UNDERWRITERS LABORATORIES INC.

UL 200A

GUIDANCE DOCUMENT

Use of Do-It-Yourself Filtration Devices During Wildfires

Guidance Document Use of Do-It-Yourself Filtration Devices During Wildfires, UL 200A

First Edition, Dated April 19, 2022

SUMMARY OF TOPICS

This guideline publication of UL 200A dated April 19, 2022 presents evidence-based, actionable procedures to help communities in need of clean air during smoke events to construct and safely use DIY filtration devices with reduced fire hazards.

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PREFACE

Do-It-Yourself (DIY) air cleaners (i.e., furnace air filter attached to electric box fans) are being used to filter out smoke particulates during wildfire smoke events. These consumer-level box fans were not being used in a manner originally intended by the manufacturers, and safety under these conditions had not been evaluated according to market accepted safety certification processes. Chemical Insights Research Institute of Underwriters Laboratories Inc. (CIRI) with support of the Office of Research and Development at U.S. Environmental Protection Agency conducted a study assessing the potential fire risks (overheating and fire ignition) of these operating DIY air cleaners. Discussions and reviews were facilitated among an expert volunteer group (the Taskforce) to discuss the implications of the research results, as well as gather and consolidate the safety considerations for the use of DIY air cleaners.

The Taskforce, consisting of public health advocates, environmentalists, fire experts, and chemical exposure experts, was instrumental in bringing the science forward and summarizing key facts and action steps that can be taken to reduce fire and other physical risks. Chemical Insights Research Institute of Underwriters Laboratories Inc. is pleased to bring you this guidance document.

The following volunteers are acknowledged for their participation in this open and engaging dialogue and documentation:

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1 Introduction and Purpose

Wildfires occur throughout the world and can begin and end any time of the year. Wildfires are fires started by unintentional ignitions (natural ignition such as lightning to accidental human ignition). From 2011-2020, there was an average of 62,769 wildfires annually and an average of 7.5 million acres of land impacted annually in the United States (U.S.).[1] There has been an increase in area burned and an increase in smoke days per year due to many factors such as land management practices, climate change, and other human factors.[2,3] Additionally, there is an increasing number of homes within the wildland urban interface (WUI) (nearly 50 million homes currently) that have the potential to be near wildfires and even more residents downwind who may be affected by poor air quality due to wildfire smoke.[3]

Wildfires are a major source of pollutants such as fine and ultrafine particulates and volatile organic chemicals (VOCs).[4,5] Estimates show that wildfires have accounted for up to 25% of $PM_{2.5}$ (particulate matter with diameter <2.5 μm) in recent years across the U.S., and up to 50% in some Western regions.[3] Wildfire $PM_{2.5}$ contributes to adverse health effects (Figure 1) such as exacerbation of asthma, chronic obstructive pulmonary diseases, and circulatory effects such as heart attacks and stroke. There is a stronger association between wildfire PM and respiratory issues than cardiovascular issues.[2,5] Wildfire PM can be of special concern to those at risk including people with preexisting health conditions (e.g. heart disease, lung disease, diabetes), pregnant women, older adults, children, people who are more likely to be exposed such as outdoor workers, and those without access to healthy environments as well as easy access to healthcare which may be the case for some underserved communities.[2,5]

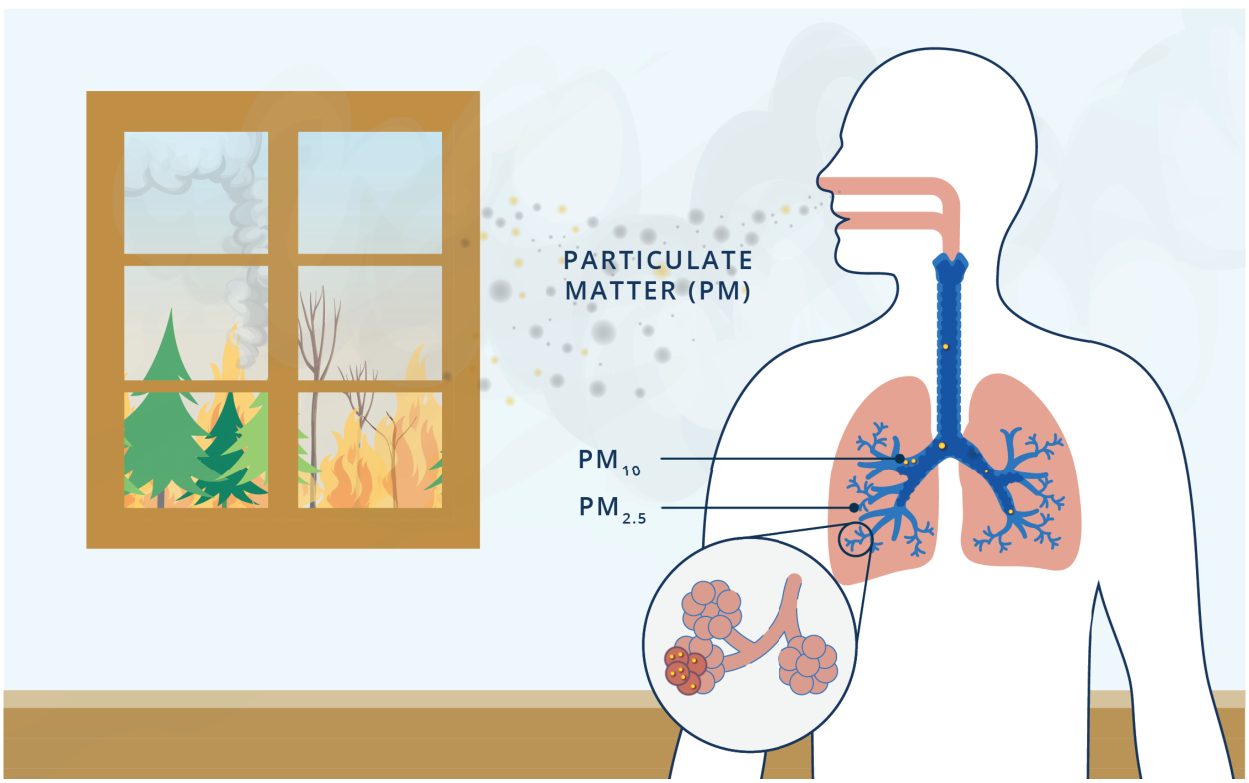


Figure 1

A schematic diagram showing the pathway of inhaled PM from smoke, through the airway and into lungs. Ultrafine particles can potentially enter the bloodstream

Combustion gases released from fires include carbon dioxide, carbon monoxide, nitrogen oxides, ozone, methane, nonmethane organic compounds (formaldehyde, formic acid, methanol acetaldehyde, acetic acid)[2,6] as well as other hazards such as polychlorinated dibenzodioxins/dibenzofurans (PCDDs/PCDFs), and polycyclic aromatic hydrocarbons (PAHs).[7] Gases emitted include irritants, carcinogens, mutagens, and neurotoxins; they can aggravate heart and lung diseases including asthma.[8]

Wildfire smoke can travel long distances and concentrations can vary from site to site and time to time based on conditions such as meteorology, topography, fuel profile, fire intensity, time of the day (diurnal effect), and chemical reactions.[2] Wildfire smoke can rise up to 2 – 6 km through the free troposphere (the lowest levels of the atmosphere), traveling over thousands of kilometers before reentering the boundary layer when the plume subsides. The smoke undergoes chemical and physical transformation as it travels though the atmosphere, affecting populations miles away with different chemical/particle composition at different exposure levels.[8] The following sections cover ways to reduce smoke exposure using a do-it-yourself (DIY) air cleaner and provide guidance on how to safely operate the DIY air cleaner to minimize any risk of the device overheating or causing fire.

2 Available Mitigation Strategies and Feasibility

There are several ways to reduce or avoid exposure to wildfire smoke, however, not all are feasible options.[9,10] The following options represent some mitigation strategies effective for reducing smoke exposure, not immediate physical fire risk.

- Relocation to safe areas may help to completely avoid exposure to wildfire smoke, however, relocation may not be possible/likely since smoke can be widespread, transportation is limited, and/or safe places are not available or inconvenient to reach.

- Indoor infiltration of smoke and exposure can be reduced by staying indoors, closing doors and windows, sealing door and window leaks, running heating, ventilation, and air conditioning (HVAC) systems in a recirculation mode in buildings that have HVAC systems. However, in the absence of cooling by ventilation or with outside air, a potential tradeoff for clean air is a higher indoor temperature. Overheating is more of an acute health risk than smoke exposure. If the indoor space cannot be adequately cooled and the smoke is intolerable, the best option may be relocation to an area where cooling is available.

- Replacement of HVAC filters with pleated ones having a Minimum Efficiency Reporting Value (MERV) of 13 is recommended, but many HVAC systems are designed to only operate with filters having MERV ratings from 8 to 11. Consult with the manufacturer of your HVAC system or a local HVAC technician to determine if your system can handle a high-MERV filter.

- Reduced physical activity can lower inhaled doses of pollutants, but this may interfere with lifestyle.

- Use of personal protective equipment such as masks are effective but only if they are selected and worn properly for $PM_{2.5}$ filtration. These include N95 masks (or equivalent) if they can be obtained. However, these only benefit those wearing them, and use can increase discomfort, breathing difficulty, and heat/sweat .

Sensors and outdoor air quality measurements can assist in deciding when to seek cleaner air. There are PM sensors ($70 – $500) that can be used for indoor and outdoor environments, specific to one's location. Outdoor air quality is monitored and forecasted by various government or community agencies and the data and exposure guidance can be found in the resources below:

Air Quality Index (AQI) by the U.S. Environmental Protection Agency[11]	https://www.airnow.gov/
Fire and Smoke Map by the U.S. Environmental Protection Agency[12]	https://fire.airnow.gov/
Air Quality Forecast by the National Oceanic and Atmospheric Administration[13]	https://www.ncdc.noaa.gov/societal-impacts/wildfires/
Websky Air Quality Forecast by the U.S. Forest Services[14]	https://tools.airfire.org/websky/v2
5-3-1 index using visibility to estimate health effects[15]	https://oregonsmoke.blogspot.com/2015/06/use-5-3-1-visibility-index-if-there-is.html?m=0

Filtration is one of the most effective and feasible controls to improve indoor air quality for many affected by smoke events. Studies have shown that air filtration devices reduce PM exposure indoors. Applying higher performance filtration on supply ventilation in homes reduced outdoor particles by up to 97%,[16] and portable air cleaners reduced PM exposure indoors by 48 – 78%.[17]

Household use of portable air cleaners has increased in the face of recent wildfire activity and in response to COVID-19, but they may be in limited supply during smoke events and cost can be prohibitive. Some organizations have begun recommending do-it-yourself (DIY) air cleaners (i.e., furnace air filter attached to electric box fans) during smoke events as DIYs offer an affordable and accessible alternative to commercially available air cleaners. Preliminary data show DIY air cleaners are effective at removing particles indoors. A MERV 13 fan filter unit was highly effective at reducing indoor $PM_{2.5}$ and particles 0.3 – 1.0 µm.[18] Early data show DIY air cleaners to be comparable to small commercial air cleaners with a clean air delivery rate (CADR) of < 100 ft^3/min to medium sized commercial air cleaners with CADR of around 200 ft^3/min.[19–21] CADR refers to the amount of filtered air that an air cleaner can deliver. Preliminary data suggest that the CADR of DIY air cleaners can range from 117 ft^3/min with a single filter attached to 800 ft^3/min with a 5 filter set up, however other parameters such as noise level can be different than commercial air cleaners (further comparison in the latter section).[20,22]

3 Use of DIY Air Cleaner

Only three parts are required to make a DIY air cleaner: a box fan, an air filter, and duct tape (or equivalent to secure the filter to the fan). The box fan used typically has a cross sectional area of 20” x 20”. The box fan must be certified to meet the safety standard for electric fans (UL 507[23] or equivalent) and must have been manufactured in 2012 or later with a fused plug. Older box fans could potentially catch fire if the motor locks up under load and overheats.[19]

To achieve a better seal between the box fan and filter, a box fan that is designed without a power cord and/or a switch/dial on the back (air intake side) of the fan is recommended. A box fan designed without a power cord and/or a switch/dial on the back (air intake side) of the fan is recommended for a better seal. An air filter with a cross sectional area of 20” x 20” with a MERV rating of 13 or higher should be used for PM removal indoors.

STEP 1:

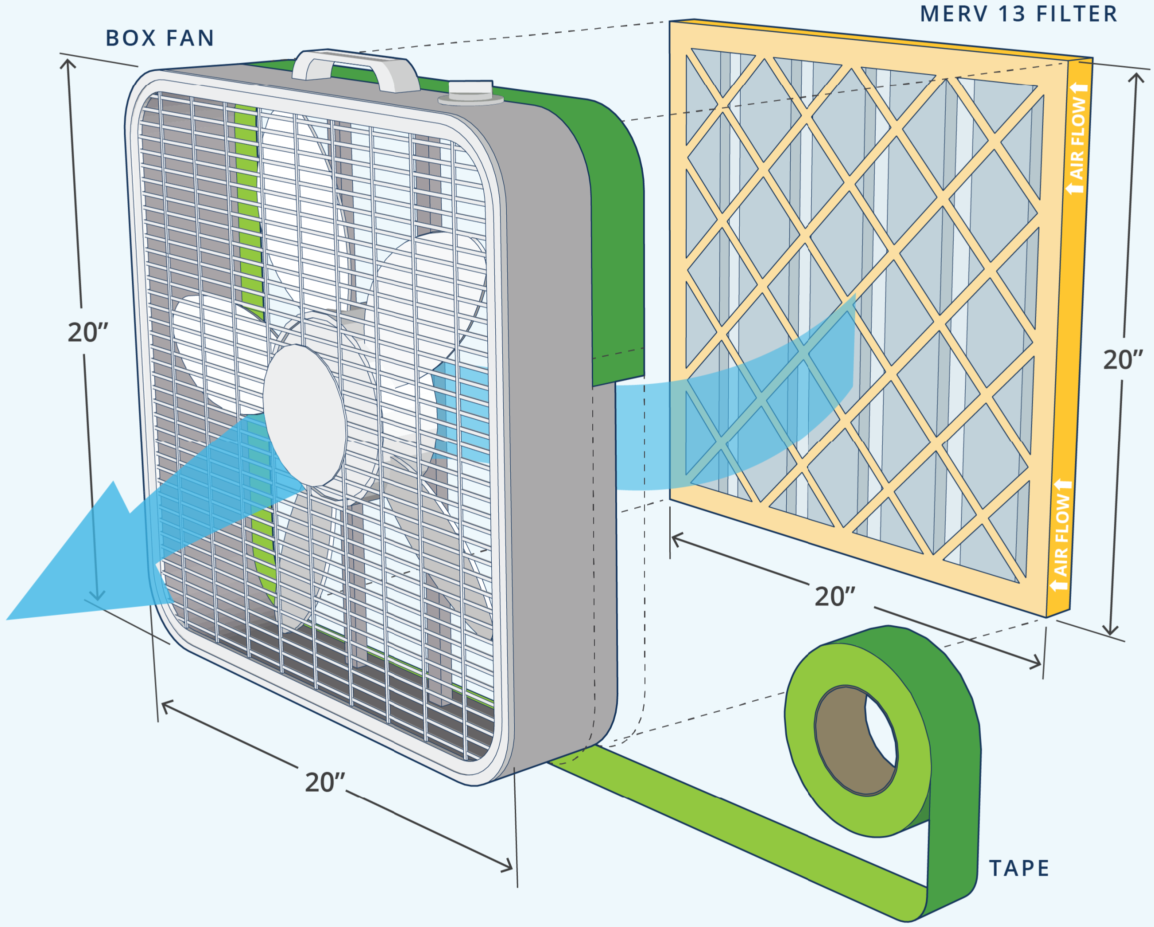
LOCATE THE FRONT OF THE BOX FAN

Identify which side of the fan is the front (the side that blows the air out) and which side of the fan is the back (the side that sucks that air in). Typically, the fan brand name or logo is located on the front of the fan.

STEP 2:

LOCATE THE FRONT OF THE FILTER

Identify which side of the filter is the front (the side that pulls the air through). There is typically an arrow on the side of the filter that indicates the direction of airflow. Place the front of the filter against the back of the fan.



STEP 3:

ATTACH THE FILTER TO THE BOX FAN WITH TAPE

Once the box fan and filter are correctly positioned (the front of filter is placed squarely against the back of fan), use tape to attach them together. Apply enough tape so that the filter is securely attached to the fan and the seam is continuous with no gaps. Clamps, bungee cords, or string may also be used in the absence of tape.

Figure 2

DIY air cleaner assembly

DIY air cleaners are constructed by attaching the air filter to the suction side (back) of the box fan, so the fan pulls air through the filter (Figure 2). Tape (e.g., duct tape or packing tape) is often used to seal the fan and the filter (wrapped around once on all 4 sides). Other options include clamps, bungee cords, and strings, as long as there is a tight seal between the filter and the fan. Sealants and wet glues are not recommended as they may be an additional source of VOCs in the room and may complicate filter replacement. The more the DIY air cleaner operates, the cleaner the air within the room will be if the filters are replaced frequently, and the fan is cleaned and well maintained. A visibly soiled filter should be replaced well before it gets clogged to the point that airflow through the filter is significantly restricted. A dirty filter (right filter in Figure 3) can be observed by the heavy collection of observable debris and in some cases by a smokey or chemical odor. The filter needs to be replaced more frequently when the fire smoke is intense.

Figure 3

DIY air cleaner with a clean filter, a used filter that should be replaced, and an overused filter (from left to right). A filter must be replaced prior to reaching the condition on the right.

Photo credit: US EPA

The benefit of using a DIY air cleaner is that it only requires three items to construct; these items are readily available in retail home improvement stores, both walk-in and on-line; and assembly is simple. A DIY air cleaner is economical with costs of about $35 in parts, compared to commercial air cleaners ranging from approximately $100 to $1200 in costs. Replacement filters are also more easily available and affordable than commercial air cleaner filters.

One tradeoff of DIY air cleaners is that they may be louder to operate especially at the highest speed setting (67 dB versus 55 dB on average for a typical commercial air cleaner). In addition, some DIY air cleaners may generate heat, and dirty filters may not be visually or olfactorily pleasing, even though the filter is still effective at removing PM in air. DIY air cleaners can also require slightly higher power usage (53 – 98 watts)[24] compared to commercial air cleaners (40 – 60 watts).[20]

There are multiple designs to attach filters onto a box fan:

- One filter attached flush against the inlet side of the fan
- Two filters to create a triangular shape
- Four or five filters to create a cube with the fan.

Generally, as more filters are attached filter surface area increases allowing increased filtration effectiveness. In addition, less backpressure is applied to the box fan as more filters are added and this may, in turn, increase the longevity of operation before filters need to be changed. The remainder of the document will discuss the most common setup of one air filter and one box fan.

4 Fire Safety of DIY Air Cleaner

There were concerns regarding the safety of DIY air cleaners as these box fans were being used in a manner not intended by the manufacturers and they had not been evaluated for safety hazards according to market acceptability. Specific safety concerns identified with the DIY air cleaner included potential electrical/fire hazards with DIY set up, especially loaded filters; tripping opportunity; and unattended/extended operation. To understand the fire potential of operating a DIY air cleaner, a study was conducted on the fire safety performance of a series of DIY air cleaners with various filter attachment scenarios.

Five box fan models (approximately 20” x 20” in size) were tested with a single layer filter (MERV 13) attached to the backside of each fan. The single filter construction was selected to put the largest stress on the box fan, since a single filter results in a larger pressure drop than multi-filter configurations. Additionally, this is the most widely used DIY configuration due to its simplicity. Six filter scenarios were evaluated with an operating box fan as described below:

1. No filter attached as the control fan;
2. New unused MERV 13 filter;
3. Smoke laden MERV 13 filter prepared with smoke from biomass burning to represent a loaded filter due to a wildfire;
4. Dust laden MERV 13 filter prepared with standardized dust composition to represent a worst-case scenario loading from typical blockage generated by extended household use;
5. One-sided obstruction (i.e., complete obstruction on the backside);
6. Two-sided obstruction (i.e., complete obstruction on the backside and the fan tipped onto its front face, resulting in blockage on both.

A single layer of duct tape was used to attach the filter to the fan by applying it to all four sides. Continuous monitoring of temperatures on the box fans' exterior surfaces (including the plastic fan guard and switches) as well as internal fan components (including the power cord connection at the motor, the motor housing, and motor windings) was performed.

For all test scenarios, fans were operated for at least 20 minutes, and for at least seven hours for the extreme conditions where both sides of the fan were blocked.

From the experiments, it was found that all measured temperatures fell below the maximum allowable thresholds defined by the market safety standard for electric fans, UL 507. Across all fan/filter test scenarios, the most notable temperature increases, although within performance acceptance values, were observed at the motor and motor windings. It was found that exterior surfaces of the fan that can come into direct contact with people remained below 36°C and was not high enough to sustain injury (first-degree burns at 47.5°C) or feel pain from heat (44 °C). An extreme scenario where both the front and back of the fan were blocked for an extended period (of 7 hours) was evaluated and found not to present any observable fire hazards.

The study demonstrated that fire ignition was not achieved with any of the filter/fan scenarios tested. Some observations included:

- Variability in maximum temperatures was noted across different brands of fans for the various filter scenarios;

- A temperature increase occurred at the motor, winding, and power cord connection at the motor regardless of filter conditions (i.e., clean, smoke-loaded, and dust-loaded filters) when a filter was attached;

- The temperatures at the guard, switch, and output air increased with the extreme scenario where both sides of the fan were obstructed, but otherwise the units remained at or below ambient temperature;

- When the temperature at various locations did increase, it increased within the first 20 minutes of the fan being turned on and remained steady for the rest of the extended time of operation;

- Air flow was reduced when a filter was attached, by 30% with a new clean filter up to 70% with a filter overloaded with dust.

This study assessed DIY air cleaners for use in indoor environments at room air temperatures near 20°C. Further analysis may be required for situations where ambient room air is higher (e.g., 40°C). Should the blade turning be obstructed in some way (i.e., locked rotor), it is possible that further heating could be created resulting in an additional hazard. However, fans that have been shown to meet UL 507 are also required to pass the locked rotor test. The study was conducted on a limited number of fans readily available in the marketplace and results may not be representative of all available fan models. Research results do not imply that the fans or fans with filters used in this study and with the described filter conditions meet UL 507; that can only be confirmed with compliant safety testing requirements and third-party verifications.

5 Safety Considerations for Community Use of DIY Air Cleaner

Key considerations for reducing fire and physical hazards that apply to DIY air cleaners are listed below (Figure 4).

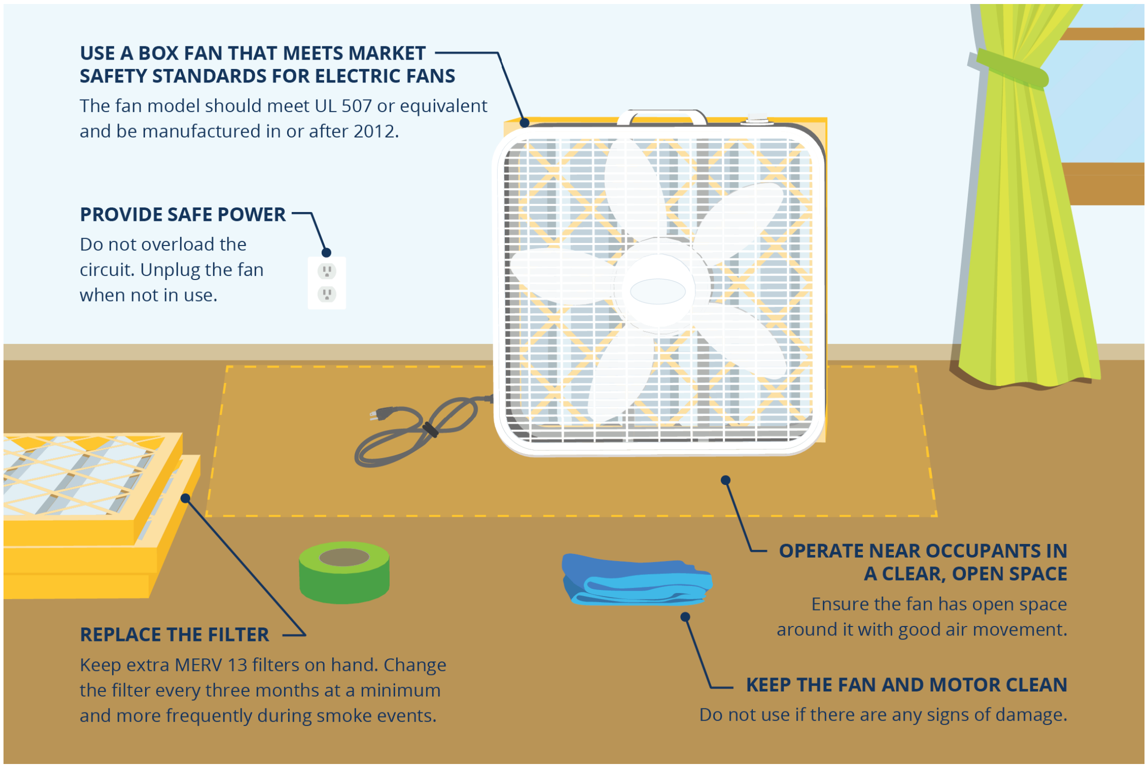


Figure 4

An infographic with safety guidance on DIY air cleaner

Set-Up :

1. Use box fans that have been verified by an accredited third party to meet the market safety standard for electric fans (UL 507 or equivalent). To find a verified fan, look for one with a UL, ETL, or other accredited safety organization marking.

    a. Use a newer model box fan (2012 or later). The newer models have added safety electrical features. Fans built prior to 2012 were not tested and may pose fire risks.

    b. While not recommended, if DIY air cleaners are built with older model box fans, they should not be used unattended or while sleeping.

2. Choose a clean, pleated high-efficiency filter, preferably rated MERV 13 for better filtration.

3. Align the arrows on the filter with the direction of the airflow through the fan.

4. Create a good seal between the fan and the filter.

5. Higher CADR may be achieved with the one-filter DIY air cleaner design when additional filters and/or filters with larger surface area (deeper filters) are used; however, the tradeoffs include larger fan footprint, cost, maintenance, and more time/skill in putting it together.

Before Use:

1. Use the fan in the room you spend the most time in.

   a. Move the DIY air cleaner from room to room where occupants are.

   b. May benefit from having more than one DIY air cleaner if smoke is very thick, your home is very leaky, or you are in a large room (approximately larger than 15' x 15').[25]

2. Keep windows and doors closed. The DIY air cleaner may not be as effective when used in a window and the filter will need to be changed more frequently.

3. Ensure the fan has open space around it with good air movement.

   a. Keep curtains and loose clothing away from the fan.

   b. Do not balance the fan on an edge or anywhere that it could fall off.

4. Keep electronics, cords, and outlets away from water sources to avoid shock.

5. Do not use if there are any signs of damage, or a broken/ frayed cord.

6. Avoid circuit overload and use an appropriate wattage extension cord when needed.

7. Avoid a tripping hazard by securing electrical cords.

8. Always ensure that there are working smoke detectors throughout the home and that family members have an escape plan in case of fire.

During Use:

1. Follow the box fan manufacturer's instructions.

2. Keep an eye on the temperature and make sure you do not overheat.[26] Some DIY air cleaners do generate heat.

3. During smoke events, filters will need to be replaced more often as well as at the end of a smoke event.

   a. Not changing the filter regularly may reduce airflow, filtration efficacy, and may re-release smoke particles/odor into the air (Figure 3).

   Note: The DIY air cleaner may start releasing an observable odor, but it may still be effective at removing particles

   b. Keep extra filters on hand and change the filter when dust accumulation becomes significant or when smoke odors are released (but at minimum every 3 months). Dust collection will reduce filter effectiveness.

After Use:

1. Always unplug the fan from the socket when not in use.

2. Keep the fan and motor clean.

3. It is important to take other steps to reduce your exposure to particles during wildfires. List from "2 Available Mitigation Strategies and Feasibility" include:

    a. Relocation

    b. Staying indoors

    c. Replacement of HVAC filters

    d. Reducing outdoor physical activity

    e. Use of personal protective equipment such as N95 mask when going outside

4. During wildfire seasons, consider operating DIY air cleaners on a routine basis.

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Appendix

DIY-Box-Fan-Report-2021.pdf (chemicalinsights.org)