



# Residential Air Cleaner Use to Improve Indoor Air Quality and Health: A Review of the Evidence

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## evidence review

### Summary

- Air cleaners are designed to remove pollutants from indoor air, but their effectiveness depends on the air cleaner design and set-up, as well as on the presence of specific pollutants, their concentrations, and air exchange rates in the room/home.
- Ozone generators and some electrostatic precipitators produce ozone at levels that pose health concerns.
- Little evidence is available on removal of gases from indoor air by air cleaners.
- Evaluations of HEPA filter air cleaners show that these units can effectively filter both indoor and outdoor-generated particulate matter (PM) from indoor air.
- On days when outdoor air quality is poor, HEPA filter air cleaners can reduce infiltration of outdoor-generated PM; lowered exposure may also lead to some health benefits, including improvements in blood vessel health.
- The use of HEPA filter air cleaners has been associated with reductions in some asthma and allergy-related

symptoms. Greater benefits are observed when other interventions, including HEPA-filter vacuums, impermeable bed coverings, and carpet removal, are employed in conjunction with air cleaners to improve indoor air quality.



### Introduction

Air cleaners can help to improve indoor air quality by removing pollutants from the air. Indoor air is a complex mixture of substances, including pollutants from both indoor and outdoor sources; health impacts of indoor air quality depend on the presence and concentrations of specific pollutants. Common indoor sources include: environmental tobacco smoke, wood stoves and fireplaces, cleaning products, personal care products, and new furniture (which can off-gas chemicals). Pollutants can also move from outdoors to indoors; common outdoor pollution sources are traffic, wood stoves, forest fires, and industry. Air cleaners differ in their set-up, operating technology, and in the volume of air they clean, all of which influence air cleaner effectiveness. Here we describe the main categories of air cleaner set-up and technology, as well as review evidence on the effectiveness of air cleaners in reducing exposure to, and health impacts of, indoor pollutants in residential settings.

We limit our discussion to common residential air cleaning technologies; ultraviolet photocatalytic oxidation and botanical air cleaning are not discussed.

This document is intended for environmental health practitioners and policy-makers who need to answer questions from the public concerning air cleaners or need to make decisions regarding the recommendation of air cleaners for reducing the public's exposure to air pollution.

## Types of air cleaners

Air cleaners can be grouped according to their set-up and operating technology.

### Set-up

Air cleaners can either be stand-alone, portable units designed to clean air in a single room or they can be in-duct units associated with the heating, ventilating, and air conditioning (HVAC) system, designed to clean air for the whole house. Each set-up is associated with its own advantages and disadvantages; while in-duct devices may be associated with higher operating costs and only clean air when the HVAC system is on, portable units only clean the air in the room in which they are placed.

### Operating Technologies

Air cleaners can also be broadly categorized into four types of operating technologies (Table 1):

- (1) **Mechanical filters** mechanically remove particles as they pass through the filter. Filters can be flat, pleated, or high efficiency particulate air (HEPA).
- (2) **Electronic precipitators (EPs) and ion generators** work to remove particles from the air by charging them. EPs charge an incoming stream of particles and collect them on an oppositely charged metal plate within the device. Ion generators charge particles, but do not collect them within the unit; instead, newly charged particles become more attracted to room surfaces (including walls, tables, floors) and are therefore, removed from the air.
- (3) **Sorption filters** remove gases through the process of adsorption whereby volatile organic compounds (VOCs) and other gases passing

through the filter bind to specific media present in the filter. The most common sorption filter is activated carbon.<sup>1</sup> Activated carbon filters are rarely found on their own in air cleaner models and are typically associated with another air cleaning technology, such as a HEPA filter.

- (4) **Ozone generators** work by releasing ozone into the air. Theoretically, ozone can remove pollutants such as VOCs by reacting with them to produce less harmless substances, such as carbon dioxide.<sup>1</sup> However, the levels of ozone produced by residential units are not effective at cleaning the air and can instead cause respiratory irritation.<sup>2,3</sup> Health Canada recommends against the use of ozone generators in residential settings, due to accompanying health concerns.<sup>4</sup> Ozone can cause further harm by reacting with other compounds in indoor air to form new pollutants. Ozone can react with terpenes (present in some household cleaning products containing pine, lemon, and orange oil) to form submicron particles (particles smaller than 1 µm) and with nitric oxide (released from indoor sources such as gas stoves and un-vented kerosene heaters) to form nitrogen dioxide, another respiratory irritant.<sup>2,5,6</sup> Some EPs can also produce ozone as a by-product and are, therefore, associated with similar health concerns.<sup>7</sup>

## Effectiveness of air cleaners in reducing indoor pollutant exposures

### Particles

Studies have found that HEPA filter air cleaners and EPs can effectively remove particles from residential settings, including those from indoor sources, such as environmental tobacco smoke (ETS), fungal spores, dust, and pet allergens<sup>8-11</sup> and from outdoor sources, such as traffic and wood smoke.<sup>12,13</sup> In general, the conditions under which air cleaners are evaluated vary between studies, which can account for the range of efficiencies found; studies vary with respect to the number, types, and period of time air cleaners are used, baseline pollutant concentrations, and air exchange (the rate by which indoor air is replaced by outdoor air) within the room/home. Most studies of air cleaner effectiveness have focused on investigating the removal of PM by portable HEPA filter air cleaners. For indoor sources, researchers have found

the use of portable HEPA filter air cleaners are associated with reductions of 90% in dog allergen concentrations compared with baseline levels in a room within 24 hours of use,<sup>9</sup> reductions of 80% in

fungal spore concentrations in a room compared with baseline levels within 24 hours,<sup>11</sup> and reductions of 30-70% in baseline ETS particles in a home after a 2-month period.<sup>10</sup>

**Table 1:** Summary of major air cleaner operating technologies

Design	Pollutants Targeted	How they Work	Limitations
Mechanical filters	Particles	<ul style="list-style-type: none"> <li>– Particles move across filter and are removed based on particle size.</li> <li>– Filters can be flat, pleated or high efficiency particulate air (HEPA).</li> </ul>	<ul style="list-style-type: none"> <li>– Portable HEPA filter cleaners have a limited volume of air they can clean; appropriate room sizing and reducing air exchange rates are important to air cleaner effectiveness.</li> </ul>
Electronic precipitators	Particles	<ul style="list-style-type: none"> <li>– Charge an incoming stream of particles and collect them within the device on an oppositely charged plate.</li> </ul>	<ul style="list-style-type: none"> <li>– Units may produce ozone as a by-product, and therefore pose a potential health concern.</li> </ul>
Ion generators	Particles	<ul style="list-style-type: none"> <li>– Charge particles in the air to increase their deposition onto room surfaces.</li> </ul>	<ul style="list-style-type: none"> <li>– Particles deposited on room surfaces can be re-suspended in the air.</li> </ul>
Activated carbon filters	Gases	<ul style="list-style-type: none"> <li>– Gases move across the filter and adsorb onto the filter.</li> <li>– Typically found in hybrid air cleaners, which incorporate the use of more than one cleaning technology, such as a HEPA filter.</li> </ul>	<ul style="list-style-type: none"> <li>– Not all gases can be removed.</li> <li>– Filters can become loaded, and need to be replaced in a timely manner.</li> </ul>
Ozone generators	Gases	<ul style="list-style-type: none"> <li>– Release ozone into the air to react with indoor pollutants.</li> </ul>	<ul style="list-style-type: none"> <li>– The levels of ozone produced are ineffective at cleaning, and pose a health concern; their use is not recommended in residential settings.</li> </ul>

Studies investigating outdoor-generated PM in homes have found that portable HEPA filter air cleaners are associated with decreased indoor concentrations. One study reported lower PM<sub>2.5</sub> concentrations during a 48-hour period in which two portable HEPA filter air cleaners were operated, compared to a consecutive 48-hour period in which cleaners were operated without filters; geometric mean PM<sub>2.5</sub> concentrations across all homes (n=21) were 4.7 µg/m<sup>3</sup> and 12.6 µg/m<sup>3</sup> for the filter and non-filter period, respectively.<sup>13</sup> Since all homes included in the study were located less than 350 m from a major road, it

was assumed that traffic-related PM was a major contributor to indoor PM. In a similar study, researchers investigated PM<sub>2.5</sub> infiltration (F<sub>inf</sub>) in homes affected by residential wood-burning smoke during a 7-day period when two portable HEPA filter units were operated and during a consecutive 7-day period when air cleaners were run without filters. Infiltration is a measure of the amount of air pollution moving indoors and remaining suspended in air; lower infiltration is expected as, theoretically, pollutants remain in indoor air for a shorter period of time when air cleaners are used. A lower average F<sub>inf</sub> across all

homes (n=25) was found during the filter period ( $0.20 \pm 0.17$ ) compared to the non-filter period ( $0.34 \pm 0.17$ ). Similar results were found when a portable HEPA filter was operated in homes affected by either forest fire or wood smoke over a 24-hour period; average  $F_{inf}$  values across all homes (n=29) of  $0.13 \pm 0.14$  and  $0.42 \pm 0.27$  were found for the filter and non-filter period, respectively.<sup>12</sup>

Fewer studies have investigated the use of EPs in reducing indoor particle levels; such studies have found that EPs can lead to substantial decreases in PM levels.<sup>14,15</sup> One study found that the use of portable EPs in homes affected by forest fire smoke resulted in 63-88% lower PM<sub>2.5</sub> concentrations compared to homes matched by age and air exchange rate where no air cleaner was used over a 24-48 hour test period.<sup>14</sup> In another study, researchers compared particle removal efficiencies of in-duct EPs operating in an unoccupied test home with those of in-duct and portable HEPA filters.<sup>15</sup> Higher particle removal rates were found for the in-duct EP compared with either induct or portable HEPA filters over an 80 minute test period; researchers concluded that in-duct EPs were more effective at removing particles compared with in-duct HEPA filters. The same study found that the use of an in-duct HEPA filter was associated with a higher particle removal rate ( $2.4 \text{ hr}^{-1}$ ) compared with the operation of a portable HEPA filter air cleaner ( $1 \text{ hr}^{-1}$ ) over an 80-minute period.<sup>15</sup> Researchers concluded that in-duct filters are more effective at reducing whole house pollutant levels compared to portable air cleaners.

Only one other study has compared the use of in-duct versus portable air cleaners. Researchers estimated indoor levels of asthma triggers, including cat allergen, ETS particles, and fungal spores with the use of in-duct HEPA filters and portable HEPA filter air cleaners in two residential settings over a 24-hour period.<sup>16</sup> Levels of these triggers were modeled for different meteorological and air exchange conditions, using empirical data from chamber studies. In-duct filters were estimated to lead to lower levels of cat allergen, ETS, and fungal spores by 30-55%, 90-98%, and 50-57%, respectively, when compared to other filtration configurations, including the use of two portable HEPA filters. Air exchange rate (AER) was found to be a major influential factor in the effectiveness of filtration, with lower levels being associated with greater effectiveness.

One main factor influencing air cleaner effectiveness is AER. Overall, studies have found greater reductions

in pollutant concentrations associated with air cleaner use when air exchange is limited within the room in which a portable air cleaner is used;<sup>10,11</sup> theoretically, a lower AER allows cleaners to clean a larger volume of air before it is replaced. AER is also an important contributing factor to overall indoor air quality; it can be increased or decreased to improve air quality, depending on whether indoor or outdoor sources are dominant. A lower AER can reduce the influence of outdoor-generated pollution on indoor air quality because less of the outdoor pollution is being introduced indoors; in some cases a reduced AER can deteriorate indoor air quality by allowing indoor-generated pollutant levels to build up. Under conditions where AER is lowered with the aim of reducing outdoor pollution from entering indoors, such as during periods of high residential wood burning activity, air cleaner use may be particularly beneficial.

## Gases

Sorption filters, such as activated carbon and ozone generators, are designed to remove gaseous pollutants from air; limited evidence is available on their effectiveness. In an evaluation of VOC removal by air cleaners, researchers found that removal efficiencies of VOCs varied even for the same air cleaner; air cleaning technologies included sorption (activated carbon) and ozone generation.<sup>1</sup> Activated carbon filters efficiently removed heavier VOCs such as ethylbenzene and n-decane, but could not remove lighter and more volatile compounds, such as formaldehyde. In general, removal efficiencies of media filters are dependent on factors such as the filter density, flow rate of air moving through the filter, and on the specific sorbent material used. Researchers noted that since sorption filters can become saturated with use, periodic replacement, as specified by the manufacturer, is important to their effectiveness. This same study found that the use of an ozone generator was associated with effective removal of only one out of 16 VOCs investigated; similar results have been found in other studies.<sup>17</sup> Since their use is associated with health concerns, residential ozone generator use is not recommended.

## Health benefits

Many manufacturers claim that the use of air cleaners is beneficial to health, but results from studies investigating the health benefits of air cleaners are mixed. No studies investigating the health benefits of gaseous pollutant removal by air cleaners were

identified. Researchers have investigated the relationship between particle removal by air cleaners and health outcomes such as respiratory symptoms related to asthma and allergies, lung function, airway hyperresponsiveness, and microvascular function (MVF). In a review of six randomized controlled trial studies, investigating the use of portable ion generators in homes, researchers found no evidence to suggest an association between use of ion generators and health benefits, including changes in asthma and allergy-related symptoms, medication use, peak expiratory flow (PEF) or forced expiratory volume in one second (FEV1).<sup>18</sup> A systematic review of 10 randomized trials involving portable HEPA filters found that the use of these air cleaners was associated with fewer asthma and allergy-related symptoms, including wheeze, cough, and rhinitis, but was not associated with medication use or peak expiratory flow values.<sup>19</sup> Findings from several studies that have found positive associations between air cleaner use and health benefits indicate that when air cleaners are used together with other interventions aimed at improving air quality, including the removal of sources (e.g., cigarette smoking in homes), removal of carpets, use of impermeable bed coverings, and reduced AER, greater reductions in asthma and allergy-related symptoms can result.<sup>20</sup>

Researchers have also investigated the use of air cleaners on health symptoms related to outdoor-generated pollution in homes, including traffic related pollution<sup>13</sup> and forest fires.<sup>21</sup> One study investigated microvascular function (MVF), a measure of blood vessel health, among participants (aged 60-75 years) following filtering of indoor air over a 48-hour period within homes located less than 350 m from a major road. MVF was improved by an average of 8% among participants during the 48-hour filter period compared with the consecutive 48-hour non-filter period. A study of respiratory symptom reporting among community members affected by forest fire smoke showed an association between the use of portable HEPA filters and decreased frequency and duration of respiratory symptoms among residents using cleaners versus those who did not use air cleaners.<sup>21</sup> Other interventions, such as mask use and evacuation from the area, were not associated with any such decrease. Although this study lacked exposure measurements, the results do suggest that the use of air cleaners could provide some health benefits under specific conditions.

## Air cleaner standards

The vast number of air cleaners available on the market, as well as manufacturers' claims on effectiveness, can make it difficult to compare between units. Performance ratings can be helpful, but they are not available for all air cleaners. No standard testing methods have been developed to evaluate the removal of gases by air cleaners. Two industry rating systems have been developed to provide a performance measure for the removal of PM: the Minimum Efficiency Reporting Value (MERV) for in-duct HEPA filters and the Clean Air Delivery Rate (CADR) for portable HEPA filter devices. The MERV rating system has been developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). This system assigns the filter with a number (from 1 to 16) based on a performance test comparing concentrations of particles sized between 0.3 and 10  $\mu\text{m}$ , upstream and downstream of the filter.<sup>22</sup> A rating for each filter corresponds to the particle removal efficiency of the filter, based on the specific size category of particles tested. The Clean Air Delivery Rate (CADR) ratings for portable units are specific to three pollutants (tobacco smoke, dust or pollen) and an air cleaner will receive a rating for each of these pollutants. The efficiency of the device is based on the difference between pollutant concentrations in a test chamber with and without air cleaner use. These efficiencies are then translated to CADR ratings which describe efficiencies at various room sizes.<sup>23</sup>

## Evidence Gaps

Several gaps exist in the current body of knowledge regarding air cleaner use. Little research is available on the effectiveness of air cleaners in removing gaseous pollutants, including VOCs. This is an important gap as many indoor sources of VOCs can contribute to poor indoor air quality. Although several studies show that HEPA filter air cleaners are effective at reducing indoor pollutant levels, the health benefits of their use are not as well established. The use of HEPA filters is a promising intervention, but more work is needed to investigate the association between their use and specific health outcomes.

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