A Healthy Home Environment?

Over the past seven years, the Science Advisory Board of the U.S. Environmental Protection Agency (EPA) has consistently ranked indoor air pollution among the top five risks to public health. This is a sobering thought, given that people in the United States spend an average of 90% of their time indoors and that many intrinsically associate home with safety and comfort. Although stories about hazards such as lead paint and asbestos in older, deteriorating homes have become commonplace, people may be surprised to learn that environmental problems can plague even the most modern homes. "Environmental health hazards occur in houses of all ages," says John Bower, cofounder of The Healthy House Institute, an independent resource center for designers, architects, contractors, and homeowners, and an editorial advisory board member for the *Indoor Environment Review.* "They just tend to be of a different nature."

Building science specialists cite a number of trends that make the indoor environment, particularly indoor air quality, a growing concern. Since the energy crisis of the 1970s, builders have concentrated on building tighter homes as a way of minimizing heating and air-conditioning costs. Tighter houses can be healthy houses, but more care must be taken to avoid generating or trapping pollutants indoors, where they can accumulate to hazardous levels.

Another energy-conscious trend is the growing popularity of ventless gas heaters. The trend started with freestanding kerosene heaters, which were purchased for millions of households during the energy crisis, and now includes ventless natural gas space heaters, fireplaces, and gas logs. Aside from the combustion gases they produce, these devices release one gallon of moisture for every 100,000 British thermal units of energy they consume each hour. Excess moisture in a home is a haven for the growth of molds and fungi, which may cause a variety of allergic, infectious, and toxic reactions in humans.

Modern building materials, furnishings, and paint and other coatings can also be a source of indoor air pollution. Often these materials are made with volatile organic compounds (VOCs) that outgas into the home, sometimes causing respiratory problems. Wall-to-wall carpeting can serve as a reservoir for pollutants, including pesticides, tracked in from outdoors, as well as for dust mites, bacteria, and asthma-inducing allergens. Even household water may not be completely safe—radon gas, a cause of lung cancer, can become aerosolized in water droplets in hot showers, and water may contain chlorinated by-products associated with elevated rates of bladder cancer and adverse reproductive outcomes.

The Carbon Connection

There are dozens of potential environmental health hazards in the home but the most dangerous are combustion gases. Oil- and gas-fired furnaces, water heaters, ovens, wood stoves, charcoal grills, and fireplaces all produce combustion gases. These gases may include carbon monoxide (CO), carbon dioxide, nitrogen dioxide, nitric oxide, sulfur dioxide, water vapor, hydrogen cyanide, formaldehyde, and various hydrocarbons.

By far the most hazardous of these is CO. In 1997, the American Association of Poison Control Centers' Toxic Exposure Surveillance System reported 20,930 cases of CO poisoning from all known sources, including 191 life-threatening cases and 37 fatalities. CO is formed when a carbon-containing fuel such as kerosene, charcoal, wood, or gasoline, is incompletely burned. Natural gas in the United States does not contain carbon, but CO may form if the gas is burned without an adequate air supply.

CO is colorless, odorless, and tasteless, which makes its presence all but undetectable to humans without the use of special equipment. When breathed, CO combines with hemoglobin to form carboxyhemoglobin (COHb), which disrupts the flow of oxygen to the body and brain. CO's potential to kill is well known, but the bigger story may be how many people suffer adverse health effects from chronic and often undetected exposure to low levels of the gas. Symptoms of CO poisoning, which include fatigue, headache, dizziness, nausea, and vomiting, so closely mimic the common cold that exposures may not be properly diagnosed.

In 1985, physicians at the University of Louisville School of Medicine in Kentucky examined 55 patients admitted to the emergency room with flu-like symptoms for possible CO poisoning. Blood tests revealed that 13 of these patients (24%) had COHb concentrations of 10% or more, indicating subacute CO poisoning. Writing in the July 1987 issue of the *Annals of Emergency Medicine*, authors Michael Dolan and colleagues stated, "The literature is well supplied with reports of patients with subacute CO poisoning who were misdiagnosed as having influenza and sent home with disastrous consequences. Emergency physicians must be aware of the protean presentations of CO poisoning and include it in the differential diagnosis of patients with flu-like illness to prevent the return of patients to hazardous environments."

In addition to causing flu-like symptoms, studies show that chronic exposure to low-level CO may also cause poor vision, retinal hemorrhaging, and behavioral impairment (specifically, the inability to judge the length of time that sound signals lasted in a controlled º

Anecdotal evidence and a number of studies point to faulty or improperly used heating appliances as the primary source of CO in the home. A study of unintentional CO poisoning by Magdalena Cook and colleagues at the Colorado Department of Health, published in the July 1995 issue of the *American Journal of Public Health,* traced 478 of 981 poisonings to faulty furnaces (363 cases), kerosene or space heaters (27 cases), gas appliances (72 cases), and fireplaces (16 cases). (The other cases were related to inhalation of smoke from fire and auto exhaust.) Common causes of furnace-related CO exposure include cracked heat exchangers, backdrafting of the furnace flue caused by depressurization, or blockage of the chimney. The study did not determine whether the kerosene or other space heaters or gas appliances were faulty or not. The report did state, "With the onset of colder weather, malfunctioning furnaces may be turned on, and kerosene or space heaters may be inappropriately used in enclosed spaces."

The problem with kerosene space heaters is that they are unvented; thus, they dump all their combustion by-products into the living space. A study by Ron Williams, a former senior research associate with Environmental Health Research and Testing in Research Triangle Park, North Carolina, published in the September/October 1992 issue of *Indoor Environment* (the former journal of the International Association for Indoor Air Quality), found that the use of unvented kerosene heaters in mobile homes caused a significant rise in indoor CO concentrations, sometimes in excess of the U.S. air exposure standard of 9 parts per million (ppm) CO over an eight-hour period.

Unvented Heaters—Gas with Nowhere to Go

Health officials are also concerned about the rising popularity of unvented natural gas appliances intended for use as supplemental heaters. According to the Vent-Free Gas Products Alliance, 1,250,000 ventless gas appliances were sold in the United States in 1998. Citing research performed by the American Gas Association research division, the alliance claims that properly sized and installed vent-free products used for no more than four continuous hours conform to "reasonable" indoor air quality guidelines set by various government agencies for CO, nitric oxide, carbon dioxide, and water vapor. However, critics say it is unreasonable to assume that all or even most of these appliances will be properly sized, used only for supplemental heating, and provided with sufficient makeup air. In a recent study by the Manufactured Housing Research Alliance, 7 of 12 manufactured homes using ventless kerosene heaters and 4 of 7 homes using liquid propane heaters were out of compliance with American National Standards Institute emission rate standards for CO. The study, titled *Manufactured Housing Fuel Switching Field Test Study*, also found that in five homes the owners operated their vented gas fireplace logs with the damper closed in order to "get more heat" out of the gas logs.

Thomas Greiner, an extension engineer with Iowa State University in Ames, has performed hundreds of indoor air quality investigations in the United States and abroad. "I've been into too many homes that use these unvented heaters as the primary source of heat," Greiner says. "I also find that as you get into colder climates, people use a larger-sized heater than is called for in the specifications. There's also a question as to whether the occupants are letting in enough outside air to dilute the combustion by-products. My opinion is that these heaters are a real step backwards [from] the goal of improved air quality in the U.S."

Michael Calderera, associate director of technical services for the Gas Appliance Manufacturers Association, based in Arlington, Virginia, counters that a distinction should be made between an unvented kerosene heater and an unvented natural gas space heater. An unvented natural gas space heater employs a device called an oxygen detection safety (ODS) pilot system, which monitors the level of oxygen in the room and automatically shuts off the supply of gas to the unit if the level of oxygen drops below a level set by the national product safety standard. ODS devices became a requirement of the national product safety standard in 1980. Since that time, says Calderera, "Over seven million unvented space heaters have been installed in the United States and, as far as we know, there has not been a single documented death resulting from emissions from an ODS-equipped unit."

Problems can occur in homes when gas ovens are used as supplemental or primary heating sources. Examining a survey of customers of the Con Edison utility company in New York City who have natural gas stoves but not natural gas heating systems, researchers observed that more than half of the 340,000 customers were using more gas than was deemed normal for cooking use. The researchers subsequently visited 120 of these homes and found that in 50% of them the occupants were using the gas range as a supplemental source of heating. Only 12% of these stoves had hoods with working exhaust fans that could eliminate stove-produced pollutants, and only 3% had working window fans. In an article published in the February 1981 issue of the *Journal of the Air Pollution Control Association*, author T. D. Sterling and colleagues concluded that a large number of urban dwellers may be chronically exposed to gas range–produced indoor pollutants, which may, in turn, result in ill health effects.

Volatile Visitors

Dozens of different VOCs have been measured in indoor air from a variety of sources including building products, cleaning agents, paints and finishes, fragrances and hair sprays, office equipment such as copiers and printers, and infiltration of outdoor air. Concentrations of VOCs measured indoors are usually far below occupational threshold limit values (TLVs), the point above which health effects may occur, but they may at times, exceed human odor thresholds, or the point at which an odor becomes offensive. A few compounds, principally aldehydes, are suspected of causing adverse health effects, but because many VOCs haven't been studied, no one knows what their effects might be.

One VOC that has been studied extensively and that is a cause of great concern in the home is formaldehyde. Formaldehyde-based resins are widely used in building materials (subflooring and paneling), furniture, and cabinets. Consumer products such as permanent-press fabric, wallpaper, and fingernail polish and hardeners can also emit formaldehyde. "By far the worst nonwood-product emissions came from acid-cured floor finishes," says Thomas J. Kelly, a senior research scientist at Battelle in Columbus, Ohio, who compared emission rates of formaldehyde from materials and consumer products in California homes in an article published in the 1 January 1999 issue of *Environmental Science and Technology*. "Even after 24 hours of drying," wrote Kelly, "each coat emitted at a steady state that was 5–10 times higher than emissions from the very worst wood product."

Airborne formaldehyde can act as an irritant to the conjunctiva and upper and lower respiratory tract. Symptoms of short-term exposure are temporary and, depending upon the intensity and length of exposure, may range from burning or tingling sensations in the eyes, nose, and throat to chest tightening and wheezing. Acute severe reactions may be associated with hypersensitivity, a condition of hyperreactive airways that effects 10–20% of the U.S. population, according to the EPA. Based on formaldehyde's potential as an irritant, the Occupational Safety and Health Administration has established an eight-hour time-weighted average of 0.75 ppm as the legal standard for exposure in the workplace. The American Conference of Governmental Industrial Hygienists, meanwhile, has established a nonenforceable TLV for formaldehyde of 0.3 ppm. However, peer-reviewed studies cited in the January 1998 issue of the *American Review of Respiratory Disease* show that concentrations as low as 0.01 ppm have been found to cause eye irritation, and upper respiratory tract irritation has been seen at levels as low as 0.1 ppm.

Formaldehyde is also known to cause nasal cancer in test animals. In 1987, the EPA listed formaldehyde as a probable human carcinogen (the EPA conducted its original cancer risk assessment in 1986 and revised it in 1991). In April 1999, the Chemical Industry Institute of Toxicology (CIIT), an industry-sponsored research organization based in Research Triangle Park, released its hazard characterization and risk assessment for cancer via inhalation of formaldehyde. The CIIT report found that a nonsmoker continuously exposed to 0.3 ppm formaldehyde over 80 years has less than a 1 in 10 million chance of developing cancer of the respiratory tract, while smokers would have a 1 in 1 million chance. The CIIT report is currently under review by the EPA and Health Canada.

Most studies of indoor air concentrations of formaldehyde were conducted in the 1970s and early 1980s in homes where urea formaldehyde foam insulation had been installed and in manufactured homes constructed with large quantities of particle board made with formaldehyde-containing adhesives. Studies of the former showed formaldehyde concentrations in the range of 0.02–0.13 ppm, and of the latter in the range of 0.02–0.78 ppm. However, the installation of urea formaldehyde foam insulation in residences largely ceased in 1982 when the product was banned by the Consumer Product Safety Commission (CPSC); since 1985, all manufactured housing has been required to be constructed of materials that meet formaldehyde limits set by the U.S. Department of Housing and Urban Development. As a result, formaldehyde levels in homes today are most likely to be less than 0.03 ppm, according to the CPSC. Thus, the health risk from formaldehyde exposure appears to be more one of irritation for sensitive individuals than of cancer.

Another type of VOC, chlorination by-products, can result when public water supplies are treated with chlorine. Some of these by-products are suspected carcinogens. Public health officials have calculated risk assessments based primarily upon exposure through ingestion of cold water. However, recent studies claim that humans are exposed to these chemicals through various means that include bathing and showering, and that the risks may have been underestimated. In a study published in the January 1996 issue of *EHP*, Clifford Weisel, an associate professor at the Environmental and Occupational Health Sciences Institute at Robert Wood Johnson Medical School in Piscataway, New Jersey, and colleagues determined that people are exposed to chloroform and trichloroethene through inhalation and dermal absorption as well as ingestion during daily bathing and showering. Weisel's studies showed that exposure through showering is roughly equal to that from drinking water. However, as to how much the former route of exposure contributes to adverse health effects, Weisel says, "At the moment, we don't understand the biological mechanisms of action well enough to establish risk estimates. The delivered dose of the metabolite varies by route of exposure, and that can affect the potential outcome." Weisel's article calls upon public health officials to raise their risk assessments to include these routes of exposure.

Concern has been expressed recently about a possible threat to human health from exposure to polybrominated diphenyl ethers (PBDEs) in the home. PBDEs are organohalogen compounds that can accumulate in human tissue. Their metabolites have been shown to interfere with the thyroid system. PBDEs are used as flame retardants in high-impact polystyrene, flexible polyurethane foam, textile coatings, wire and cable insulation, and electrical connectors. In consumer products, PBDEs are typically used in interior parts and incorporated into the polymer matrix, which minimizes the potential of exposure to the public. However, new evidence raises concerns that PBDE vapors might emanate from television sets and be absorbed by human tissue.

In a paper published in volume 35 of *Organohalogen Compounds* and presented at "The 18th Symposium on Halogenated Environmental Organic Pollutants," held in Stockholm in August 1998, Jacob de Boer, director of the DLO-Netherlands Institute for Fisheries Research, and colleagues examined the case of a male Israeli citizen who suffered from headaches, painful lesions, dizziness, and other symptoms after prolonged television watching in a small, unventilated room. Blood samples taken after the onset of these symptoms revealed chromosomal abnormalities consistent with chemical exposure. Ten years after the exposure, sampling of both the subject's adipose tissue and the television set revealed the presence of PBDEs. While proof of a relationship could not be established, the authors hypothesize that exposure to vapors from the television set may have played a role in the observed health effects.

"I think PBDEs are the sleeper compounds of the future," says Larry Robertson, a professor of toxicology at the University of Kentucky in Lexington and a coauthor of the article. "They are slowly but irrevocably accumulating in human tissue." Robertson says more research is needed to determine how these compounds break down in the environment.

Of Mites and Molds

Biological pollutants are found to some degree in every home, school, and workplace. They come from outdoor air in the form of pollen and other allergens, from human occupants who expel viruses and bacteria, from pets that shed dander, from insect pests, and from moist surfaces that allow mold and fungi to grow.

In the publication *Indoor Air Pollution—An Introduction for Health Professionals*, the EPA cites a number of factors that allow biological agents to grow and be released into the air. High relative humidity (more than 50%) encourages dust mite populations to increase and allows fungal growth on damp surfaces. Damp carpeting as well as moisture from inadequate ventilation of bathrooms and kitchens can promote mite and fungus contamination. Appliances such as humidifiers, dehumidifiers, air conditioners, and drip pans under cooling coils can also support the growth of bacteria and fungi. Finally, components of heating, ventilating, and air-conditioning (HVAC) systems may serve as reservoirs of microbial growth and distribution. The EPA states in its online publication *Biological Pollutants in Your Home* (located at **http://www.epa.gov/iaq/pubs/bio_1.html**) that 30–50% of all structures in the United States and Canada have damp conditions that may permit the growth and buildup of biological pollutants.

Biological agents in indoor air are known to cause infections, hypersensitivity, and toxic effects. The EPA indicates that allergic reactions may be the most common health problem with indoor air quality in homes. Such reactions can range from mildly uncomfortable to life-threatening. Allergic reactions to dust mites are particularly problematic. Bower's book *The Healthy House* states that dust mite allergy affects approximately 10% of the U.S. population. Several studies have shown that exposure to house dust mite allergens is associated with asthma in susceptible children.

Recently, David Straus and colleagues at Texas Tech University Health Sciences Center in Lubbock completed an in-depth study of 48 schools where health complaints ranging from watery eyes to increased incidence of respiratory infection were common. The study, published in the September 1998 issue of *Occupational and Environmental Medicine*, found a high correlation between health complaints and increased indoor levels of *Penicillium* and *Stachybotrys*. *Stachybotrys* is a black, slimy mold that grows on water-saturated cellulose products such as insulation and ceiling tile. It has been connected with an unusually high number of cases of pulmonary hemorrhage and hemosiderosis among young infants in Cleveland, Ohio, 12 of whom died during the period from 1993 to 1998. The Centers for Disease Control and Prevention entered the victims' homes following their deaths and discovered *Stachybotrys* growing in places that had suffered water damage from flooding, plumbing leaks, or roof leaks. The spores of this fungus were found to contain very potent mycotoxins that appear to be particularly toxic to the rapidly growing lungs of young infants. Health officials say that not all black mold is *Stachybotrys* and not all *Stachybotrys* is toxigenic to the point of health concerns, but they warn homeowners to be aware of this dangerous mold and to eliminate moisture conditions that might cause it or other molds to grow.

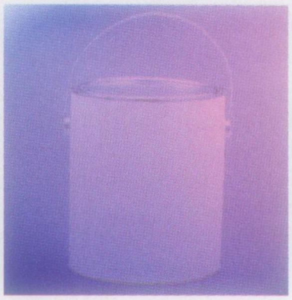
Dirty Dusting

The expression "dusting the house" may conjure an image of a housewife with a feather duster, whisking the lampshades and tables to give them an extra shine. But studies in recent years indicate that house dust is often not so benign and that the health problems it can cause are nothing to sniff at.

House dust contains all manner of particles from such activities as cooking, other household processes, and smoking. It may also contain pollutants brought in from outdoors such as pollen, pesticides, and heavy metals, some of which are known or suspected human carcinogens. Outdoor pollutants are tracked in on shoes or brought in on clothing or the fur of household pets. In fact, concentrations of pesticides and other outdoor organic pollutants may be higher inside the house than outside.

"We've found concentrations of pesticides . . . 10–100 times higher in carpet dust than in yard soils," says Robert G. Lewis, a senior scientist with the National Exposure Research Laboratory of the EPA in Research Triangle Park. "And these compounds last far longer indoors than they do out of doors. In a study we did in 1990, we found DDT to be the highest in concentration of all particles found in the dust of an old carpet. DDT use was banned in the United States in 1972."

Lewis says young children who spend lots of time at floor level are at the greatest risk for exposure to such chemicals by ingestion and inhalation of resuspended house dust, which exists at highest concentrations close to the floor. "We don't have risk criteria on many of these compounds in dust and we don't know what the bioavailability is once the dust is ingested or inhaled," Lewis says. "But given that most pesticides are toxic to humans and some are potentially carcinogenic, we should try to limit our exposures by whatever means."



Hidden Hazards

Radon. Radon, a colorless, odorless gas found to varying degrees in soil and subsurface water, is a pollutant that has received a great deal of attention in recent years. The EPA estimates that radon pollution is responsible for up to 20,000 lung cancer deaths each year. The agency has prepared a map of the United States showing the geologic potential for radon in different parts of the country; however, no region of the nation should be considered entirely safe. Most of the time, radon gas leaves the soil and dissipates into the atmosphere, but it can be drawn into the living space of a house through leaky floors or duct systems. As radon starts to decay, it gives off a series of radioactive particles that can damage lung tissue if inhaled. Radon is measured in units of picocuries per liter. The EPA suggests that people exposed to more than 4 picocuries per liter in the home should take remedial action to remove the source of radon.

Lead and asbestos. Two other materials, lead and asbestos, may be a problem in older homes. Lead was commonly used in household paints up to the 1950s, when its use began to decline. In 1978, the CPSC banned the manufacture of house paint containing more than a trace amount (0.06%) of lead. Lead is highly toxic and has been linked to a variety of neurodevelopmental problems among children living in older homes with peeling or chipping lead paint [see *EHP* 107(6):A302–A307 (1999)]. Exposure comes through children either eating the chips directly or crawling on carpets contaminated with lead dust and then putting their hands in their mouths. According to Bower, when children eat paint chips, the majority of the lead is excreted because the chips are fairly large. However, when children eat dust, the majority of the lead is absorbed, making lead dust a more dangerous hazard.

Asbestos is a mineral that was commonly used for insulating hot water pipes in homes built between 1920 and 1972. It was also used as a component in joint finishing and patching compound, in the backing of vinyl, asphalt, and rubber flooring, and in textured ceilings. If inhaled, asbestos fibers can lodge in the lungs and lead to a variety of diseases including lung cancer and asbestosis, a chronic fibrotic lung disease. Recognizing its dangers, manufacturers eliminated asbestos from most building products by the 1970s, and its use in household products was banned by the CPSC in 1977. Still, older homes may have asbestos in some locations and it can become hazardous if the materials begin to deteriorate and become airborne.

Cleaning House

People who have the luxury of building their own home can now employ a wide variety of measures and materials to minimize their potential exposure to indoor environmental hazards. Such materials range from ventilation tubes that purge radon gas from the crawl space, to electrical heating and hot water systems that do not emit combustion gases, to steel kitchen cabinets that do not emit VOCs. However, the vast majority of people in the United States live in homes that are not custom-built to avoid such environmental health problems. A number of strategies can help people avoid adverse health effects within the home.

For homes that have gas- or oil-fired heating systems, experts recommend yearly servicing by a qualified heating technician. Gas stoves and ranges should only be operated with the exhaust fan turned on. If the range lacks an exhaust system, one should be installed. Many building science experts recommend against using ventless gas-fired heating systems in the home. If these are used, experts recommend they be operated in accordance with manufacturer instructions and for only a few hours at a time. Experts also recommend that CO detectors be installed in every home.

The EPA recommends that every homeowner and every condominium owner living below the third floor have his or her home tested for radon, either by a professional or using a radon kit (available in most hardware stores). Long-term (90-day) testing kits are recommended, as radon concentrations can fluctuate at different times of the year. If high levels of radon are found in the home, several strategies can be pursued including ventilating the living space, sealing off the floor from the crawl space or basement, and depressurizing the subfloor through the use of vents and fans.

For people sensitive to VOCs, the EPA recommends limiting the use of personal items such as scents and hair sprays; household products such as rug and oven cleaners; paints, lacquers, and finishes; dry-cleaning fluids; office equipment such as copiers and printers; office products such as correction fluids and graphics materials; and craft materials such as glues and adhesives. If new carpeting, paints, or finishes containing formaldehyde are installed or applied, the home should be well ventilated for several days afterward. Pesticides and biocides that emit VOCs should only be used outdoors and should be stored outside the living space.

Experts say the best strategy for avoiding the buildup of mold and mildew is to reduce moisture levels in the home. Exhaust fans should be used in bathrooms and kitchens, where high levels of moisture are produced. Clothes dryers should be vented outside the house. Roof or plumbing leaks should be repaired immediately. Humidifiers and drip pans for HVAC systems should be cleaned regularly. Flood-damaged carpets, draperies, or furniture should be thrown out.

Dust mites require food, water, and moderate temperatures for growth. The EPA advises maintaining a low relative humidity (below 45%) in the home, vacuuming often and, if necessary, using EPA-approved pesticides. Mattresses are a prime haven for dust mites because they are made of fluffy materials and they are a site of extended human exposure (dust mites feed off of skin flakes). Allergists recommend that both mattresses and box springs be covered with special covers made of tightly woven material or plastic. Bedding should be washed in water of at least 130°F.

Airborne pollutants cannot be totally eliminated from the home, but they can be kept to a minimum. Health officials warn against smoking indoors. Air filters in HVAC systems should be changed monthly.

Home Air Purifiers

With the growing concern about indoor air pollution, many people are looking for a quick fix to problems with indoor air. The marketplace has responded with a barrage of appliances promising to "purify" household air. Research shows that most of these appliances work to some degree to remove air contaminants, but they rarely reduce a broad spectrum of pollutants and they sometimes create their own health hazards.

Home air cleaners being marketed today generally fall under two categories. The first category includes appliances that separately generate ozone and negative ions as a means of killing undesirable organisms and cleansing particulates from air. Advertisements claim that these devices will reduce contaminants including dust, odors, allergens, mold, mildew, secondhand smoke, fungi, dust mites, pet dander, bacteria, and pollen, as well as static electricity. The second category of cleaners consists of filtration devices that trap airborne particulates by drawing household air through a filter medium. These appliances sometimes incorporate activated granular carbon filters or other sorbents to adsorb gaseous pollutants such as smoke, aerosols, and volatile organic compounds (VOCs).

The typical ozone generator consists of a tabletop appliance that draws household air over a high-voltage plate. When oxygen molecules pass through the electric discharge, some of them are ionized. The ions combine with oxygen to form ozone, which theoretically kills contaminating organisms in the air and on surfaces.

Ionizers work by sending out radio waves that electrically charge airborne particles within a prescribed radius (typically 60 feet) of the unit. These negatively charged particles then attach themselves to surfaces such as draperies, walls, and tabletops, which must be cleaned or else the particles will become resuspended in the air.

Air filtration units rely on various media to trap respirable particulates—those within the range of 0.02–10.0 micrometers in diameter. Air filters are often referred to in terms of basic, medium, and high efficiency. Basic-efficiency filters use media such as spun fiberglass and polyester panels, and are less than 20% efficient at removing respirable particles. Medium-efficiency filters, which usually consist of pleated elements several inches thick, are about 20–35% efficient. High-efficiency particulate arresting (HEPA) filters use dense weaves of microfibers to remove up to 99% of airborne particulates.

Still other portable air cleaners employ so-called electric filters made of electrically polarized polyester mesh to trap dust particles. And electrostatic precipitators charge particles by passing them over a high-voltage wire. The particles on them are collected on electrically polarized metal plates.

In 1993, Richard J. Shaughnessy and colleagues at the University of Tulsa (Oklahoma) Center for Environmental Research and Technology conducted a comparative test of 14 different portable air cleaners employing the technologies described above. The study, published in the September 1994 issue of Indoor Air, measured the units' effectiveness in reducing dust, pollen, spores, tobacco smoke particulate, nicotine, vinyl pyridine, formaldehyde, nitrogen dioxide, and carbon monoxide.

The study found that portable air cleaners are overall far more effective at reducing particulate-phase contaminants than gaseous-phase contaminants. For removal of dust, smoke particulates, spores, and pollen, HEPA filters exhibited the highest removal efficiencies (72–96%). Electrostatic precipitators were next (39–95%), followed by electric filters (49–91%). Ionizers and ozone generators were least efficient at reducing particulates. The researchers note that the efficiency for both the HEPA units and the electrostatic precipitators dropped significantly over time as the filter media became packed with particulates, emphasizing the need for routine maintenance of the cleaners.

With respect to gaseous pollutants, none of the units removed more than 49% of any pollutant, and many showed no effect at all. HEPA systems loaded with additional carbon sorbent proved most effective in the removal of vinyl pyridine (28%), formaldehyde (30%), and nitrogen dioxide (49%). The ozone generators were marginally effective (7–15%) with respect to nicotine, vinyl pyridine, and nitrogen dioxide, yet displayed no effect on formaldehyde. None of the units were effective at removing carbon monoxide.

The authors note that while ozone may reduce some VOCs, it will produce others, mainly aldehydes, in reaction with various organics. Thus, the net effect of using ozone may be to increase exposure to VOCs. Ozone can also cause irritation of the lung tissue over the short term and decreased lung function over the long term.

The Food and Drug Administration limits the ozone output of indoor medical devices to no more than 0.05 parts per million. Tests of some home ozone models resulted in production of ozone far in excess of this level. For this reason, various state and federal agencies warn against the use of this type of air cleaner in occupied spaces.

If occupants continue to suffer allergic reactions to pollens and other allergens, experts say a more sophisticated filtration system may need to be installed. High-efficiency particulate accumulator (HEPA) filters remove 99% of particles larger than 0.3 microns, which includes pollens and household dust. These filters are most effective when installed in a building's ductwork, but the fans on most residential HVAC systems are not powerful enough to draw air through HEPA filters. Freestanding HEPA filters are available (see box insert); however, these filters are expensive and may have to be installed in every room of the house to be effective.

While vacuuming is always recommended to reduce the biologicals, pesticides, and heavy metals that can build up in carpets, studies show that standard housecleaning strategies are often not sufficient to significantly reduce these pollutants. In order to improve indoor air quality, cleaning must be thorough and well thought out. Deborah Franke, a senior research scientist with Research Triangle Institute, an independent research laboratory in Research Triangle Park, and colleagues analyzed the effectiveness of routine and improved housecleaning methods against dust, bacteria, fungi, and VOCs in an institutional building in North Carolina. Their findings, published in the December 1997 issue of *Indoor Air*, include a list of procedures most effective in improving indoor air quality. These include the use of HEPA vacuum cleaners with high-efficiency bags and filters, hot-water extraction cleaning methods in the deep cleaning of carpets, the use of disposable damp cloths for dusting and mopping, low VOC-emitting cleaning agents, and interior doormats to trap and collect particles at entrances.

Unlike outdoor air quality, which is protected by the Clean Air Act and other legislation, the responsibility for clean indoor air falls primarily on the individual. Although information on hazardous indoor air exposures is often lacking (for example, manufacturers may not be required to list all of the chemicals that are contained in household products), the homeowner is not without resources. Information is available on the World Wide Web and through many publications produced by the EPA, the CPSC, and private organizations such as The Healthy House Institute. Given the amount of time spent indoors, ensuring a healthy home environment may soon become a quest for everyone—not just homeowners—to consider.

John Manuel