Clearing the Air on Indoor Air Cleaners / Purifiers

No matter the type or size of the building – single family home, apartment, office, school, store, hotel, restaurant, hospital, church or arena – creating and maintaining good indoor air quality (IAQ) requires three key strategies: source control, ventilation and air cleaning. Although the overall strategies for air cleaning are the same for most building types, not all of the methods and devices used accomplish this goal are the same. In fact, some air cleaners can emit dangerous indoor pollutants, such as ozone.

This report reviews the common types of contaminants found in indoor air and examines the use of air cleaning as an effective IAQ strategy. It also describes different air cleaning methods, clarifies how these methods differ, which air cleaning devices may cause more harm than good and what to look for when selecting an air cleaner, including the importance of third party product testing to ensure air cleaners are operating as intended and are not contributing to indoor air pollution.

Indoor Air: An Intriguing, Complex Environment

Indoor air is an intriguing, complex environment that contains a myriad of visible and invisible contaminants, some of which can lead to health problems, lower worker productivity and result in building occupant complaints. These contaminants generally fall in one of two categories: particulates or gases, vapors and odors. The following provides a brief description of each category.

Particulates. Particulates are particles that are small enough to suspend in the air. Suspended inorganic particles, such as dust, pollen, fibers or smoke to name a few examples, are often referred to as *aerosols*. Suspended organic compounds and small living organisms, such as bacteria and viruses; mold spores and pieces of a mold colony; dust mites feces and body fragments; cockroach body parts; and dander from cats, dogs and other mammals, are called *bioaerosols* (McDonald and Ouyang 2000).

Particle size is measured in terms of its aerodynamic properties and is expressed as microns (µm) in diameter. Particles can range in size from very small (0.001 µm to 10 µm), which can remain in the air for a long time, up to relatively large (100 µm), which quickly settle out of calm air. Table 1 lists common indoor contaminants and their particle sizes.

Table 1. Particle Sizes of Common Indoor Contaminants*

Particle	Size (µm)	Particle	Size (µm)
Skin flakes	1 – 40	Asbestos	0.25 – 1
Visible dust, lint	> 25	Re-suspended dust	5 – 25
Dust mite	50	Environmental tobacco smoke	0.1 – 0.8
Mite allergen	5 – 10	Diesel soot	0.01 – 1
Mold, pollen spores	2 – 200	Outdoor fine particles (sulfates, metals)	0.1 – 2.5
Cat dander	1 – 3	Fresh combustion particles	<0.1
Bacteria+	0.05 – 0.7	Metal fumes	<0.1
Viruses+	<0.01 – 0.05	Ozone	<0.1
Amoeba	8 - 20	Mineral fibers	3 – 10

* McDonald and Ouyang 2000. + Occurs in larger droplet nuclei.

Inhaling particulates can cause eye, nose and throat irritation and increase the risk for respiratory infections. Health care professionals are especially concerned about the long-term effects of inhaling fine particles (less than 2.5 µm), because they can travel deep into the lungs where they can remain embedded for years or be absorbed into the bloodstream. Asbestos and various substances in environmental tobacco smoke (ETS) are well-known examples and some are recognized carcinogens. Exposure to high levels of fine particles also can play a role in developing respiratory diseases such as

asthma, pneumonia and chronic obstructive lung disease (COPD), which includes chronic bronchitis and emphysema. Larger particles (greater than 10 µm) do not cause as much concern, because they get caught in the nose and throat and are cleared from the respiratory tract by coughing or swallowing (ALA Special Report on Air Cleaners).

Gases, Vapors and Odors. The types of gases or vapors most often found in indoor environments include combustion byproducts, such as carbon monoxide, nitrogen oxides, sulfur dioxide, soot particles and polycyclic aromatic hydrocarbons (PAHs); pet, human and cooking odors; environmental tobacco smoke (ETS); volatile organic compounds (VOCs); ozone; microbial VOCs; and mycotoxins. Many of these substances also produce odors, some of which are pleasant while others can be distracting and irritating. Moisture also is a vapor that must be monitored as too much moisture can support indoor mold growth.

Volatile organic compounds are prevalent in all indoor environments, with as many as 100 to 1,000 different VOCs in the air where people can easily inhale them. Exposure to VOCs in offices and other business establishments can cause building occupants to feel uncomfortable, distracted or sick to the point that it interferes with their ability to do their work or reduces their motivation to work (Heerwagen et al). Missed work days or days with reduced activity can cost businesses billions of dollars in lost productivity (Dixon 1985, Fisk 2000, AAAAI 2005). Reducing the level of VOCs also is very important in homes and schools, because children breathe in more air with respect to their body mass than adults and thus have greater exposure to indoor air pollutants.

Ozone generators sold as air cleaners generate ozone for the purpose of air cleaning, air cleaners of other types may generate ozone as a by-product of their intended function. Ozone is a very reactive compound that is easily generated in high concentrations by air passing through an electrostatic field. For ozone generators, the idea is ozone reacts with odor-causing VOCs and removes the odor while leaving a fresh, clean smell like after a thunderstorm. In indoor environments, ozone, even in very small amounts, can cause significant health problems. See the detailed discussion below on *Air Cleaners Generating Ozone May Be Hazardous to Health*.

Some types of mold also emit VOCs, known as microbial VOCs or MVOCs, which are responsible for the characteristic musty, earthy odors associated with mold. People who are sensitive to MVOCs may experience eye, nose and throat irritation. A wide variety of molds also can produce mycotoxins at various times during their lifecycles. Building occupants can experience potentially serious health problems if they are exposed to high levels of these compounds, but this is rare in most indoor environments.

Although becoming a lesser issue in public buildings, ETS is still found in many homes, hotels, casinos, and in some restaurants and bars. Environmental tobacco smoke alone contains more than 4,700 airborne substances, including gases and particles from incompletely burned tobacco, of which 243 are known carcinogens.

Air Cleaning: Among the Top Three in Strategies for Good IAQ

Regardless of whether an indoor environment is the product of new construction or renovation, providing good indoor air quality starts during the design and construction phases and continues throughout a building's life, and, it is never too late to start managing IAQ in older buildings. Indoor environmental experts recommend three primary strategies for good IAQ, especially when integrated into a building's overall operation and maintenance. The following highlights each of these strategies: source control, ventilation and air cleaning.

Source Control. The US Environmental Protection Agency (USEPA), the American Lung Association (ALA) and other experts agree that source control is the only completely effective way to remove pollutants from indoor environments. They also agree that total eradication of indoor air contaminants often is not feasible or practical. A more realistic goal is to use building materials, furnishings, finishes,

office equipment, and cleaning products and processes that emit low levels of VOCs. Surface cleaning also removes larger particles and kills bacteria and viruses on floors, furniture, walls, doorknobs, bedding and linens, and bathroom fixtures. In addition, keeping the heating, ventilating and air-conditioning (HVAC) system in good working order and air ducts and drip pans clean is important for minimizing dust and particle accumulation and indoor mold growth within the system.

Products that are regularly tested to ensure that their chemical and particle emissions meet acceptable IAQ pollutant guidelines and standards may be found in the GREENGUARD Product Guide, which can be accessed at no charge on the GREENGUARD Environmental Institute's (GEI) website – **www.greenguard.org**. For more information on cleaning products and processes and indoor air quality, refer to the AQS white paper, *Cleaning Products & Processes: Partnering for Healthier Indoor Environments*, which is available free from the AQS Aerias IAQ Resource Center's website at **www.aerias.org**.

Source control also involves inspecting a building regularly inside and out for any signs of water damage, which is a good indicator that moisture levels are high enough to support indoor mold growth. If water damage or signs of mold are found, they should be remediated immediately. The best way to prevent indoor mold growth is to eliminate all sources of excess moisture, from leaks in the building envelope, improper building pressurization, an inefficient or malfunctioning HVAC system and appliances to building occupant activities.

Ventilation. Ventilation and air cleaning are invaluable for picking up where controlling sources of indoor air pollutants leaves off. The two work hand-in-hand, as many types of air cleaners are an integral part of the HVAC system.

A well-designed and properly operating HVAC system brings in and conditions outdoor air and circulates the air through the building. The primary benefit beyond warming, cooling and managing the humidity the air is to dilute indoor air pollutants to minimize their impact on the indoor environment and building occupants. The HVAC system also transports indoor air contaminants outside. In addition, the HVAC system is invaluable for maintaining appropriate building pressurization, which is critical for preventing moisture intrusion. The downside is the HVAC system may bring in outdoor air pollutants as well as pick up indoor pollutants, such as mold spores, allergens, dust and VOCs from one area of the building and transport them to another.

Air Cleaning. Simply stated, with respect to air cleaning the goal is to remove indoor pollutants by trapping them inside a mechanical device. Effective air cleaning:

- Protects HVAC systems and components
- Protects furnishings and décor of occupied spaces
- Reduces housekeeping and building maintenance
- Protects building occupants (USEPA 2006, ALA Special Report on Air Cleaners)

Experts emphasize, however, that air-cleaning devices alone cannot ensure good IAQ, particularly where ventilation itself is inadequate. As noted, air cleaning is most effective when used in conjunction with source control and ventilation (USEPA 2006).

Air Cleaning Devices: How They Work, How They Differ

Air cleaners / purifiers employ various types of filtration technologies, which can be attached to HVAC systems or used in portable units that can be moved from room to room. The following provides an overview of these technologies.

Mechanical Filtration. Capturing particles in a filter via physical mechanisms without electrostatic forces characterizes this air cleaning method. A common misperception is that fibrous filters (the most extensively used in mechanical filtration) work like a sieve, with particles becoming trapped within the spaces between the fibers. What actually occurs is that once the particles make contact with the fibers, they remain attached due to strong molecular forces between the particles and fibers. As a result, the particles become a part of the filter structure and contribute to a filter's efficiency by creating resistance of air flowing through the filter (McDonald and Ouyang 2000).

Mechanical filtration works best at capturing large (greater than 0.5 µm) or very small particles (less than 0.2 µm). Because of the opposing trends in how large and very small particles behave in the air stream, mechanical filters are less efficient at capturing particles measuring between 0.1µm to 0.4 µm. For example, air molecules heavily influence the motion of very small particles in the air stream. As a result, the particles' motion around their basic path becomes random. Air traveling at lower velocities provides more time for these small particles to move away from their primary path through the air stream and increases their chances of being caught and held via molecular forces as noted above. This process is called *diffusion,* and is the key factor in the how high efficiency particle air (HEPA) filters remove submicron particles from the air (McDonald and Ouyang 2000). .

Large particles, on the other hand, tend to follow the air stream exactly and are intercepted by the filter's fibers due to their size and their inability to follow the air stream as it bends around the fibers. The reason is larger, heavier particles or those traveling at high velocities have significant inertia, meaning they do not vary in their path along the air stream. As a result, they tend to keep going straight and smack into whatever is in their way and in some cases can even bounce off. This filtration process is referred to as *impingement* or *inertial impaction*. Air stream velocity minimally affects the chances of these particles being captured (McDonald and Ouyang 2000).

Sometimes, electrically charged fibrous filters are used to increase filter efficiency without contributing to airflow resistance. These are different than air cleaners that use electrostatic forces to trap particles (see discussion on Electronic Filtration below). Also, some mechanical filters use an adhesive coating to keep particles from bouncing off or shedding. Dry-type filter media includes open-cell foams, non-woven textile cloths, paper-like mats of glass or cellulose fibers, wood fill, animal hair, synthetic fibers, slit and expanded aluminum (USEPA 2006, ALA Special Report on Air Cleaners).

Filter Types. The two filters often used in commercial and residential HVAC systems are pre-filters and HEPA filters. Some box or pleated type filters can be as thin as 2 inches to 4 inches or as wide as 8 inches to 12 inches. A bag type HEPA filter can extend up to 24 inches. Bag type filters typically have a lower pressure drop than the pleated or box type HEPA filters. Pre-filters and HEPA filters, whether bag or box type, will filter particles as small as 1 µm or less, but with varying efficiencies. Different filters have different air pressure drop characteristics, which is a factor in energy and cost analysis (Penn State 2006).

High-efficiency particulate air filters are typically rated as 99.97 percent effective in removing dust and particulate matter above 0.3 µm, based on DOP (diocytl phthalate) testing (see the discussion on Selecting Whole Building Air Filtration Systems and Room Air Cleaners below). In theory, HEPA filters should be highly effective against bacteria and fairly effective against viruses, but real world installations do not always achieve performance as measured in laboratories. Pre-filters are typically 70 percent to 90 percent efficient. Ultra low penetration air (ULPA) filters are like an ultra-HEPA filter, which are designed to capture 99.999 percent of all airborne particles 0.3 µm or smaller (AHAM 2006).

Electronic Filtration. Electronic filtration devices use electrostatic forces to trap particles. In commercial or industrial applications, these devices are referred to as charged media precipitators or electrostatic precipitators (ESPs). In residential applications, they are called electronic air cleaners, some of which are portable and can be moved from room to room.

The simplest form of electronic air cleaner is the negative ion generator, which uses static charges to make the particles larger and thus they settle out of the air faster (Penn State 2006). These less sophisticated models have a significant disadvantage in that by charging the particles in a room, the particles can become attracted to and deposit on surfaces such as walls, floors, table tops and curtains, where they may cause soiling problems (ALA Special Report on Air Cleaners).

More advanced ion generation technology reduces potential soiling in a room. These air cleaners generate negative ions within a space just outside the air cleaner through which the air flows, causing airborne particles to become charged. The charged particles are then drawn back into the cleaner by a fan, where they are collected on an electrostatic-charged panel filter. In other air cleaners using ion generation, a stream of negative ions is generated in pulses, and the negatively charged particles are drawn passively back to the air cleaner, which contains a positively charged sleeve or cover (ALA Special Report on Air Cleaners).

Electrostatic precipitators employ a one- or two-stage design for particle collection. In the single-stage design, a charged medium acts to both charge and collect airborne particles (ALA Special Report on Air Cleaners). A typical two-stage electrostatic precipitator has a stage of corona wires and a stage of collecting plates. The corona wires are maintained at several thousand volts, which produces a corona that releases electrons into the air stream. These electrons attach to dust particles and give them a net negative charge. The collecting plates are grounded and attract the charged dust particles. Many industrial designs include mechanical rappers that periodically rap the collecting plates to dislodge the collected dust, which then drops into hoppers below. The air velocity between the plates needs to be sufficiently low to allow the dust to fall and not to be re-entrained in the air stream. Industrial systems are capable of removing particles in the range 0.01 µm to 10 µm and can achieve efficiencies around 95 percent (Penn State 2006).

Small electrostatic precipitators designed for home or other non-industrial applications do not have rappers, so they must be taken apart and cleaned from time-to-time. Further, these devices are often inserted into airstreams without regard to air velocities, and as a result efficiencies can be much lower than those used in industrial applications. How efficiently electronic air cleaners collect particles depends on the area of the collecting plates, the flow rate and the strength of the electrical field (Offerman, Sextro and Fisk et al 1985). Although the airflow remains constant with use, the particle capture efficiency declines rapidly as the charged collector plates become coated with particles. Cleaning the plates restores the initial efficiency and as noted must be done regularly to maintain adequate performance (King 1973).

The advantages of electronic air cleaners are they generally have low energy costs because of low air pressure drop, the airflow through the units remains constant with use and the precipitating cell is reusable, which avoids long-term filter replacement costs. The major disadvantages are they become less efficient with use, precipitating cells require frequent cleaning, and those installed into HVAC systems have a relatively high initial cost, including expensive installation because of the size of the unit and its related wiring cost (ALA Special Report on Air Cleaners). Another disadvantage is even a well-sized, efficiently operating air cleaner cannot achieve the efficiency necessary to guarantee complete interception of airborne bacteria and viruses, but they can be very effective in decreasing dust and airborne microbes in homes and office building environments (Penn State 2006).

An important note: Electronic air cleaners that use ionization, electrostatic precipitation or both to charge the particulates in the air also can create ozone as a byproduct of ionization. These devices are not considered to be “ozone generators”, but their level of emissions should be evaluated to ensure they meet current health requirements. See discussion below on Air Cleaners Generating Ozone May Be Hazardous to Health.

Removal of Gases, Vapors and Odors. Some air cleaners are designed to remove gases, vapors and odors as well as particulates. The removal process, called *adsorption*, is relatively simple in that air passes through an adsorption bed(s), which filters out the gases, vapors and odors. Adsorption beds are

made up of *sorbents*. Solid sorbents, such as activated carbon, are especially useful for removing diesel fumes, hydrocarbons, ETS, body odor, cooking odors and high-molecular weight VOCs. The performance of solid sorbents depends on several factors, including:

- The airflow rate through the sorbent
- The concentration of the pollutants
- The presence of other gases or vapors, such as humidity
- The physical and chemical characteristics of both the pollutants and the sorbent; for example, weight, polarity, size and shape
- The configuration of the sorbent in the device
- The quantity of sorbent used and the sorbent bed depth (Underhill 2000, USEPA 2006)

Activated carbon is not effective in removing low-molecular weight compounds, such as ammonia, hydrogen sulfide and formaldehyde, but it can be impregnated with chemicals that do react with these contaminants. This process is called *chemisorption*. The impregnated activated carbon serves as a carrier for the chemicals and enhances the reaction rate by providing a large surface on which the chemical reaction can occur (Underhill 2000). One major disadvantage to impregnated activated carbon is chemisorbents are specific for one or a limited number of reactive pollutants. Consequently, they should not be expected to efficiently reduce pollutants for which they are not specifically designed (USEPA 2006).

Many reactive compounds also can be removed from the air by chemisorption on potassium permanganate-impregnated alumina. When compared with unimpregnated activated carbon, this method is superior in removing most highly reactive compounds, such as nitric oxide, sulfur dioxide, formaldehyde and hydrogen sulfide, with unimpregnated activated carbon being better able to remove nitrogen dioxide and toluene (Underhill 2000).

Although adsorption is commonly used in many types of buildings, it does have limitations. One of the most significant is where there is a high level of contaminants, adsorption may not be cost effective as the adsorption bed(s) will eventually become saturated with contaminants and must be replaced. In circumstances where there are low concentrations of contaminants, however, this process may be a good choice as saturation over a short period of time is less likely to occur (Underhill 2000). This limitation underscores the importance of not relying on just one air cleaning strategy, but using all three strategies described above, with source control leading the way.

An important note: Sometimes relatively small quantities of activated carbon will reduce odors to imperceptible levels, especially in residential applications. What this means is because many chemicals produce health effects at levels below those where odors are perceived, removal of odors alone does not ensure healthy indoor air (USEPA 2006).

Other Air Cleaning Technologies. In addition to the mechanical filtration and electronic air cleaning, other technologies are being developed and used, including the following examples:

- **Outdoor Air Purging.** Airborne pathogens, such as bacteria and viruses, can be removed by purging the indoor environment with outside air, which is naturally sterilized. Airborne bacteria and viruses that cause illnesses in people rarely occur in the outdoor air and cannot survive long if they do. The only condition in which purging with outside air is not a solution to an indoor mold growth problem is when mold is found inside the HVAC system's air handling unit, because the purging may spread high levels of mold spores, allergens and pieces of the mold colony

throughout the building. As a result, sensitive people may experience health problems, and mold may establish itself in other areas of the building that were previously clear of any indoor mold growth (Penn State 2006).

- **Room Isolation and Pressurization.** In healthcare facilities, isolating some patients is a critical need, which can be met by using either negative or positive pressurization. Negative pressure isolation rooms maintain a flow of air into the room, thus keeping contaminants and pathogens from reaching surrounding areas. The most common application is for tuberculosis (TB) rooms. Tuberculosis is extremely infectious, and these rooms are essential to protect healthcare workers and other patients. Positive pressure isolation rooms maintain a flow of air out of the room, thereby protecting the patient from possible contaminants and pathogens that might otherwise enter. The most common application is isolation rooms for patients with HIV or other types of immunodeficiency. For such patients, it is vital to keep any pathogens from getting into the room, including common molds and bacteria that may be harmless to healthy people (Penn State 2006).

  Room pressurization also is used to manage indoor air quality in hospitality venues, such as casinos, restaurants and bars. As with isolation rooms, positive pressurization keeps contaminated air from entering a particular area, such as a non-smoking area, while negative pressurization pulls the air into the space, such as the kitchen or bathroom where it can be removed via exhaust fans. In addition, proprietors often use a combination of mechanical and electronic air cleaners to remove particulates and odors.

- **Ultraviolet Germicidal Irradiation.** The use of ultraviolet germicidal irradiation (UVGI) for sterilizing microorganisms has been studied since the 1930s. Microbes, including *pathogens*, bacteria and viruses that can be harmful to people, are uniquely vulnerable to the effects of light at wavelengths at or near 2537 Angstroms. In other words, a quanta of energy of ultraviolet light possesses just the right amount of energy to break organic molecular bonds, which causes cellular or genetic damage. The same damage occurs to humans, but is limited to the skin and eyes (Penn State 2006).

  The ultraviolet component of sunlight is the main reason microbes die in the outdoor air. The die-off rate in the outdoors varies from one pathogen to another, but can be anywhere from a few seconds to a few minutes for a 90 percent to 99 percent of viruses or contagious bacteria. Mold spores and some environmental bacteria, tend to be resistant and can survive much longer exposures (Penn State 2006).

  Ultraviolet germicidal irradiation systems typically use much more concentrated levels of UV energy than are found in sunlight. Some properly designed and well-maintained UVGI installations are very effective, such as in hospitals, schools and prisons. The Centers for Disease Control and Prevention recommends the use of UVGI only with the simultaneous use of HEPA filters and high rates of outdoor air purging. This is because even though viruses are especially susceptible to UVGI, more so than bacteria, they are very difficult to filter (Penn State 2006).

  In actual applications, many factors can alter the effectiveness of UVGI, including:

  - Exposure time (the air velocity must allow for a sufficient dose)
  - Room air mixing (for non-powered applications like ceiling units)
  - Power levels
  - The presence of moisture or particulates provides protection for microbes

- Dust settling on light bulbs can reduce exposures, requiring regular maintenance

One especially effective UVGI application controls mold growth in air handling unit cooling coil and filter assemblies. The constant exposure either inactivates spores or perhaps prevents mycelial growth from being sustained. Certain types of UVGI designs seem to provide a much higher disinfectant rate than standard models operating at nearly identical spectrums. The difference is from improvements in the electrical power controls and regulation of internal plasma temperature, resulting in the generation of a more constant energy density at a distance from the light source (Penn State 2006).

- **Pressure-Swing Adsorption.** In pressure-swing adsorption, two adsorption beds work in parallel (Skarstrom 1972). While the first bed is purifying a stream of compressed air, the second bed uses a fraction of the clean air output from the first bed to back flush from it any adsorbed contaminants. Then the roles of the beds are reversed. This method's advantages are the adsorbent is constantly renewed and very high purification factors are readily attainable. This technology is appropriate where the power required from the pressure cycle is readily available and a high decontamination factor is required (Underhill 2000).

Ozone-Generating Air Cleaners May Be Hazardous to Health

Ozone is a very reactive compound that is easily generated in hazardous concentrations by air passing through an electrostatic field. In air cleaning, ozone is used to remove odors from odor-causing VOCs while leaving a fresh, clean smell like after a thunderstorm. Research has shown, however, that ozone generators use as air cleaners or purifiers are not particularly effective and in fact can be hazardous to health (Underhill 2000). Also see the USEPA web page – *Ozone Generators that are Sold as Air Cleaners* (**www.epa.gov/iaq/pubs/ozonegen.html**) for summaries of additional studies regarding the effectiveness of ozone-generating air cleaners.

Ozone is a very strong lung irritant, which can result or exacerbate respiratory disease. It can react with VOCs to produce additional VOCs such as aldehydes, which have a more unpleasant odor, are far more irritating, and are more toxic than other VOCs in the indoor air (Boeniger 1995). Further, unreacted ozone at low concentrations around 120 ppb (0.12 ppm) can cause eye irritation, visual disturbances, headaches, dizziness, dry mouth and throat, chest tightness and coughing (Sittig 1991).

Several health standards address levels of ozone, but these apply to occupational and healthcare settings – not residences. The Food and Drug Administration (FDA), for example, requires ozone output of indoor medical devices to be no more than 50 ppb (0.05 ppm). The Occupational Safety and Health Administration (OSHA) requires that workers not be exposed to an average concentration of more than 100 ppb (0.10 ppm) for 8 hours, and the National Institute of Occupational Safety and Health (NIOSH) recommends an upper limit of 100 ppb (0.10 ppm), not to be exceeded at any time. The US EPA National Ambient Air Quality Standard for ozone is a maximum 8-hour average outdoor concentration of 75 ppb (0.075 ppm) (US EPA 2007). The Standard for Electrostatic Air Cleaners, ANSI/UL 867 requires ozone emissions of no more than 50 ppb.

Not all electronic air cleaners that make ozone are classified as "ozone generators," as the levels of ozone, created as a byproduct of ionization or electrostatic precipitation, are very low. As noted, there is a class of products, however, that does produce ozone for the purpose of air cleaning, which have regulators and healthcare providers concerned. Some marketing claims for these products refer to ozone as "activated oxygen," "super oxygenated" or "energized oxygen," and thus imply that ozone is a healthy kind of oxygen (CARB 2006). These claims can be confusing and the lack of disclosure as to the potential health effects associated with exposure to ozone may put unsuspecting consumers at risk. In fact, the California Air Resources Board (CARB) recommends not using these air cleaners.

In September 2007, CARB approved a regulation to limit the concentration of ozone emissions from indoor air cleaning devices to 0.050 ppm. Manufacturers must have compliant products on the store

shelves within two years of the regulation effective date or risk potential citations and/or fines for noncompliance. Compliance is demonstrated by having their products tested by a nationally recognized testing laboratory to the revised edition of UL 867, the Standard for Safety of Electrostatic Air Cleaners. Updated with input from the CARB, manufacturers and other stakeholders, UL 867 incorporates process changes to increase the repeatability and reproducibility of testing. The regulation is expected to become effective upon approval by OAL, which is anticipated to occur in August 2008.

To support its recommendation not to use air cleaners that generate ozone, CARB conducted studies on four models of ozone generators that were widely marketed in California. Tests were conducted in a small room furnished with a desk and chair, under temperature, humidity and air exchange conditions common in homes. The devices were operated according to manufacturers' instructions, with a few adjustments due to facility limitations. Prior to the room concentration tests, measurements were made at 2 inches, 6 inches, 12 inches and 24 inches from the face of each device to locate the major output stream for each and identify the range of emissions in preparation for the room concentration tests. After the room concentration tests were completed, emission rates were measured using non-reactive ducting (Phillips and Jakober 2006).

The results showed that all of the models tested produced room concentrations that exceeded health-based standards. Three models produced room concentrations that substantially exceeded both the California Ambient Air Quality Standards (CAAQS) of 90 ppb (0.09 ppm), one-hour average and the 70 ppb (0.07 ppm), eight-hour average, for ozone. They also exceeded the US Food and Drug Administration (USFDA) standard of 50 ppb (0.05 ppm) that applies to medical devices; devices for which the manufacturers make health-related claims. In addition, one unit exceeded the 70 ppb CAAQS and the USFDA standard of 50 ppb when set at a medium setting (ozone output for a 1,000 square foot area). This unit was not tested at its highest setting, but has been shown in other studies to produce room levels over 300 ppb (0.3 ppm) at its highest settings (Phillips and Jakober 2006).

The face test and emission test results correlated reasonably well with the room concentration results. The face test results at two inches from the face of the air-cleaners range from 379 ppb to 1287 ppb across the four models tested. Emission rates ranged from 0.29 mg/h to 94 mg/h (Phillips and Jakober 2006).

The report concluded that the use of ozone generators in enclosed spaces presents a serious public health risk from exposure to ozone and its toxic byproducts. The use of such devices in close proximity to people cannot be justified based on any purported air cleaning or germicidal properties of ozone. Even if operated according to manufacturer's instructions, the safe operation of these devices by the general public cannot be ensured, especially those devices that have extremely high emission rates for ozone (Phillips and Jakober 2006).

Testing ozone levels in outdoor air is nothing new, but a cottage industry is sprouting up featuring products that also can be used to test ozone levels in indoor air. The idea is to use these products along with electronic air cleaners / purifiers; especially those that use ozone to purify the air to make sure ozone levels are not so high as to be hazardous to health (Kanan 2005).

Selecting Whole Building Filtration Systems and Room Air Cleaners

Determining what type of air cleaning system or room air cleaner / purifier to use depends on several factors, including what types of indoor air pollutants are to be removed, the size(s) of the indoor space(s), the type of building and what activities are going on in the building. Budgetary (first cost and maintenance) and energy costs and conservation considerations also must be taken into account.

An important guide in choosing an air cleaning system or room air cleaner / purifier to is review the results of independent product testing for performance. While there are a number of test methods and standards

for measuring the effectiveness of removing particulates from the air, there are no standards that set forth test methods to measure the ability to remove VOCs or that measure ozone emissions – until now. Following the discussion of the primary test methods used to test the ability of air filters to remove particulates, newly introduced test methods from Air Quality Sciences, Inc. (AQS) for VOC removal and ozone emissions will be presented.

Standards and Test Methods for Removing Particulates. As noted, one of the most important considerations with respect to mechanical filtration for particulates is the air filter's performance. Key issues are the filter efficiency rating, amount of air pressure drop and life in application. In this instance, efficiency refers to the percentage of pollutants removed by the filter. The following are the major industry standards used to test fibrous media filters:

- ASHRAE Standard 52.1 – 1992, *Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter*, features three primary filter test methods for filters used in HVAC systems, two of which measures filter efficiency and one which measures dust-holding capacity. The arrestance test is primarily used to test relatively low-efficiency filters and measures the filters mass efficiency. The dust-spot efficiency test measures an air filter's capacity to reduce soiling, and the dust-holding capacity test measures the filter's air pressure drop; that is, how much the air pressure drops as the air stream moves through the filtration system. Dust-holding capacity is the total dust held by the filter up to termination of the test (McDonald and Ouyang 2000).

- ASHRAE/ANSI Standard 52.2 – 1999, *Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size*, contains two methods to measure a filter's efficiency. Particle size removal efficiency measures the filter's efficiency for removing particle sizes in the range of 0.3 µm to 10 µm in 12 size ranges. The minimum-efficiency reporting value (MERV) provides a single number to characterize filter efficiency, based on a minimum efficiency curve. Because air filter performance is a strong function of airflow, MERV also includes a test flow rate (McDonald and Ouyang 2000).

- Military Standard 2823 for HEPA filters is the only standard the federal government recognizes to rate particle reduction in HEPA and ULPA filters. This test rates HEPA filters by the percentage of 0.3 µm size particles of dioctylphtalate (DOP) smoke they remove. The DOP Oil-Like Material Test is actually comprised of several tests. Because DOP has been listed as a suspected carcinogen, it has largely been replaced by poly (α-olefin) (PAO) synthetic oil, which has the same physical characteristics as DOP (McDonald and Ouyang 2000, ALA Special Report on Air Cleaners).

  To some extent these same test methods can be used for electrostatic precipitators, but there are challenges; for example, at this time there is no standard definition for the life of ESPs. To address this issue, these methods have been adapted to measure the ESPs initial efficiency. Because of high voltages used with ESPs, additional testing for safety of the high voltage supply is recommended. The American Refrigeration Institute (ARI) has two test methods for evaluating ozone production, a potential byproduct of ESPs. These methods are outlined in ARI Standard 680 – 2004, *Residential Air Filter Equipment*, and ARI Standard 850 – 2004, *Commercial and Industrial Air Filter Equipment* (McDonald and Ouyang 2000).

- European Norm 1822 – 2000, *HEPA and ULPA Filters*, certifies a filter's absolute minimum efficiency for all particles and is primarily used to certify air filters for clean room applications. Although the efficiency of HEPA filters has been traditionally measured at 0.3 µm, many particles in the air are much smaller than this. The two-part EN 1822 test identifies the particle size that penetrates the HEPA or ULPA filter most easily, known as the Most Penetrating Particle Size (MPPS), and challenges the filter with only these particles, creating an absolutely worst-case scenario (Schroth and Caesar 2001).

- ANSI/AHAM AC-1 – 2006, *Method for Measuring the Performance of Portable Household Electric Room Air Cleaners*, evaluates portable household electric room air cleaners, regardless of the particle removal technology. The performance metric, known as Clean Air Delivery Rate (CADR), measures the appliance's ability to reduce smoke, dust and pollen particles in the 0.10 µm to 11 µm size range. The Federal Trade Commission endorses this test method as a reasonable basis for measuring the degrees of reduction of airborne solid particulate matter from household rooms. The US Environmental Protection Agency also uses the test method in its Air Cleaner Energy Star Program. In addition, Consumers Union uses it to determine the air cleaner ratings and product comparison information that are published in its *Consumer Reports*® magazine and website (AHAM 2006).

  ANSI/AHAM AC-1 – 2006 does not cover portable room air cleaner's ability to reduce gases, odors or microbiological components, or the sound and ozone emissions levels of the product. The Association of Home Appliance Manufacturers has developed a separate standard for measuring the sound rating of portable room air cleaners (ANSI/AHAM AC-2 – 2006) and is working on a standard for evaluating performance of air cleaners following accelerated loading (draft AHAM AC-3) (AHAM 2006).

  Since 1985, AHAM has administered a portable room air cleaner certification program based on the ANSI/AHAM AC-1 standard whereby AHAM, acting as third party using an independent testing laboratory, verifies product ratings certified by program participants (AHAM 2006).

AQS Test Methods for VOC Removal and Ozone Emissions. To help manufacturers develop effective and safe air cleaning devices, AQS offers a comprehensive test method that assess the effectiveness of air cleaners /purifiers in four distinct areas, which are not covered by other test methods:

- Particle removal efficiency, which measures the percentage of dust removed from the air, which differs from other test methods that measure how much dust a filter collects

- Chemical removal efficiency, which measures the percentage of VOCs and formaldehyde removed from the air

- Ozone emissions, which measures the amount of ozone released during operation

During this test, a dynamic environmental chamber is contaminated with a known concentration of particles and specific chemicals and malodors. The air cleaner /purifier is turned on and airborne levels of VOCs, dust and ozone are measured before, during and after operation. Manufacturers can order all or parts of the method depending on their specific requirements, and AQS product evaluation experts can consult with manufacturers about possible changes to their product to achieve better performance. Independent testing, such as that offered by AQS, also allows manufacturers to demonstrate their products effectiveness and safety, especially for air cleaners that remove VOCs and odors or that may generate ozone. Independent testing also gives consumers peace of mind that the air cleaning products are operating as intended and are not contributing to indoor air pollution.

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