New Guidance for Residential Air Cleaners

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As HVAC&R professionals, we in the ASHRAE community are sometimes asked questions about residential indoor air quality (IAQ) and how to improve it. What contaminants are most hazardous? How do I get rid of a particular smell? Should I use this air cleaner or that filter? Sadly, our friends and family generally lose patience when we helpfully suggest: "Well, it's complicated. But just read Chapters 46, 60 and 62 in the *ASHRAE Handbook—HVAC Applications,* because there's great information in there." In general, we find that information seekers are frustrated by such helpful advice. Usually, the question is repeated (with some heat) in a form such as: "You're the professional. Can't you boil it down? What should I DO in my HOUSE?"

Fortunately, two new resources can help you better answer such questions. First, the ASHRAE *Residential Indoor Air Quality Guide*[1] is a comprehensive summary of IAQ for homes and apartments, written by our member colleagues and published by ASHRAE in 2018. This book will be useful for professionals, and for others who have a deeper interest in understanding and improving residential IAQ. Still, a 280-page book is more than most consumers might choose to digest. Frequently, the homeowner or renter's IAQ concern is simpler and more specific, having to do with air filtration, i.e.: "What kind of air filter should I use?"

Some of us have heard more questions lately, because public awareness about particle air pollution is high. Wildfires in North America and Europe, blowing dust in Asia and Africa, and burning biomass in South America and Southeast Asia are often highlighted in both mainstream and social media. When you get questions from friends and family about residential air filtration and air cleaners, you may find the U.S. Enivronmental Protection Agency's recently updated publications helpful.[2] The 2018 EPA guidance is specifically written to inform consumers, as well as technical professionals. Here's a simple summary of that guidance:

- First, the most effective ways to improve indoor air quality are to reduce or remove the sources of pollutants and to ventilate using clean outdoor air. For example, refraining from smoking or vaping indoors makes an immediate and important improvement.
- If those measures don't address the problem or can't be done, running a portable air cleaner and/or upgrading the air filter in a central furnace or HVAC system can help to improve IAQ.
- Portable air cleaners can be used to filter the air in a

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single room or area. To filter particles, choose a portable air cleaner that has a high clean air delivery rate (CADR). More specifically, choose a portable with a CADR label that indicates it is large enough for the size of the room or area in which you will use it. The higher the CADR, the more particles the air cleaner can filter and the larger the area it can serve. However, the CADR certification only addresses particles. To filter gases, one can choose a portable air cleaner that has a large amount of adsorbent or chemisorbent media, such as an activated carbon filter. Be aware, however, that currently there is no industry consensus test method or certification program that provides assurance of the effectiveness and safety of portable, consumer-grade gaseous filtration devices.

- Central furnace and HVAC system filters are designed to filter air throughout a home rather than only in a single space. When the goal is to remove a significant amount of airborne fine particles (i.e., particles with a diameter of 2.5 micrometers and smaller: [$PM_{2.5}$]) or even ultrafine particles (i.e., particles smaller than 100 nanometers), a good choice for a central HVAC system filter is one rated at a minimum efficiency reporting value (MERV) of 13 or higher.
- Be aware that for both portable air filters and central systems, filtration *effectiveness* (i.e., the actual removal of particles from a conditioned space) is limited by the number of hours of fan operation. When a portable unit is not operating, it's not removing particles. And the run time of fans in residential systems is generally less than 25% of the hours in a year. To provide effective removal of $PM_{2.5}$ from the space, much longer runtimes will be needed for both portables and central systems.

EPA Guidance

The EPA guidance published in July 2018 includes two documents in PDF format: brief answers for consumers and a comprehensive technical summary for professionals. These documents are in the public domain. They may be distributed, printed, and copied as needed. The *"Guide to Air Cleaners In The Home"* is a consumer-targeted, 8-page document that answers many of the questions most frequently received by the staff at the Indoor Environments Division at the EPA. It also provides tips to help consumers make choices based on current understanding of conclusions from health intervention studies and ASHRAE research. The *"Residential Air Cleaners - A Technical Summary"* is a much longer 74-page document summarizing current research about the impact of residential air cleaning equipment on pollutant concentrations and human health. It also describes some important gaps that remain in our understanding. Several specific recommendations from these documents are discussed in more detail below.

FIGURE 1 New residential IAQ guidance, over photos of August 2018 wildfire smoke in Sacramento, Calif.

Reducing $PM_{2.5}$ Exposure Can Provide Health Benefits

Although many contaminants have unfortunately not been comprehensively studied, decades of research provide ample documentation of the negative effects of fine particulate matter exposure, including increased mortality and other outcomes.[3,4] For example, epidemiology studies have generally reported increases in all-cause mortality across study populations of ~6 to ~7% per 10 $\mu g/m^3$ increase in annual average outdoor $PM_{2.5}$ concentrations.[5,6] These studies have traditionally only used outdoor concentrations as surrogates for exposure. However, one recent study makes clear that indoor exposures are quite important, as indoor exposure to particles of both indoor and outdoor origin likely accounts for about 70% of total $PM_{2.5}$ exposure in the U.S., on average.[7] A detailed review of this large body of research is beyond the scope of this article. But to help the reader assess the value of minimizing exposure, it may be useful to summarize a few more examples from the literature, particularly as they pertain to air cleaners.

Portable air cleaners can improve health outcomes. Numerous air cleaner intervention studies have found statistically significant associations between the use of portable air cleaners in homes and (1) reductions in indoor particulate matter exposure and (2) at least one measure or marker of improved health outcomes. For example, Allen et al. deployed portable HEPA air filters and placebo filtration in a randomized crossover intervention study of 45 healthy adults in a woodsmoke-impacted community during consecutive seven-day periods of filtered and non-filtered air.[8] Portable HEPA filters reduced indoor $PM_{2.5}$ concentrations by 60% on average. That level of $PM_{2.5}$ filtration was associated with improved endothelial function (9.4% increase in reactive hyperemia index) and decreased concentrations of inflammatory biomarkers (32.6% decrease in C-reactive protein). Other studies of interventions with portable units have shown similar effects. Much less is known about central air filtration, primarily because it has been studied far less than portable air cleaning units that have high CADRs.

FIGURE 2 Outdoor air concentration of $PM_{2.5}$ in Santa Barbara, Calif., during 2017.

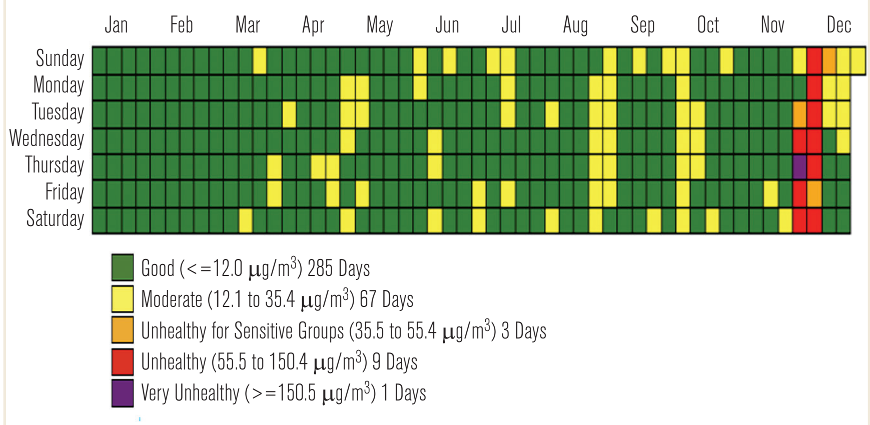

FIGURE 3 Wildfire in Southern California–2017.

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Short term exposure can also affect health. Most studies have documented the negative effects of long-term exposure. However, there is also direct epidemiological evidence that short term exposure affects health. Schwartz, et al.,[9] performed an analysis of U.S. mortality (7.5 million deaths in 135 U.S. cities) and compared death rates with locally-reported outdoor air concentration of $PM_{2.5}$ at the time of death. Over the period examined, each 10 μg/m^3 increase in daily $PM_{2.5}$ concentrations was associated with a 0.6 to 1.5% increase in daily deaths (approximately 112,500 individuals).

To put this finding into perspective, consider the measurements of outdoor airborne particulate shown in *Figure 2*. In Santa Barbara Calif., during December 2017, airborne $PM_{2.5}$ increased from less than 12 μg/m^3 to over 150 μg/m^3 because of the local wildfire. The health-relevance of such short-term exposure suggests that in areas prone to wildfires, it would be wise to prepare by acquiring one or more portable air cleaners rated as having a high CADR for smoke. Then operate them when or if smoke builds up in the outdoor air. More comprehensive measures beyond air filtration are also discussed in separate EPA guidance for response to wildfires.[10] Readers interested in further details of health effects of $PM_{2.5}$ are encouraged to consult the studies referenced in the technical summary of the EPA guidance.

Indoor $PM_{2.5}$ Concentrations Frequently Exceed Outdoor Concentrations

Indoors, $PM_{2.5}$ concentrations vary widely depending on many factors. In the absence of indoor sources, indoor concentrations are sometimes lower than outdoors, especially in modern tight houses which greatly reduce particle infiltration from outdoors. But studies have also measured indoor concentration at higher levels than outdoor concentrations. One review of 28 large-scale field studies measuring indoor and outdoor concentration in non-smoking homes in North

America noted that in 17 studies, indoor concentrations were between 1.5 and 3.5 times higher indoors than outdoors.[11]

These results are not surprising, since there are many particle sources present in most homes. Heating food in the oven and cooking on the stove are generally the largest contributors, which is why it's important to operate the range hood exhaust when cooking. Also, resuspension of settled particles can raise indoor concentration above the outdoor level. For example, walking across floors can account for a significant increase in $PM_{2.5}$ concentration in the breathing zones of both adults and infants. Also, simply sitting down in upholstered furniture generates a cloud of resuspended particles, as does movement while sleeping.

Interestingly, researchers in Taiwan recently quantified the increase in airborne particle concentration that comes from children bouncing on their beds.[12] In a field study of 60 occupied bedrooms, researchers found increases in airborne $PM_{2.5}$ concentrations of 353 $\mu g/m^3$ using "standardized percussion" as an approximation of bouncing children. (One can only regret the lost opportunity for STEM education by using researchers rather than actual children to whack beds in 60 houses with sticks!)

Operating Hours Limit Filtration Effectiveness

Portable air cleaners and central systems equipped with high efficiency filters can improve indoor air quality by removing small particles. But not if the system fan is not operating.

For example, public health interventions using portable air cleaners have shown improvements in health markers (5% to 10% compared to control groups in some short-term studies), and sometimes more substantial improvements (close to 50% improvement in markers for inflammation and cardiovascular function in other studies). But without consumer education, the portable air cleaners may not be turned on, or may not be operated in bedrooms where they usually provide the greatest benefit.

For central HVAC systems, there is very little research that documents a health benefit from better filtration. While logic suggests that better filters can make a positive difference, achieving and documenting measurable improvements is apparently difficult. Perhaps this is because central systems have been less-studied, and because fans operate for a surprisingly short number of hours over the course of a year.

For example, in a 2018 study of three years of run-time records from 7,000 residential forced-air heating and cooling systems in North America, Touchie and Siegel[13] found that typically, system fans operate for less than 20% of the hours in a year. Clearly, if air is not being filtered and recirculated through occupied spaces for 80% of the year, central systems are challenged to make a significant reduction in $PM_{2.5}$ exposure. In light of this limitation, the updated EPA guidance recommends using a MERV 13 filter or higher to provide a more useful degree of fine particle removal during its few operating hours.

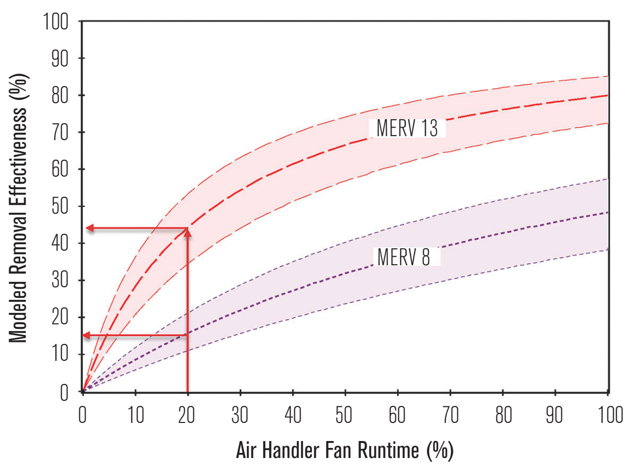
Further, many homes are now heated and cooled with the increasingly popular mini-split systems. These homes face a different challenge with respect to fine particle control. In that class of equipment, fans often operate continuously, using a strategy of variable but continuous airflow to provide air mixing. Although this provides a large number of filtration hours, the washable screens in most of these units are designed for equipment protection rather than for removal of fine particles. The revised EPA guidance suggests that adding high-CADR portable units to specific spaces can be a practical alternative, when heating and cooling equipment does not accommodate air filtration at MERV 13 or above.

Residential Central System Recommendations

The EPA recommends using a filter rated at MERV 13 or higher in central systems. To be rated at MERV 13, the filter must have achieved a defined level of fine particle removal efficiency.

That simple recommendation, more or less understandable by consumers is based on a (very) long examination and evaluation of the technical and economic issues for both existing and new systems by the EPA and it's consulting team. Most HVAC professionals will understand the confounding and critical issues of run time, filter bypass, airflow velocity, filter cleanliness, air distribution resistance versus fan static pressure, along with the variability of building airtightness and domestic cleaning and furnishing preferences. For example, professionals know that if the filter is not snugly-fitted into the filter slot, or if the air velocity through the filter is not ideal, or if the filter is clogged because it has not

FIGURE 4 Modeled fine particle removal.



Monte Carlo model simulating removal of 1 to 3μ particles from a home, based on a range of air leakage rates from outdoors. Upper boundaries estimate effectiveness of a perfectly installed system and filter in a tight house. Lower boundaries estimate effectiveness in a leaky house.

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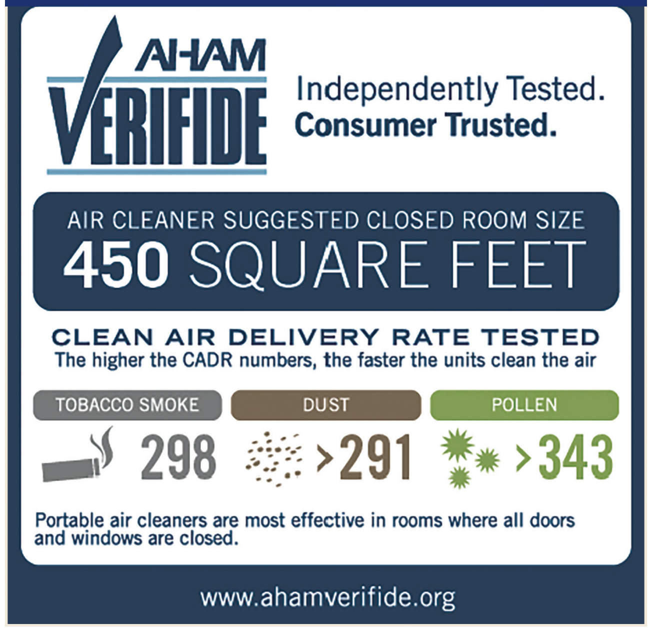
FIGURE 5 CADR rating label for portable air cleaners.



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been changed for a few years, or if the system simply does not run for more than a small percentage of the hours in a year, then its effectiveness (removal of fine particles *from the space*) will be far below the lab-tested removal of particles *from the airstream*.

Ultimately, the advice to consumers to choose a MERV 13 filter is based on the fact that with the low run-times typical of houses and apartments in North America, the MERV 13 filter has a better chance of removing a significant percentage of the fine particles of greatest health concern. At present, an informal survey of residential air filter distribution conducted by one of the authors suggests that filters rated at MERV 13 and above currently account for about 15% of annual residential air filter sales.[14] It could be interesting to follow how this percentage changes over the next few years, in light of the EPA guidance.

Figure 4 shows the results of a mathematical model that compares the best-case effectiveness of an ideal system with respect to removing fine particles from a home. (Note that perfect installation and maintenance of filters is the modeling assumption, namely: no air bypasses the filter, the filter is clean and remains so over a year, and that air velocity is ideal rather than the lower-than-ideal flow that is more commonly-observed in domestic HVAC systems.) This Monte Carlo simulation of 1,000,000 cases estimates removal of fine particles (from the space) using MERV 8 and MERV 13 filters. Recall that domestic systems typically operate less than 20% of the hours in the year.[13] The model suggests that if all other factors were equal, a perfectly installed MERV 13 filter has the potential to remove 3x more fine particles than a MERV 8 filter (45% v. 15% of particles in the 1-3 micrometer range).

HVAC professionals will also understand that improved indoor air quality comes with some increase in operational cost. The technical summary addresses the issues of energy and HVAC system capabilities. Certainly for all portables, better filtration effectiveness (through increasing operating hours) comes at the cost of its fan energy consumption. Also, in central systems more hours of operation mean better filtration—but also more fan energy cost. Also higher levels of filtration can sometimes add pressure drop that reduces airflow low enough to affect heating and cooling effectiveness, although certainly not in all systems.[15,16] So the advice to select a MERV 13 filter was not arrived at casually. The technical summary addresses these issues in considerable detail, based on field measurements of both energy consumption and airflow rates through different MERV-rated filters in typical residential HVAC systems.

Portable Air Cleaner Recommendations

The EPA recommends choosing a portable air cleaner that provides a high clean air delivery rate (CADR) when removing smoke-sized particles. There are challenges when providing technically-robust guidance that consumers can absorb, in part because portable units are not covered by ASHRAE Standard 52.2, the standard that establishes performance criteria for MERV ratings.

Consequently, for portable unit performance ratings, the EPA guidance refers to the Association of Home Appliance Manufacturers (AHAM), an organization that offers performance ratings and certification for particle removal by portable air cleaners.

AHAM testing measures the “clean air delivery rate” (CADR) of the device. The CADR is the amount of air (in cfm) that has been cleaned of particles in three size ranges. The ranges are described by names that consumers can relate to, namely: “smoke”, “dust” and “pollen.” AHAM defines these as 0.09 to1.0 µm for smoke, 0.5 to 3 µm for dust, and 5 to 11 µm for pollen.

Further, the CADR also estimates the filtration *effectiveness* of the device—the reduction in particle concentrations in the occupied space, based on the maximum recommended floor area for the rated unit. Rated units are expected to remove 80% of the airborne small particles (0.09 to 1.0 µm) over an hour, above and beyond the number of particles that would naturally settle out. Rated removal is also based on the assumptions that the ceiling height is no higher than 8 ft (2.4 m) and that the space exchanges less than one air change per hour with other spaces. The EPA guidance to consumers notes that units with larger CADR ratings are better, and that if ceiling heights are greater than 8 ft (2.4 m) (such as spaces with cathedral ceilings) a consumer might consider using a larger unit or multiple units to achieve 80% reduction in particle concentration.

Note the most important but unstated assumption is that the unit is *running continuously when the space in question is occupied*. Short runtimes limit the effectiveness of portable air cleaners, just as they limit the filtration effectiveness of central systems. And with portable air cleaners, operating noise can be an issue. The noise levels at which a given unit’s CADR was achieved are not currently described on the AHAM-verified label. It would be helpful if consumer packaging displayed the sound levels at which the CADR rating was achieved, to provide a basis for better-informed consumer choices.

Advertisement formerly in this space.

Efforts to Improve ASHRAE and Industry Standards

Helping to update the EPA guidance has reinforced the authors' opinion that there is an urgent need for a test method and certification program for portable air cleaners that measures safe removal of gaseous contaminants. Progress in this area has been slower than the proliferation of consumer products.

AHAM is participating in the arduous process of international consensus to establish a set of facility and instrumentation requirements for testing gaseous contaminant removal by consumer devices. After those decisions are eventually agreed upon, we might expect they will begin the even more arduous effort to achieve international agreement on a test method and rating system for labels on consumer products. This would be an important tool to protect the public from ozone and from potentially unwanted by-products of emerging gas cleaning technologies.

Devices that claim to remove gaseous contaminants through electrochemical or photochemical means are not yet tested nor rated by any independent organization. The EPA guidance clearly states that ozone is a pollutant to be avoided, and that without independent testing and certification neither the safety nor the effectiveness of technologies that rely on ozone, plasma, ionization and photocatalysis (as implemented in air cleaners in the consumer space) can be easily assessed at present. The guidance suggests that until testing and certification is available, the consumer can be aware that activated carbon filters have been shown to absorb airborne gaseous contaminants and that chemisorption and contaminant conversion by sorbents such as potassium permanganate have been widely used for gas cleaning in the past.

ASHRAE standards could also be improved to assist homeowners. ASHRAE-funded research confirms that while MERV ratings are useful for abstract comparison of products, there is an equally important need to define the requirements for the frames that holds such filters. In addition to short run times from oversizing equipment, air bypassing the edges of filters is responsible for significant shortcomings in particle removal from conditioned spaces. Future ASHRAE standards could contribute to better indoor air quality in homes by limiting the amount of airflow that can bypass a residential air filtration assembly (the filter as installed in its holding frame and surrounding duct).

Finally, for better health outcomes through air cleaning we need more filtration operating hours. For portables, this suggests reduction of current noise levels. For central systems, the need for more operating hours means we need to reduce the energy penalty of continuous fan operation. In the HVAC community, we know how to do this: supply and return ducts need to be short, straight, big, airtight and heavily-insulated. In other words, we need the construction budgets and architectural designs that allow systems to be designed and installed the way all HVAC professionals would choose to do, when indoor air quality excellence is the consumer's goal.

Summary

Based on the research that supports the 2018 EPA residential air cleaner guidance, there are relatively simple answers that can help when our friends, relatives or clients ask for advice about filtration and air cleaning in their homes. First, let them know that reducing the concentration of fine particles ($PM_{2.5}$) has provided the best-documented health benefits. Next, the best way to reduce particles is to avoid producing it by not smoking or vaping indoors, and by exhausting the large amounts of particles produced by cooking. After those basic steps, to remove $PM_{2.5}$ using portable air cleaners, choose units that have a high CADR rating for smoke. And when using a central system, choose a filter rated at MERV 13 or higher. Finally, keep in mind that for any filtration method, longer operating hours provide better particle removal effectiveness, which in turn increases the potential for health benefits.

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