we did not see efficacy against microorganisms on surface, or reduction of VOCs like formaldehyde and toluene in air. Therefore, we are inconclusive about the applicability of the technology to these situations

Our overall conclusions are in line with the following comment6 by ASHRAE regarding bipolar ionization, corona discharge, needlepoint ionization, and other ion or reactive oxygen air cleaners, and the response provided by the CDC to an inquiry from the ASHRAE Epidemic Task Force:

- Air cleaners using reactive ions and/or reactive oxygen species (ROS) have become prevalent during the COVID-19 pandemic. New devices that are not mentioned elsewhere in this guidance likely fall into this category
- Technologies utilize various methods to create reactive ions in air that react with airborne contaminants, including viruses. The design of the systems can be modified to create mixtures of reactive oxygen species (ROS), ozone, hydroxyl radicals and superoxide anions.
- Systems are reported to range from ineffective to very effective in reducing airborne particulates and acute health symptoms.
- Convincing scientifically-rigorous, peer-reviewed studies do not currently exist on this emerging technology; manufacturer data should be carefully considered.
- Systems may emit ozone, some at high levels. Manufacturers are likely to have ozone generation test data.

Response from the CDC to the ASHRAE Epidemic Task Force:

Thank you for your question. Although this was pointed out in the earlier CDC responses, it is important for me to re-emphasize that CDC does not provide recommendations for, or against, any manufacturer or manufacturer's product. While bi-polar ionization has been around for decades, the technology has matured and many of the earlier potential

safety concerns are reportedly now resolved. If you are considering the acquisition of bi-polar ionization equipment, you will want to be sure that the equipment meets UL 2998 standard certification (Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners) which is intended to validate that no harmful levels of ozone are produced. Relative to many other air cleaning or disinfection technologies, needlepoint bi-polar ionization has a less-documented track record in regard to cleaning/disinfecting large and fast volumes of moving air within heating, ventilation, and air conditioning (HVAC) systems. This is not to imply that the technology doesn't work as advertised, only that in the absence of an established body of evidence reflecting proven efficacy under as-used conditions, the technology is still considered by many to be an "emerging technology." As with all emerging technologies, consumers are encouraged to exercise caution and to do their homework. Consumers should research the technology, attempting to match any specific claims against the consumer's intended use. Consumers should request efficacy performance data that quantitatively demonstrates a clear protective benefit under conditions consistent with those for which the consumer is intending to apply the technology. Preferably, the documented performance data under as-used conditions should be available from multiple sources, some of which should be independent, third party sources.

DISCLAIMER: There is evidence from ASHRAE and other sources that HVAC technologies can mitigate the risk of exposure to infectious aerosols in built environments; however, the transmission of SARS-CoV-2 and mitigation of COVID-19 in buildings is yet to be tested and confirmed.

[1] For more information on the transmission of SARS-CoV-2, see https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html.

[2] For more information on air cleaning, including a white paper about Synexis and DHP, please visit https://trane.com/wellsphere.

[3] An introductory discussion of the physics and chemistry of ionization can be found in S. L. Daniels, ""On the ionization of air for removal of noxious effluvia" (Air ionization of indoor environments for control of volatile and particulate contaminants with nonthermal plasmas generated by dielectric-barrier discharge)," in IEEE Transactions on Plasma Science, vol. 30, no. 4, pp. 1471–1481, Aug. 2002, doi: 10.1109/TPS.2002.804211. A similar version of the paper can be found at https://www.plasma-air.com/resources/397.

[4] The device was a Phenomenal Aire® Series C6.0 Cold Plasma Generator manufactured by Top Product Innovations (https://www.topproductinnovations.com/); the core BPI component of the device is manufactured by Global Plasma Solutions® (https://globalplasmasolutions.com/).

[5] Generally, enveloped viruses are more easily inactivated than large non-enveloped viruses and large non-enveloped viruses are more easily inactivated than small non-enveloped viruses:

Firquet, S., et. al (2015). Survival of Enveloped and Non-Enveloped Viruses on Inanimate Surfaces. Microbes Environ, 30(2), 140–144. doi:10.1264/jsme2.ME14145

Swan, W. (2015, October 1). Overview of Current Disinfection Hierarchy Models. Retrieved from https://www.epa.gov/sites/default/files/2015-10/documents/rutala_overview_of_current_disinfection_hierarchy_models_final.pdf.

[6] https://www.ashrae.org/technical-resources/filtration-disinfection#bipolar.

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