A Comparison of Air Treatment Technologies to Confirm the Efficacy of Filtering Air with UV-C Radiation in Industrial HVAC Systems for the Purpose of Air Sanitization

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1 Introduction

Air treatment technologies are becoming a focal point of infrastructure design and discussion. The recent pandemic has shown businesses, policymakers and private citizens that the air around us is full of unseen dangers in the form of bacteria, pathogens, inorganic material and other microorganisms. These airborne contaminants can enter our bodies through our airways, causing infections, tissue damage and other health-related effects. Resulting from an increased awareness brought on by the massive changes that began in early 2020 due to the SARS-CoV-2 pandemic, decision-makers at all levels are beginning to understand how different air treatment options affect air quality. These devices are quickly becoming a crucial consideration for those designing new buildings, as well as those in charge of existing ones. Having the right information available can help these individuals make informed decisions about which air treatment solution is right for their facility. It is critical to understand the benefits and drawbacks of each technology and which combination of them produces a balanced approach that is economical, effective and efficient. The goal of this document is to provide further information on this topic with descriptions of the various air treatment options available, including comparative factors that can be used to assess the viability of each as a sole air treatment method. After comparing each of the air treatment technologies through the lens of the various factors, we offer suggestions for a balanced approach to air treatment that best satisfies all factors.

2 Comparative Factors

The factors this document focuses on are particulate size, treatment method and ozone generation. These factors allow for direct comparisons between air treatment technologies that do not necessarily share similar designs, mechanical effects or purposes.

2.1 Particulate Size

All air treatment technologies are designed to target a specific particulate size. Generally, these particles are separated into three categories: coarse, fine and ultra-fine. The diameter of coarse particulates is between 2.5-10 μm (micrometres). Fine particles measure 2.5 μm and smaller. Ultra-fine particles are any that are smaller than 1 μm.

The design and mechanics of an air treatment technology often dictate which particle size it can affect. For instance, a mechanical air filter's inability to affect ultra-fine particles settled on a surface is likely due to a lack of mechanical force that agitates the light particulate matter.

The most effective air treatment technology should address all particulate sizes, as Volatile Organic Compounds (VOCs) exist in all size ranges. The diameter of fungal spores varies between 2-4[1] μm, bacteria between 1-10[2] μm and only the largest viruses measure more than 0.5[3] μm. However, even when a technology can affect all sizes, it is often disproportionately more effective with one of the sizes, making a multi-stage solution necessary.

2.2 Treatment method

Air treatment technologies can be divided into three treatment methods: collection, destruction and conversion.[4] The majority of air treatment technologies are considered collection-type devices. Only one technology is destructive, namely Ultraviolet Germicidal Irradiation (UVGI).

2.2.1 Collection

Examples of collection-type air treatment technologies include high-efficiency particulate air (HEPA) filters, adsorbent and chemisorbant media filters, and electrostatic air cleaners. The main function of these technologies is collecting particulates or gases for a period of time before they become saturated or lose their effectiveness. After this period, the filters will need to be replaced or renewed and the previous filters properly disposed of.

2.2.2 Destruction

UVGI uses electronically powered lamps to produce shortwave ultraviolet light (UV-C) that pierces microorganisms and disrupts their RNA, killing them and rendering them inert. While the majority of this range (100—280 nm)[5] can produce germicidal effects, the ideal wavelength is 253.7 nm. The VOCs killed by this treatment are expelled as the system continues to process volumes of air.

2.2.3 Conversion

Conversion-type air treatment creates the conditions for a chemical reaction to occur. An example of this is intentional ozone generation, which purposefully introduces ozone through uncoated UV lamps or corona discharge to interact with and ionize gases, particles and other odorous compounds[4]. This method can be dangerous without proper ventilation and planning, but can be very effective in the right applications.

2.3 Ozone Generation

Ozone is a proven irritant and health concern for humans. It is a molecule made of three oxygen molecules (O_3) and is both naturally occurring and a by-product of human constructions. In sufficient concentrations, or with enough exposure, medical issues such as irritated airways, frequent asthma attacks and the aggravation of existing lung diseases, like emphysema and bronchitis, can occur. These concerns make ozone generation and management a serious design consideration for air treatment technologies that can produce deleterious amounts of ozone.

The methods of air treatment that can produce ozone include intentional ozone production, plasma, UVGI, ionizers, and electrostatic air cleaners.[4] Several of these methods cannot affect the amount of ozone generated, with the notable exception of UVGI. By coating the fused quartz that houses the gas and filament of a UV-C-producing lamp with titanium particles, manufacturers of UV-C-producing bulbs sometimes create doped fused-quartz lamps, which block ozone-producing wavelengths of light. Not all UVGI products use this material, as ozone can be used as an independent air treatment method in certain applications.

3 Air Treatment Technologies & Their Relationship with the Complicating Factors

We will now describe in more detail the various air treatment technologies and their relationship with the factors described in the section above.

3.1 Mechanical Air Filtration

Mechanical air filters are defined as air filters without any specific filtration present. They simply move the air through ducting and fans to circulate the volume of air in an enclosed space, like a building or room. Mechanical air filters are often an essential component of other treatments, as they circulate the air and ensure the whole interior volume is exposed to whichever additional treatment(s) are present. They are capable of addressing all sizes of airborne particulates. However, their large size does not make them well-suited to the task of removing fine or ultra-fine particles settled on surfaces or in the most isolated spaces within the system. They are classified as a collection treatment method. They collect a volume of indoor air and expel it out of the building by means of an exhaust. They are often also responsible for reintroducing new air at an equivalent volume to that which is expelled. There is no ozone production in mechanical air filtration systems on their own, but they may aid the spread of ozone when paired with other ozone-producing technologies.

3.2 High-Efficiency Particulate Air (HEPA) Filtration

High-efficiency particulate air (HEPA) filtration refers to a number of air treatments. In fact, HEPA is a designation that varies by locality, describing similar guidelines on the manufacturer and capabilities of an air treatment solution, like fibrous media air filters. Usually, these guidelines vary in their specific requirements, but still focus on the average particle size that can pass through the filter. Generally, the treatments are constructed into a semi-random screen of small fibres with minute distances between the individual strands. As airborne particulates interact with the filter, they become stuck or lodged in place.

HEPA air treatments are standardized to ensure they can handle all particle size categories described above. This includes even ultra-fine particles, which are larger than 0.3 μm.

HEPA air treatments are an example of the collection filtration method. They capture particulates in their fibres, and may become more efficient over time as particles get lodged and block pathways. However, this also means they become more dangerous, potentially, as the increased concentration of foreign particles means more trapped microorganisms, inorganic matter and other dangerous airborne particulates.

HEPA air treatments do not produce ozone due to their simple design, but they may be part of other air treatment systems that do.

3.3 Electrostatic Air Cleaners

Otherwise known as electrostatic precipitators (ESPs), electrostatic air cleaners electrically charge airborne particles to attract them to negatively charged surfaces, removing them from the indoor air stream. They do this with a high-voltage wire suspended in the air stream, followed by a collection plate on the far side of the intake.

Electrostatic air cleaners can handle all particle sizes, including coarse, fine and ultra-fine categories. However, the nature of the air treatment means that certain particles are more susceptible than others, varying the overall effectiveness.

Electrostatic air cleaners are another example of collection air treatment. Much like HEPA filtration, they may suffer from inadequate cleaning, as the collection plate can fill with charged particles, decreasing their effectiveness.

Ozone generation is a serious concern with electrostatic air cleaners. They produce substantial quantities during operation and must be designed in systems that allow for proper ventilation and removal of the gas.

3.4 Needlepoint Ionization

The process of needlepoint ionization is very similar to electrostatic air cleaners. It involves using a high-voltage wire or carbon fibre brush to charge air molecules, which produces ions that attach to airborne particles. The particles can then attach to other surfaces, eventually falling out of the air. These devices do not require additional airflow from a mechanical device, which makes them much less effective than other methods on this list.

Needlepoint ionization is effective in treating all particle sizes, including ultra-fine particles. However, it shares a similarity with electrostatic air cleaners in that different particles will be affected differently by the treatment method.

Needlepoint ionization is another example of a collection filter. These filters can become less effective as they receive regular use and fill with captured material, but regular cleaning can mitigate this problem.

Needlepoint ionization can produce significant amounts of ozone during operation. As a result, special considerations need to be made to ensure the safe collection and removal of the dangerous gas. The ozone produced by these devices, as a result of not being installed in HVAC systems exclusively, creates a higher risk of reaction with other chemicals and objects inside a building.

3.5 Ultraviolet Germicidal Irradiation (UVGI)

Ultraviolet germicidal irradiation (UVGI) uses shortwave light to disrupt the RNA of microorganisms. The optimal wavelength for this process is 254 nm, but most of the UV-C light range (100-280 nm) is considered germicidal. A controlled, enclosed area is often required to ensure the intensity of the light remains constant. Several factors affect the efficacy of these devices, such as the number of bulbs, the proximity of those bulbs to one another, the other components of the treatment system and the amount of air moving through the UVGI unit at any one time. UVGI is the only destructive filtration method available. It is designed to target organic matter with a fine or ultra-fine diameter, although it is still effective with some coarse particles. While certain UV-C lamps can produce ozone, technologies exist to eliminate any ozone production from the filtration process.

4 Summary

When comparing the many available air filtration technologies, UVGI comes out ahead in every category. One of the strongest cases against widespread adoption was the production of ozone present in some lamps, but newer technologies have made this issue one of the past. Ask about UL-2998 certification when selecting an air purification partner to be sure that the equipment in question is certified as operating free of ozone. In terms of the filtration method, UVGI is the only destructive option available, making it the best defence against living microorganisms like bacteria and some viruses, which continue to pose a risk if captured live in a filter medium such as in a HEPA system. Finally, the particle sizes that UVGI can affect cross all three categories of coarse, fine, and ultra-fine, protecting from particulate and pathogens across the widest range of particle sizes.

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