

# Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events

## SECTION 1: PURPOSE

This planning framework provides recommended heating, ventilation, and air conditioning (HVAC) and building measures to minimize occupant exposures and health impacts from smoke during wildfire and prescribed burn smoke events. Wildfire smoke is composed of fine particulate matter ( $PM_{2.5}$ , particles less than 2.5  $\mu m$  in diameter) and gases. Although wildfire smoke contains multiple contaminants, this document focuses on controlling exposure to  $PM_{2.5}$ . Breathing high concentrations of these pollutants has many potential acute and chronic health consequences, including reduced lung function, pulmonary inflammation, bronchitis, exacerbation of asthma and other lung diseases, exacerbation of cardiovascular diseases, such as heart failure, and even premature death (1). While most healthy people will recover quickly from exposure to smoke during a wildfire episode, some susceptible populations are at greater risk of health effects, including people with existing health conditions, particularly of the heart or lungs (e.g., asthma or chronic obstructive pulmonary disease (COPD)), pregnant women, infants, children and older adults (1).

State and local health departments may issue air quality notifications and guidelines when actions are needed to protect the public. Building managers should use these notifications to know when to initiate smoke mitigation efforts, termed the "Smoke Readiness Plan". See Table 1 for further guidance on when to implement the plan. Consider implementing the plan when vulnerable populations are anticipated to be impacted by smoky conditions. To find out more about local ambient air quality see [AirNow.gov](https://airnow.gov) and state websites (2, 3). The US Air Quality Index, shown on [AirNow.gov](https://airnow.gov), has six categories indicating levels of health concern as a function of  $PM_{2.5}$  concentrations (4).

Table 1. Decision matrix for implementation of Smoke Readiness Plan.

Smoke Conditions <sup>1</sup>	Answers	Action
Currently smoky? Forecasted to be smoky in the coming days?	No No	Carry on with normal operations. Have your Smoke Readiness Plan prepared and ready.
Currently smoky? Forecasted to be smoky in the coming days?	Yes No	Consider implementing Smoke Readiness Plan.
Currently smoky? Forecasted to be smoky in the coming days?	No Yes	Consider implementing Smoke Readiness Plan.
Currently smoky? Forecasted to be smoky tomorrow?	Yes Yes	Implement Smoke Readiness Plan.

<sup>1</sup>To find out more about local ambient air quality see AirNow.gov and state websites (2, 3).

This planning framework focuses on reducing exposure to particulate matter. These recommendations apply to most commercial buildings, schools, multi-unit residential buildings and similar buildings that use air handling units to provide HVAC for occupied areas. However, these recommendations may not be feasible or optimal in some cases, and the building-specific relevance of each recommendation should be considered. In general, these recommendations are not intended for single-family houses or individual dwelling units. Healthcare facilities and other specialized buildings should rely on qualified HVAC staff and consultants. Being prepared to make quick and temporary modifications is key to protecting indoor air quality from high levels of smoke-related particulate matter. Ideally, implementing these measures will clean the air coming into the building and prevent infiltration of wildfire smoke. However, some buildings and HVAC systems are not designed and/or maintained to accommodate the modifications recommended in this guidance. In these cases, use of appropriately sized portable air cleaners can help (see Section 2.4) to create temporary cleaner air spaces. Building managers will need to assess whether these measures are sufficiently reducing the levels of smoke particulate matter (see Section 5). Assistance from an HVAC professional is generally required to assess existing HVAC equipment capabilities and implement portions of these recommendations.

The air needs to be cleaned as much as reasonably achievable whether ventilating with outdoor air or recirculating indoor air. To help building managers accomplish this, members of the ASHRAE committee drafting the Guideline 44P for Protecting Building Occupants from Smoke during Wildfire and Prescribed Burn Events developed this planning framework. This document outlines a process (shown in Figure 1) for making a building Smoke Ready. Figure 2 provides a flow chart of actions within this process, including assessing whether these actions have been

effective in reducing indoor PM<sub>2.5</sub> levels. This document explains how and why these actions should be taken before and during wildfire smoke episodes.

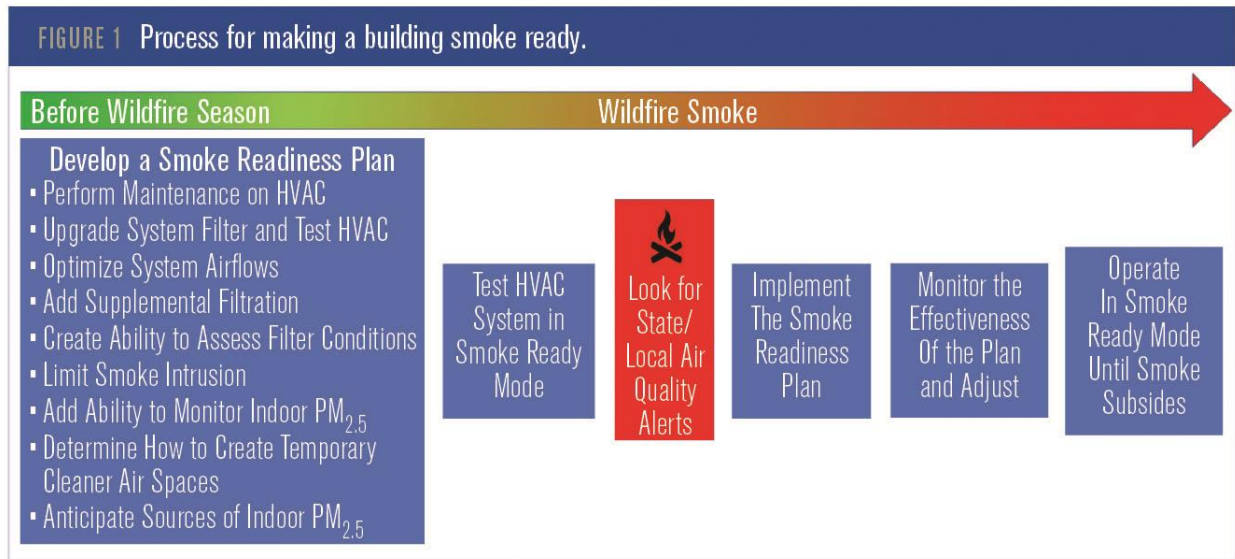


Figure 1. Process for making a building ready for a smoke event (Smoke Ready).

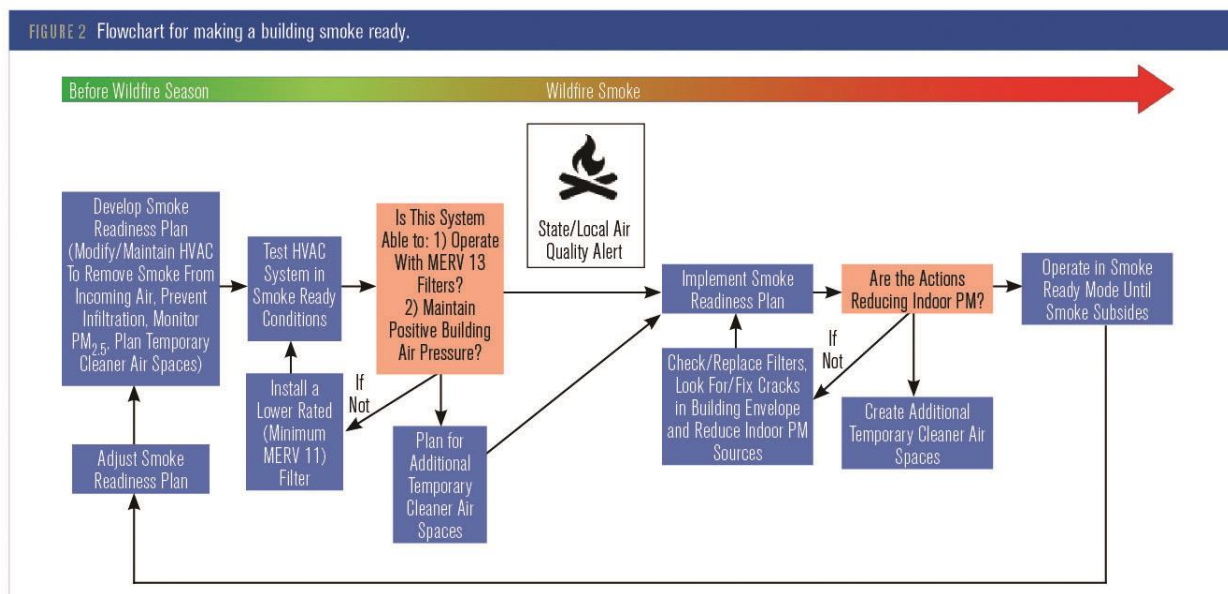


Figure 2. Flow Chart for making a building Smoke Ready.

## SECTION 2: DEVELOP A SMOKE READINESS PLAN

Create a written Smoke Readiness Plan specific to each building. Include checklists (examples below). The building-specific plan should address the following elements:

1. **Smoke Preparation Supplies.** Before wildfire season, purchase materials and supplies needed for the plan. For example, purchase portable air cleaners and extra filters in advance, as they may become difficult to find during a smoke event. Wildfire smoke can quickly load filters (see Figure 3) and they may need to be changed as frequently as daily. Purchase additional high-quality air filters; ones that are rated MERV 11 to 13 and higher can remove smoke particles. Preparedness is vital for smoke readiness. Plan ahead!
2. **Upgrade HVAC System Recirculation Filter(s).** MERV 13 or higher filters are recommended during smoke events. However, prior to wildfire season, HVAC systems must be assessed for ability to function properly with the upgraded filters. Before using higher MERV filters, check that your system can accommodate them (see Appendix).
3. **Maintenance of the HVAC system.** Repair broken dampers, actuators and HVAC controls prior to fire season. Pay special attention to economizers because they can be complex and may not be installed correctly. Well maintained equipment with known operating conditions is critical to providing good indoor air quality. See Section 2.1 HVAC checklist and Section 2.2 Special Note on Economizers, below.
4. **Optimization of System Airflows.** Economizer operation questions will often be the most difficult to answer and take the most time to research, so put them high on your list of things to address when making your Smoke Readiness Plan. Assess and maintain adequate airflows that are protective of human health and equipment health during smoke events. Prior to wildfire season, determine an outdoor air intake level that controls odor, temperature, CO<sub>2</sub> levels, and maintains a positive building pressure consistent with building and HVAC system design. Reduced ventilation may be acceptable for short periods to protect vulnerable populations (see Section 2.3). Care must be taken to avoid reducing the intake air too much, as this may create a negative building pressure, drawing smoke-laden air into the building through cracks around windows and doors as well as other unintentional openings in the building enclosure. Conducting a trial run of the system in smoke-readiness mode is described below.



Clean filter

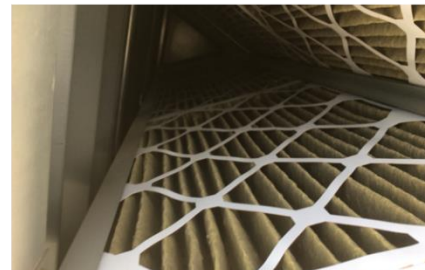


Figure 3. Picture comparing a clean filter to a filter heavily loaded with wildfire smoke.

5. **Supplemental Filtration.** During a smoke event, add additional filtration at the intake air vent where possible. Figure 4 shows a MERV 13 filter installed on an intake air vent. A minimum of a MERV 13 filter on the outdoor air intakes will capture a large fraction of the  $PM_{2.5}$ . Prior to fire season, inspect the air intake and make a list of filters (including the specific quantity and size of the filters), tape, temporary ducting materials and other items needed to mount filters to the air intake with minimal bypass around the filter (include these items in a list of Smoke Preparation Supplies, above). Ensure that proper installation instructions have been developed and are up to date. A filter with activated carbon may help control odors and the gases that cause them. Consult a licensed HVAC design professional to prescribe the right filter for your system. Consider having a contractor install permanent filter racks on the outdoor air intake.



Figure 4. Picture of a MERV 13 filter installed on an outdoor air intake

6. **Assessing Filter Conditions.** Prior to fire season, add a port or pressure gauge to measure the filter pressure drop on at least one air handling unit. This will simplify determining when to change filters. A rule of thumb is to change the filter when two times the initial pressure drop is observed. When the  $PM_{2.5}$  levels are high, these filters may need to be changed daily.
7. **Limit Smoke Intrusion.** Prior to wildfire season, weatherize the building envelope, doors and windows to reduce infiltration by sealing and caulking cracks. Keep doors and windows closed to limit smoke intrusion. If possible, plan to limit the allowable entrances to ones with a vestibule or airlock. If this is not possible, prepare to limit door use to only the doors on the opposite side of the building from prevailing winds during the smoke event. In advance, prepare signage to use on doors that will remain closed.
8. **Indoor  $PM_{2.5}$  Monitoring.** Prior to wildfire season, purchase one or more low-cost air monitors equipped with a  $PM_{2.5}$  sensor and install it in the facility, aiming to stay away from potential indoor sources of  $PM_{2.5}$  and outside of planned temporary cleaner air spaces (5). These monitors will not be as accurate as regulatory monitors but can show whether your interventions are reducing indoor  $PM_{2.5}$ . For example, upward trends in  $PM_{2.5}$  levels can indicate that doors or windows are open, air filters are degrading, or portable air purifiers



should be turned on. Make a plan for how the data from the monitor will be accessed and the actions that will be taken during a smoke event.

9. **Temporary Cleaner Air Spaces.** Determine how to create temporary cleaner air spaces within the building prior to fire season. Use portable room air cleaners of the appropriate size for the room with HEPA filters (or other high efficiency filters) and other methods to clean the air (see Section 2.4). Some portable air cleaners come with indicators that change color as the air quality improves. If the air cleaner does not come with an indicator function, it may be helpful to purchase a low-cost air monitor equipped with a  $PM_{2.5}$  sensor to determine whether the air is being cleaned. A low-cost air monitor may also help to verify that the  $PM_{2.5}$  concentration is in fact lower in the cleaner air space relative to other spaces in the building. Avoid air cleaners that produce ozone or are ion generators (see list of certified cleaners on California Air Resources Board website (6)).
10. **Anticipate Sources of Indoor  $PM_{2.5}$ .** Cooking, vacuum cleaning, printers, copy machines, and smoking are examples of activities that increase indoor  $PM_{2.5}$  levels. Understanding potential sources in the building can assist in the reduction of these sources during wildfire or prescribed burn events (7).

## SECTION 2.1: CHECKLIST TO DETERMINE IF THE HVAC SYSTEM IS READY FOR SMOKE

If the owner/occupant does not understand some of these questions or how to accurately answer them, they should find an HVAC professional who does.

1. Do the outdoor air dampers function correctly? Figure 5 shows a picture of a warped damper blade unable to close.
2. Are the damper blades, linkage and edge seals in good condition?
3. Does the building have a commercial thermostat or control system that allows the outdoor air dampers to remain closed when the system is set for an unoccupied state?
4. Are there record drawings, blower door tests, commissioning reports, equipment installation and service manuals or other information available?
5. Does the outdoor air economizer work correctly?
6. Can the minimum damper set point be changed, and the economizer function be temporarily shut off? How is this accomplished for each air handler?
7. Is it possible to disable or reduce the relief fan air flow?
8. Can the unit use MERV 13 or higher filters? Check the manual. If the building is LEED certified, MERV 13 filters should be easy to use without any alterations. If system cannot use



Figure 5. Picture of a warped damper blade unable to close.

MERV 13, use the highest MERV rated filter possible. There are alternative filtration technologies that allow filtration at a range of pressure drops.

9. An HVAC or Test Adjust and Balance (TAB) technician will be able to evaluate if installing MERV 13 filters will cause too much pressure drop for the system. Beyond the filters in the unit, system characteristics such as the duct configuration and dirt on air coils can also affect pressure drop. The goals are to maintain adequate airflow across the evaporator coil for the direct expansion cooling systems to function safely and to not overload the supply fan motor.
10. Confirm that all filters are properly seated, and edges are sealed. Air leakage around the filters will greatly reduce their ability to clean the air. Figure 6 shows a filter that is not seated correctly.
11. Check that the filter and fan access doors are fastened and sealed.
12. Have the building envelope, doors and windows been weatherized to reduce infiltration?
13. Where are the exhaust fans and how are they controlled?
14. Which exhaust fans are critical for safety?  
Examples are those serving isolation rooms, commercial kitchen hoods (if cooking is occurring) and hazardous locations.
15. Where are the locations of exhaust grills? Can they be partially blocked to reduce flow?
16. If the building has more than one air handler or rooftop AC unit, can some of them be set to recirculation and a small number used to provide filtered outdoor air?
17. Does the building have an air conditioning system or portable cooling units to prevent heat-related illness?



Figure 6. Picture of filter not seated correctly.

## SECTION 2.2: SPECIAL NOTE ON ECONOMIZERS

Most roof top units and larger HVAC systems are equipped with an outdoor air economizer. To save energy, the economizer uses outdoor air to replace the mechanical cooling system when temperatures allow. This can bring in large amounts of smoke and particulate matter into a building during wildfire season. The economizer control also maintains a minimum outdoor air damper position for ventilation, controls relief fans and may close the outside damper when the building is unoccupied. Care and regular maintenance are recommended to ensure the economizer operates as intended.

There are numerous manufacturers and control schemes for economizers. Finding effective work arounds to temporarily limit the economizer damper operation in response to wildfire smoke is challenging. It is recommended to plan and investigate what actions are needed to limit operations,



this may include adding switches and control relays. Other work arounds may also be required. Ensure that the system can be restored to its normal operating conditions after the smoke event. For example, a simple solution is to place the outdoor air damper in manual control and set the position to allow the minimum air required for ventilation. A building automation system may have this ability. Another technique is to disconnect the damper actuator and manually set the damper position, then physically hold the damper position in place with blocking, wire or a clamping tool. Regardless of the method, installing filters on the air intake is recommended.

These temporary economizer bypass measures are to limit the amount of outdoor air and  $PM_{2.5}$  brought into the building. Having the ability to quickly respond to changing conditions is needed to minimize adverse health outcomes.

### SECTION 2.3: CONSIDERATIONS FOR SARS-COV-2

HVAC filtration and air cleaning recommendations for smoke and SARS-CoV-2 are similar due to similar respirable particle sizes. The difference is the outdoor air ventilation rate: a low rate is desirable for smoke control and a high rate is desirable for removal of SARS-CoV-2 virus particles (8,9). Additionally, improved HVAC filtration must be located in the recirculation air to mitigate risk from SARS-CoV-2. The building manager's challenge is to monitor system components and indoor conditions and change system settings as outdoor air quality changes to balance potential tradeoffs between smoke and SARS-CoV-2 exposure. Portable air cleaners with a HEPA filter (or other high efficiency filters) may be helpful in removing virus particles as well as smoke particles without increasing the amount of outdoor air. Additional COVID-19 considerations for cleaner air spaces and cleaner air shelters are available (10).

### SECTION 2.4: USE OF PORTABLE AIR CLEANERS

If the HVAC system is not able to reduce the  $PM_{2.5}$  concentrations sufficiently throughout the building, a cleaner air space can be created using one or more portable air cleaners with a HEPA filter (or other high efficiency filter) in a closed room. It is important to have a correctly sized air cleaner(s) for the space. Multiple devices may be needed for larger rooms. The Association of Home Appliance Manufacturers has developed a rating system and room size recommendations for portable air cleaners (11). The smoke clean air delivery rate (CADR) is the rating for 0.09 to 1.0 micron particles and represents the amount of clean air delivered on the high-speed setting. Units with a sufficient Smoke CADR, recommended room size for the application, and low noise ratings are recommended (12). For wildfire smoke, AHAM recently updated their sizing recommendation to a Smoke CADR equal to the size of the room in square feet (13). EPA also provides additional information on the selection and use of portable air cleaners (7, 14). Do-it-yourself room air cleaners using a box fan and a MERV 13 filter provide air cleaning similar to a small room (100 ft<sup>2</sup>) air cleaner but with more noise, which may limit their usefulness. These fans should not be left unattended or placed near water (15) and users should read the fan's safety information and follow the fan's operating instructions. Additional information on creating cleaner air spaces can be found in the references and additional resources (16, 17).

## SECTION 3: TEST HVAC SYSTEM IN SMOKE READY MODE

When the Smoke Readiness Plan is prepared and before the start of wildfire season, test the HVAC system with the additional filtration and adjusted flow settings. There may be several non-functioning items that will take more time to fix than emergency conditions allow. Tips for the trial run:

- If there is a building automation system, make a list of controller settings and changes that need to be made. It will speed and simplify implementing the plan during a smoke emergency. Install the filters and test the system.
- When adding filters, adjusting dampers and exhaust settings, position a person with a cell phone/walkie talkie at an exterior door to observe and confirm that the building pressure remains slightly positive to the outside. To check that the building pressure is positive, use a flutter strip (flagging tape or toilet paper) taped to the outside edge of the door. If the pressure is positive, the strip should be flowing outward (indicating that air flow is moving out of the door).

## SECTION 4: IMPLEMENT THE SMOKE READINESS PLAN

Be ready to implement the plan when smoke mitigation is needed. Use the operations checklist that is in your plan. Some examples include:

1. Are windows and doors closed and sealed, and building envelope weatherized?
2. If limiting door use, is signage posted on the closed entrances?
3. Are the outdoor air economizers disabled and minimum damper settings adjusted?
4. Are upgraded filters installed?
5. Are exhaust airflows minimized and balanced to maintain positive air pressure?
6. Is the system fan set to run continuously to maximize the air filtration benefits?
7. Is there a plan to monitor the ambient air  $PM_{2.5}$  and to frequently check filters and replace as needed?
8. Are the portable room air cleaners ready for service with fresh filters?
9. Is the building manager or HVAC technician ready to change back to normal operations when the smoke clears?
10. If part of your Smoke Readiness Plan, create your cleaner air space.
11. After the smoke event, return system to normal operation and determine the need to clean or change filters.

## SECTION 5: MONITOR EFFECTIVENESS OF PLAN AND MAKE ADJUSTMENTS

Once the plan is implemented, use the data from the indoor  $PM_{2.5}$  monitor to determine whether the actions taken have reduced the  $PM_{2.5}$  levels. If an upward trend in  $PM_{2.5}$  levels is observed, check filters and replace as needed, look for cracks in the building envelope and seal them, and reduce indoor particulate matter sources. If levels are still not decreasing after these adjustments, create temporary cleaner air spaces using portable air cleaners or consider relocating to another building.

Temporarily reducing the amount of ventilation air may create unexpected conditions. Track important information with handheld devices or a Building Automation System. Knowing the levels of  $PM_{2.5}$ , temperature, relative humidity, carbon dioxide concentration, and number of occupants will allow problems to be addressed as they arise.

## SECTION 6: ADJUST THE PLAN

After implementing the plan, incorporate any adjustments and lessons learned into your Smoke Readiness Plan prior to the next wildfire season.

## SECTION 7: REFERENCES

- 1) California Air Resources Board; California Office of Environmental Health Hazard Assessment; U.S. Centers for Disease Control and Prevention; U.S. Forest Service; and U.S. Environmental Protection Agency. [2019] *Wildfire Smoke: A Guide for Public Health Officials*. Retrieved from <https://www.airnow.gov/wildfire-smoke-guide-publications/>
- 2) U.S. Environmental Protection Agency. [2020] *AirNow website*. Retrieved from <https://www.airnow.gov/>
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## SECTION 8: ADDITIONAL RESOURCES

### Wildfire Smoke

- 1) U.S. EPA Smoke-Ready Toolbox for Wildfires: <https://www.epa.gov/smoke-ready-toolbox-wildfires>
- 2) U.S. CDC Wildfires Website: <https://www.cdc.gov/disasters/wildfires/index.html>
- 3) BCCDC Wildfire Smoke Website: <http://www.bccdc.ca/health-info/prevention-public-health/wildfire-smoke>

### Filter upgrades for buildings

- 1) ASHRAE guidance for Reopening Schools and Universities, Filtration Upgrade Section: <https://www.ashrae.org/technical-resources/reopening-of-schools-and-universities>
- 2) ASHRAE Building Readiness Guide: <https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-building-readiness.pdf>

### Box Fan Filters

- 1) Climate Smart Missoula: DIY Fan/Filter Combos: <https://www.montanawildfiresmoke.org/diy-fan-filter.html>
- 2) New York Times, Wirecutter: How to Make a DIY Air Purifier: <https://www.youtube.com/watch?v=YnlvLBe6xUE>
- 3) Oregon Health Authority: Fact Sheet: Do It Yourself (DIY) air filter: <https://www.oregon.gov/oha/PH/PREPAREDNESS/PREPARE/Documents/Fact-Sheet-DIY-Air-Filter.pdf>
- 4) Puget Sound Clean Air Agency: DIY Air Filter: <https://www.pscleanair.gov/525/DIY-Air-Filter>
- 5) The Confederated Tribes of the Colville Reservation, Air Quality Program: Box Fan Filter, A DIY Users Guide: <https://www.youtube.com/watch?v=ukyF2xm8cws&feature=youtu.be>
- 6) Climate Smart Missoula, How to build a Do-It-Yourself Fan/Filter Air Cleaner, [https://www.montanawildfiresmoke.org/uploads/8/3/5/9/83593314/diy\\_boxfan\\_filter\\_2020.pdf](https://www.montanawildfiresmoke.org/uploads/8/3/5/9/83593314/diy_boxfan_filter_2020.pdf)

- 7) Washington State Department of Ecology, Instructional Video for Building Your Own Air Cleaner, <https://www.youtube.com/watch?v=4qr1Aj6Di7w>



## SECTION 9: ACKNOWLEDGEMENTS

This document was prepared and reviewed by a work group of the GPC44P Committee including the following people. Thank you for your contributions to protect public health

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## APPENDIX:

# USE CAUTION WHEN UPGRADING AIR FILTERS

### Introduction

How can I tell if my system can safely use MERV 13 filters? When upgrading filters to ones with higher efficiency, there is concern that the additional pressure drop will stress or harm the fan motor or other HVAC components. Monitoring the fan motor operation and checking temperatures at a few key locations will provide information to determine safe operation or the inability to use higher MERV rated filters.

### Overview

Air handlers and roof top package units are designed with a fan sized to provide air flow for adequate heating and cooling. To do this, the supply air fan provides static pressure to move the air through dampers, filters and heat exchangers as well as ductwork, registers and the conditioned space. The amount of air must be adequate to transfer heat in and out of the conditioned space within the design parameters of the equipment. Cleaning the fan and finned air coils will provide additional capacity for air filtration. These systems are dynamic: as filters load with dust and heat exchangers become fouled with dirt, the performance is affected and the potential for failure increases. To gain an understanding of important benchmark temperatures and pressures, reference the manufacturer's literature. Rule of thumb guidance is presented as a starting point.

### Centrifugal fan surge

Surge is a natural phenomenon that occurs when the maximum head pressure and minimum flow is reached by a centrifugal fan. When the head pressure is greater than the outlet pressure the air will reverse and try to flow back into the fan inlet. This unstable pressure cycling creates pulsing noises and vibrations known as surge. If surge is created by the addition of MERV 13 filters the fan design has been exceeded. Another method should be used to clean the indoor air.

### ECM fans

Electronically commutated motors (ECM) for fans are electronically speed controlled for constant torque. These motors will increase in speed and power usage to maintain a constant air flow. Up to a point this is a good thing. These motors should be monitored for amperage to verify they do not overload when upgraded filters are installed and whenever the filter loading is checked. Do this until there is adequate history that demonstrates the motors do not exceed their rated electrical capacity (full load amperage) during a wildfire smoke event. As the static pressure increases ECM fans may become noisy.

## VFD controlled fans

Fan motors on a variable frequency drive (VFD), also known as a variable speed drive, typically are controlled to maintain a duct static pressure set point. These motors need to be monitored as well for overloading. Check the drive parameters to verify they match the motor name plate information. Most VFDs will provide adequate motor protection if these parameters are correct. If the drive display shows the motor operating continuously at 100% speed, the unit or filters may need additional corrective actions.

## Other AC induction motors

Constant speed induction motors typically used with fans will decrease the power usage as the filters load with dirt and the air flow decreases. These motors will not overload with a greater pressure drop but lower air flow may harm other parts of the system. When increasing the fan speed do not exceed the maximum tip speed or the maximum motor power.

## Direct expansion cooling

Low air flow can lead to loss of cooling and compressor failure. Air temperature measurements are a simple way to verify safe operation. The manufacturer's literature or the startup records will have a recommended air temperature difference ( $\Delta T$ ) across the evaporator coil. The rule of thumb is 20°F (11°C)  $\Delta T$  with a minimum discharge temperature of 55°F (13°C) measured after 20 minutes of continuous running. If the discharge temperature is below 55°F (13°C), visually check for frost or ice on the evaporator coil. Frost is an indication that there is inadequate air flow and the filters, or the level of dust loading are too restrictive. Some fan motors may have the ability to increase speed by changing electrical connections or VFD settings. After adjusting the fan speed, re-check the temperatures.

As the filters load with dust the air flow may fall below the acceptable rate. Piston (reciprocating) compressors are most likely to be damaged by low air flow; scroll compressors are a little more resilient. Units with compressor staging may require additional observation and testing. It is up to the operator to determine that conditions for safe operation are in place.

## Heat pumps

While cooling, follow the guidelines above. While heating, low air flow may cause the unit to shut down when the high-pressure safety trips. Review the manufacturer's instructions to determine the appropriate limits for the maximum discharge temperature and  $\Delta T$ .

## Electric Resistance Heating

Electric heating elements must have sufficient air flow to operate. Review the manufacturer's instructions to determine the appropriate discharge temperature limit.

## Combustion appliances

Roof top units and air handlers with natural gas or propane heat need adequate supply air flow for heat transfer and to prevent damage to the heat exchanger. The unit label or manufacturer's literature will list a maximum discharge air temperature and a range of temperature differences that indicate acceptable operation. Rule of thumb is 160°F (71°C) maximum discharge temperature and 40 to 60°F  $\Delta T$  (22 to 33°C) across the heat exchanger. Direct fired units and oil-fired units have similar parameter. Always use the manufacturers recommended settings to determine that safe operations are being met.