THE RETURN TO ACTIVITIES AND THE AIR PURIFICATION

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Content

Abstract

This article was elaborated during the development project of industrial indoor air purification and filtration systems, and intends to offer a summary of the documents *"Position Document on Filtration and Air Cleaning"* and "*Position Document on Infectious Aerosols"* both from ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and freely available at their site.

Considering the above-mentioned scope, we selected the most relevant parts of the documents to the subject filtration and purification of indoor air. For those who want a broader and more complete view on the subjects covered here, we recommend reading the complete original texts.

Glossary

For the ones less familiarized with the subject, we believe that some terms and abbreviations used in the documents should be clarified, so that they can be understood in their real scope and limitation. Therefore, we list below some terms we consider important to explain and contextualize:

HVAC – Abbreviation of "Heating, Ventilation and Air-Conditioning" and is normally used in the context of projects and applications of climatization systems. However, the term can also be applied to ambient air ventilation and filtration systems.

Building – ASHRAE publications frequently refer to Buildings, what, many times, can lead to the wrong idea of commercial or residential buildings. In fact, the term here refers to any construction for human occupation, including buildings for industrial activities for example.

Filtration and Purification – The term may, at first glance, appear redundant, but it has a technical significance. Although subject to different interpretations, Filtration means here the capture and retention of airborne particles. Purification though, means reaching a certain grade of purity in the air related to any contaminants defined in a standard including, for example, gases.

UVGI – Ultraviolet Germicide Irradiation, commonly called UV Light with germicide activity. The other derivate term UV-C means the same radiation in a specific wavelength range that does not generate Ozone.

Introduction

The document "ASHRAE Position on Filtration and Air Cleaning", in its section "The Issue", introduce the problem very clearly:

> *"Air in buildings contains various classes of contaminants: particulate matter (some biological in origin), gases, and vapors. Sources for many of these contaminants may be located either indoors (building components, occupants, and occupant activities), outdoors, or both indoors and outdoors. Filtration and air-cleaning technologies are used to reduce exposures to these contaminants in buildings by intentionally removing them from the air. The contaminants are either physically removed or participate in chemical reactions (i.e., are transformed with the intent of producing innocuous compounds). Different filtration and air-cleaning technologies are in use, depending on the class of contaminants that needs to be removed.*

Filtration and air cleaning are methods for reducing exposures to contaminants indoors and thus improving indoor air quality. These methods may create viable alternatives and/or supplements to other methods for exposure reduction by supporting dilution via outdoor air ventilation by ensuring that the outdoor and/or recirculated air supplied indoors by HVAC systems is less contaminates and by improving ventilation efficacy by removing contaminants that have an indoor origin. Because these methods reduce concentrations, and thus, exposures to contaminants, many conclude that their application allows reducing outdoor airflow levels for ventilation; this belief is especially valid when outdoor air is heavily contaminated or is burdened with high humidity and thermal loads and when these technologies can remove contaminants at a lower cost than through ventilation alone."

Although the readers will find that in most of the topics addressed, throughout this article and also in the original documents, there is an observation that there are no conclusive studies regarding one or other hypothesis, this paragraph clearly states the position of the entity and reinforces the benefits of ventilation systems with filtration and purification to improve the air in the indoor environment and reduce the exposure to internal or external contaminants.

The Issue of Contamination

The ASHRAE document on Filtration and Air Cleaning states:

"This document informs ASHRAE membership and the public about the positive, benign, or negative effects of filtration and air-cleaning technologies on health. Health effects, in the context of this position document, are understood as the effects on biomarkers, quality of life, physiological impact, symptoms, clinical outcomes, or mortality (American Thoracic Society 2000).

The document briefly characterizes the major categories of filtration and air-cleaning technologies, and their applications for removing contaminants from outdoor air brought into buildings and/or indoor air."

Meanwhile, the document on Aerosols says:

"The risk of pathogen spread, and therefore the number of people exposed, can be affected both positively and negatively by the airflow patterns in a space and by heating, ventilating, and air-conditioning (HVAC) and local exhaust ventilation (LEV) systems."

"ASHRAE will continue to support research that advances the knowledge base of indoor air management strategies aimed to reduce occupant exposure to infectious aerosols. Chief among these ventilation-related strategies are dilution, airflow patterns, pressurization, temperature and humidity distribution and control, filtration, and other strategies such as ultraviolet germicidal irradiation (UVGI).

With infectious diseases transmitted through aerosols, HVAC systems can have a major effect on the transmission from the primary host to secondary hosts. Decreasing exposure of secondary hosts is an important step in curtailing the spread of infectious diseases.

Infectious diseases can be controlled by interrupting the transmission routes used by a pathogen. HVAC professionals play an important role in protecting building occupants by interrupting the indoor dissemination of infectious aerosols with HVAC and LEV systems."

“Now that microbiologists understand that many pathogens can travel through both contact and airborne routes, the role of indoor air management has become critical to successful prevention efforts.”

“Many buildings are fully or partially naturally ventilated. They may use operable windows and rely on intentional and unintentional openings in the building envelope. These strategies create different risks and benefits. Obviously, the airflow in these buildings is variable and unpredictable, as are the resulting air distribution patterns, so the ability to actively manage risk in such buildings is much reduced. However, naturally ventilated buildings can go beyond random opening of windows and be engineered intentionally to achieve ventilation strategies and thereby reduce risk from infectious aerosols. Generally speaking, designs that achieve higher ventilation rates will reduce risk. However, such buildings will be more affected by local outdoor air quality, including the level of allergens and pollutants within the outdoor air, varying temperature and humidity conditions, and flying insects.”

We can therefore conclude from both statements that, in terms of health impact, it is all about reducing contaminants, including pathogens, circulating in the environment and that can contaminate the occupants. Although seeming an obvious question, we will see further on that an important concept is introduced here: that both contamination by biologic agents and inorganic pollution (dust and gases) are of outmost importance for health impact.

The new revision of the Aerosols document dated April 14^{th}, 2020, brings also specific considerations about SARS-CoV-2:

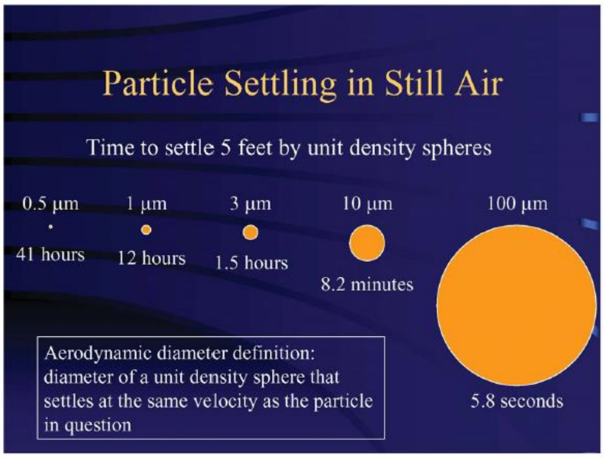
“Statement on airborne transmission of SARS-CoV-2: *Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.*

Statement on operation of heating, ventilating, and air-conditioning systems to reduce SARS-CoV-2 transmission: *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.”*

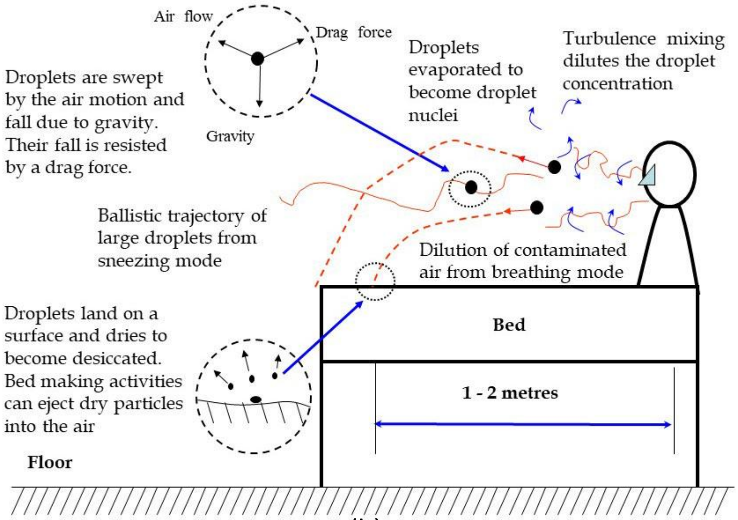
Not directly related to the Coronavirus pandemic but nonetheless related to the subject, there is a paragraph in the same document that is worth mentioning:

“3.4 Emerging Pathogens and Emergency Preparedness
Disease outbreaks (i.e., epidemics and pandemics) are increasing in frequency and reach. Pandemics of the past have had devastating effects on affected populations. Novel microorganisms that can be disseminated by infectious aerosols necessitate good design, construction, commissioning, maintenance, advanced planning, and emergency drills to facilitate fast action to mitigate exposure. In many countries, common strategies include naturally ventilated buildings and isolation.”

The document on Aerosols also brings a familiar graphic that shows the dispersion process of the airborne particles and, in case of contaminants, its potential pollutant. The picture is self-explainable, but it worth mentioning the importance of the adequate air flow in the environment, as the document states:



(a)



(b)

Picture 1: *(a) Comparative settling times by particle diameter for particles settling in still air (Baron n.d.) and(b) theoretical aerobiology of transmission of droplets and small airborne particles produced by an infected patient with an acute infection (courtesy Yuguo Li).*

The text follows:

"Airborne Dissemination
Many diseases are known to have high transmission rates via larger droplets when susceptible individuals are within close proximity, about 3–7 ft (1–2 m) (Nicas 2009; Li 2011). Depending on environmental factors, these large (100 µm diameter) droplets may shrink by evaporation before they settle, thus becoming an aerosol (approximately <10 µm). The term 'droplet nuclei' has been used to describe such desiccation of droplets into aerosols (Siegel et al. 2007). While ventilation systems cannot interrupt the rapid settling of large droplets, they can influence the transmission of droplet nuclei infectious aerosols. Directional airflow can create clean-to-dirty flow patterns and move infectious aerosols to be captured or exhausted."

Rationale on Necessity

The recommendations for the use of Air Ventilation, Filtration and Purification systems in confined spaces are spread throughout the documents. We collected in this item the more relevant parts of such recommendations.

Item 2.1.2 – Filtration and Air Cleaning document:

"An extensive body of epidemiological research indicates that death rates, hospital admissions, and asthma exacerbations, as well as other adverse health effects increase with increased concentrations of particles in outdoor air (e.g., Brunekreef and Forsberg 2005; Delfino et al. 2005; Pope and Dockery 2006).

Because much of a person's exposure to outdoor air particles occurs indoors and because this exposure can be reduced by filtration, it is reasonable to expect associated health benefits from particle filtration that is effective in removing particles having outdoor origin.

Published relationships between outdoor air particle concentrations and adverse health effects have been used in models to predict the related health benefits of particle filtration. The resulting papers, reviewed by Fisk (2013), indicate substantial health benefits associated with filtration, with benefits generally proportional to the reduction in total exposure to particles less than 2.5 µm in diameter. The models considered numerous health or health-related outcomes, including mortality, cardiac or respiratory-related emergency room visits or hospital admissions, chronic bronchitis, and asthma exacerbation. Because most of these health outcomes occur in a small portion of the population, very large empirical studies would thus be needed to confirm these predictions, and such studies have not been performed. Two studies found statistically significant improvements with filtration in biomarkers that predict future adverse coronary events (as cited in Fisk 2013), providing some empirical support for the model predictions of health benefits.

A few studies investigated whether use of particle filtration systems in offices or schools reduce nonspecific self-reported health symptoms, often called sick-building syndrome (SBS) symptoms, in the general population. The origin of the particles removed was not identified. Most of these studies report reduced indoor air particle concentrations of 20% to 80%, and 50% a typical reported value. Nearly all the studies used mechanical filters. Several communicable respiratory diseases are transmitted, in part, by inhalation of small airborne particles containing infectious virus or bacteria produced during coughing, sneezing, singing, and talking.

Filtration may thereby reduce the incidence of the associated communicable respiratory diseases, provided the airstream transports the particles to the filtration system. The results of modelling suggest that having filters in HVAC systems, relative to having no filters, will substantially decrease the portion of disease transmission caused by these small particles (Azimi and Stephens 2013).”

Item 1: Aerosols Document

“Dilution and extraction ventilation, pressurization, airflow distribution and optimization, mechanical filtration, ultraviolet germicidal irradiation (UVGI), and humidity control are effective strategies for reducing the risk of dissemination of infectious aerosols in buildings and transportation environments. Ventilation, filtration, and air distribution systems and disinfection technologies have the potential to limit airborne pathogen transmission through the air and thus break the chain of infection.”

Item 3.1 Aerosols Document - Varying Approaches for Facility Type

*“Healthcare facilities have criteria for ventilation design to mitigate airborne transmission of infectious diseases (ASHRAE 2013, 2017a, 2019a; FGI 2010); however, infections are also transmitted in ordinary occupancies in the community and not only in healthcare or **industrial occupancies**.*”*

Air Ventilation, Filtration and Purification

The document on Filtration and Air Cleaning, in its Abstract, brings an important information:

*“One key statement is that, at present, **there is only significant evidence of health benefits for porous media particle filtration systems**. For a few other technologies, there is evidence to suggest health benefits, but this evidence is not sufficient to formulate firm conclusions. Finally, it is stated that there are limited data documenting the effectiveness of gas-phase air cleaning as an alternative to ventilation.”*

* Commentator emphasis.

Understanding this affirmation is vital for all involved with air ventilation, filtration and purification projects. We can assert from this affirmation that whatever the filtration and air purification method is chosen, it must contain a physical filtration media, i.e., a mechanic filter.

The publication also mentions the wide variety of alternatives available in the market for air filtration and purification and brings an interesting summary of the main ones. The document says:

"Evaluation and guidance are also needed because of the increasing number and variety of filtration and air-cleaning alternatives available on the market and because filtration and air cleaning are considered attractive alternatives to outdoor air ventilation by providing exposure control with less energy use.
Various filtration and air-cleaning technologies are available, depending on the type of contaminants removed and the principle of contaminant removal."

Following the document, another remarkably interesting exposition about the main technologies available for this application is presented:

Item 1.1 – Mechanical and Electronic Air Filters

"2.1.1 Principles of Efficiency and Use.

Mechanical filters use media with porous structures that contain fibers or stretched membrane material in a variety of fiber sizes, densities, and media extension configurations to remove particles from airstreams. A portion of the particles in the air entering a filter attaches to the media and is removed from the air as it passes through the filter. Removal occurs primarily through particle impaction, interception, and Brownian motion/diffusion, depending on particle size. Some filters have a static electrical charge applied to the media to increase particle removal.

Electronic filters include a wide variety of electrically connected air-cleaning devices that are designed to remove particles from airstreams. Removal typically occurs by electrically charging the particles using corona wires or through generation of ions (e.g., using pin ionizers) and by collecting the particles on oppositely charged deposition plates (precipitators) or by the particles' enhanced removal to a conventional media filter or to room surfaces.

For most technologies, the lowest particle removal efficiency typically occurs for particles with an aerodynamic diameter of approximately 0.2 or 0.3 µm; the removal efficiency increases above and below this particle size. The efficiency of mechanical and electronic air filters varies with filter design and particle size. The efficiency of electronic air cleaners also depends on how they are maintained.

Recirculation of indoor air through filters and refiltering blended outdoor air with return air are particularly effective for maximizing filter system effectiveness*. *Filtering the incoming outdoor air before this air enters the occupied space is effective in reducing indoor air concentrations of outdoor air particles, especially in airtight buildings."*

Mechanical filters comprehend a large variety of equipment with different types of filter medias in a number of steps. For Air Filtration and Purification, it is necessary that the filtration grade reaches the equivalent to an HEPA filter, commonly known as "Absolute Filter", normally commercialized under the following specifications:

* Commentator emphasis.

Filtration Efficiency > 99,95%, according to Regulation ABNT NBR 16101 (EN 1822).

A particularly important observation is necessary here. The filtration efficiency of the cartridge or filter media used in air ventilation, filtration and purification equipment do not necessarily define the equipment efficiency as the construction characteristics may affect its performance. Therefore, it is especially important that this kind of equipment are thoroughly tested in a way that its efficiency is assured as a complete set and not only the filter medias.

Electronic filters are more commonly known as "Electrostatic Filters" and its characteristics and limitations are well known in other applications as they are rarely used for ambient air filtration and purification. The main advantage of electrostatic filters is that they do not require cartridge filters and do not demand periodic replacement, thus reducing operation costs. On the other hand, its efficiency varies a lot along the time from the beginning of operations, with clean electrostatic cells, until when the cells are cleaned. They also require a lot of maintenance as the cells must be frequently cleaned and its handling must be careful.

Item 2.2 – Sorbent Air Cleaners

"2.2.1 Principles Efficiency, and Use.

Sorbent air cleaners involve physical adsorption (physisorption) and chemisorption to remove gaseous contaminants from airstreams. Physisorption is adsorption of gaseous contaminants onto solid porous materials due to Van derWaals forces (nuclear attraction) and condensation in the small pores.

Adsorbent-based systems can remove a broad range of contaminants with moderate to high efficiency. The net rate of adsorption depends on the rate at which contaminant molecules reach the surface of the media, the percentage of those making contact, which are adsorbed, and the rate of desorption.

Some evidence is available on the long-term performance of sorbents in commercial buildings in studies that have examined the performance and effectiveness of air-cleaning systems that have been in continuous use for up to 30 years (Bayer et al. 2009; Lamping and Muller 2009; Burroughs et al. 2013). Actual sorbent life may be determined by taking periodic samples for life testing or through direct contaminant monitoring.

More often, though, sorbents are replaced based on routine maintenance cycles or fiscal considerations*[*]*.

***At present, almost no empirical data are available to enable drawing conclusions about the health benefits of using sorbents in typical buildings*[*]*.** There are, on the other hand, data from laboratory studies that investigated the effects of sorbent air cleaning on initial perceptions of air quality immediately upon entering a laboratory or upon smelling air drawn from a test system.*

***These studies showed significantly improved ratings of acceptability or satisfaction with air quality and odor intensities with sorbents**. Although perception of air quality comfort is not a health outcome, it may be considered an indicator of a potential subsequent effects of exposures on health."*

In practical terms, in most situations, when we talk about absorbent filters, we are talking about Activated Carbon. This substance presents absorbent properties that are largely known and used in different fields, including air filtration. It is frequently used to reduce odours, what is in line with what the text above states.

[*] Commentator emphasis.

Another typical characteristic of those filters is the difficulty to control the saturation level of the cartridge and the frequent excessive use, compromising its performance and the filtration results. This is also clearly stated in the ASHRAE text.

Finally, considering the lack of evidence of health benefits – that, by the way, does not apply only to this type of filter – added to operational difficulties (maintenance and high cost of replacement), its utilization is recommended only when the objective is clearly to reduce odours in the environment. Under no circumstances an absorbent filter should be used to reduce particle concentrations (solid or liquid) in the air.

2.3 – Air Cleaners Using Photocatalytic Oxidation

*"**Principles Efficiency and Use.***

Photocatalytic oxidation (PCO) is defined as a light mediated, redox reaction of gases and biological particles adsorbed on the surface of a solid pure or doped metal oxide semiconductor material or photocatalyst. The photocatalyst generates oxygen species (or reactive oxygen species [ROS]) that remain surface-bound when exposed to light of particular wavelengths in the ultraviolet (UV) range.

*The advantages of PCO are the relatively low pressure drop, ability to treat a wide variety of compounds, and theoretically long-life cycle of the reactive process (the self-cleaning or regenerating feature of a photocatalyst). The disadvantages include the lamp energy, lamp replacement costs, and the **likelihood of ozone generation*** depending on lamp source employed (e.g. UV-V lamps ~185 nm produces ozone (O_3).*

There is also the 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). The catalysts can be contaminated (poisoned) by airborne reagents and/or products of oxidation, which results in reduced or total efficiency failure of the process.

No studies are available with respect to the direct health effects associated with the use of PCO air-cleaning equipment in indoor environments. Some studies looked at the effects of PCO on perceived air quality, which, as mentioned above, may be considered as an indicator of potential subsequent effects of exposures on health."

This technology is rarely used in Brazil, especially for Indoor Air Filtration and Purification. The costs limitations and the complexity to control and monitor added to the risk of generating Ozone and other dangerous contaminants, definitively do not put it in the list of most attractive options for the application we are considering in this article.

2.4 - Air Cleaners Using Ultraviolet Germicidal Energy (UV-C)

"*Principles of Efficiency and Use.*
Ultraviolet (UV-C) disinfection (also called ultraviolet germicidal irradiation [UVGI]) is used to degrade organic material and inactivate microorganisms. The system is not a filter; thus, inactive particles remain in the airstream, which, in the case of dead fungal spores, may still cause a negative human response to their integral mycotoxins. The most effective wavelength range for inactivation of microorganisms is between 220 and 300 nm, with peak effectiveness near 265 nm. UV-C systems may be installed inside HVAC systems, irradiate air near the ceiling, or be incorporated in a stand-alone (portable) air cleaner. The effectiveness of a UV-C system to inactivate microorganisms in the air and/or on surfaces has been amply demonstrated;…

* Commentator emphasis.

Experience suggests that control of a moving airstream does not provide favourable killing rates because of the short dwell time. Under ideal conditions, inactivation and/or killing rates of 90% or higher can be achieved but depend on the following: the type of microbial contaminant; specific species; physical or mechanical factors such as UV-C intensity, exposure/dwell time, lamp distance and placement, and lamp life cycle and cleanliness; Airborne removal is best applied in conjunction with filtration of particles with prefiltration in order to protect lamps and mechanical filtration downstream for microbial particles.

Several studies have addressed the application of UV-C systems in health-care facilities. Some of these studies show health benefits for highly susceptible patients (Miller et al. 2002; CDC/NIOSH 2009; Memarzadeh et al. 2010). ***However, there is limited evidence on the direct effects of UV-C on health, particularly when applied outside of health-care settings*.*** *Upper-room air UV-C systems applied in studies in schools, military barracks, and homeless shelters provide inconsistent effects on tuberculosis, measles, influenza, and common colds (Kowalski 2009).*

In the laboratory studies, UV-C has been effective in removing bacterial aerosols and viral aerosols (Xu et al. 2003).To this end, UV-C for upper air, in-duct, and in-room systems was named by ASHRAE's 2014 Position Document on Airborne Infectious Diseases…"

This is a polemic issue even for ASHRAE membership. Note that the above text, extracted from the document Position on Filtration and Air Cleaning, is contradictory, to a certain point, with the content of the document about Aerosols, as shown in its item 3.2:

"While ASHRAE Position Document on Filtration and Air Cleaning (2018) does not make a recommendation for or against the use of UV energy in air systems for minimizing the risks from infectious aerosols, Centers for Disease Control and Prevention (CDC) has approved UVGI as an adjunct to filtration for reduction of tuberculosis risk and has published a guideline on its application (CDC 2005, 2009) - (Evidence Level A)."

To better analyse this apparent contradiction, it is important to add to this article some parts of the document on Aerosols (ASHRAE Position Document on Infectious Aerosols) that address the subject:

*"**Abstract***
Chief among these ventilation-related strategies are dilution, airflow patterns, pressurization, temperature and humidity distribution and control, ***filtration*****, and other strategies such as* ***ultraviolet***** germicidal irradiation (UVGI)."*

1. "The issue
Dilution and extraction ventilation, pressurization, airflow distribution and optimization, ***mechanical filtration, ultraviolet germicidal irradiation (UVGI)*** **, and humidity control are effective strategies for reducing the risk of dissemination of infectious aerosols in buildings and transportation environments.."*

"3.2 – Ventilation and Air-Cleaning Strategies
The entire ultraviolet (UV) spectrum can kill or inactivate microorganisms, but UV-C energy (in the wavelengths from 200 to 280 nm) provides the most germicidal effect, with 265 nm being the optimum wavelength. The majority of modern UVGI lamps create UV-C energy at a nearoptimum 254 nm wavelength. UVGI inactivates microorganisms by damaging the structure of nucleic acids and proteins with the effectiveness dependent upon the UV dose and the susceptibility of the microorganism. The safety of UV-C is well known."

* Commentator emphasis.

The contradiction that arises from simple reading the above items and its comparison with the Filtration and Air Cleaning Document is, in our point of view, solved by the final part of the Aerosols Document (4.1 below) that makes it clear that ASHRAE position on UVGI application refers to "rooms", meaning that, according to our interpretation, it is regarding environment for health care treatments.

*"**4.1 ASHRAE's Positions***
Based on risk assessments, the use of specific HVAC strategies supported by the evidence-based literature should be considered, including the following:
*- Upper-room UVGI (**with possible in-room fans**)* as a supplement to supply airflow (Evidence Level A)"*

The contradiction seems finally overcome when we compare this text with part of the Filtration and Air Cleaning Document already stated above:

"Several studies have addressed the application of UV-C systems in health-care facilities. Some of these studies show health benefits for highly susceptible patients (Miller et al. 2002; CDC/NIOSH 2009; Memarzadeh et al. 2010).
***However, there is limited evidence on the direct effects of UV-C on health, particularly when applied outside of health-care settings*.**"*

The conclusion, thus, becomes simple: the application of UVGI techniques for Air Filtration and Purification in non-health care environments is not among ASHRAE recommendations in the documents here analysed.

2.5 - Packaged Air Cleaners Using Multiple Technologies

"Many air-cleaning devices use a combination of filters (i.e., particle air-cleaning Technologies and gas-phase air-cleaning technologies). The devices are often stand-alone (portable), incorporate a fan, and are intended for residential use. These devices are frequently called air purifiers or clean-air delivery (CAD) devices, but many other names are used as well.

Presently, minimal data are available on the health consequences of using packaged air cleaners employing multiple technologies."

The conclusion here is simple. These domestic devices do not have the minimum capacity to address industrial or commercial environments: they are neither specified nor tested for that. Therefore, they should not be considered for these applications.

2.6 - Ozone-Generating Air-Cleaning Devices

"Certain air cleaners produce ozone by design to achieve air-cleaning effects and the removal of contaminants. Additionally, ozone can be produced as a by-product of air-cleaning processes. Any air-cleaning device that uses electricity during air cleaning process has the potential to generate ozone. In practice, ozone generation is associated with air cleaners that use high-voltage coronas or pin ionizers (e.g., some precipitators or ionizers), UV light of a sufficiently small wavelength (some photocatalytic oxidizers and UV-C air cleaners), and by some plasma air cleaners.

* Commentator emphasis.

Packaged air cleaners employing different air-cleaning technologies may use or produce ozone; examples include ozone generators or ionizers. Ozone is harmful for health and exposure to ozone creates risk for a variety of symptoms and diseases associated with the respiratory tract (Koren et al. 1989; Touloumi et al. 1997; Bell et al. 2004).

Many products of ozone homogeneous and heterogeneous reaction processes also create risks for health, including formaldehyde, unsaturated aldehydes (produced during the reaction of ozone with ketones and alcohols), and ultrafine particles (secondary organic aerosols) (Weschler 2006). Ozone emission is thus undesirable.

The current state of the science regarding the health effects of ozone strongly suggests that the use of air cleaners that emit ozone by design should not be permitted; the same information and advice is given by the U.S. EPA, among others (EPA 2013).

In the absence of robust information regarding safe levels of ozone, the precautionary principle should be used. Any ozone emission (beyond a trivial amount that any electrical device can emit) should be seen as a negative and use of an ozone-emitting air cleaner, even though the ozone is an unintentional by-product of operation, may represent a net negative impact on indoor air quality and thus should be used with caution. If possible, non-ozone-emitting alternatives should be used."

This topic from the Air Filtration and Purification document is quite straight. Referring to the largely proved Ozone toxicity and also to the EPA regulations (American Environmental Protection Agency), the text vetoes the use of filters based on Ozone and strongly adverts against the use of systems that can generate Ozone like, for example, system based on ultraviolet light.

Therefore, it is extremely prudent to carefully evaluate the risks of using processes that use UV and its potential to contaminate the environment.

Systems with direct generation of Ozone for Air Filtration and Purification are strictly vetoed.

2.7 - Filtration and Air Cleaning Versus Ventilation

"Filtration and air cleaning reduce exposures to selected air contaminants generated indoors, similar to outdoor air ventilation. Unlike ventilation, these methods can also reduce exposures to contaminants in outdoor air. The effectiveness of filtration and air cleaning is frequently expressed as the equivalent rate of outdoor air ventilation intake flow that would have to be provided to achieve the same effect.

However, unlike outdoor air ventilation (essentially reducing concentrations and exposure to the majority of indoor-generated contaminants), filters and air cleaners (unless integrated) deal with one group of contaminants: either with particles, some types of gases, or microbial contaminants. The effectiveness is consequently the removal efficiency for a single contaminant, a class of contaminants, or a mixture of contaminants (Zhang et al. 2011).

Furthermore, the cost and energy implications must be taken into account when comparing the effect obtained by filtration and air cleaning with outdoor air ventilation*.

* Commentator emphasis.

One consideration that warrants discussion is that the overlap between contaminants with indoor sources versus those with external (outdoor) sources is relatively small and the use of increased ventilation air without filtration and air cleaning can result in substituting one set of contaminants (internally generated) with a different set (externally generated) with any associated health effects.

This is especially important in regions that do not meet national or regional air quality standards for one or more criteria pollutants (i.e., ozone, PM10, PM2.5) or where there may be local sources of air pollution. In these instances, outdoor ventilation air should be cleaned before being introduced into the building."

Although the balance between advantages and disadvantages of external air ventilation must be carefully analysed by the technical body responsible for the environmental governance in the company and a number of factors must be taken in consideration, the intake of duly filtered external air is essential in many cases despite of the air purification method used. That is what can be directly interpreted form this specific and important topic of the ASHRAE document.

We can point out on the other hand, the energy question (loss of climatization energy), added power consumption of the air purifiers, type of internal and external pollutants, among others, as stated above. In any case however a good association of Ventilation, Filtration and Purification systems with efficient air recirculation brings the best results in terms of balance between IAQ (Indoor Air Quality) and energy consumption.

2.8 - Maintenance, Commissioning, and Long-Term Performance of Filtration and Air-Cleaning Devices

"At the design phase, filters and air cleaners are generally assumed to be installed and operating correctly. In actual installations, there could be air and contaminant bypass around air cleaning devices (Ward and Siegel 2005), degradation in the performance of some technologies over time (Lehtimäki et al. 2002), and potential for the emission of primary and/or secondary by-products (Zhao et al. 2007; Rim et al. 2013).

Commissioning, active maintenance, and monitoring of filtration and air-cleaning devices are needed to ensure design performance."

It is difficult to assert that the correct commissioning and maintenance of Air Ventilation and Filtration are fundamental as it applies to any equipment and systems. The question is that in the case of Ventilation and Filtration, in most cases, the equipment or system can continue operating without manifesting problems when, in reality, is contaminating the air instead of filtering or purifying it.

The best way to maintain air ventilation, filtration and purification equipment and systems and assure its performance is to strictly follow the manufacturer recommendations, establishing maintenance routines that guarantees the operation within the necessary requirements.

Equipment with modern monitoring resources, including remote real time monitoring, should have preference when selecting solutions for demanding applications.

Executive Summary

The Executive Summary of the Filtration and Air Cleaning Document offers a quite interesting summary about the different filtration technologies presented above:

"Based on the accumulated information, statements on the effectiveness and use of different technologies are proposed and are briefly summarized as follows:

• Mechanical filters have been shown to reduce significantly indoor concentrations of airborne particles. Modest empirical evidence shows that their use will have positive effects on health.

• Electronic filters have been shown to range from being relatively ineffective to very effective at removing indoor airborne particles. Studies of ionizers have shown results ranging from no benefit to some benefit for acute health symptoms.

• There are some sorbent air cleaners that have been shown to substantially reduce the concentrations of gaseous contaminants. There are minimal empirical data that indicate the effects of sorbent air cleaners on health.

• Ultraviolet germicidal energy (UV-C) has been shown to inactivate viruses, bacteria, and fungi. A few studies have shown that air-cleaning technologies using UV-C disinfection (also termed ultraviolet germicidal irradiation [UVGI]) produce beneficial health effects. There are also studies that have failed to detect health benefits.

• 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."

Conclusions and Recommendations

To start with let us see the conclusions and recommendations from the Aerosols Document:

"Infectious aerosols can be disseminated through buildings by pathways that include air distribution systems and interzone airflows. Various strategies have been found to be effective at controlling transmission, including optimized airflow patterns, directional airflow, zone pressurization, dilution ventilation, ***in-room air-cleaning systems****[*], *general exhaust ventilation, personalized ventilation, local exhaust ventilation at the source, central system filtration, UVGI, and controlling indoor temperature and relative humidity.*

Design engineers can make an essential contribution to reducing infectious aerosol transmission through the application of these strategies. Research on the role of airborne dissemination and resuspension from surfaces in pathogen transmission is rapidly evolving. Managing indoor air to control distribution of infectious aerosols is an effective intervention which adds another strategy to medical treatments and behavioural interventions in disease prevention."

[*] Commentator emphasis.

Conclusions and Recommendations from the Filtration and Air Cleaning Document brings a more detailed analysis in this respect, as follows:

"3.1- Summary Statements on Performance of Filtration and Air-Cleaning Devices

The following statements on filtration and air cleaning are proposed taking into account the evidence in the literature on their effects on health outcomes in public and residential buildings (excluding health-care facilities which were briefly summarized in the preceding chapters). Finally, the statements do not take any position on whether certain types of filtration and air-cleaning technologies should or should not be used in the built environment and under which conditions (except the position on ozone-generating devices and the long-term performance of filtration and air-cleaning devices);…

Filtration technologies, in which particles are removed by attaching them to the media (often called mechanical or media filters), have been documented to be capable in many cases of reducing particle concentrations substantially, … Modest empirical evidence suggests that mechanical filters will have positive effects on health,… Models predict large reductions in morbidity and mortality associated with reduction of indoor exposures to particles from outdoor air, but these health benefits have not been verified empirically*.

Filtration technologies that generate electrical fields and/or ions, often called electronic filters, ***have been documented to range from relatively ineffective to very effective in reducing particles substantially**** *,… Within this broad characterization of air cleaners, ionizers have been evaluated to either show benefits or no benefits for acute health symptoms.* ***Many electronic air cleaners emit significant ozone**** *and are subject to special attention.*

There are sorbent air cleaners that have been documented to ***reduce concentrations of harmful gaseous contaminants substantially**** *, … There are very limited data on long-term effectiveness of these air cleaners for indoor air applications with mixtures of contaminants at low concentrations.* ***Minimal empirical data exist on the health effects of using sorbent-based air-cleaning technologies*.***

Air cleaners using photocatalytic oxidation (PCO) have been documented ***to remove harmful contaminants to levels being below the associated regulatory exposure limits**** *… No empirical data exist on the health effects of using PCO technologies. Different UV lamps used in* ***many PCO devices can emit significant ozone**** *and are thus subject to special attention as advised by Position 1 in Section 3.2.*

Short-wave ultraviolet (UV-C) energy has been documented to inactivate viruses, bacteria, and fungi* *. Some air-cleaning technologies using UV-C disinfection (also termed ultraviolet germicidal irradiation [UVGI]) have been documented, in a few studies, to show beneficial health effects when upper-room air, ventilation ducts, and evaporator coil surfaces were irradiated with UV-C.* ***Some studies have failed to detect health benefits. Some UV lamps can emit significant ozone**** *and are thus subject to special attention as advised by Position 1 in Section 3.2.*

Packaged air cleaners using multiple filtration and air-cleaning technologies are room air appliances ***intended for residential and small-space application**** *. Their performance is subject to the advantages and disadvantages of the filtration and air-cleaning technology incorporated within the devices. Scientific documentation of the health effects of these devices on occupants is sparse and inconclusive.* ***Some of the technologies incorporated into these devices either produce or rely on ozone**** *for application and are thus subject to special attention as advised by Position 1 in Section 3.2.*

* Commentator emphasis.

Filtration and air-cleaning technologies are often regarded as an attractive alternative to ventilation, enabling a reduction of outdoor air ventilation rate *. The Indoor Air Quality (IAQ) Procedure of ASHRAE Standard 62.1 allows lower ventilation rates if alternative methods are used to reduce exposures to contaminants of concern, including the use of filtration or air cleaning.*

3.2 - Positions on the Use of Filtration and Air-Cleaning Devices

1. Devices that use the reactivity of ozone for the purpose of cleaning the air should not be used in occupied spaces because of negative health effects that arise from exposure to ozone and its reaction products. Extreme caution is warranted when using devices that emit a significant amount of ozone as by-product of their operation, rather than as a method of air cleaning. These devices pose a potential risk to health*.

***2.** All filtration and air-cleaning technologies should be accompanied by data documenting their performance regarding removal of contaminants; these data should be based on established industry test standards. If not available, scientifically controlled third-party evaluation and documentation should be provided."*

Finally, to conclude our work in this article, let us consider the final part of Aerosols Document to extract what interest us: what applies to Air Filtration and Purification in production environments:

4.1 ASHRAE Positions

• Mitigation of infectious aerosol dissemination should be a consideration in the design of all facilities, and in those identified as high-risk facilities the appropriate mitigation design should be incorporated.

• Based on risk assessments, buildings and transportation vehicles should consider designs that promote cleaner airflow patterns for providing effective flow paths for airborne particulates to exit spaces to less clean zones and use appropriate air-cleaning systems. (Evidence Level A)

• Based on risk assessments, the use of specific HVAC strategies supported by the evidence-based literature should be considered, including the following:

*- **Enhanced filtration*** *(higher minimum efficiency reporting value [MERV] filters over code minimums **in occupant-dense*** *and/or higher-risk spaces) (Evidence Level A);*

*- Upper-room UVGI (**with possible in-room fans**)* as a supplement to supply airflow (Evidence Level A);*

*- **Portable, free-standing high-efficiency particulate air (HEPA) filters*** *(Evidence Level B).*

*• **Non-healthcare buildings*** should have a plan for an emergency response. The following modifications to building HVAC system operation should be considered:*

- Improve central air and other HVAC filtration to MERV-13 *(ASHRAE 2017b) or the highest level achievable.*

- Keep systems running longer hours (24/7 if possible)*.

- Add portable room air cleaners with HEPA *or high-MERV filters with due consideration to the clean air delivery rate (AHAM 2015).*

- Add duct- or air-handling-unit-mounted*, upper room, **and/or portable UVGI devices in connection to in-room fans in high-density spaces.***

* Commentator emphasis.

Article Conclusion

The texts from “ASHRAE Position Document on Filtration and Air Cleaning” and “ASHRAE Position Document on Infectious Aerosols” clearly define the recommendation of using air filtration and purification systems in diverse environments, not only for health care but also for commercial and industrial facilities. This requirement must be a focus of attention from responsible designers and managers.

The only air filtration media with clear evidence, although limited, of positive impact on health are the porous media, i.e., the Mechanic Filter. To retain particles, including biologic agents, these filters must have high filtration grade, such as HEPA.

Other filtration technologies do not have conclusive evidence about the positive impact on health yet, and many of them can generate dangerous by-products that contaminate the air like the Ozone generated by ultraviolet light, for example. The use of Ozone generator for direct purification is vetoed according to the publications.

The use of absorbents filters, normally equipped with activated carbon media, can be justified for filtration and purification system only when there is a presence of gas in the environment, especially the ones that cause unpleasant odours. Although there is no evidence of its positive impact on health, there is evidence that it brings a feeling of improved indoor air quality. The decision about its use should consider clear criteria for the filter cartridge replacement: as there are no practical means to control the saturation, the replacement must be dully scheduled in time. This must be taken in consideration when evaluating the ownership cost of the purifying systems.

There is an apparent contradiction between the two documents regarding the use of UVGI to purify the environment. According to the interpretation presented in this article, it can be explained by the fact that the text regarding Aerosols refers mainly to applications in health care environments.

Finally, the documents show the possibility of energy savings and improved indoor air quality with the use of Air Filtration and Purification systems with the recirculation of internal air, reducing significantly but not exempting the external air admission.

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