ASHRAE Position Document on Filtration and Air Cleaning

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ASHRAE
1791 Tullie Circle, NE • Atlanta, Georgia 30329-2305
404-636-8400 • fax: 404-321-5478 • www.ashrae.org

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 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 em- ployed (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 form- aldehyde, 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). Other details about PCO can be found in reviews (e.g., Mo et al. 2009) as well as ASHRAE RP-1134 (Tompkins et al. 2005).

2.3.1 Evidence on Health Effects. 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. These studies found significant reductions in the percentages of persons dissatisfied with air quality in rooms contaminated by nonhuman sources of contamination during operation of PCO (Kolarik and Wargocki 2010; Kolarik et al. 2010). However, when the air was contaminated by human bioeffluents, the percentages of persons dissatisfied with air quality significantly increased, suggesting that the air quality was considerably worsened (Kolarik and Wargocki 2010). It was suggested that the alcohols that are a major part of human bioeffluents and their incomplete oxidation are responsible for the observed results.

3. CONCLUSIONS AND RECOMMENDATIONS

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).The positions do not define minimum efficiency levels at which the effect of filtration and air cleaning can be regarded as providing health benefits, because the magnitude of the effects obtained by filtration and air-cleaning technologies depends on the design, operation, and setting in which these technologies are operated in a building. Also, in many cases there are no thresholds available for health effects, and regulatory exposure limits vary greatly among different cognizant authorities. 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); it was not the objective of the present document. It is regarded that the decision on this matter belongs to other committees setting out regulatory and guiding documents (codes, standards, and guidelines).

- 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, including reductions from levels being above to levels being below the associated regulatory exposure limits for reducing health risk set by recognized cognizant authorities. Modest empirical evidence suggests that mechanical filters will have positive effects on health, especially for reducing adverse allergy or asthma outcomes, but not on acute health symptoms in the general population, often called *sick-building syndrome (SBS) symptoms*. 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, including reductions from levels being above to levels being below the associated regulatory exposure limits for reducing health risks set by recognized cognizant authorities. 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 thus subject to special attention as advised by Position 1 in Section 3.2.
- There are sorbent air cleaners that have been documented to reduce concentrations of harmful gaseous contaminants substantially, including reductions from levels being above to levels being below the associated regulatory exposure limits for reducing health risks set by recognized cognizant authorities. 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 for reducing health risks set by recognized cognizant authorities. However, there are PCO technologies that are ineffective in reducing concentrations significantly, and there are PCO technologies that have also been shown to generate harmful contaminants during the air-cleaning process. 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.
- 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. Limited data exist documenting the effectiveness of air cleaning, in particular gas-phase air cleaning, as an alternative to ventilation