ASHRAE Position Document on Filtration and Air Cleaning

Approved by ASHRAE Board of Directors
January 29, 2015

Reaffirmed by Technology Council
January 13, 2018

Expires January 23,
2021

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COMMITTEE ROSTER

The ASHRAE Position Document on Filtration and Air Cleaning was developed by the Society's Filtration and Air Cleaning Position Document Committee formed on January 6, 2012, with Pawel Wargocki as its chair.

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HISTORY OF REVISION/REAFFIRMATION/WITHDRAWAL DATES

The following summarizes this document's revision, reaffirmation, or withdrawal dates:

01/29/2015—BOD approves Position Document titled Filtration and Air Cleaning

01/23/2018 - Technology Council approves reaffirmation of Filtration and Air Cleaning position document

Note: ASHRAE's Technology Council and the cognizant committee recommend revision, reaffirmation, or withdrawal every 30 months.

Note: ASHRAE position documents are approved by the Board of Directors and express the views of the Society on a specific issue. The purpose of these documents is to provide objective, authoritative background information to persons interested in issues within ASHRAE's expertise, particularly in areas where such information will be helpful in drafting sound public policy. A related purpose is also to serve as an educational tool clarifying ASHRAE's position for its members and professionals, in general, advancing the arts and sciences of HVAC&R.

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ABSTRACT

Filtration and air cleaning are used to improve indoor air quality and occasionally to enable a reduction in rates of outdoor air ventilation. This Position Document addresses the health consequences of filtration and air cleaning. Data from refereed archival literature are used to form summary statements on performance as well as the positions with respect to specific technologies. 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. A key position is that filtration and air-cleaning technologies are not recommended for use if they produce significant amounts of contaminants that are known or expected to be harmful for health. Finally, it is stated that there are limited data documenting the effectiveness of gas-phase air cleaning as an alternative to ventilation. ASHRAE should continue supporting research and standardization of contemporary filtration and air-cleaning technologies and should focus on performance testing, maintenance procedures, and development of new innovative technologies.

EXECUTIVE SUMMARY

ASHRAE needs to address heating-, ventilation-, and air-conditioning- (HVAC) related technologies that change exposures to airborne contaminants harmful for humans. As part of ASHRAE's mission, it is imperative to assess the effectiveness of HVAC technologies in reducing exposures so that the risks for harmful effects on health and comfort are minimized and to establish and promote the Society's positions that will guide ASHRAE membership and the public in technology selection and use. This need applies to filtration and air-cleaning technologies because they traditionally are part of the HVAC system, their use is included and/or required in many guidelines and ventilation standards published by ASHRAE, and they are addressed by technical committees within ASHRAE. 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. This Position Document briefly characterizes these technologies and their applications. The focus is to summarize and examine the existing archival literature describing the direct effects of application of these technologies in public and residential buildings (excluding health-care facilities) on the health of building occupants. 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.
- Photocatalytic oxidation technologies have been shown to remove harmful contaminants, to be ineffective in removing contaminants, and/or to generate harmful contaminants during the air-cleaning process. There are no data on how their use affects 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.
- Many types of packaged stand-alone air cleaners using combinations of air-cleaning technologies are available. Scientific data addressing the effects of these air cleaners on health are sparse and inconclusive.
- 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.

- There has been much research done on ventilation providing the solution to contamination by dilution, while the body of research on using air cleaning as an effective, energy-saving alternative to ventilation has not been equally large, especially as regards gas-phase air cleaning. Still it should be noted that the information on the effective use of air cleaning as an alternative to ventilation is growing. Limited data exist documenting the effectiveness of air cleaning as an alternative to ventilation. This applies in particular to gas-phase air cleaning. All filtration and air-cleaning technologies should be accompanied by data documenting their performance in removal of contaminants. These data should be based on established industry test standards or third-party evaluations.

The Position Document advocates that ASHRAE lead efforts in research and standardization of filtration and air cleaning. First priority should be given to advancing methods for testing performance of filtration and air-cleaning technologies, in particular the emerging technologies. Second priority should be given to maintenance procedures of filtration and air-cleaning technologies.

1. THE ISSUE

1.1 Justification of Need

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.

Abundant published data show the effectiveness of different filtration and air-cleaning technologies in removing contaminants from indoors and outdoors. However, few studies document the direct effects of these technologies on health and their long-term performance, as well as their potential limitations and shortcomings. A recent comprehensive review (Zhang et al., 2011) reaffirms these observations.

1.2 Purpose and Scope

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. The air-cleaning effects of plants and new air-cleaning technologies, for which there is very limited scientific and technical literature, are not considered.

The archival studies are reviewed to examine measurable health effects associated with the application of various filtration and air-cleaning technologies in public and residential buildings (excluding health-care facilities) and the extent to which cleaning and filtration technologies can offset ventilation with outdoor air for acceptable indoor air quality.

This document also describes the role and health implications of optimal use of air cleaners and the maintenance and replacement of air-cleaning media. The health issues related to disposal of filters and the elements of air cleaners are not considered.

Packaged stand-alone air cleaners using one or multiple technologies and air-cleaning and filtration systems integrated in the ventilation systems are considered as well as technologies available to and used by commercial or residential consumers.

2. BACKGROUND

2.1 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.

The fraction of particles removed from air passing through the filter is termed *particle removal efficiency* or simply *filter efficiency* or *single-pass filter efficiency* (e.g., provided by the minimum efficiency reporting value [MERV]). For electronic filters that are portable and self-contained, the rate of particle removal from air passing through the filter is expressed as clean air delivery rate (CADR), which is approximately equal to the product of airflow rate and the contaminant removal efficiency. 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.

The overall effectiveness of reducing indoor particle concentrations depends on several factors that are either related or independent of a filtration system such as the following: single-pass particle removal efficiency of the filter, the rate of airflow through the filter, location of the filter, and size of the particles. The latter include outdoor air ventilation rate, rate of deposition to surfaces, and total volume of the indoor space and related air change rate, particularly important for stand-alone (portable) air cleaners (see Section 2.5). 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.

ANSI/ASHRAE Standard 52.2, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size* (2012a), provides a method of measuring the particle removal efficiency of particle filters for particles that range in size from 0.3 to 10 μm and provides a scale for ranking filters, based on their particle removal efficiencies, called MERV; similar test methods and ranking scales are also available from other organizations. *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commis-*

sioning (2009a) and Chapter 29 in the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* (2012b) and provide additional information on particle filtration technologies and test methods.

2.1.2 Evidence on Health Effects. 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.

Many studies have experimentally investigated whether the use of particle filtration systems in homes reduces self-reported symptoms of allergies or asthma or improves related objectively measured health outcomes such as forced expiratory volume or biomarkers of inflammation in people who are allergic or asthmatic. Most of these studies used stand-alone (portable) fan filter systems incorporating high-efficiency particle air (HEPA) filters that can remove particles with a minimum efficiency of 99.97% for 0.3 μm particles. 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 of the studies used mechanical filters. A recent review on the effects of air filtration (Fisk 2013) considered the recently published literature and the results of prior reviews (IOM 2000; Reisman 2001; McDonald et al. 2002; Wood 2002; Sublett et al. 2010; Sublett 2011). It concluded that particle filtration could be modestly effective in reducing adverse allergy and asthma outcomes, particularly in homes with pets. It also concluded that particle filtration systems that deliver filtered air to the breathing zone of sleeping allergic or asthmatic persons might be more consistently effective in improving health than use of room or whole-house filtration systems. The review additionally concluded that the limited available evidence suggests that particle filtration in buildings (homes, offices and schools) is not very effective in reducing acute health symptoms (SBS symptoms) in persons without asthma and allergies.

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. The portion of total disease transmission that occurs via this mechanism is uncertain and debatable. Particle filtration systems can reduce indoor airborne concentrations of these particles by removing them from the airstream but not by inactivating infectious species. 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 modeling 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). However, the model assumptions and inputs have a high level of uncertainty. In addition, experimental data outside of health-care facilities are not available to confirm the predictions; there are no strong studies empirically documenting that filtration reduces respiratory infections in people outside of a health-care environment with highly susceptible patients.

The data on the health consequences of electronic particle air cleaners are sparse, but it is reasonable to expect that electronic air cleaners affect health similarly to mechanical filters of equivalent particle removal performance. There are electronic air cleaners (e.g., ion generators) that produce ozone and thus may cause deleterious health effects, as described in Section 2.6, Ozone-Generating Devices. One class of particle air cleaners, ion generators, has been investigated for its ability to reduce acute health symptoms (SBS symptoms), but the literature is unclear as regards the presence and size of effects on symptoms. Of the eight studies on the subject, there are an approximately equivalent number of findings of a positive effect and of no significant effect (or a negative effect) on one or more SBS symptoms (Hawkins and Barker 1978; Fishman 1981; Laws 1982; Hawkins and Morris 1984; Wyon 1992; Shaughnessy et al. 1994; Rosen and Richardson 1999; Richardson et al. 2001). Variations in sample size, presence or lack of a placebo, and presence of a control group make it difficult to form conclusions that are more definitive.

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 der Waals forces (nuclear attraction) and condensation in the small pores. This is a reversible process due to relatively weak forces: gases once adsorbed can later desorb back into the airstream. The most common adsorbent used is activated carbon; others include activated aluminas (aluminum oxides), natural and synthetic zeolites in granular form, oxides of silicon, molecular sieves, and various polymers. Chemisorption involves both adsorption and instantaneous irreversible chemical reactions on the sorbent surface to which specific chemical additives or impregnates are added during the manufacturing process to make them more or less specific for individual contaminants or contaminant types (e.g., acid gases). Common adsorbents include activated alumina impregnated with potassium or sodium permanganate and activated carbons impregnated with acidic or basic compounds. Desorption of target contaminants, once adsorbed and chemically reacted, does not occur.

An air-cleaning system using a single gas-phase (or dry-scrubbing) air-filtration medium may not be adequate for the control of multiple contaminants (Muller and England 1994, 1995). Thus, it is common to have a system that uses a combination of both physical and chemisorptive media to provide removal of a wide range of gaseous contaminants.

Adsorbent materials do not adsorb all contaminants equally. The adsorption capacity for nonpolar organics increases with the boiling point, molecular weight, and concentration of the air contaminant. Low molecular weight (less than 50 u [previously termed amu]) and/or highly polar compounds such as formaldehyde, methane, ethanol, etc., will not be readily adsorbed at low concentrations. Compounds with molecular weight >80 u and nonpolar compounds may be preferentially adsorbed over lower molecular weight and polar compounds. In physical adsorption, polar gas molecules are best removed by polar adsorbents, while nonpolar adsorbents are best for removing nonpolar gases (e.g., activated carbon has a nonpolar surface). The initially adsorbed compounds with lower molecular weight and nonpolar compounds may also be desorbed when a higher molecular weight and polar compounds are present through competitive adsorption. A sufficient depth of sorbent bed may re-adsorb some displaced molecules.

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). Relatively accurate estimates of sorbent lifetimes can be obtained when target contaminants are identified and by using their known or expected concentrations in air and the individual removal capacities for each (Muller 2012). 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. Although there exist physisorbents that may be regenerated, this is not economically viable for the amounts typically contained in commercial HVAC systems and portable air cleaners; thus, they need to be periodically replaced.

Other details regarding removal of gaseous air contaminants can be found in *ASHRAE Handbook—HVAC Applications*, Chapter 45, Control of Gaseous Indoor Air Contaminants (2011) and in *ASHRAE Handbook—Fundamentals*, Chapter 11, Air Contaminants (2013a).

2.2.2 Evidence on Health Effects. At present, almost no empirical data are available to enable drawing conclusions about the health benefits of using sorbents in typical buildings, other than anecdotal data describing ancillary benefits of air cleaning on elementary school studies and human embryos (Cohen et al. 1997; Hall et al. 1998; Lamping et al. 2009).

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 (i.e., on perceptions of unadapted individuals, such as visitors to a space, and not on perceptions of adapted persons, such as occupants staying for an extended time in a space) (e.g., Shaughnessy et al. 1994; Fang et al. 2008; Bekö et al. 2008, 2009). 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.

2.3 Air Cleaners Using Photocatalytic Oxidation

2.3.1 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 most common photocatalyst is TiO_2 (titanium dioxide), while zinc oxide (ZnO), tungsten trioxide (WO_3), zirconium dioxide (ZrO_2),cadmium sulfide (CdS), and iron (III) (Fe(III)-doped TiO_2), among others, are also used. Dopants (e.g., iron [Fe], platinum [Pt], silver [Ag]) can have a beneficial effect on the performance of the metal oxide 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 oxygen species are highly reactive with adsorbed gases and biological particles. A variety of UV light sources can be used in PCO, including black lights (UV-A: long-wave; 400 to 315 nm), germicidal lamps (UV-C: short-wave; 280 to 200 nm), and lamps that generate ozone (vacuum UV [UV-V]: under 200 nm). Under reaction conditions allowing for deep oxidation (referred to as mineralization), carbon, hydrogen, and oxygen atoms in the reacting species are converted completely via chemical reaction to water vapor and carbon dioxide. In case the conditions do not promote deep oxidation, for example, due to insufficient residence time because of increased airflow through reactor or the presence of halogenated compounds, PCO can produce intermediate species (by-products) that remain bound to the surface of the photocatalyst or desorb and become airborne.

Nearly all organic, gaseous indoor air contaminants and microbes are subject to PCO decomposition (e.g., Zhang et al. 2011; Dalrymple et al. 2010). The efficiency of catalytic oxidizers depends partially on the functional group of contaminants passing through the PCO device. Higher efficiency is observed for oxygenated compounds such as alcohols, ketones, and some aldehydes; intermediate efficiency for aromatics; and lower efficiencies for chlorocarbons. The PCO conversion rates (or fraction of contaminant removed in a single pass) vary depending on the contaminant and the system design from 0% to nearly 100%, with longer residence times needed to achieve higher (single-pass) efficiencies. Efficiencies of PCO air cleaners and by-products formed by them depend on the design of the device, the indoor air setting (e.g., contaminant composition, relative humidity, temperature) in which they are used, and how the device is maintained.

A systematic parametric evaluation of several performance variables was reported for two styles of PCO air filters: TiO_2 coated on fiberglass fibers (TiO_2/FGFs) and TiO_2 coated on carbon cloth fibers (TiO_2/CCFs) (Zhong et al. 2013). The contaminant destruction rates varied with contaminant class and type of UV source, while formation of by-products correlated with PCO reaction mechanisms for each VOC.

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). (It has been shown by Ohtani et al. [1992] that irradiation greater than 200 nm and less than 400 nm, in particular UV-C (254 nm), over TiO_2 will decompose 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. Incomplete decomposition of some organic contaminants and net production of formaldehyde, acetaldehyde, formic acid, and acetic acid were shown by Hodgson et al. (2007), who investigated PCO using mixtures of up to 27 organic contaminants in concentrations reflecting the levels typically occurring indoors. Chemisorbent media positioned downstream of a UVPCO air cleaner effectively counteracted the generation of aldehydes due to incomplete oxidation of volatile organic compounds (VOCs) in UVPCO reactors (Hodgson et al. 2007).