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BEST PRACTICES GUIDE FOR IMPROVING INDOOR AIR QUALITY IN COMMERCIAL/ PUBLIC BUILDINGS DURING WILDLAND FIRE SMOKE EVENTS

Office of Research and Development

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Purpose of this Publication

This publication provides recommendations and resources to reduce indoor exposure to elevated particulate matter (PM) and gaseous pollutant concentrations in public, commercial, and multi-unit residential buildings during wildland fire (see Terminology box) smoke events.

Note this document is intended to inform actions to minimize smoke impacts indoors and create a **Smoke-Ready Plan**. It is not intended to address all aspects of indoor air quality. A Smoke-Ready Plan is a list of actions to take before, during, and after a smoke event.

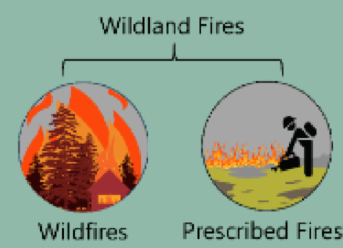
Intended Audience

This publication is for (1) individuals and groups with decision-making abilities for public, commercial, and multi-unit residential buildings including building owners and managers, school administrators, and facility managers; (2) federal, state, local, and Tribal environmental and public health organizations that provide information to communities to reduce exposure to wildland fire smoke in public or commercial spaces.

This document is not intended to provide a rigorous review of mitigation measures for technical audiences. Heating, Ventilation and Air Conditioning (HVAC) professionals, architects, design engineers, and construction contractors should consult standards and guidance for their industry and the ASHRAE Guideline 44-2024, Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events.[1]

Terminology

The term "*wildland* fire" is overarching and describes fire that occurs in wildland vegetation. The term encompasses both *prescribed* fire and *wildfire* (below).



A graphical representation of wildfires and prescribed fires, both of which are included in the term "wildland fires".

A *prescribed* fire is a planned fire intentionally ignited to meet land management objectives such as restoring ecosystem health and reducing vegetation buildup. A *wildfire* is an unplanned fire which may be caused by lightning or other natural causes or by human ignitions, accidental or intentional. Prescribed fires are typically planned when weather conditions are favorable for keeping the fire under control and minimizing smoke impacts to population centers.

Individual prescribed fires are typically short duration, e.g., hours to days, but there may be many occurring at the same time in some regions during some parts of the year. Wildfires can last weeks to months during dry periods and often impact the western U.S. during the summertime.

[1] This guideline is available from the ASHRAE Bookstore at https://store.accuristech.com/ashrae/standards/guideline-44-2024-protecting-building-occupants-from-smoke-during-wildfire-and-prescribed-burn-events?product_id=2923808

Table 1 provides a roadmap of this best practices guide and identifies sections/topics that may be of most use. Each section of this guide starts with a "Be Smoke Ready" overview box, intended to provide a shortlist of actions to perform:

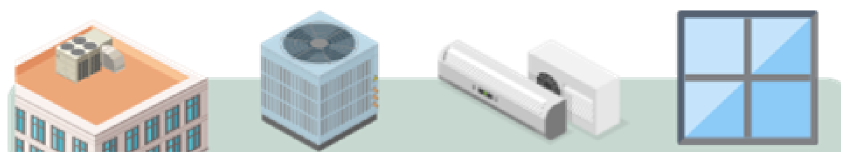
Before a smoke event

During a smoke event (or when smoke is forecast)

After a smoke event

The same symbols used in the overview boxes can be found throughout the text to help the reader find more information about the recommended actions.

Table 1. A roadmap of this best practices guide for readers to identify which sections are most applicable to their building's HVAC characteristics.



Section	**Centralized HVAC system** Industrial or commercial grade	**Centralized HVAC system** Residential grade	**Standalone AC units** Single or multiple units	**No existing air conditioning in building**
1. Wildland Fire Smoke Background information on smoke impacts on air quality	● Key	● Key	● Key	● Key
2. HVAC Information for understanding your system and how to adjust it during smoke events	● Key	● Secondary		
3. Building Usage & Weatherization Controlling building infiltration and leaks	● Key	● Key	● Key	● Key
4. Portable Air Cleaners Using additional filtration methods to improve indoor air quality	● Secondary	● Secondary	● Key	● Key
5. Air Sensors Leveraging air sensors for monitoring indoor pollutant levels	● Key	● Key	● Key	● Key

● Key relevant sections ● Secondary sections that may also prove useful

Managing Smoke and Airborne Virus Concerns

Ventilation, the amount of air moving in and out of a building, is an important component of indoor air quality management.

Increasing ventilation is a principal way of reducing the spread of common respiratory viruses indoors and concentrations from indoor sources of air pollution. However, recommendations for when to increase the amount of ventilation may differ depending on certain situations, such as when smoke is affecting outdoor air quality.

During smoke episodes, when it is important to reduce the amount of smoke that makes it ways indoors, ventilation should be minimized to pull in as little outdoor air as possible.

However, when smoke episodes occur at the same time as periods of increased illness in a building or community, building decision makers will need to balance the challenges of adequate ventilation by monitoring indoor and outdoor conditions, and adjusting building operations appropriately.

Here are two common approaches to help with airborne virus spread and smoke reduction indoors:

1. **Increasing indoor filtration** rates using the central HVAC system by increasing run time and/or upgrading to a more efficient filter. This can reduce both concentrations of smoke and virus particles when ventilation with outdoor air is not possible and may need to be done in recirculation or fan only modes during smoke events.

2. **Using Portable Air Cleaners** (PACs) with effective particle filtration to reduce smoke and virus particles indoors.

For more information, see the ‘Indoor Air Quality and Airborne Viruses’ section of Appendix: Resources for Indoor Air Quality.

Information from:
https://www.epa.gov/indoor-air-quality-iaq/covid-19-wildfires-and-indoor-air-quality

1. Introduction to Wildland Fire Smoke

Wildland fire smoke is a complex mixture of PM and gases. Its composition is closely related to fire and weather conditions and the material burned, which differs between fire events. For example, prescribed burns and some wildfires burn purely vegetation (e.g., plants and trees), while wildfires in the wildland urban interface (WUI) - where the built environment adjoins with the natural environment – can also burn vehicles, and structures.

Wildland fire smoke consists of both **fine particles** (particles less than 2.5 μm in diameter, known as $PM_{2.5}$) and **coarse particles** (known as $PM_{10-2.5}$, which are particles smaller than 10 μm and larger than 2.5 μm in diameter). The $PM_{2.5}$ portion is mostly composed of **submicron particles** (smaller than 1 μm in diameter).[2] $PM_{2.5}$ is formed during combustion, while $PM_{10-2.5}$ consists of larger ash particles that remain after material is burned and can include windblown soil. $PM_{2.5}$ is the main PM component of smoke and poses the greatest short-term (i.e., days to weeks) risk to public health because these particles can penetrate deep into the lungs and enter the bloodstream.[3]

Figure 1 shows general categories of pollutants produced during wildland fires. Smoke also contains polycyclic aromatic hydrocarbons (PAHs) and pollutant gases, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and volatile organic compounds (VOCs)[4]. Some hazardous VOCs produced by wildland fires

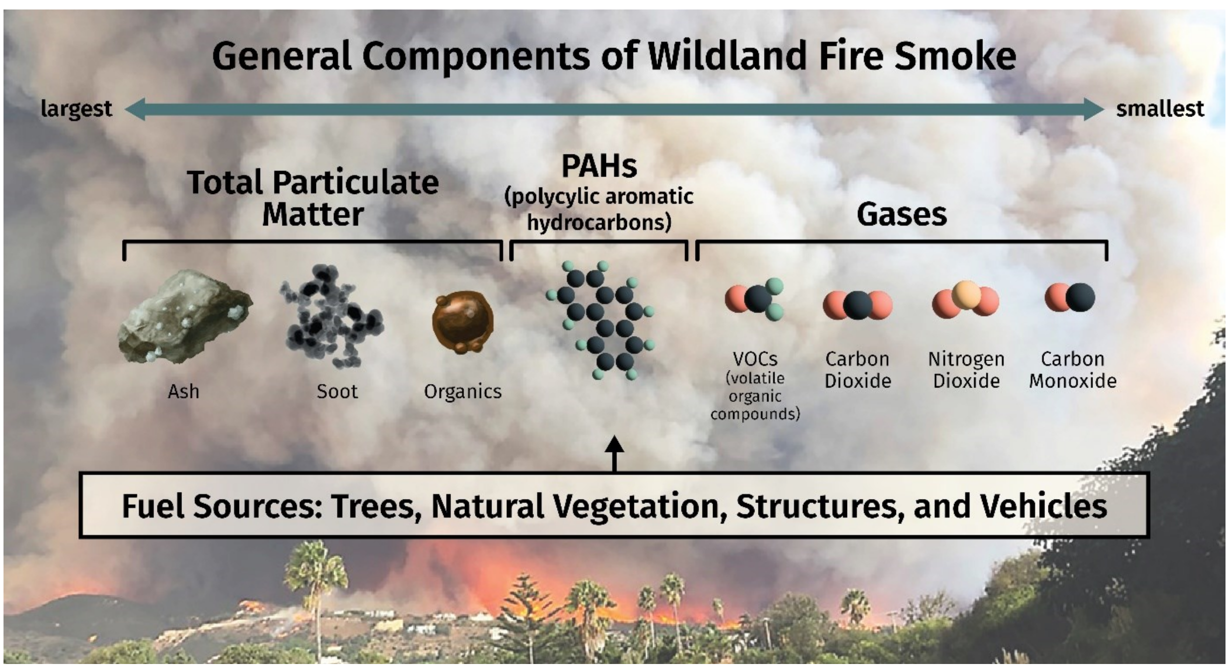


Figure 1. Typical components of wildland fire smoke.

2 https://acp.copernicus.org/articles/5/799/2005/
3 https://www.epa.gov/wildfire-smoke-course/why-wildfire-smoke-health-concern
4 VOCs are a diverse class of compounds with varied effects on health. For more information, see https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

include acetaldehyde, acrolein, formaldehyde, and benzene. **This publication primarily focuses on indoor PM and VOC reduction strategies.**

1.1 Health Impacts from Smoke

Both $PM_{2.5}$ and VOCs in smoke present health risks. $PM_{2.5}$ is the pollutant of greatest concern because it is a major component of smoke and there is extensive scientific evidence that show its impact on health.[5] Short-term exposure to high concentrations of PM can lead to respiratory symptoms, reduction in pulmonary function, airway inflammation, and aggravate chronic heart and lung diseases. Prolonged exposure to $PM_{2.5}$ can lead to decreased lung function and increased respiratory symptoms. Short-term exposure to high concentrations of VOCs can lead to health effects including eye, nose, and throat irritation; headaches; nausea; and dizziness. Prolonged exposure to certain VOCs has been linked to cancer.

Certain life stages and populations may be at greater risk of experiencing health effects and may experience more severe effects due to wildland fire smoke exposure. These groups are referred to as at-risk populations or "sensitive groups" (used in the Air Quality Index, see Table 2).[6]

Smoke exposure in people with asthma and other lung diseases can lead to breathing issues, coughing, wheezing, chest tightness, and worsening of lung diseases. For those with pre-existing cardiovascular diseases, smoke exposure can trigger heart attacks and stroke.

Children under 18 tend to spend more time outdoors and inhale more air per pound of body weight compared to adults, both of which impact the dose of smoke they experience and their risk of health effects. Children are also at greater risk of smoke-related health effects because their lungs are still growing. As such, they are more susceptible to breathing problems such as coughing, wheezing, chest tightness, and decreased lung function. Older adults (65 years of age or older) are more likely to have chronic lung or heart conditions and thus are at risk of exacerbating these conditions with smoke inhalation. In addition, the body's ability to respond to health challenges generally declines with age.

Pregnancy increases breathing rates, which may lead to increased smoke sensitivity. Smoke inhalation may lead to gestational diabetes, high blood pressure, low birth weight, or pre-term birth.

People of low socio-economic status may have reduced access to health care resources, leading to undiagnosed underlying health conditions, including asthma and diabetes. They may also have reduced access to wildland fire smoke mitigation measures (e.g., air cleaners), be more likely to live in leaky housing with less access to air conditioning, or be unhoused.

During smoke episodes, outdoor workers are exposed to high concentrations of $PM_{2.5}$ for extended periods of time, which can result in worsening of health conditions.

[5] Cascio, 2017, https://doi.org/10.1016/j.scitotenv.2017.12.086

[6] Which Populations Experience Greater Risks of Adverse Health Effects Resulting from Wildfire Smoke Exposure? https://www.epa.gov/wildfire-smoke-course/which-populations-experience-greater-risks-adverse-health-effects-resulting

For more information on health impacts from smoke, see the Wildfire Smoke Fact Sheet: At-Risk Groups of People.[7]

1.2 Smoke Information Sources

The Air Quality Index

The U.S. EPA has established the Air Quality Index (AQI)[8] to aid public understanding of **outdoor air quality** based on pollutant concentrations and it can be used to trigger actions to improve indoor air quality. The AQI converts pollutant concentrations to a number on a scale from 0 to 500. These values are tiered into six color-coded categories that provide information about potential health effects and protective actions. Higher AQI values correspond to greater levels of air pollution and higher health concern (**Table 2**). In lower AQI categories, different groups of people are anticipated to experience health effects. During smoke events, it is not uncommon to see AQI levels of 200 and higher. Under very unhealthy (AQI 201-300) and hazardous conditions (AQI 301 and higher), EPA and the interagency Wildfire Guide for Public Health Officials[9] recommend all people stay indoors with filtered air and take additional steps to keep indoor air clean. Those who are sensitive to smoke exposure are recommended to relocate to a cleaner air room. To read more about recommendations when pollution is hazardous, see the Reduce Your Smoke Exposure factsheet[10].

Table 2. EPA's Air Quality Index (AQI) levels and PM-driven descriptions.

Air Quality Levels of Concern (values of index)	Recommended Actions
Good (0-50)	**Everyone:** Don't see or smell smoke? It's a good time to open windows or go outdoors.
Moderate (51-100)	**Everyone:** Don't see or smell smoke? It's OK to open windows or go outdoors. **Unusually Sensitive People:** Consider making outdoor activities light and short. Go inside to cleaner air if you have symptoms.
Unhealthy for Sensitive Groups (101-150)	**Everyone:** Consider lighter and shorter outdoor activities. **Sensitive Groups:** Go inside to cleaner air if you have symptoms.
Unhealthy (151-200)	**Everyone:** Keep outdoor activities light and short. Go inside to cleaner air if you have symptoms. **Sensitive Groups:** Consider moving all activities inside. Go inside to cleaner air if you have symptoms.
Very Unhealthy (201-300)	**Everyone:** Limit outdoor physical activity. Go inside to cleaner air if you have symptoms. **Sensitive Groups:** Avoid all outdoor physical activity.
Hazardous (301-500)	**Everyone:** Avoid all outdoor physical activity. **Sensitive Groups:** Stay indoors and keep activity levels light. Stay indoors and consider creating a cleaner air room.

[7] Wildfire Smoke Fact Sheet: At-Risk Groups of People: https://document.airnow.gov/at-risk-groups-of-people-fact-sheet.pdf

[8] Air Quality Index: https://www.airnow.gov/aqi/aqi-basics/

[9] https://www.airnow.gov/publications/wildfire-smoke-guide/wildfire-smoke-a-guide-for-public-health-officials/

[10] Reduce Your Smoke Exposure Factsheet: https://www.airnow.gov/publications/wildfire-guide-factsheets/reduce-your-smoke-exposure/

AirNow Fire and Smoke Map

During wildland fire smoke events, detailed and timely information on outdoor air quality, active fires, and smoke conditions can be found on the **AirNow Fire and Smoke Map website**[11] **and mobile phone app.** The Fire and Smoke Map allows you to see current $PM_{2.5}$ air quality information from permanent and temporary air quality monitors as well as air sensors; the locations of fires and smoke plumes; and recommendations for actions to take to minimize exposure to smoke from wildland fires. When clicking on a monitoring location the map will also alert you if a Smoke Forecast Outlook has been issued in your area by an Air Resource Advisor (see Location Alert in **Figure 2**), which provides anticipated smoke concentrations for the next few days.

During wildland fires, employers should pay close attention to Federal[12] and State[13] Occupational Safety and Health Administration (OSHA) recommendations and standards to protect employees from the effects of air pollution.

Where Smoke is Likely

Parts of the U.S. are prone to wildfires, such as California and other western states. However, other parts of the country may experience regular prescribed burns or are impacted by smoke events from distant wildland fires. Smoke can travel hundreds to thousands of miles under certain weather conditions, impacting regions far from the fire locations. For example, in 2023, the eastern U.S. was inundated by smoke from wildland fires burning in Canada, which impacted air quality for weeks.

When Smoke is Likely

Figure 3[14] shows historical fire activity across the U.S. during different seasons. Fires impact every state. Generally, in western states such as

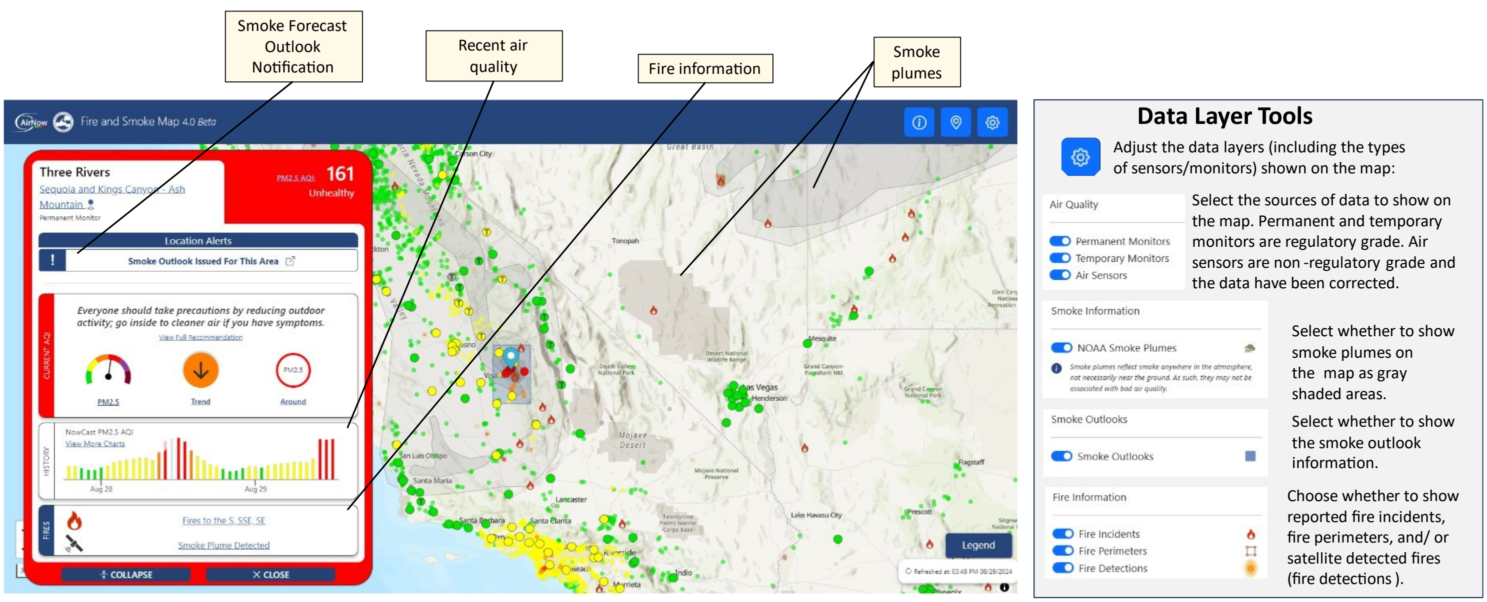


Figure 2. A screenshot from the AirNow Fire and Smoke Map.

[11] AirNow Fire and Smoke website: https://fire.airnow.gov/

[12] U.S. Dept of Labor, Occupational Safety and Health Administration Wildfires page: https://www.osha.gov/wildfires

[13] Example: Cal/OSHA Worker Safety in Wildfire Regions page: https://www.dir.ca.gov/dosh/Worker-Health-and-Safety-in-Wildfire-Regions.html

[14] Simon et al., 2024, https://doi.org/10.1016/j.dib.2024.111208

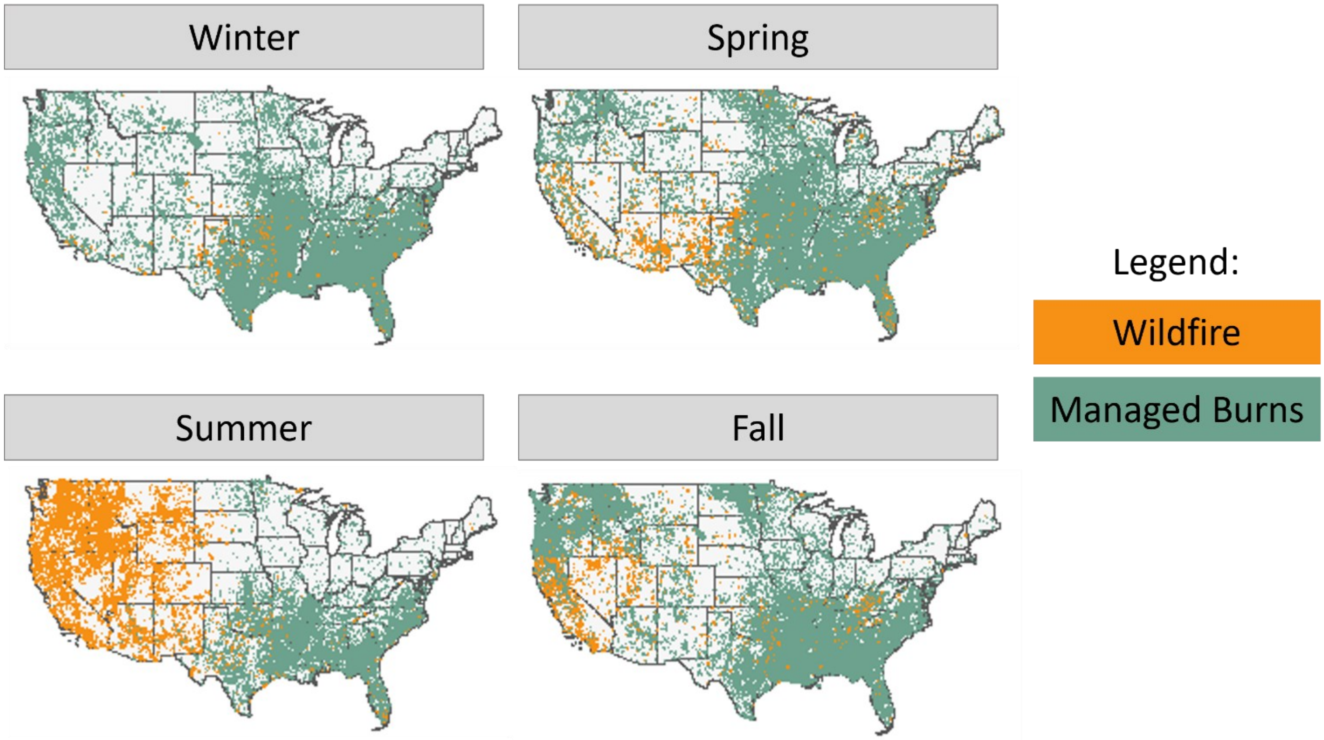


Figure 3. Seasonal prevalence of wildfire and managed burns across the contiguous United States derived from the EMBER dataset. Source: Simon et al. 2024.

California and Oregon, wildfire events are most prevalent between July and October. Prescribed burns in these states occur mainly in late fall, followed by winter and spring. Grassland burns in central states occur in spring months. In southeastern states, prescribed fires occur across several months between late fall and early spring.

When to Prepare for Smoke

If you are in a region known to be impacted by wildland fire smoke, **you should prepare your building before fire season begins.** Those who may not have a clear fire season should still prepare in the event that smoke from distant fires is transported to the region and impacts air quality. Smoke from wildland fires can travel thousands of miles from the active fires.

Historical $PM_{2.5}$ concentrations across the U.S. may be helpful in identifying when your location is most likely to be impacted by

Where to Get Information About Wildland Fire Smoke

During wildland fire smoke events, refer to the following sources for timely information about smoke:

1. **AirNow Fire and Smoke Map** website or cell phone app https://fire.airnow.gov/
2. **Smoke outlooks (available on the Fire and Smoke map)**
3. **State and local smoke blogs**
4. **Air Quality Alerts** issued by National Weather Service (https://weather.gov)

smoke. EPA provides plots of daily $PM_{2.5}$ data across an entire year for locations across the U.S.: https://www.epa.gov/outdoor-air-quality-data/air-data-tile-plot. Additional historical $PM_{2.5}$ data can be found here: https://tools.airfire.org/historical/ by clicking on a monitor nearest your location.

The following resources can help you determine where and when fires are most likely to occur in the short term:

- The **National Interagency Coordination Center Wildland Fire Outlook** website is updated frequently and shows both the 7-day significant fire potential outlook across the country and a 4-month prediction of above-, below-, and near-normal significant fire potential: https://www.nifc.gov/nicc/predictive-services/outlooks

- Some **state or local air agencies** are responsible for issuing permits for controlled (prescribed) burns, and their websites may be the best resource for a list of past and upcoming prescribed fires. Examples are:
  - Arizona: https://smoke.azdeq.gov/
  - California: https://ww2.arb.ca.gov/smoke-current-wildfires
  - Montana and Idaho: https://mi.airshedgroup.org/
  - Florida: https://www.fdacs.gov/Forest-Wildfire/Wildland-Fire/Burn-Authorizations
  - Georgia: https://georgiafc.firesponse.com/public/

1.3 Smoke Impacts Indoors

During wildland fire events, large amounts of smoke can infiltrate and accumulate indoors, leading to elevated air pollutant concentrations inside buildings. Pollutants, such as PM and VOCs, are also generated by indoor activities such as cooking, smoking, and using wood burning stoves and fireplaces, and contribute to poor indoor air quality (IAQ).

AQI values are informative for understanding *outdoor* air quality, but do not reflect the concentration of pollutants *indoors,* which may be quite different. However, outdoor AQI levels can help inform when additional measures are needed to keep indoor air as clean as possible.

Factors that impact IAQ during smoke events can be grouped into three categories:[15]

- **Occupant behavior** - the operation and maintenance of HVAC and additional filtration (including portable air cleaners, PACs), opening/closing windows and doors, and moving between spaces (**See Sections 2, 3, and 4**).
- **Building characteristics** – gaps and cracks around doors and windows, vents, pipes, and HVAC air intakes. (**See Section 3**).
- **Pollutant properties and environmental factors** – particle size, gaseous component(s), particle concentration, and wind speed and direction.

The third category is governed by local smoke properties[16] and behavior. **This document focuses on the first two categories, as these are within building management's control.**

[15] Luo et al., 2019, https://www.sciencedirect.com/science/article/pii/S0048969719325276

[16] Jaffe et al. 2020, https://doi.org/10.1080/10962247.2020.1749731

Smoke Infiltration Indoors

People spend most of their time in buildings, especially when outdoor air quality is poor.[15,17,18] During a smoke event, people are advised to stay indoors and to keep doors and windows closed. However, not all buildings are equal in keeping smoke from coming indoors. Recent studies have shown that some commercial and school buildings have higher indoor PM concentrations during smoke events than residences. However, more studies are needed to determine if this trend is ubiquitous across the U.S.[19]

Smoke infiltrates through open windows and doors, and cracks, gaps, and other penetration points in the building envelope (e.g., holes drilled for lighting fixtures, internet/TV/phone service cables, or security cameras). Smoke can also enter a building's ventilation system through outdoor air intakes (**Figure 4**). Building exhausts, such as those in bathrooms and kitchens, can create negative pressure and draw in smoke.

1.4 Strategies for Improving Indoor Air Quality During Outdoor Smoke Events

The strategies described in this document are meant to provide a variety of options to reduce indoor air pollutant concentrations in non-residential spaces during smoke events as part of a Smoke-Ready Plan that is unique for your building. For residential spaces, see the EPA Wildfires and Indoor Air Quality website.[20] The

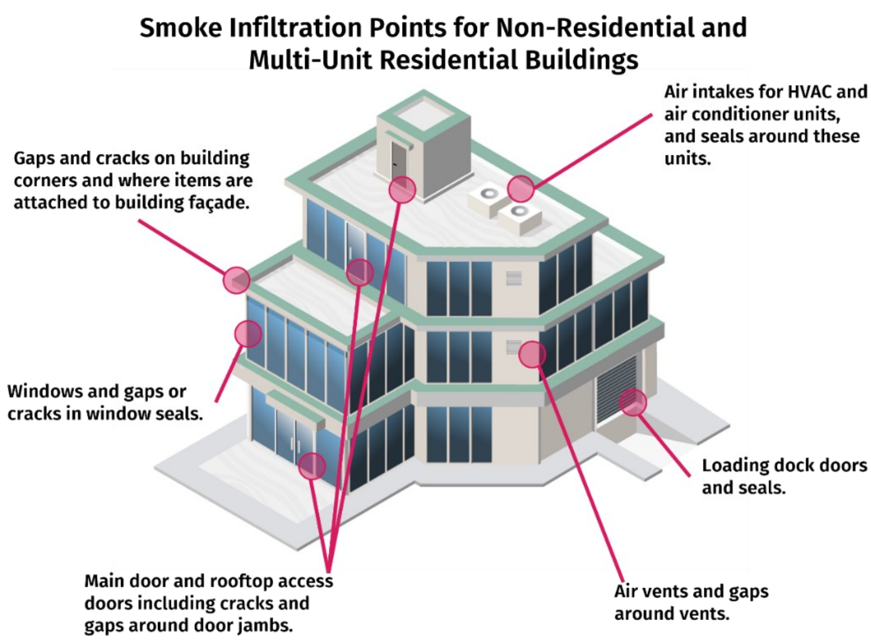


Figure 4. Examples of smoke infiltration points for non-residential and multi-unit residential buildings.

[17] Nguyen et al., 2021, https://www.mdpi.com/1660-4601/18/18/9811
[18] Leech et al., 2002, https://www.nature.com/articles/7500244
[19] May et al., 2021, https://aaqr.org/articles/aaqr-21-03-tn-0046
[20] Wildfires and Indoor Air Quality (IAQ): https://www.epa.gov/emergencies-iaq/wildfires-and-indoor-air-quality-iaq

most beneficial strategies will depend on building type, existing infrastructure (such as HVAC systems or the number of openable windows and doors), building use, occupant behavior, and other factors. Not every strategy will apply to every situation, and it is important to consult an expert who can evaluate your building and HVAC system prior to investing in significant changes. It is also important to develop your Smoke-Ready Plan well before a smoke event occurs. Strategies will be provided throughout this document and an example Smoke-Ready Plan and checklists are provided in **Appendix 1**.

The key strategies discussed further in this document are:

1. **Improvements to HVAC systems** and filtration and modifications to HVAC settings during smoke episodes.
2. **Building usage and weatherization adjustments**, including reducing indoor sources of air pollution and adjusting occupant access.
3. **Use of Portable Air Cleaners (PACs),** including creating a cleaner air space.
4. Use of **air sensors** to monitor pollutant levels inside compared to outside.

2. HVAC Systems: Improvements and Recommended Settings

BE SMOKE READY

Before a Smoke Event:

- Properly maintain your HVAC system.
- Determine the highest rated filter your HVAC system can use. Consider upgrading the system for a MERV 13 or higher filter, if needed.
- Determine minimum ventilation requirements to develop a “smoke ready mode” and test the modifications.
- Stock necessary filters and supplies.

During a Smoke Event: When smoke is forecast...

- Install higher-rated filters in your HVAC system.
- Install supplemental filtration.
- Implement Smoke-Ready Plan modifications to your system settings.

After a Smoke Event:

- Remove supplemental filters.
- Reset HVAC system to normal settings.
- Increase building ventilation to fully clear the air.
- Change filters and order replacements.
- Evaluate and adapt the Smoke-Ready Plan.

This section will be most useful for buildings with *commercial* HVAC systems but may also apply to those with *residential* HVAC equipment. **Assistance from qualified HVAC professionals is generally recommended.**

HVAC systems vary widely, and their operational modes are often complex. Understanding the design limitations, normal operations, and how to adapt operations during smoke periods for your unit(s) are critical parts of a Smoke-Ready Plan. Building managers should schedule tests prior to wildfire season and prescribed burn periods to evaluate optimal air intake settings and ensure the configurations are effective and switches between “normal” and “smoke” protocols are smooth. Retain detailed notes, checklists, and photos documenting normal operations of the HVAC system(s), as well as any changes made during smoke events. This will help build a clear understanding of effective actions and staff roles and responsibilities.

Following a smoke event, consider a flush-out period when the outdoor air intake is increased to bring in clean outdoor air to replace smoky indoor air. The HVAC system should be returned to normal operating procedures, and building pressure should be verified to ensure it is typical for normal operation.

2.1 Overview of HVAC Systems

It is important to understand the different types of HVAC systems in commercial and residential buildings.

HVAC systems in commercial buildings can be categorized depending on their design features or operation, including (1) centralized, where a central heating or cooling plant provides chilled or heated water used to condition air in multiple buildings or areas (e.g., university campus or hospital complex); (2) decentralized, where each building or area has its own HVAC system (e.g., window AC units in a residential system); or (3) a combination of both. HVAC systems can be designed from multiple components and 'built up' in a customized configuration of components or can be purchased as a single 'packaged system'. Some common categories for HVAC systems used in commercial or public buildings include, but are not limited to:

- **Rooftop units** are self-contained, packaged HVAC systems that connect to the building's ductwork and provide heating, cooling, and filtration. Packaged units may also be installed near the building and function similarly to rooftop installations. These are often used in light commercial buildings (e.g., strip malls).
- **Variable Air Volume (VAV) Systems** vary air flow in response to heating and cooling needs of the space. These systems have terminal units with some form of flow control (fan or damper) and potentially filtration sections to achieve desired conditions in the space. VAV systems are often found in commercial buildings.
- **Variable Refrigerant Flow (VRF) Systems** accomplish heating and cooling with a variable flow of refrigerant transferring heat to or from indoors to outdoors. These systems are larger than mini split systems (see below) and serve multiple occupied spaces. They may also include dedicated outdoor air systems (DOAS), which may contain a filtration section, to achieve ventilation requirements (see subsection on Outdoor Air Intakes for more information on **DOAS**).
- **Mini Split Systems,** like VRF systems, use a refrigerant to transfer heat from the indoors to outdoors. They either have a short run duct or are 'ductless,' but generally condition air in the occupied spaces and do not bring in outside air and may not have a filtration section. Window air conditioning units are similar to ductless mini splits, but the entire system is contained in a single package. Mini split systems are often used in small spaces, such as offices, shops, and cafes, in a small area in a building with central HVAC, or in buildings that only have central heating.

Residential central air conditioning systems have many components similar to commercial HVAC systems, including air handlers, heating and cooling sections, and ducting to deliver air to occupied spaces and return it to the air handler. Residential systems may use a or heat pumps) or may use evaporative coolers (also called swamp coolers).

Unlike commercial systems, most residential refrigerant-based air conditioning systems do not have an outdoor air intake for ventilation but recycle indoor air with a filtration section before cycling back through the air handler. A heat recovery ventilator (HRV) or energy recovery ventilator (ERV) may provide ventilation in residential systems, but these are not common. Evaporative coolers bring in large amounts of unfiltered outdoor air (see **Modifications to Evaporative Coolers** call out box). Residential systems typically do not run continuously, but cycle on and off to meet temperature setpoints.[21] These systems are often used in smaller commercial buildings (e.g., daycares) or to condition smaller spaces in larger buildings (e.g., an office in a warehouse).

HVAC Components and Subsystems

The systems summarized above share many of the same components and subsystems, which can directly impact smoke infiltration into the HVAC system and the ability of the HVAC system to remove smoke from indoor air. Key HVAC components, subsystems, and potential smoke filtration points are shown in **Figure 5**.

These key components and subsystems use similar equipment, such as: fans and ducts to move air, mixing boxes to mix different air streams, heating and cooling coils (or other elements) to control air temperature, louvered intakes or dampers to control flows, diffusers and return registers to bring air into or out of a space, filter racks or other in-duct cleaning technologies (e.g., UV lights) to remove contaminants from the air, and a variety of sensors to ensure the system is operating properly (e.g., pressure, temperature, relative humidity, CO_2, or PM). Overall, there are many HVAC components and systems that must work together to achieve thermal comfort and improve indoor air quality.

Modifications to Evaporative Coolers

Wildfires often occur during the hottest months when air conditioning is needed to keep temperatures comfortable indoors. In some parts of the country, evaporative coolers (or "swamp coolers") are commonly used to cool indoors by bringing in large amounts of humidified outdoor air. During smoke events, evaporative coolers can also bring in smoke.

If the indoor air temperature is comfortable, evaporative coolers should not be used during smoke events. If cooling is necessary, the amount of smoke that comes indoors can be reduced by completely covering the outside air intakes with a 4-inch-thick filter with a MERV 13 rating (or better). Because the air will only pass through the filter a single time, reducing smoke concentrations by ~50 percent, you will also want to use portable air cleaners to clean your indoor air.

If you cannot cover the outdoor air intakes with efficient filters, either do not use the evaporative cooler, or use an air cleaner and shut off the cooler as soon as your room reaches a comfortable temperature. Note the external filters will be vulnerable to damage from wind, rain, and mist from the cooler and may need to be replaced frequently.

Examples of swamp coolers with MERV 13 rated filters attached. Photo credit: FRESSCA Study Research Team.

[21] Touchie and Siegel, 2018, https://doi.org/10.1111/ina.12496

Outdoor Air Intakes

Outdoor air intakes are designed to bring outdoor air into occupied space and can be key entry points for smoke.

Outdoor air intakes, depending on ventilation objectives, may have different components and use different control strategies. All have some method of controlling the amount of outdoor air brought inside, often through the use of an outdoor air damper or an adjustable speed fan. Dampers may have a fixed position or be actuated to actively control ventilation. Actuated dampers are an often-overlooked component and may malfunction (see callout box on Common HVAC Maintenance Issues). Dampers should be inspected prior to smoke events to ensure they are in good working order (not warped, stuck in one position, or otherwise broken). If the damper cannot close properly, it will not regulate outdoor airflow. There may also be a separate, uncontrolled outdoor air intake to maintain a minimum outdoor air flow to the HVAC while outdoor air dampers are closed. The outdoor air system may also have thermal, humidification, and filtration sections to act on the outdoor air before mixing it with return air from the building.

Examples of outdoor air intake systems:

- **Economizers** - Outdoor air economizer technology saves energy by bringing in cooler outdoor air to replace warm indoor air when the outside air is cooler. The economizer may have a minimum outdoor air damper position to achieve ventilation objectives when outdoor air is warmer than indoor air and may be set to close the damper if the building is unoccupied.

- **Demand Control Ventilation (DCV)** – Outdoor air is supplied only when needed, which can be determined by occupancy or CO_2 sensors. When CO_2 concentrations rise indoors, more outdoor air will be brought in to ventilate the space. These systems reduce energy requirements by only providing ventilation when dictated by occupancy levels and may be inactive overnight when buildings are empty.

- **Dedicated Outdoor Air Systems (DOAS)** – These systems are outdoor air intakes that include fresh air fans, outdoor air fans, or make-up air fans that provide a continuous flow of outdoor air into a building separate from the HVAC system. A DOAS may be used in buildings that need additional makeup air to offset large exhausts (e.g., commercial kitchens), that have HVAC systems with no outdoor air intake (e.g., VRF), or to save energy or meet minimum ventilation requirements.

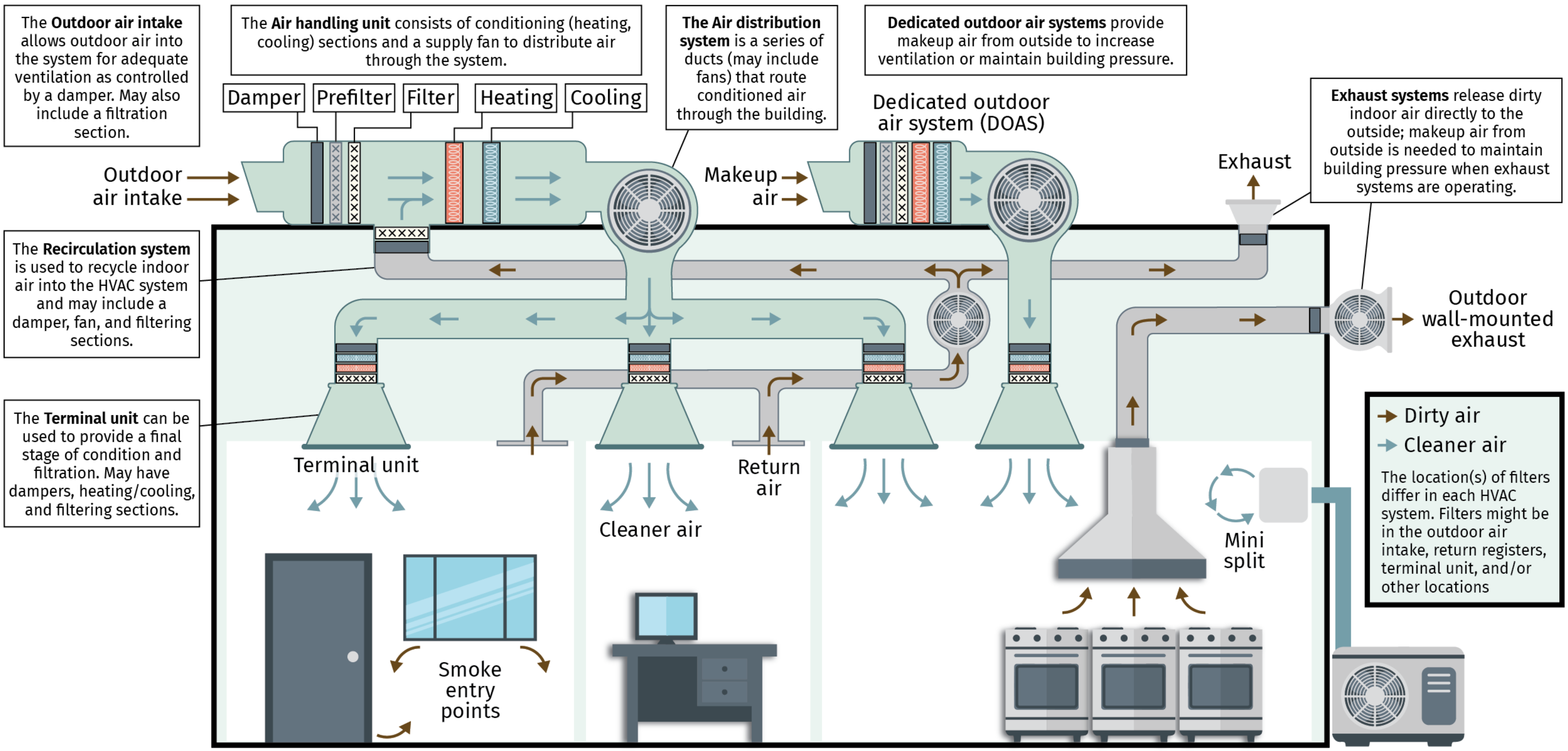


Figure 5. Anatomy of an HVAC system.

Common HVAC Maintenance Issues

A properly functioning HVAC system is helpful in reducing smoke concentrations indoors. Additionally, components must be functional to make modifications during a smoke event. Here is a list of common maintenance issues that should be addressed before smoke events occur:

- **Filter bypass** (i.e., when smoky air gets around the filter) can be caused by poorly fitting filters, damaged filters, damaged gaskets, or damaged filter rack doors.
- **Broken dampers** in the open position can let in large amounts of smoky air, while those broken in the closed position can impact the pressure balance of the HVAC system and not provide adequate ventilation.
- **Leaky seals** on dampers can let smoky air leak through a closed damper.
- **Leaky ducts** can let smoky air into the HVAC system potentially bypassing filtration sections.
- **Broken or uncalibrated sensors** can prevent the HVAC from operating as designed.

Smoke-Ready HVAC Strategy

Often, a single building may have multiple types of systems with different components. In such cases, it is important to understand which areas of the building are served by each HVAC system and how each should be adjusted to reduce wildland fire smoke infiltration and increase HVAC filtration. The following information is intended to assist with preparing and implementing a Smoke-Ready Plan.

Modified HVAC settings should be used as temporary measures during smoke events and should be restored to normal operation when air quality returns to normal. However, in regions that experience frequent wildfire smoke (e.g., western states) or those with prolonged prescribed burn seasons, (e.g., southeastern states) it may be more efficient to make some modifications permanent. More costly modifications may be made on a seasonal schedule to coincide with smoke-prone periods, and easily implemented changes can be made during smoke episodes or when air quality alerts are issued.

HVAC system operation changes during a smoke event may include adjusting settings to limit outdoor air intake, changing system flows, and/or changing and supplementing air filtration. Because HVAC systems vary widely, it is recommended that you consult an HVAC professional or your system's manufacturer for help. A testing, adjusting, and balancing (TAB) evaluation (See **Section 2.4**) may also be useful.

Have your HVAC system serviced to ensure it is working correctly before you begin testing smoke settings.

2.2 Air Flow Optimization

During smoke events, reducing the amount of smoky outdoor air being pulled into a building is critical for maintaining cleaner air indoors. However, a lack of ventilation can lead to a buildup of air pollutants from both indoor and outdoor sources. Proper ventilation and air flow are key factors for controlling air stagnation (e.g., CO_2 build up) and maintaining positive building pressure, which prevents outdoor air from infiltrating the building.

Reducing outdoor air intake levels to a minimum, while maintaining positive pressure relative to the outdoors, can limit smoke entering the HVAC system. First, determine the minimum outdoor air intake that is protective of human health and equipment by controlling odor, temperature, and indoor contaminants while maintaining positive building pressure. The minimum outdoor air intake is often based on the maximum design occupancy, but current or anticipated occupancy levels may be lower and minimum air intake requirements should be reconsidered. **Closing all outdoor air intakes completely is never advised.**[22]

Larger HVAC systems and rooftop units are typically equipped with air intakes to bring outdoor air into a building. Economizer, DCV, and DOAS settings in these systems will likely need to be adjusted to limit the amount of smoke brought indoors. Modifying these systems can involve adding control relays or switches to limit operation, manually adjusting the air damper position, or finding other effective modifications. Installing filters on the air intake is recommended (see **Section 2.5**). Due to the variability in manufacturers and control schemes, there is no one-size-fits-all solution for settings on outdoor air intakes.

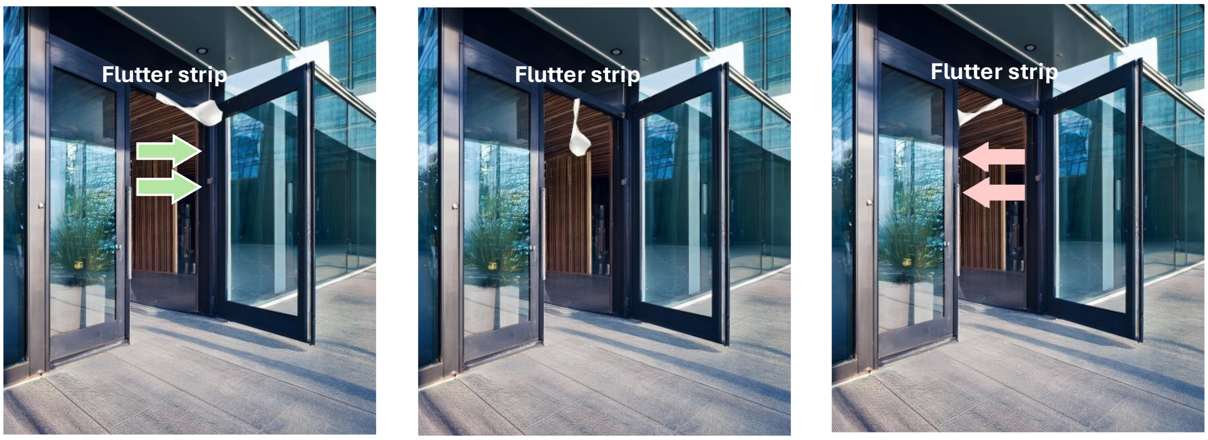
When reducing outdoor air intake, strive to maintain an overall positive pressure in the building. Negative building pressure will allow smoke to be drawn into the building through cracks around windows and doors as well as other unintentional openings in the building envelope. To determine if the building pressure is positive, you can hold a flutter strip, such as tissue paper, to the edge or frame of an external door (see **Figure 6** for example). During a smoke event, perform this check regularly.

The **ASHRAE Epidemic Task Force Building Readiness** document outlines additional steps to identify leaks and other issues in the filter assembly which should be addressed (see Common HVAC Maintenance Issue box).

Negative pressure may occur when there is insufficient makeup air supplied by the system to balance airflow lost through an exhaust fan (e.g., kitchen, bathroom, or laundry room exhaust vents). Additionally, if it is hot outside and the outdoor air intake is reduced, a reverse stack effect can occur, with cold indoor air flowing out of lower levels and warm outside air being pulled in through upper levels. Understanding what impacts building pressure under normal operation will help optimize conditions when a smoke event occurs.

When ventilation is reduced, decrease or pause indoor activities that contribute to poor indoor air quality, such as spraying aerosols, cooking, and vacuuming. Using PACs can help improve indoor air quality if additional filtration is needed (see **Section 4**).

[22] ASHRAE: Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events available from the ASHRAE Bookstore at https://store.accuristech.com/ashrae/standards/guideline-44-2024-protecting-building-occupants-from-smoke-during-wildfire-and-prescribed-burn-events?product_id=2923808



Positive Building Pressure	Neutral Building Pressure	Negative Building Pressure
• If the building pressure is positive, the strip will flow <u>outwards</u> • Air is flowing out of building	• Flutter strip on the door frame is hanging downwards • Smoke-laden air *may* flow into building	• Door frame flutter strip is blowing <u>inwards</u> • Smoke-laden air will flow into building

Figure 6. Examples of flutter strip test results under different building pressure scenarios.

2.3 HVAC Run Time Changes

Indoor air filtration occurs when the fan(s) is running and filters are placed securely. Some HVAC systems under normal conditions may be programmed to turn off at night and on weekends when the building is unoccupied. Demand-controlled ventilation systems may also turn off or reduce flow with changes in occupancy. In these systems, the HVAC may not keep indoor air clean during low occupancy because indoor air does not recirculate through filters when the HVAC is off. During smoke events, consider operating the HVAC system continuously without heating or cooling (for reduced energy costs) to reduce smoke even when unoccupied or occupancy is low. If running the HVAC system continuously is not viable, consider turning the HVAC system on before the building is occupied to reduce smoke indoors.

Building managers should learn how to modify HVAC run-time and outdoor air intake settings and practice shifting between normal and smoke operation before smoke events occur. A successful test would include:

- Maintaining positive building pressure
- Maintaining a comfortable indoor temperature for occupants
- Successfully switching between "smoke ready mode" and normal operation based on documentation developed in the plan and/or completed during the test

Document the procedure in your Smoke-Ready Plan. When a smoke event is forecasted, switch the system into your smoke-ready mode, and continue to run it in that mode until the smoke event ends. During major smoke events, air quality forecasts can be found on the AirNow Fire and Smoke Map (see **Section 1.2 Smoke Information Sources**). After a smoke event, switch the system back to normal operations.

2.4 Filtration

Filtration is important to improve indoor air quality during wildland fire smoke events. Filters should fit properly in the filter rack without bending or crushing and there should not be gaps around the filter frame. Improve the filter fit with gasketing material, or seal off gaps with duct tape or silicone sealant.

Not all filters are effective at removing smoke particles (see **MERV Rating Scale box**). MERV 8 filters are commonly used in HVAC systems and need to be upgraded to a higher MERV rating to effectively remove smoke. **MERV 13 or higher filters are recommended for use during smoke events as they can remove at least 50% of the smallest particles (0.3 – 1.0 µm; the size of most smoke particles) with each pass through the filter.** However, not all systems can accommodate MERV 13 filters. In those cases, use the highest rated filter compatible with the system.

Below are steps to determine the maximum MERV-rated filter for your system. See pg. 45 of the ASHRAE Epidemic Task Force Building Readiness document for more details.[23] While this document is aimed at airborne infection control, the MERV-rating evaluation steps are the same. You may wish to consult a qualified design professional, certified commissioning provider (CxP), or certified Testing, Adjusting, and Balancing (TAB) service provider for larger, more complex HVAC systems. If you plan to assess the system yourself, some information might be available in the most recent TAB report. If the building has been renovated or occupancy has significantly changed since the last report, consider requesting a new TAB service evaluation. To determine the maximum MERV-rated filter:

a. Determine the manufacturer, size, thickness, MERV rating, and pressure drop of the **current** filters in use. (see **Filter Efficiency and Pressure Drops** callout box for a description of pressure drop).

b. Identify upgraded filters and their operating characteristics from the manufacturer, which may be found in ASHRAE 52.2[24] test data.

c. If the higher rated MERV filter has the same or a lower pressure drop than the current filter, your system can be upgraded without modification. Thicker filters can have a low pressure drop and high MERV ratings, but they need to fit snugly to effectively reduce smoke. If the system can accommodate a MERV 13 filter or higher, install this filter when smoke is forecast or before seasons when smoke is likely. If the system is unable to accommodate a filter of this rating, install the highest rated filter the system can handle and operate PACs (see **Section 4**). Additionally, if your area is frequently impacted by smoke, you may consider upgrading the HVAC system to accommodate higher rated filters.

[23] ASHRAE Epidemic Task Force Building Readiness: https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-building-readiness.pdf

[24] https://www.ashrae.org/File%20Library/Technical%20Resources/COVID-19/52_2_2017_COVID-19_20200401.pdf

The MERV Rating Scale and How it Applies to Smoke

Minimum Efficiency Reporting Value (MERV) is the primary rating system used to indicate how efficiently a filter removes particles from the air. The MERV scale is for PM only and is not used to rate gas-phase pollutant removal. MERV ratings have different requirements for various particle size ranges. Wildland fire smoke is predominantly in the 0.3 – 1 µm size range, which is typically the most difficult particle size to filter from the air.

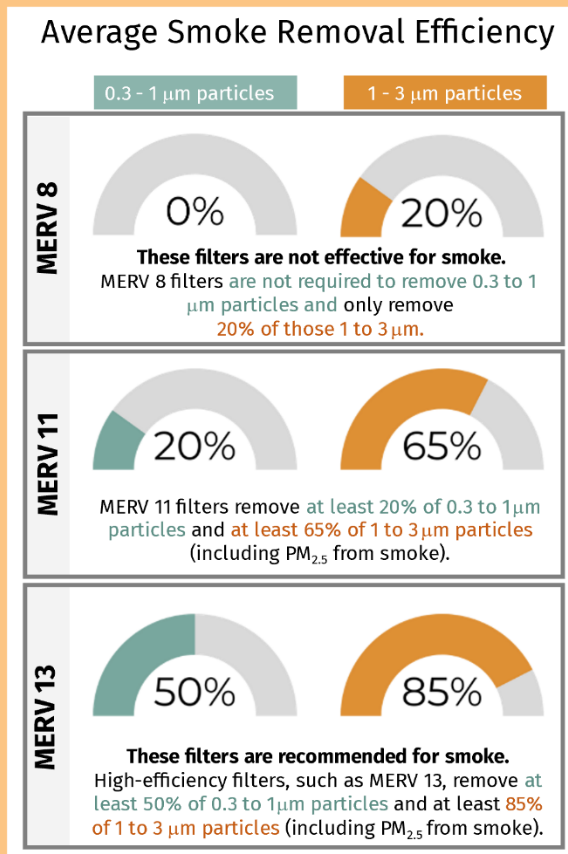
MERV values vary on a scale from 1 to 16. The higher the MERV rating of a filter, the more particles it removes as air passes through.

Other rating systems also exist, including Micro-particle Performance Rating (MPR) and Filter Performance Rating (FPR). The explanation below focuses on MERV as the industry standard; however, the table below shows approximate equivalency between filter rating metrics derived from a study of a limited subset of filter types.

	MERV 8	MERV 11	MERV 13
Comparable to	MPR 600	MPR 1000-1200	MPR 1500-1900
	FPR 5	FPR 7	FPR 10

High-efficiency Particulate Air (HEPA) filters are another filter rating. HEPA filters are not typically used in everyday applications for HVAC and are more commonly used in air cleaners.

The figure below shows the efficiency with which different MERV-rated filters remove 0.3 – 1 µm sized particles from the air.



Data adapted from US EPA " What is a MERV Rating ", originally derived from a test method developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE)

For more information on how efficiently MERV-rated filters remove particles from the air, see
EPA: https://www.epa.gov/indoor-air-quality-iaq/what-merv-rating,
EPA AirNow: https://www.airnow.gov/sites/default/files/2021-09/wildfire-smoke-guide_0.pdf
CARB: https://ww2.arb.ca.gov/resources/fact-sheets/air-cleaning-devices-home
Research: https://doi.org/10.1111/ina.12566

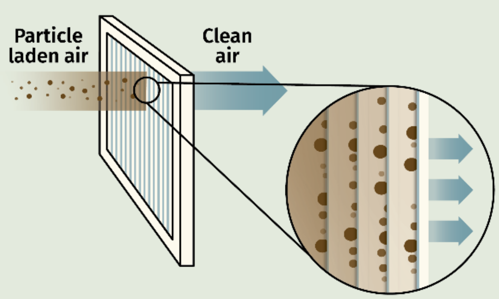
Electrostatic Filters

Many filters with higher MERV ratings use electrostatically charged fibers to capture small smoke particles. However, these filters may become less effective quickly during smoke events, even at moderate smoke loading (see the **Mechanical vs. Electrostatic Filters** callout box). Although the MERV evaluation accounts for the effectiveness of a dust-loaded filter, effectiveness may differ for a smoke-loaded filter because PM from wildland fires has characteristics that differ from the dust used in filter evaluations.

When to Change Filters

During wildland fire events, filters may become difficult to obtain, so stock up on replacements prior to wildfire season and prescribed burn events. If not already being used with your HVAC system, install the selected higher MERV-rated filters when smoke is forecast. Note you may need to change your filter(s) more frequently during smoke events depending on the smoke concentration and event duration, to ensure that the HVAC system is filtering adequately. Smoke can load filters quickly and it may be challenging to determine when a filter has become less effective. If fitted snuggly in the filter slot, a mechanical filter loaded with smoke or dust may have an increased pressure drop across the filter over time. You can monitor the pressure drop using a differential pressure sensor as a way to keep track of filter effectiveness. However, this approach may not work well with electrostatic filters, and a visual inspection may be needed. If filters are very dark or have a strong smoky odor, the filter likely needs to be changed. For any filtration approach, **air sensor(s) can be placed in the building to monitor PM concentration changes over time to help identify when filters are loaded** and are losing their ability to remove smoke particles. There are many nuances to using sensor data to understand if filters have lost their effectiveness at reducing smoke indoors, See **Section 5** for more in-depth discussion on how to use sensors for assessing wildfire smoke impacts indoors.

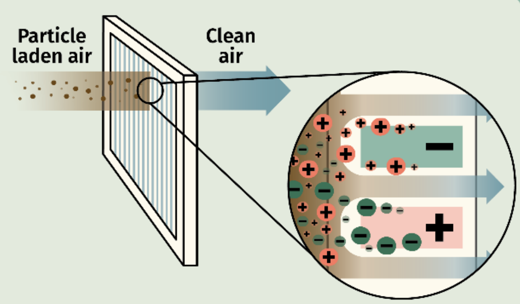
Mechanical vs. Electrostatic Filters



Mechanical Filters

In mechanical filters, air is forced through filter material, causing particles to stick to the filter surface. A dense mat of fibers is required for effective particle removal, which results in a larger resistance to air flow. This is measured as pressure drop.

As particles build up on the filter this further reduces flow through the filter and increases pressure drop.



Electrostatic Filters

In electrostatic filters, also called electret filters, the filter material is electrostatically charged. This charged surface attracts charged particles, like a magnet, removing them from the air. Electrostatic filters require fewer fibers for effective particle removal and often have lower pressure drops than equivalent rated mechanical filters.

Over time some particles, like wildfire smoke, can mask the charge resulting in electrostatic filters losing their ability to attract particles to the filter surface.

Following a smoke event, replace filters to avoid recirculation of odors from dirty filters. Also consider increasing ventilation (i.e., increasing outdoor air intake) when the outdoor air quality has improved to clear the air in the building. Restock any filters that were used during the smoke event.

If power is lost during a smoke event, the ability to filter the air using the HVAC system is lost. It may be helpful to create a contingency plan for power outages.

Sorbents for Gas Removal

Typical MERV 13 and higher-rated filters will remove smoke-related PM from the air, but not harmful gas phase species in smoke. Adding VOC sorbent filters, separate or integrated with MERV-rated filters, can remove VOCs and some other gases from the air. The sorbent in these filters traps gases as air flows through the filter. Activated carbon is the most widely available sorbent, but it may not be effective for all gases in wildland fire smoke. Evaluation standards for gas removal are not commonly reported by sorbent filter manufacturers, so picking an effective sorbent for wildland fire smoke is not straightforward.

The ASHRAE Handbook provides comprehensive information on how to design gas removal components for HVAC systems and contains more technical details for removing specific pollutants.[25] Helpful metrics to consider when choosing a sorbent filter include the:

- **Type of sorbent.** Activated carbon is recommended for removing many types of VOCs, but other sorbents like potassium permanganate more effectively remove certain harmful compounds in smoke, such as formaldehyde, acetaldehyde, and hydrogen cyanide. Multiple-sorbent filters may more effectively reduce a broad range of compounds.

- **Amount and thickness of sorbent in the filter.** More sorbent allows for longer use. A larger sorbent surface area increases the efficiency of pollutant gas removal from the air.

- **MERV rating.** Some sorbent filters are not MERV-rated, so it is important to determine if the MERV rating is still met with the chosen filter. Sorbent-impregnated filter media may have high MERV ratings and be effective at removing some gases and PM. Alternatively, if the HVAC system can accommodate multiple filters, a sorbent filter with a low (or no) MERV rating can be combined with a higher rated MERV filter to remove particles and gases.

2.5 Supplemental External Filtration

Additional filtration on outdoor intakes during wildland fire smoke events may be beneficial. In addition to higher efficiency MERV filters within the HVAC system, you can supplement filtration by attaching additional filters directly to the outdoor intake.

Your HVAC system may need evaluation from a professional to determine its ability to accommodate the additional pressure drop caused by a temporary supplemental filter without damaging other equipment.

Filters can be temporarily installed on outside air intakes using an appropriately sized filter

[25] https://www.ashrae.org/file%20library/technical%20resources/ashrae%20handbook/i-p_a19_ch47.pdf

Filter Efficiency and Pressure Drops

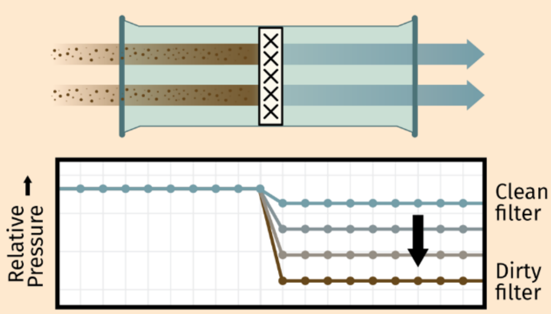
The information in this box relates to mechanical filters. The efficiency of electrostatic filters may decrease before they experience significant pressure drop. See ***Section 2.4: Electrostatic Filters*** *for more information.*

A decrease in pressure from one point in a duct to another is called a pressure drop. This is a measure of resistance to air passing through a filter. If there is too much resistance (too high a pressure drop), the air handling system works harder to move air, potentially leading to equipment damage. It is important to understand how filter characteristics and particle deposition affect pressure drop in the HVAC system.

Generally, the higher the filtering efficiency rating (MERV rating), the higher the pressure drop. The pressure drop across a filter is also based on the thickness of the filter, with thicker filters generally having lower pressure drop than thinner ones. The pressure drop will also increase as the filter becomes heavily loaded with particles.

Ways to minimize the risk of equipment damage from pressure drop while reducing smoke concentrations include:

- **Select the appropriate filter for your system.** The filter needs to have the correct length, width, and thickness to fit snugly and have the highest MERV-rating with a pressure drop suitable for your HVAC system.
- **Regularly change your filter.** Recommended filter change frequency is between 1 and 6 months, but this may be more often in smoky conditions. Regular visual checks of the condition of the filters can aid in setting a schedule. Generally, if you cannot see the filter media under the smoke trapped on the filter or the filter has a noticeable smoke odor, it needs to be replaced.
- **Monitor filter pressure drop**. If pressure drop through the filter is reported by your HVAC system, you need to know the clean filter pressure drop and the recommended maximum pressure drop for a heavily loaded filter. The initial filter pressure drop will vary by filter type, MERV rating, thickness, and size. When the pressure drop reaches the maximum limit, it is time to change the filter. During smoke events, you may need to rely on visual inspection or the use of an air sensor to determine when filters need to be changed.



Over time, particle build up reduces the air flow through a filter, leading to a greater pressure drop across the filter and added strain on the HVAC system with tape or sealant (**Figure 7**). Consider having an HVAC professional install permanent filter racks on the outdoor air intake if you use this strategy frequently.

If possible:

- When smoke is forecast, **install the filter with minimal gaps around the seal/tape.** Perform periodic checks to see when to change the filter(s), and that seals remain intact.

- After a smoke event, remember to **remove the supplemental filter(s) and inspect the main filter and replace it,** if needed. Order replacement filters for future smoke events.

Figure 7. Images showing additional filters attached to HVAC air intake. Images from ASHRAE: Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events.

3. Building Usage and Weatherization Adjustments

BE SMOKE READY

Before a Smoke Event:

- Evaluate building for air leaks and repair them.
- Check that doors and windows close and seal properly.
- Plan adjustments to building entrances to reduce outside air infiltration.

During a Smoke Event: **When smoke is forecast...**

- For air leaks, implement emergency strategy to seal the leak.
- Apply building entrance adjustments.
- Run PACs and air curtains (if part of your Smoke-Ready Plan).

After a Smoke Event:

- Repair leaks found during the smoke event.
- Return building entrances to normal use.
- Replace PAC filters.
- Discontinue air curtain use if not part of year-round operations.
- Evaluate and adapt the Smoke-Ready Plan.

3.1 Overview

Smoke can infiltrate buildings through gaps or broken seals around doors, windows, vents, fans and other penetration points in the building envelope (e.g., holes drilled for lighting fixtures, internet/TV/phone service cables, or security cameras). Sealing the building envelope reduces potential entry points for smoke and provides additional benefits, including improved energy efficiency through reduced heating and cooling costs (i.e., weatherization) and reduced entry points for pests. It is especially important in buildings that do not have mechanical ventilation or that cannot maintain positive pressure during a smoke event.

3.2 Sealing the Building

Doors and windows may leak over time due to weathering, cracks, or wear. Doors and windows that do not close properly will also allow outdoor air inside. In addition to improving indoor air quality, identifying and fixing leaks reduces heating and cooling expenses and minimizes water leaks when it rains. Comprehensive energy audits performed by registered energy experts are available for residential and commercial buildings and can identify areas that need sealing. As part of these audits, building air tightness is tested using large fans and thermal imagers (also called thermal cameras). To learn more, reach out to your local utility company and/or your local or state government department of energy or energy commission.

Prior to wildfire season and prescribed burns, evaluate the building for cracks, leaks, or gaps around the building exterior and interior.

Places to check on a building's exterior:

- Windows
- Doors
- Vents and fans
- Skylights
- Siding (especially where siding and other building features, such as AC units or chimneys meet)
- Exterior building corners
- Around window or wall-mounted air conditioner units
- Roof access doors
- Loading docks
- Service penetrations (e.g., pipes, plumbing, security cameras)

Places to check on a building's interior:

- Windows
- Weather stripping around doors
- Vents and fans
- Baseboards
- Electrical and cable outlets
- Attic hatches
- Fireplace dampers
- Around pipes that traverse the ceiling and or walls

Visual: Visual inspection is a good first step to help identify certain leaks (**Figure 8**). For

Figure 8. Example of cracks around a window and a gap under a door that may lead to leaks and infiltration of outdoor air.

example, when indoors, if you can see light from outside along window or door seals or wall joints, there is likely a leak.

Leak tests: You can also perform a leak test prior to a smoke event. Turn off the ventilation system, fans, and air conditioning. Slowly move a smoke pen (handheld device that creates a small mist or smoke stream commonly used for leak detection) around the edge of the window, door, or other seals. If at any point the smoke flows away from the seal, there is likely a leak.

If you can access a thermal imager (**Figure 9**), you can use it to identify leaks around windows and doors by visualizing heat differences. Thermal imager attachments are also available for cell phones.

Figure 9. A thermal imager being used indoors to assess windows for leaks.

Identify leaks by turning down the ventilation system, fans, and HVAC inside your building in winter. Direct the thermal imager at door and window seals. Leaks will appear as cold spots (e.g., blues and purples) that indicate cold air from outside is leaking in. In the summer when the air outside is warmer, leaks will show up as warmer spots (e.g., reds, oranges, yellows), indicating warm air from outside is leaking in.

If a smoke event is already underway and you have a mobile PM sensor, you can check window and door seals by holding the sensor close to the seal. Note that sensors may have a delay in collecting and displaying the measurement so it may need to be held in place for a period of time. If the PM values are higher closer to the seals when the windows or doors are closed and were not opened recently and there are no other nearby sources of PM, there is likely a leak. This method may not be helpful in identifying small leaks.

You can also consult a professional to determine leakage rates at a fixed pressure across the building. For more on do-it-yourself (DIY) leak detection and sealing, see the Department of Energy Detecting Air Leaks webpage.[26]

Fix leaks by applying caulking, spray foam, weatherstripping, or other material to seal small gaps. Perform repairs where necessary. During a smoke event, consider emergency strategies to help seal leaks (i.e., masking tape, duct tape, or caulking) until a more permanent fix can be employed after the smoke event has passed.

3.3 Entrance Adjustments

Adjusting entrance usage during smoke events may minimize smoky air infiltration when doors are open. **Prior to smoke periods, create a building plan outlining how to ensure windows remain closed, which doors will remain in use, and where PACs will be placed.**

Automatic Doors: For buildings with automatic and manual doors, **reduce the use of automatic doors during smoke events.** Automatic doors stay open longer than needed and are easily triggered even when not needed.

Manual Doors: Ensure manual doors are closed when not in use. If entrances have vestibules with double doors, keep both sets of doors closed.

Air Curtains: These are powerful vertical streams of air positioned above doors, especially those without vestibules (**Figure 10**) Air curtains pull recirculated air from inside the building and create a wall of additional positive pressure when the door is open. **During smoke events, properly installed air curtains can provide an air buffer to minimize smoke infiltration when someone is entering or exiting the building.** Additionally, air curtains can keep conditioned air inside when doors are open. Air curtains also keep sight or access clear, meaning patrons are still easily able to enter or exit the building as necessary. After a smoke event, discontinue air curtain use, if desired.

Figure 10. Example of air curtains installed above a door frame.

[26] https://www.energy.gov/energysaver/detecting-air-leaks

Limit doors in use: During a smoke event, plan to limit the use of allowable building entrances and exits to ones with a vestibule, air curtain, or revolving door, if available. Consider outdoor conditions to select doors that are least impacted by smoke, e.g., those away from the prevailing winds, for continued use during the smoke event. Limit the use of other doors when it is safe and reasonable to do so. Large entrances such as loading docks can let in large amounts of smoke.[27] Consider limiting their use to short time periods or after hours when there are fewer occupants in the building or delaying deliveries until smoke has passed.

Mitigation near open doors: In some instances, doors and windows need to be opened, such as when outdoor temperatures are hot, and the building is not cooled. In this case, **PACs are most effectively used in the vicinity of open doors (see Section 4) to minimize the amount of smoke that enters deeper into the building.**[28] Keep in mind, the filters in these air cleaners may need replacing more frequently, as they will be drawing in more polluted air than other units in the building.

Safety Considerations

When adjusting door usage, always consider evacuation safety and accessibility to ensure building occupants can evacuate in case of an emergency. Instead of locking doors to prevent use during smoke conditions, place a sign on the door stating: "Do not use for air quality," or "Please use other door." This ensures the door remains operable during an emergency. Additionally, maintain accessibility and American Disability Act (ADA) compliance.

After a smoke event, resume full use of windows or doors.

[27] Nguyen, P.D.M., et al., 2021, https://doi.org/10.3390/ijerph18189811

[28] Novoselac and Siegel 2009, https://doi.org/10.1016/j.buildenv.2009.03.023

4. Portable Air Cleaners (PACs)

BE SMOKE READY

Before a Smoke Event:

- Evaluate the need for PACs.
- Select a PAC that removes particles and/or gases, produces little or no ozone, is energy efficient, and meets noise requirements.
- For particles, calculate the smoke CADR and number of PAC units needed.
- Purchase replacement filters.

During a Smoke Event: **When smoke is forecast...**

- Deploy PAC unit(s).
- Assess PAC effectiveness and replace filters as needed.
- Create a cleaner air room (if part of your Smoke-Ready Plan).

After a Smoke Event:

- Change PAC filters and order replacements.
- If the PAC removes gases consider running it after PM levels decrease.
- Store the PACs for next use.
- Evaluate and adapt the PAC section of your Smoke Ready Plan.

4.1 Overview

A PAC is a commercially available standalone unit that can be plugged into a wall outlet and moved as needed. These units differ from HVAC systems as they are not installed on the roof or walls of a building and serve only the immediate space around where they are located. PAC units are not typically designed to heat or cool a space.

There are many different PACs available. Although they cannot eliminate all pollutants from the air, they help improve air quality indoors when used properly. Some PACs may remove only particles or only gases, while others remove both. As wildland fire smoke contains both particles and gases, an air cleaner that can reduce one or more pollutants would be beneficial. U.S. EPA provides detailed guidance for residential PAC use[29]. This

[29] Air Cleaners and Air Filters in the Home. https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home

document will address larger and commercial spaces.

Before a smoke event, decide if PACs will be needed in your building. Create a plan of where to operate PACs and how many devices will go in each space. If power is lost during a smoke event, the ability to filter the air using PACs is also lost. It may be helpful to create a contingency plan for power outages.

4.2 When to Use a PAC

There are several scenarios where you may opt to use PACs to clean indoor air during smoke events:

- Your building does not have an HVAC system, or your HVAC does not accommodate MERV 13 rated filters.
- The building has areas that need additional filtration beyond what your HVAC system can deliver during a smoke event. This might be determined using an air sensor (see **Section 5** for more information).
- You have not yet been able to adjust the HVAC system settings.
- You are setting up a cleaner air room (see **Section 4.7**).

Section 4.4 highlights what to consider when selecting a PAC, including optimal operation, maintenance considerations, the steps involved in using a PAC, and additional resources.

If you decide a PAC is helpful for your location **during a smoke event, run the unit at all times when the building/room is occupied.**

If commercial PAC units are unavailable, you may consider creating a do-it-yourself air cleaner. For more information, see the **DIY Air Cleaners** call out box.

After a smoke event, gases may linger in indoor air or continue off-gassing from surfaces. Dust and ash may be resuspended during clean up**. Continue to run your PAC in the cleanup period. If you have a PAC that also removes gases, continue to run it after PM levels have reduced because VOCs may remain elevated for several days or weeks after a fire.**

4.3 Types of Air Cleaners

PAC technology can be categorized based on the technique used to eliminate pollutants. Choosing a unit with technology that produces little to no ozone is very important.[30] Ozone is a harmful gas that can damage lungs when inhaled.[31] The California Air Resources Board (CARB) provides a list of air cleaners that meet the California ozone emissions limit.[32]

Below are the general categories of PAC technologies used to reduce PM and gaseous air pollutants.

Particle Removal

1. **Mechanical air cleaners** pull air through a filter (either a mechanical filter or an electrostatic filter) to remove particles, and do not involve electric fields. Periodically, the filters will need replacing. PACs using

[30] "Wildfire Smoke, A Guide for Public Health Officials." https://www.airnow.gov/sites/default/files/2021-09/wildfire-smoke-guide_0.pdf
[31] https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution

[32] List of CARB-Certified Air Cleaning Devices: https://ww2.arb.ca.gov/list-carb-certified-air-cleaning-devices

HEPA filters are effective at removing smoke particles from the air.

2. **Electronic air cleaners** do not use filters and instead use electric fields to remove particles from the air. **These devices include electrostatic precipitators (ESPs) and ionizers and are not recommended for smoke removal.** Electronic air cleaners that use oxidants or radicals do not decrease PM concentrations. [33,34,35] Electronic air cleaners that generate ions can reduce PM concentrations but often generate harmful ozone or other byproducts.

Note that a single air cleaner can have both mechanical and electronic air cleaning technology. Some allow the user to turn off the electronic component. In some cases, the order of the technologies in the air cleaner is important to reduce potential byproducts being released back into the room (e.g., fewer charged particles might be released if a mechanical filtration component follows an ionizing component).[36]

Gaseous Pollutant Removal

Gases and odors can be removed from the air using certain types of PACs that capture gases on filter media (such as activated carbon). Others add gas or odor removal compounds (such as ozone) to the air to transform gases.

1. **Sorbent filters**: Some PAC units include gas removal technologies, such as activated carbon or alumina coated with potassium permanganate (an oxidizing substance that can remove odors and gases from the air). Ensure you change gas removal filters regularly, as they can quickly become ineffective in smoky conditions.

2. **Other gas removal technology:** Sometimes ozone generators are sold for gas pollutant removal. They produce large amounts of ozone **and should not be used in schools, homes, or occupied areas.**

Other PAC technologies for removing gaseous air pollutants are still under investigation and their effectiveness is unclear, for example:

- Air cleaners with high-temperature heating elements claimed to render contaminants inactive and remove gaseous pollutants.
- Technologies with ultraviolet (UV) bulbs, plasma, and surface coatings like titanium dioxide to enhance pollutant removal.
- Others may be sold as "hydroxyl" generators[37] or "air washers." These devices and others also emit ozone and can emit additional gas-phase pollutants (such as VOCs). Electronic PAC units that produce any amount of ozone are not advised.

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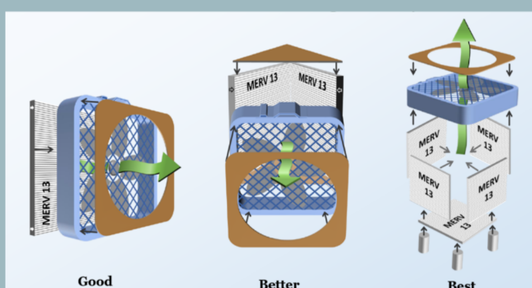
[33] Stinson et al. 2024, https://doi.org/10.1021/acsestair.3c00083
[34] Zeng et al. 2022, https://doi.org/10.1016/j.buildenv.2022.108858
[35] Zeng et al. 2022, https://doi.org/10.3390/pollutants2020010
[36] Residential Air Cleaners: A Technical Summary: https://www.epa.gov/sites/default/files/2018-07/documents/residential_air_cleaners_-_a_technical_summary_3rd_edition.pdf
[37] Wildfire Smoke, A Guide for Public Health Officials, https://www.airnow.gov/sites/default/files/2021-09/wildfire-smoke-guide_0.pdf

Research has not shown that plasma, heat, surface coating-technology, or UV light effectively remove gases in PAC units.[38] In some cases, these technologies may increase gaseous pollutants present[39] and generate ultrafine particles in the air.[40]

DIY Air Cleaners

When commercial PACs are unavailable, it is possible to build a do-it-yourself (DIY) air cleaner, sometimes called a "box fan filter" by attaching a furnace filter(s) to the back of a box fan.

Thicker filters or multiple filters (forming a triangle or box) increase particle removal by increasing the filter surface area and reducing the load on the fan motor.



To ensure the DIY air cleaner is effective:

- Use MERV 13 rated filters that are the same size as the fan (typically 20" x 20").
- Attach filters with the air flow arrows on the filter matching the direction of the fan.
- Use more filters or thicker filters to increase effectiveness.
- Replace filters when dirty or as instructed by the manufacturer directions.

Many online resources provide instructions, safety tips, videos, test results, and parts lists for building a unit, including this resource from EPA: https://www.epa.gov/indoor-air-quality-iaq/diy-air-cleaner-reduce-wildfire-smoke-indoors-infographic

Safety Tips

Important safety steps should be followed when running a DIY air cleaner, including (but not limited to):

- Use only **NEWER** box fans (manufactured after 2012) with safety features such as fused plugs and thermal cutoffs.
- Use fans that meet **UL 507 or ETL** safety standards and follow the manufacturer instructions.
- Follow manufacturer instructions and do not use the fan with an **extension cord** or leave **unattended.**

[38] https://www.epa.gov/sites/default/files/2018-07/documents/guide_to_air_cleaners_in_the_home_2nd_edition.pdf

[39] Ye et al, 2021, https://doi.org/10.1021/acs.estlett.1c00773

[40] Link et al, 2024, https://doi.org/10.1021/acs.est.3c09331

4.4 How to Select a PAC

Particles, Gases, or Both?

During smoke events, reducing gases in spaces occupied by individuals with sensitivity to poor air quality is important.

Because no air cleaner is capable of removing all air pollutants, it is important to check which gases, VOCs, and particles each PAC removes. The PAC specification sheet, label, or manual indicates which pollutants are targeted for removal. Most PACs state PM removal capacity (e.g., clean air delivery rate), but have minimal information on removal effectiveness for gases or VOCs. A recent study[41] suggests an air cleaner with a large bank of activated carbon will remove gases and VOCs better than an air cleaner with a thin activated carbon filter or additive media such as a hydroxyl generator. When air quality is very poor (e.g., AQI is in the Hazardous category), smoke components that are not effectively removed by air cleaners, like CO, may cause adverse health effects. Additionally, at these extreme smoke concentrations, PACs may not be able to keep up and keep indoor air clean. At these times, relocating to a place with better outdoor air quality may be the best option to reduce smoke exposure.

Room Size

The most important consideration is sufficient cleaning capacity for your space. In this section we consider (1) PACs for smaller spaces (e.g., individual offices, classrooms, meeting rooms) and (2) options for larger spaces (e.g., grocery stores, libraries, large open offices).

Smaller Spaces and Clean Air Delivery Rate

The **Clean Air Delivery Rate** (CADR) is a rating system developed by the Association of Home Appliance Manufactures (AHAM) to determine how much air a PAC can filter in a given time period, and solely applies to particle removal, not gases. **To effectively use PACs, you will need to calculate the smoke CADR and number of PAC units needed for your space.** CADR values are typically advertised on PAC units intended for residential or small non-industrial settings, and values are reported in units of cubic feet per minute (CFM) for the highest fan setting. Be aware that some devices may report in units of cubic meters per hour (m^3/hr) or no units at all. If you wish to run the PAC(s) on slower settings (and thus quieter), more PACs or larger PACs will be required to reach the desired CADR. Noise considerations are discussed further in **Section 4.5**.

Typically, a higher CADR rating indicates a PAC removes particles faster by moving more air through the filter and thus is appropriate for a larger room. CADR is measured separately for tobacco smoke, dust, and pollen, and the **tobacco smoke** CADR is the most appropriate rating to use for reducing wildland fire smoke.

During smoke episodes, AHAM recommends selecting an air cleaner with a **smoke CADR that <u>matches</u> your room size in square feet**[42] (choosing a PAC with a larger CADR will clean the air faster). For example, an air cleaner with a smoke CADR of 200 CFM would be appropriate for a 200 square-foot room with 8-ft ceilings. During non-smoky periods, a PAC with a tobacco smoke CADR 2/3 the room size is typically considered sufficient (i.e., CADR of 133 CFM for the previous example).

[41] Stinson et al., 2024, https://doi.org/10.1021/acsestair.3c00083

[42] https://www.aham.org/AHAM/News/Latest_News/Air_Cleaner_Wildfires.aspx

Table 3. Examples of CADR calculations.

Example of a room this size	Room area (square feet)	Ceiling height (ft)	Actual room volume (ft^3)	Equivalent room area assuming 8 ft ceiling (ft^2)	Number of PACs needed
A single office room	100	8	800	100	1 at CADR of 100 CFM
Average conference room	400	10	4,000	500	1 at a CADR of 500 CFM 2 at a CADR of 250 CFM Etc.
Average classroom	800	8	6,400	800	2 at a CADR of 400 CFM 3 at a CADR of 200 CFM Etc.
Small retail space	1000	12	12,000	1500	3 at a CADR of 500 CFM 5 at a CADR of 250 CFM Etc.

Some PAC units note a suggested room size based on tobacco smoke CADR. You can also search the AHAM Certified Room Air Cleaner Directory.[43] However, these recommendations assume a goal of 80% reduction in PM in a room with **an 8-ft ceiling**, which may not be appropriate for commercial and non-residential spaces. If your ceilings are higher than 8 feet or if you need greater reduction in PM concentrations, a higher CADR is needed.

To assess the most appropriately rated PAC for your room, calculate the minimum CADR rating using the dimensions of your room. **Figure 11** shows how to determine the CADR for your space with example calculations. The maximum AHAM verifiable (and therefore certifiable) smoke CADR rating for PACs is 600 CFM[44]. If your calculation results in a CADR greater than 600 CFM, you need to use multiple PACs. As PAC CADRs are additive[45], you can use multiple units with smaller CADRs to reach the optimal CADR. An advantage to multiple PACs distributed throughout large spaces is that they will help circulate clean air through the room.

Note that the "number of PAC units needed" column in **Table 3** assumes the room has no additional air filtration, such as an HVAC system. If you have an HVAC system in place, you may be able to use fewer PAC units or a lower fan setting (see **Appendix 1 Example Smoke-Ready Plan** for an example of how to use a staged approach to PAC use with HVAC to stay ahead of smoke infiltration). The best way to ensure the combination of HVAC and PACs is sufficient to clean the air in your space is to use an air sensor to check indoor pollutant concentrations (see **Section 5**).

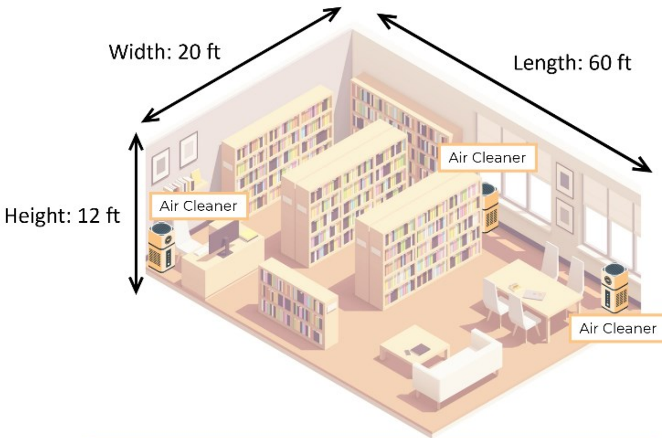
If you are using a DIY air cleaner, researchers at EPA have calculated CADR values for different configurations of fans and filters.[46] These are shown in **Table 4**.

[43] AHAM Certified Room Air Cleaner Directory to find the CADR rating: https://www.ahamdir.com/room-air-cleaners/

[44] ANSI/AHAM AC–1–2020

[45] https://www.epa.gov/indoor-air-quality-iaq/guide-air-cleaners-home

[46] https://www.epa.gov/air-research/research-diy-air-cleaners-reduce-wildfire-smoke-indoors

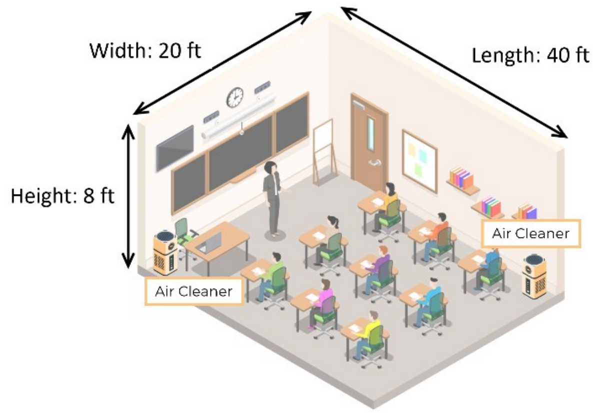


Actual Room Volume = Length x Width x Height
= 60 ft x 20 ft x 12 ft
= 14,400 ft^3

Equivalent Room Area = Actual Room Volume ÷ 8 ft
= 14,400 ft^3 ÷ 8 ft
= 1,800 ft^2

Using an air cleaner with CADR of 600: 1,800 ft^2 ÷ 600 = 3

This room would need 3 air cleaners with a CADR of 600



Since the room has 8 ft tall ceilings, we can simply calculate the area:

Room Area = Length x Width
= 40 ft x 20 ft
= 800 ft^2

Using an air cleaner with CADR of 600: 800 ft^2 ÷ 600 = 1.3

This room would need ~2 air cleaners with a CADR of 600

Figure 11. Example cleaner air space scenarios.

Table 4. CADR values for DIY air cleaners based on design.

DIY Air Filter Design	Wildfire smoke CADR
Box fan with one 1" MERV 13 filter	111 ± 1
Box fan with one 1" MERV 13 filter and cardboard shroud	156 ± 4
Box fan with one 4" MERV 13 filter and cardboard shroud	248 ± 15
Box fan with two 1" MERV 13 filters and cardboard shroud	263 ± 22
Corsi-Rosenthal Box with four 1" MERV 13 filters and cardboard shroud	401 ± 31

Air Cleaners for Larger Spaces

For larger facilities, the number of residential PAC units required to clean the air may be unreasonable. In this situation, the cost for many PACs should be compared to the cost to upgrade the HVAC system or install a new one. Consider not only the initial price to purchase PACs but also the ongoing estimated cost to run them (electricity, filter replacements, storage, etc.).

Another option for very large spaces is to use industrial-sized PAC units (e.g., commercial air scrubbers) often intended for smoke remediation efforts. The cost of each of unit will be higher, but the number of units needed for large spaces will be lower and may result in lower operating costs (for example, fewer filters to replace, lower energy costs). Larger units may also be available to rent. Note that these devices can be quite large, have high airflows, and may be noisy. In addition, many industrial-sized, commercial-grade units can be used as negative air machines by connecting a hose that exhausts outside. **Do not use air scrubbers as negative air machines during a smoke event** as it could draw in smoke via infiltration.

Industrial air cleaners are classified by their Air Changes per Hour (ACH), which represents the number of times per hour the volume of air in a space is replaced. Unlike CADR, ACH is not a reliable indicator of air cleaning effectiveness, so consider using air sensors to verify air cleaning. Note that some industrial-sized commercial-grade PACs may report a CADR, but it will not have been tested to ANSI/AHAM AC-1 methods. If you do not achieve sufficient air cleaning based on sensor data, you can increase the number of industrial PACs in your space.

4.5 Other Considerations

Cost/Availability

There are a number of costs associated with PACs that should be considered when selecting the correct unit for your space, including:

- **Purchase cost.** PACs range from <$100 to thousands of dollars. Cost can increase if multiple units are required.
- **Maintenance cost.** This includes replacement filters, which need to be replaced more in smoky conditions.
- **Storage and deployment.** Storage for PACs when not in use and staff time for deploying units and changing filters increases expenses.
- **Filter availability.** Replacement filters may be unavailable for discontinued air cleaners, requiring a new PAC purchase.

Electricity Consumption

Consider selecting a PAC that is ENERGY STAR certified. This certification is a U.S. EPA and Department of Energy designation indicating the unit meets strict energy efficiency standards. Models that earn the ENERGY STAR are independently certified to ensure they save energy without sacrificing performance, which means they deliver the same amount of filtered air as a standard model with less energy.[47]

Noise

Noise is important to consider because a loud PAC may cause distractions, discourage people from occupying a space, or may be switched off. A balance between acceptable noise levels for the space and filtration is important.

Many PACs will list a noise level in decibels (dB) on their specifications, which can help assess how loud the unit will sound in a space. Keep in mind PACs may have different operating fan speeds, so it is important to know which mode applies to the listed noise level. The noise level rating is commonly listed for the low mode, while the CADR is reported for the high mode, therefore the unit may be noisier than you anticipate. Ask the manufacturer or vendor if this information is not listed on the specification sheet. **Table 5** provides context for assessing noise levels.

Noise perception will vary based on room size, sound dampening surfaces, distance from occupants to the air cleaner, building use (e.g., quiet library versus bustling office), variation (i.e., cycling on and off versus a constant hum), and pitch. Some noises are viewed as unacceptable based on the type of noise, even at low levels. For example, some people find a

[47] How to Choose a Room Air Cleaner: https://www.energystar.gov/products/ask-the-experts/how-choose-room-air-cleaner

DIY air cleaner operating at 55 dB (the highest fan setting from 2 feet away) to be distracting.[48]

Table 5. Average (avg.) noise levels of some common activities to compare to PAC noise specifications.[49,50,51]

Everyday sounds (distance)	Avg. noise level (dB)
Normal breathing	10
Whisper (5 ft)	20
Dishwasher (next room)	50
Normal conversation (5 ft) /Air conditioner (100 ft)	60
Vacuum cleaner (10 ft)	70
Garbage disposal (3 ft)	80
Hair dryer (at ear)	82-100
Dog barking (near ear)	110

4.6 Filter Replacement and Maintenance

PAC maintenance should be performed according to manufacturer specifications. This may include cleaning components, replacing parts, or changing filters. When the PAC is being used during a smoke event, the filter will need to be replaced more often than during times when air quality is good.

Frequent filter replacement may be especially necessary depending on PAC location. For example, units in areas where doors/windows open regularly and allow in polluted outside air may need replacing more regularly than those in isolated or enclosed environments without exterior doors. **Ensure you have replacement filters on hand prior to smoke events.**

It is also important to know whether your PAC includes an alert to tell you when a filter needs to be changed. Some have an indicator that changes color based on the air quality, while others simply have a light that turns on after a set period of time. Make sure you understand your unit's alert system before a smoke event. Also be aware that filter-change indicators may not function properly under smoky conditions.

If your PAC only has a run time indicator or does not have an indicator, you should periodically manually inspect the filter to determine if it needs changing.

Steps to Check You Filter

1. Compare a photo of a new filter to the one you remove from the PAC (**Figure 12**). Filters with activated charcoal or other coatings might appear dark to begin with, so a visual inspection would not be useful. Some PACs contain pre-filters, which remove large dust particles or pet hair and may need to be changed more frequently.

Figure 12. Clean (left) and dirty (right) air filters.

2. **Measure PM levels with an air sensor to determine how effectively air is being**

[48] Prathibha et al., 2024, https://doi.org/10.1016/j.atmosenv.2024.120650
[49] https://www.cdc.gov/nceh/hearing_loss/what_noises_cause_hearing_loss.html
[50] https://multimedia.3m.com/mws/media/888553O/noise-navigator-sound-level-hearing-protection-database.pdf
[51] https://www.sandiegocounty.gov/dplu/docs/081024/TM5499-NOISE-T.pdf

cleaned during smoke events.[52] This technique will help you recognize when PAC filters need changing (see **Section 5**).

3. **Periodically measure the PAC flow rate**. On most mechanical air filters, the flow rate through the filter decreases as particles build up and restrict air flow. However, electrostatic filters continue to maintain airflow even after their ability to filter particles degrades, so it is important to know what kind of filter you have. To test flow rate, use a commercially available flow meter, such as a handheld anemometer, or set up a flutter strip. A flutter strip is a piece of light material, such as tissue paper, taped to the side that the air is blowing out of on your PAC. As the flow rate through the filter begins to decrease, the movement of the flutter strip and its angle will also decrease. See **Figure 13** for an example.

Also check filters after a smoke episode and replace dirty filters in preparation for future smoke events. Some filters will off-gas smoky odors and gases after smoke events, so you may need to change them regardless of appearance.

Evaluate and Adapt

After a smoke event, evaluate how well PAC units worked by examining air sensor measurements taken while they were running. Did they keep the indoor air cleaner? Did they remain effective over time as they ran? Do you need to adjust locations or purchase more units? Note filter loading, the number of high PM concentration days, and take photos of dirty filters and clean ones for future reference and update your Smoke-Ready Plan.

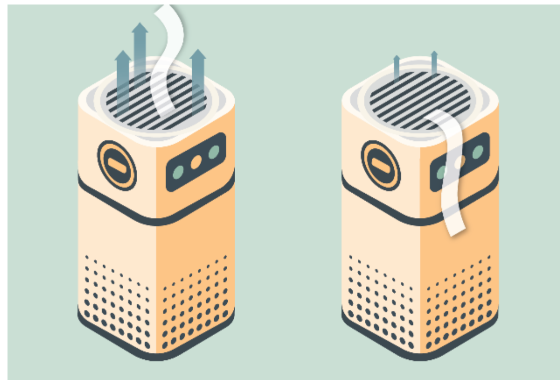


Figure 13. (Left) a PAC with a flutter strip exhibiting air flow and (Right) reduced air flow

4.7 Creating a "Cleaner Air Room"

A cleaner air room[53] is an isolated space within a building set up with PACs such that extra-purified air is available for those at greater risk from health complications due to smoke. This category includes children, older adults, pregnant people, and those with breathing problems or heart disease. It is important to remain aware of air quality updates and fire and smoke movement, as conditions can change quickly. Follow the AirNow Fire and Smoke website or app,[54] your state or local air quality agency, or your local news for timely information on air quality status.

[52] https://www.epa.gov/sites/default/files/2021-05/documents/ashrae_journal_article_march_2021-tagged.pdf

[53] U.S. EPA: Create a Clean Room to Protect Indoor Air Quality During a Wildfire: https://www.epa.gov/indoor-air-quality-iaq/create-clean-room-protect-indoor-air-quality-during-wildfire

[54] AirNow Fire and Smoke website: https://fire.airnow.gov/

A cleaner air room is best achieved in buildings with multiple rooms where one room can be closed off. For example, an office building can use a small conference room, a library or church can use a multipurpose room, and a daycare can use a playroom. A cleaner air room may not be possible in establishments like stores, call centers, or large warehouses that typically have one large space with doors that open outside.

Steps for setting up a cleaner air room:

1. Identify a room large enough to accommodate the expected occupancy.

2. Keep windows and doors closed to keep smoke out but maintain clear exits.

3. Keep the space cool. Run fans and air conditioners that do not pull in outside air. See the "Heat Caution" callout box.

4. Filter air in the room using a non-ozone-producing PAC or a DIY air cleaner.

5. Be sure to use one or multiple PACs or DIY air cleaners with a CADR appropriate for the room size.

6. Avoid activities in the space that degrade indoor air quality (i.e., prohibiting smoking and vaping, reducing or eliminating cooking, spraying aerosols, burning candles or incense, sweeping, and vacuuming - unless the vacuum has a HEPA filter).

The more time individuals spend in the cleaner air room, the more benefits they will gain. Be mindful of changing PAC filters and performing maintenance when necessary.

Heat Caution

Wildfires frequently occur during the height of summer when temperatures are the hottest. As such, there is a significant risk for heat-related illnesses. In addition to providing protection from smoke inhalation, cleaner air spaces should also prioritize keeping occupants cool to avoid heat-related health impacts. This will likely be achieved by running fans or air conditioning. For more information, see

CDC Heat Safety page - https://www.cdc.gov/disasters/extremeheat/index.html

AirNow Heat and Smoke Fact Sheet - https://document.airnow.gov/protect-yourself-from-smoke-and-extreme-heat.pdf

5. Air Sensors

BE SMOKE READY

Before a Smoke Event:

- Assess number and type of sensors needed using sensor selection guidance.
- Assess need for outdoor sensor(s).
- Purchase sensors and accessories.
- Consider deploying sensors before smoke events to understand typical conditions.

During a Smoke Event: When smoke is forecast...

- Ensure sensors are functional and data are accessible.

If concentrations indoors are increasing:

- Compare concentration trends to outdoor trends.
- Adjust HVAC settings, filtration, and PAC use as necessary.
- Reduce indoor activities contributing to increased concentrations.
- Check the building for new leaks.
- Check HVAC and PAC filters and replace as needed.

After a Smoke Event:

- Perform any required maintenance or cleaning on sensors
- Remove and store sensors.
- Evaluate and adapt the Smoke-Ready Plan.

5.1 Overview

Some air pollutants can be measured with air sensors. Air sensors are relatively low cost, portable, and easy to operate devices that can provide localized air quality data. They are not intended to replace the highly accurate readings taken by regulatory monitors used by government agencies.

Air sensors can be used to compare pollutant levels in different locations (e.g., indoors vs. outdoors, in different rooms) or evaluate trends in pollutant concentration over time (i.e., whether pollutant levels are increasing, decreasing, or staying the same). During smoke events, air sensors can identify spaces with lower pollutant levels and evaluate the effectiveness of mitigation techniques, such as HVAC adjustments or PAC usage.

Sensors that measure $PM_{2.5}$ (the primary pollutant of concern in smoke) are the most useful for indoor air measurements during smoke events.[55] Though not covered here, CO_2 sensors can also be used to ensure adequate ventilation.

5.2 Choosing an Air Sensor

If you are interested in monitoring pollutants with air sensors during a smoke event, first identify the most important sensor characteristics for your application. This ensures you **(1) choose a sensor that reliably measures your pollutant(s) of interest during smoke events; (2) meet needs for data communication, processing, and display; and (3) stay within your budget.** The questions in **Figure 14** can guide you.[56] **Purchase sensor(s) and accessories before smoky periods** and identify where they will be located, how to use them, and how to access data. Note details in your Smoke-Ready Plan.

Note that lower-cost sensors are less accurate than regulatory monitors and may have biases (e.g., report higher or lower concentrations than regulatory monitors) or reduced precision. To guide sensor purchases, U.S. EPA, the Air Quality Sensor Performance Evaluation Center (AQ-SPEC), and other organizations conduct outdoor and laboratory performance evaluations of some commercially available air sensors.[57,58] These assessments are available for free online and detail accuracy, precision, bias, and ease of use. Current evaluations do not cover every low-cost option available.

The U.S. EPA has a website regarding **Air Sensor Technology and Indoor Air Quality,** including information on the performance metrics of air sensors indoors.[59] For monitoring smoke-related air pollutants indoors, a sensor reported to have a precision and accuracy greater than 70% is advisable.[60]

5.3 Installing Air Sensors Indoors

There are several important considerations when choosing where to site a sensor:

Location: Sensor placement is important, and locations need to be carefully selected. **Figure 15** shows examples of sensor placement in various environments. Sensors should be placed in locations representative of the area where most people are being exposed. For example, you may consider placing sensors in the following areas:

- **Where high risk groups (see Health Impacts from Smoke in the Introduction) spend significant time** (e.g., daycare, care facility resident rooms).

[55] Children's Health and Wildfire Smoke Exposure Work: https://www.airnow.gov/sites/default/files/2022-01/childrens-health-wildfire-smoke-workshop-recommendations.pdf

[56] To find your local air district, visit https://www.airnow.gov/partners/state-and-local-partners/
EPA Sensor loan programs: https://www.epa.gov/air-sensor-toolbox/air-sensor-loan-programs; https://www.epa.gov/air-sensor-toolbox/wildfire-smoke-air-monitoring-response-technology-wsmart-pilot

[57] U.S. EPA Air Sensor Evaluation: https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance

[58] AQ-SPEC: http://www.aqmd.gov/aq-spec

[59] U.S. EPA Air Sensor Technology and Indoor Air Quality: https://www.epa.gov/indoor-air-quality-iaq/air-sensor-technology-and-indoor-air-quality

[60] U.S. EPA Air Sensor Performance Targets and Testing Protocols: https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols

* Check state or local air management districts for available sensor loan programs (see citation in text for how to find your local air district and EPA air sensor loan programs).

Figure 14. Key considerations when selecting an air sensor.

- **With the highest occupancy,** such as classrooms, offices with many workers, congregation space, or on sales floors.
- **With the greatest foot traffic**, such as hallways, lobbies, or cafeterias.

Within chosen space(s), sensors should be:

- **Free of obstructions** (e.g., large furniture) that may inhibit airflow to the sensor.
- **Away from strong air flow** (e.g., air vents), **high humidity, and high temperatures** (e.g., radiators, hot water pipes, non-energy saving lights). If sensors are overly influenced by airflow from vents, they can poorly represent indoor air quality.
- **Protected:** Sensors should be placed in locations where they cannot be tampered with. This may involve adding caging, or "camouflaging" the sensor, so it blends in with the surroundings and draws less attention (**Figure 16**).

Figure 15. Examples of sensor placement in public and commercial environments.

Sensor Needs: Consider access to power outlets and any structural support needed for mounting the sensor. If wall outlets are scarce, use a power strip or label the plug "do not unplug" to avoid accidental unplugging. Avoid using extension cords and long power cord runs to reduce trip hazards.

Figure 16. A camouflaged indoor air sensor. The sensor is in populated hotel lobby where air can flow into and around the sensor. Placing it inside a non-functional lamp shade keeps it out of sight.

Placement: It is best to position indoor air sensors at or slightly above the average occupant height. Positioning sensors slightly higher than the average height ensures the air being breathed is measured by the sensor and reduces the chances of tampering and accidental bumps.

Communication: If your sensor requires a Wi-Fi or cellular connection, make sure the location chosen has reliable signal strength. Wi-Fi in public places or schools may require authentication or input from administration. If data are stored on an SD card in the sensor, make sure the installation location allows access to the card.

Sensors with Displays: Sensors displaying current PM concentrations can help occupants identify when air quality conditions indoors are poor.

Ensure the Sensor is Working: After installation and when smoke is forecast, ensure the sensor is working and transmitting data. **Look at the data management system to ensure data are being transmitted and seem reasonable.**

5.4 Multiple Sensors

Running one air sensor may be sufficient in small buildings or where the chosen air sensor is portable and can easily be moved from one location to another. However, in larger buildings, installing multiple stationary sensors may be advantageous. If your building has multiple separate spaces, multiple HVAC systems, or air cleaning strategies, consider installing sensors in key locations to provide representative air quality information for different spaces. For a large space, such as a supermarket, gym, or place of worship, consider placing one sensor near the entrance and others where people congregate.

The number of sensors you place will depend on the building size, budget available for sensor purchase, and availability of resources to monitor data from multiple sensors.

You may find that a portable sensor is helpful to initially map pollutants in a space to identify hot spots (i.e., higher-concentration locations) for permanent sensor placement. Alternatively, a mobile sensor can survey pollutant concentrations in different locations. Keep in mind, the latter approach requires more attention from the operator. Namely, moving the sensor during the day to various locations of concern and recording sensor readings and locations for consistent comparison. Note that when moving a sensor or using a handheld sensor, the operator will need to keep the sensor in place for a period of time (usually at least a few minutes) for the sensor to accurately register pollutant concentration in the new location.

If you plan to use multiple sensors, you should check the sensors before installing them to make sure they are performing similarly. This is often referred to as a "precision check," and is performed to ensure that when the sensors are measuring the same air, no one sensor is measuring much higher or lower values than expected (bias) compared to the others. Details on how to perform a precision check are included in **Appendix 4**.

If during the precision check the readings from one sensor consistently differ greatly from the others, do not show a similar trend (such as sporadic data spikes), or do not measure at all, there is an issue with the unit and you should contact the manufacturer or vendor for repair or replacement. Once you complete the precision check and understand the nuances of your sensors, install them in their permanent locations.

Periodic precision checks are recommended to ensure sensors continue to perform as expected. Precision checking the units at least once a year prior to smoke season to ensure they still respond similarly to one another is advised.

Outdoor Sensor

An outdoor sensor can help inform your understanding of indoor measurements – if you note an increasing trend in indoor concentrations, an outdoor sensor can confirm the trend is reflective of outdoor conditions. A note of caution: during smoke events, outdoor concentrations of pollutants can reach levels above those that some air sensors are equipped to measure. This can lead to sensor overload and the values become unreliable. This may cause sensors to report errors, stop responding to concentration changes, or otherwise malfunction. Using sensors of the same brand and model of sensor inside and outside and, through collocation, will facilitate direct comparison between indoor and outdoor sensors.

For PM, some air sensors report data at higher concentrations than measured by regulatory monitors. As such, EPA and other agencies have developed correction algorithms to improve the accuracy of sensor data under a variety of conditions and concentration ranges. If you decide to locate a sensor outdoors, you should familiarize yourself with correction factors that should be applied to obtain accurate data.

When using an outdoor sensor to compare to indoor sensor measurements during a smoke episode, ensure the indoor and outdoor data have the same correction applied (if one is applied at all). Be aware that large differences in relative humidity and temperature indoors/outdoors may affect data comparability.

Remember, PM data on the AirNow Fire and Smoke map[61] are accurate even during extreme smoke events. Sensor data shown on the Fire and Smoke map have had correction algorithms applied and do not need to be further adjusted.

For more information on siting a sensor outdoors, see the U.S. EPA Guide to Siting and

[61] AirNow Fire and Smoke Map: https://fire.airnow.gov/

Installing Air Sensors[62] and Section 4-2 of the South Coast Air Quality Management District (South Coast AQMD) Sensor Guidebook.[63]

If you do not have an outdoor air sensor, you can use websites that show publicly available sensor data, such as the AirNow Fire and Smoke Map[61] to find outdoor air quality data.

5.5 Using Air Sensor Data During a Smoke Event

Air quality data collected indoors should represent exposure for building occupants. When smoke is forecast, ensure sensors are running and data are accessible.

Running your sensor(s) in the months leading up to wildfire season is strongly recommended to get an idea of typical indoor concentrations for your building. This will also help you identify indoor activities that generate pollution and may need to be stopped during a smoke episode to improve indoor air quality.

Sensors may have options for how frequently they report data, also called the averaging time. Selecting an averaging time is a balance between infrequent reporting that will not capture rapid building responses to filtration changes (such as reporting hourly) and not reporting so frequently that the data is erratic (such as reporting every minute). ASHRAE guideline 44-2024 suggests 15-minute intervals provide the most meaningful estimates. [64]

Additional Considerations

If you notice an issue with your air sensor, such as missing data, long periods of zero concentration, or long periods of the exact same concentration, your sensor might have an error. For more information and suggested action, see Section 4-2 of the South Coast AQMD Sensor Guidebook[65].

After a smoke event, use indoor air sensors to ensure air quality returns to normal and document observations and lessons learned in your Smoke-Ready Plan. Finally, refer to manufacturer recommendations for maintenance that may be needed for sensors after high pollution concentration exposure. This is especially important if you placed a sensor outdoors.

[62] U.S. EPA Guide to Siting and Installing Air Sensors: https://www.epa.gov/air-sensor-toolbox/guide-siting-and-installing-air-sensors

[63] South Coast AQMD Sensor Guidebook: http://www.aqmd.gov/docs/default-source/aq-spec/star-grant/community-in-action-a-comprehensive-guidebook-on-air-quality-sensors.pdf

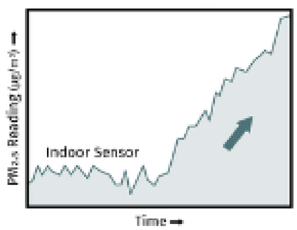
[64] This guideline is available from the ASHRAE Bookstore at https://store.accuristech.com/ashrae/standards/guideline-44-2024-protecting-building-occupants-from-smoke-during-wildfire-and-prescribed-burn-events?product_id=2923808

[65] South Coast AQMD Sensor Guidebook: http://www.aqmd.gov/docs/default-source/aq-spec/star-grant/community-in-action-a-comprehensive-guidebook-on-air-quality-sensors.pdf

Possible Sensor Data Scenarios

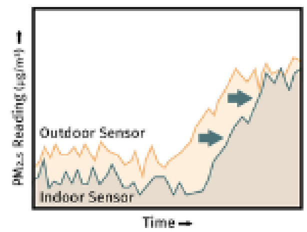
Below are scenarios you may encounter when reviewing sensor data during a smoke event. They are accompanied by suggested checks to determine the cause and recommended actions.

Indoor Concentrations Increasing



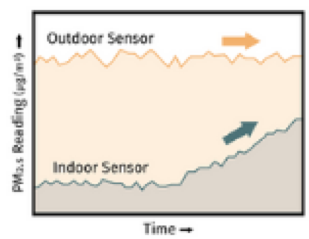
There may be several reasons why indoor concentrations are increasing. Using an outdoor sensor for comparison can help you identify the cause and which actions to take.

Indoor lags outdoor



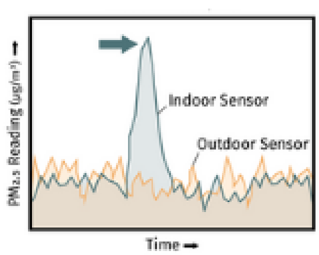
If indoor data patterns are similar to outdoor or lag behind, smoke is entering the building. Consider enacting your Smoke-Ready Plan, or adjusting HVAC or PAC settings if the plan is already in use.

Outdoor constant while indoor increases



Could an indoor source (cooking, candles, vacuuming) be contributing to indoor PM? Has a door or window been left open? Are HVAC and PAC units working as expected?

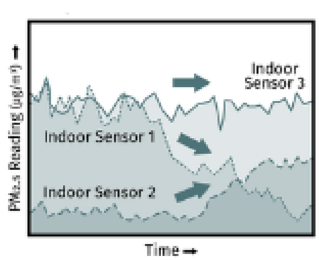
Short $PM_{2.5}$ Increase



Short lived spikes in $PM_{2.5}$ could be caused by indoor activities such as cooking or cleaning.

- Limit indoor activities that can increase concentrations during smoke events.
- Use a PAC to reduce the impact of indoor activities.

Indoor $PM_{2.5}$ Sensors Shows Different Trends

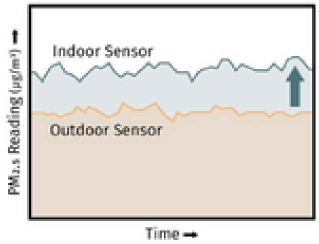


There are many reasons why indoor concentrations may vary in different parts of the building

- Is the sensor in an area with higher foot traffic or frequent door opening?
- Are the different parts of the building served by different HVAC systems?
- Is a window or door open near the sensor?
- Are indoor activities (e.g. cooking) contributing?

Depending on the cause, you can seek to reduce door openings, deploy PACs in affected areas, or investigate HVAC settings that may be contributing to increased indoor $PM_{2.5}$.

Indoor $PM_{2.5}$ Remains Higher Than Outdoors



If the air quality outside has improved, smoke may be trapped indoors and airing out the building by increasing the ventilation or opening doors and windows may help clear smoke out of the building.

5.6 Caveats and Cautions

Despite recent advances, there are still gaps in our understanding of data quality and sensor performance indoors. Air sensors do not give a complete representation of indoor air quality, as they only detect certain pollutants. Despite limitations, air sensors are useful *informational* tools to support indoor air quality management during smoke events.

In general, PM sensors require little maintenance but may drift or malfunction over time. Gaseous sensors, however, may require periodic calibration or replacement to ensure they continue to perform at an acceptable level. Refer to the manufacturer's manual and/or the EPA Air Sensor Toolbox[66] for instructions on proper maintenance and calibration procedures.

There are some limitations of consumer-grade air sensors that should be considered.

- **Sensors tend to overpredict (outdoor) concentrations vs. regulatory-grade monitors.** Adjustment factors for some air sensors are available from outdoor studies, but they have not been evaluated for indoor use. These adjustment factors are not available for all commercially available sensors. Currently, there are no equivalent reference methods or regulatory grade air monitoring networks for indoor air.

- **Air sensor measurements can vary based on temperature, relative humidity, and particle type.** This sensitivity to operating conditions can lead to uncertainty in data quality.[67] The sensor evaluation reports discussed in **Section 5.2** can help you understand how your chosen sensor will respond under various conditions.

- **Sensor performance can vary widely between different manufacturers' sensors**. When comparing data from different types of indoor sensors, take care not to misinterpret data.

[66] EPA Air Sensor Toolbox: https://www.epa.gov/air-sensor-toolbox

[67] Nguyen et al., 2021, https://www.mdpi.com/1660-4601/18/18/9811

Appendix 1: Building Smoke-Ready Planning

This appendix provides a **starting point** for developing a Smoke-Ready Plan for your building. Each section includes an **example check list which can be adapted based on your building**. In the checklists not everything will be relevant to your building or more details may need to be made. For additional detailed information, see ASHRAE Guideline 44-2024, Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events, Section 6.1.

Develop Your Plan

Begin preparations in the off season for wildland fire smoke in your area (see **Section 1.2** and **Figure 3**). Make a plan on how to prepare your building for smoke. Use the following steps:

1. **Predict the building usage during smoke episodes**
2. **Assess the current state of your building**
3. **Define the elements of your Smoke-Ready Plan**
4. **Test your Smoke-Ready Plan**

Suggested elements to include in your Smoke-Ready Plan are listed in **Table A1.1**. For more details on each, see the associated section in the main text or ASHRAE guideline.

Table A1 1. Elements to include in your Smoke-Ready Plan.

Element	Location of Details
Building Envelope Measures	• Section 3.2 – (Building Use) Sealing the Building • Section 3.3 – (Building Use) Entrance Adjustments
HVAC Measures	• Section 2.2 – (HVAC) Air Flow Optimization • Section 2.3 – (HVAC) HVAC Run Time Changes
Pressurization Measures	• Section 2.2 – (HVAC) Air Flow Optimization • ASHRAE 44-2024* Section 5.5.2 Building Controls
Filtration Measures	• Section 2.4 – (HVAC) Filtration • Section 2.5 – (HVAC) Supplemental External Filtration • Section 4.2 – (PAC) When to Use a PAC • Section 4.3 – (PAC) Types of Air Cleaners • Section 4.5 – (PAC) Other Considerations • ASHRAE 44-2024* Section 5.5.5 – Portable Air Cleaners
Sensing	• Section 5.2 – (Air Sensors) Choosing an Air Sensor • Section 5.5 – (Air Sensors) Using Air Sensor Data During a Smoke Event • ASHRAE 44-2024* Section 5.5.1 – Monitoring • ASHRAE 44-2024* Section 6.2.8 – Indoor and Outdoor $PM_{2.5}$ Monitoring
Logistics/Supply Considerations	• Section 2.4 – (HVAC) Filtration • Section 2.5 – (HVAC) Supplemental External Filtration • Section 4.6 – (PAC) Filter Replacement and Maintenance • Section 5.2 – (Air Sensors) Choosing an Air Sensor

* ASHRAE Guideline 44-2024, Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events

1. Predict building usage during smoke episodes

To understand what measures you need in place, assess how the building will be used. Below are example questions to consider prior to creating a Smoke-Ready Plan checklist:

1. Will all spaces be used?
2. What hours/days will spaces be used?
3. Who will occupy them?
4. How many people?
5. Are any people in at-risk groups?
6. What will they be doing?
7. How could their activities affect IAQ or their exposure to smoke?

2. Assess the current state of your building

Before attempting to create a plan for smoke conditions, you need to know the specifics of your building filtration and ventilation systems. Example questions to answer include:

1. What kind of filtration measures does the building have in place?
2. Does the building have air conditioning or portable cooling units to maintain comfort levels?

HVAC status questions may be answered with existing building documentation or by meeting with an HVAC contractor prior to creating a Smoke-Ready Plan.

General

1. What HVAC equipment is in use?
2. Which parts of the building are served by each piece of equipment?
3. Where are the air intakes? Where are the exhausts?
4. Where are the filters? What type of filters are they?
5. Can the unit use MERV 13 filters? If not, what is the highest rating possible?
6. Can you add supplemental filtration to the outdoor air intakes?

HVAC Condition

1. Are damper blades, linkages, and edge seals in good condition (i.e., providing a proper seal)?
2. Are filters undamaged, clean, properly seated, and edges sealed?
3. Do outdoor air dampers function correctly (e.g., open and close on command)?
4. Does the air economizer work correctly?
5. Does the demand control ventilation system work correctly?

Settings

1. What is the minimum outdoor air intake level you need to control odor, temperature, etc. while maintaining positive pressure?
    a. Which exhaust fans are critical for safety? (e.g., isolation rooms, kitchen hoods, hazardous materials handling)
    b. How will you adjust the system to maintain that level?
2. Can some building air handlers be set to full recirculation, while leaving one or a small number of others still bringing in outdoor air?

Spaces have been added to the example lists below for customization. Alternatively, create new lists that fit your unique building situation.

Example Checklist: Smoke-Ready Preparation

Smoke Trigger and Team Roles

☐ Determine and document what your trigger level will be to enter smoke-mode.

☐ Define and document roles/responsibilities of the implementation team.

☐ Decide how the plan will be distributed to the team and how communication will occur.

☐ ______________________________

☐ ______________________________

☐ ______________________________

HVAC Measures

☐ Develop smoke-ready settings (with HVAC contractor, if needed).

☐ Practice switching building HVAC to smoke-ready mode and back to normal mode.

☐ Test the HVAC smoke-ready mode with all adjustments and higher-efficiency filters in place to ensure it works.
- Document the final implementation process.
- After the test, return to normal operations and document the process.

☐ Stock replacement filters and supplies.

☐ Ensure you know how to access filters or that a contractor is identified to perform potentially frequent replacements during smoke periods.

☐ ______________________________

☐ ______________________________

☐ ______________________________

Building Measures

☐ Walk the building **exterior** for smoke entry points:
- Exterior doors, windows, vents and fans, skylights, siding connections with other features (chimneys) corners, window/wall AC units, and service penetrations.

☐ Walk the building **interior** for smoke entry points:
- Windows, doors, attic hatches, baseboards, soffits, electrical outlets, service shafts such as those for an elevator, and plumbing stacks or conduits.
- Note any obvious maintenance issues to address (e.g., cracks or gaps around doors/windows that can be caulked, broken windows/doors to be repaired or replaced).
- Note obvious smoke entry points that may be modified during smoke events (e.g., closing off a fireplace flue damper or ceasing laundry activities and closing off the dryer exhaust vents.)

☐ Make repairs to minimize leaks
- Caulking around doors/windows, glass panes, ceiling penetrations, outlets/switches; seal ductwork; use weatherstripping around moving openings.

☐ Identify doorways that could house air curtains.

☐ Identify which windows should be closed.

☐ Identify which doors should be closed and which entrances should remain in use.

☐ Identify activities that could be discontinued or limited to reduce sources of indoor PM.

☐ ______________________________

☐ ______________________________

☐ ______________________________

Filtration Measures

- ☐ Determine if a cleaner air room is needed and where it would be located.
- ☐ Determine if PACs are needed and how many are needed for the space.
- ☐ Determine where to store PACs when not in use.
- ☐ Identify where PAC units will be placed.
- ☐ Purchase PAC units and replacement filters/supplies.
- ☐ ______________________________
- ☐ ______________________________
- ☐ ______________________________

Sensing Measures

- ☐ Determine if air sensor(s) are needed.
- ☐ Identify where air sensors will be used.
- ☐ Purchase air sensors and practice using the unit, checking the data, and establish an understanding of non-smoke concentrations in the building.
- ☐ ______________________________
- ☐ ______________________________
- ☐ ______________________________

Implement Your Plan

During a smoke event, or when one is forecast, implement your plan guided by your checklist.

<u>**Example Checklist: Plan Implementation**</u>

HVAC Measures

- ☐ Install higher-efficiency filters.
- ☐ Install supplemental filtration on outdoor air intake.
- ☐ Adjust air dampers or manually set damper position.
- ☐ Adjust relief fan airflow.
- ☐ Adjust exhaust fans to reduce air flow.
- ☐ Ensure building is operating at positive pressure.
- ☐ Ensure spaces are conditioned adequately
- ☐ ______________________________
- ☐ ______________________________
- ☐ ______________________________

Building Measures

- ☐ Reduce indoor PM sources.
- ☐ Restrict entrances and window usage, put up signs.
- ☐ ______________________________
- ☐ ______________________________
- ☐ ______________________________

Filtration Measures

- ☐ Deploy PACs to sensitive locations.
- ☐ Establish a cleaner air room if part of plan.
- ☐ ______________________________
- ☐ ______________________________
- ☐ ______________________________

Sensing Measures

- ☐ Note the $PM_{2.5}$ levels outdoors (using the EPA Fire and Smoke Map or an air sensor) and indoors (with an air sensor) and monitor throughout the smoke event to determine if extra filtration measures are needed.
- ☐ ______________________________
- ☐ ______________________________
- ☐ ______________________________

After a Smoke Event

Return settings and operations to normal using the checklist.

<u>**Example Checklist: Return to Normal Operation**</u>

Documentation

- ☐ Use notes/pictures to guide return to normal settings.
- ☐ Verify normal operation is accomplished.
- ☐ Revise Smoke-Ready Plan with lessons learned.
- ☐ ________________________________
- ☐ ________________________________
- ☐ ________________________________

HVAC Measures

- ☐ Remove temporary outdoor air filters.
- ☐ Inspect and replace filters as needed.
- ☐ Reconnect/enable outdoor air dampers.
- ☐ Return thermostat to normal settings.
- ☐ Re-enable economizer systems.
- ☐ ________________________________
- ☐ ________________________________
- ☐ ________________________________

Building Measures

- ☐ When building is fully aired out, collect PACs and return to storage area.
- ☐ Inspect PAC filters to determine if replacements are needed.
- ☐ Remove signs restricting entranceways or window use.
- ☐ Clean indoor surfaces as needed.
- ☐ Air out building, open doors and windows to allow fresh air in and push out smoky air.
- ☐ ________________________________
- ☐ ________________________________
- ☐ ________________________________

Other Considerations

- ☐ Stock up on new HVAC and PAC filters.
- ☐ Inspect air sensors, if used, and return to storage.
- ☐ ________________________________
- ☐ ________________________________
- ☐ ________________________________

Example Smoke-Ready Plan

Building Description: Fitness facility inside an older strip mall with wood frame construction and exterior masonry. Facility is a single story 30,000 ft^2 area which consists of an open gym area, group fitness room, spa, locker room, laundry, and an associated childcare space. There is one primary entryway with double doors and a vestibule in which almost all the occupants use to enter and exit. There are two emergency exits that are on the side of the building and are rarely used. The front of the building is a solid wall of unopenable windows. A view of the building exterior and schematic floor plan are shown in **Figures A1-1 and A1-2.**

The space is conditioned by 9 roof top units that serve various parts of the facility. Some units are dedicated to a single space (e.g. locker room), while other spaces have multiple units that serve the area (e.g., the gym has two units serving the area). The building is open 24 hours a day, 7 days a week.

The fitness facility is located in the Western United States, a region that is frequently impacted by wildfire smoke in the summer and early fall.

In this scenario, the key personnel involved are listed below.

Gym owner – Owns the gym. Hires a facilities manager to control day-to-day facilities issues.

Gym facilities manager – May be a dedicated facilities manager for the gym or could be a staff member with expanded responsibilities. Responds to day-to-day issues regarding gym facilities. Is responsible for implementing many of the changes during a smoke event, such as PAC set up, sensor setup and data retrieval, implementing changes to door usage, and signage.

Building manager – Manages the building on behalf of the building owner. Is responsible for hiring contractors to fix building issues reported by the gym facilities manager or gym owner on behalf of the building owner.

Building owner – Owns the building, hires a building manager. May also be responsible for hiring building contractors.

The following sections are examples of written documents developed collaboratively by the gym owner, gym facility manager, and the building manager. The document would be used as a reference for all parties listed above. In the sections below, tasks intended for each key person are indicated in colored text.

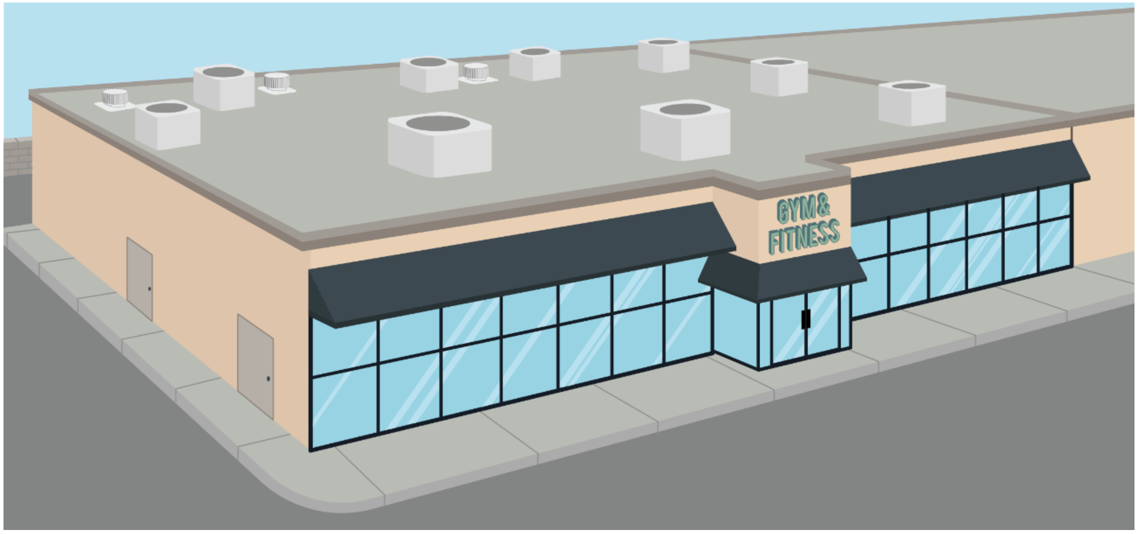
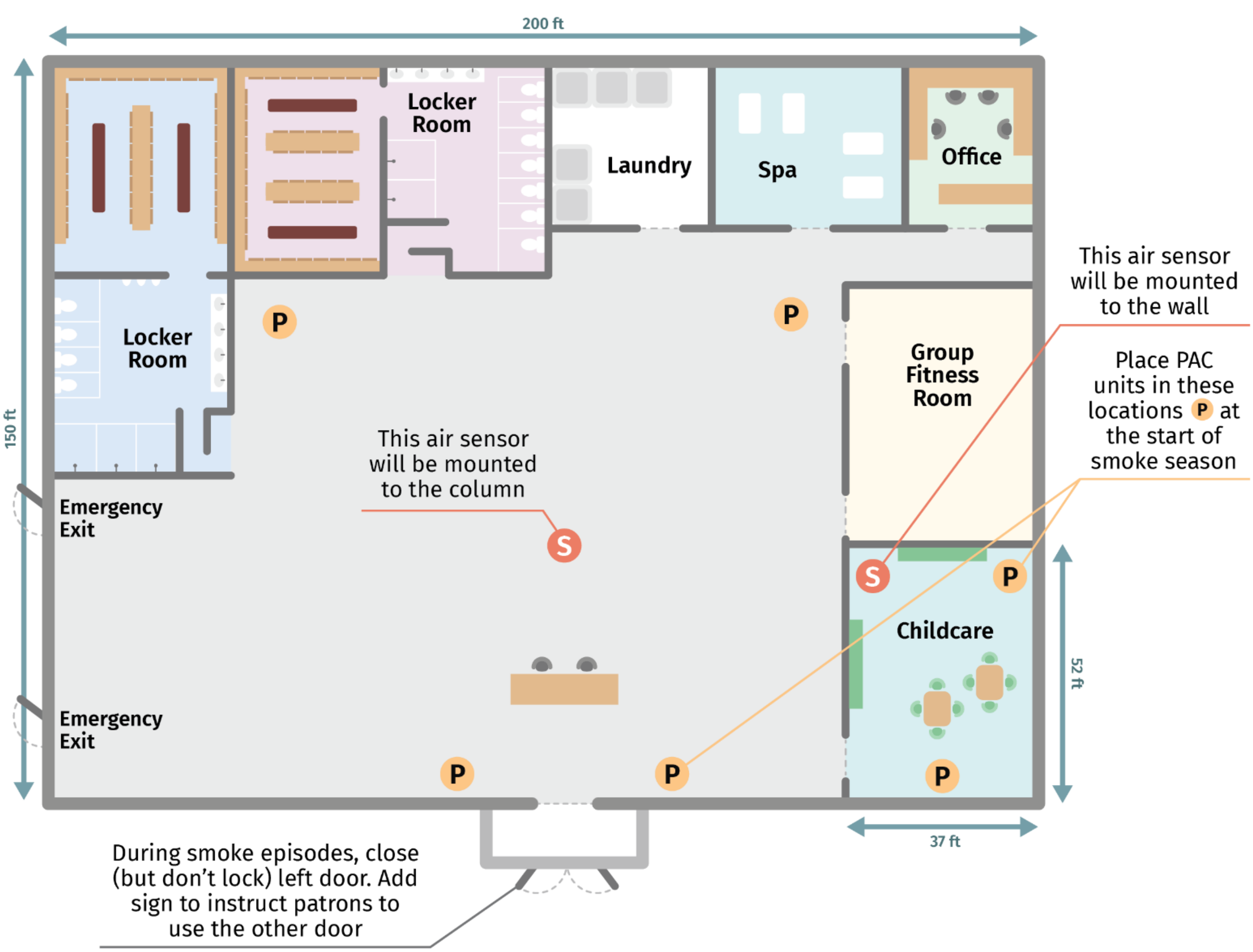


Figure A1-1. Outside perspective of fitness facility showing rooftop units and roof fans.



Considerations for Developing a Smoke-Ready Plan

Permissions:

According to the lease agreement, the building manager is responsible for repairs/modifications. The building manager notifies the building owner and directly hires a contractor to perform repairs or modifications to the building or HVAC system.

We have agreed that the gym facilities manager will directly contact the building manager regarding smoke issues, and that the gym facilities manager will also notify the gym owner of any planned changes.

- ☐ Develop cost estimate for smoke readiness. (**Gym owner**)

Building Envelope Measures:

- ☐ Since we only have one building entrance, to minimize door use during smoke events, we will put a sign on the left door to have people only use the right door for entering and exiting. Will need to acquire signage. (**Gym facilities manager**)
- ☐ In November, when the outdoor air temperature is cold and indoors is warm, walk around the inside and outside of the building to identify leaks and note them. (**Gym facilities manager**)
  - Look for cracks, gaps, etc. in exterior.
  - Check indoors around the front and emergency exit doors, electrical outlets, and laundry room vents for cold air infiltration or daylight shining through cracks.
  - Check the wall of windows at the front of the building using our new IR camera to find leaks around the window frames.

For any issues discovered during the above checks:

- ☐ The building manager has approved us to use caulking as needed. (**Gym facilities manager**)
- ☐ For other repairs, contact the building manager to hire a contractor. (**Building manager**)

HVAC Measures:

- ☐ In the winter or early spring (outside of fire season), contact the building manager to hire an HVAC contractor for a consultation. It may be helpful for both the gym facilities manager and the building manager to be present during this initial consultation meeting. (**Gym facilities manager** / **Building manager**)

- [ ] The building manager should communicate with the HVAC contractor that more frequent HVAC filters replacements will be needed if there is a prolonged or frequent smoke events. (Building manager)

- [ ] The table below lists what we already know about the building HVAC system, and questions we need to ask about the system in order to develop a smoke-ready mode. (Gym facilities manager / Building manager)

1. Known About the HVAC System	2. Items to Discuss with HVAC Contractor
▪ The locker rooms have dedicated exhaust fans and dedicated rooftop units (RTU). ▪ Current thermostat programs are varied to allow for some HVAC to operate in a continuous occupied setting while others match the more frequently occupied building hours 6 am – 9 pm.	▪ Identify all HVAC and exhaust systems, which locations they serve, and their normal operation settings. ▪ What is the maintenance state of current HVAC system (evaluate economizer installation and damper actuator performance). **To help develop a smoke-ready mode:** ▪ Are there any exhausts that are not necessary and can be sealed off during smoke– e.g., unused dryer exhaust? ▪ Can the system handle MERV 13 filters during the summer and fall– if so, what performance measures are required (e.g., pressure drop limits)? ▪ Which RTUs can be put into recirculate mode and which must maintain outdoor air intake to ensure positive building pressure? ▪ Can they help develop control logic for programmable thermostats to enter into smoke ready mode. ▪ How can we make modifications to the childcare space RTU (sensitive area) to ensure it remains positively pressurized versus the surroundings? ▪ How can we ensure we maintain positive pressure in the doorway vestibule (since it does not have a dedicated RTU)?

Filtration Measures

- [ ] Identify areas that may need supplemental filtration (childcare space and near the vestibule). **Note, the HVAC system should be providing clean air after it is switched into smoke-mode, so PAC units will be supplemental. We will use air sensors to determine if the HVAC system is sufficiently cleaning. If it is not, we will use PACs in the childcare space and by the front doors as an added filtration measure.** In the absence of an HVAC system, the number of PACs we would need to use are: (Gym facilities manager)

- ☐ Calculate square footage of the spaces to keep clean.
  - Dimensions of childcare area = 37 ft (W) x 52 ft (L) x 12 ft (H) = 23,088 ft^3. The equivalent area for a space with 8 ft tall ceilings = 23,088 ft^3 ÷ 8 ft = **2,886 ft^2**.
  - Dimensions of the open gym area are approximately = 104 ft(W) x 163 ft (L) x 14 ft (H)=16,952 ft^3. The equivalent area for a space with 8 ft tall ceilings is 16,952 ft^3 ÷ 8 ft =**237,328 ft^2**.

- ☐ Estimate the number of PACs needed for the space.
  - The number of PAC units with a CADR of 600 needed for the childcare area = 2,886 ÷ 600 = 4.81, so we would need **5 PAC units for the childcare area**.
  - The number of PAC units with a CADR of 600 needed for the open gym area = 395.5, so we would need **396 PAC units for the open gym area**.
  - **The number of PACs needed for the open gym area is obviously infeasible. We will implement a staged approach based on the air sensor data:**
    1. If we discover the HVAC system is not able to keep up with cleaning the air indoors, we will implement four PAC units in the main gym, and two in the childcare space.
    2. If the PACs are not able to help enough, we will investigate industrial sized air cleaner(s) for the open gym which provide 1200 cfm of air movement. Once implemented, we will move the PAC units from the front vestibule to the childcare space (where an industrial cleaner may be too noisy to use), so the childcare space has 4 PACs.

- ☐ Estimate the number of filters needed and identify where to purchase. (**Gym facilities manager**)
- ☐ Research and purchase PAC units with HEPA filtration that will work for the space (consider noise level, unit cost, and cost of replacement filters). (**Gym owner**)

Sensing Measures

- ☐ Ensure thermostat sensors are operating correctly. (**Gym facilities manager**)
- ☐ Estimate air sensor needs (include considerations for power, Wi-Fi or cellular. connectivity, and data services plans) and identify potential supplier. (**Gym facilities manager**)
- ☐ Purchase indoor PM sensors to be used to ensure smoke plan is effective. One will go in the main gym, and the other will go in the childcare area. (**Gym facilities manager**)
- ☐ Consider purchasing indoor CO_2 sensors to ensure ventilation during smoke mode is adequate. (**Gym owner**)

Implement the Smoke-Ready Plan

Before Smoke Season

Shortly before smoke season, perform the following tasks to prepare for and make pivoting into smoke-mode more streamlined.

- ☐ Inspect doors and replace weather stripping as needed. (**Gym facilities manager**)
- ☐ Get the PAC units out of storage and place them in the chosen areas near the front vestibule and in the childcare area, where they will be used during a smoke event. (**Gym facilities manager**)
- ☐ Install air sensors and start using them to capture the non-smoke event PM levels. (**Gym facilities manager**)
- ☐ The building manager should schedule an HVAC contractor to install MERV 13 filters. (**Building manager**)

Our trigger level: **We will enter Smoke-mode when it is smoky outside (there's a visible haze or it smells like smoke) and the AQI for $PM_{2.5}$ hits unhealthy for sensitive groups and is projected to remain elevated for more than a day. To determine the AQI and smoke forecast, use fire.airnow.gov and local or state smoke blogs or outlooks from air resource advisors assigned to nearby fires.** (**Gym facilities manager**)

Enter Smoke-Mode

- ☐ Adjust thermostat programming as developed. (**Gym facilities manager**)
- ☐ Check building pressure is still positive. (**Gym facilities manager**)
- ☐ Run the PACs near front vestibule and in childcare area. (**Gym facilities manager**)
- ☐ Put up signs to limit cooking activities in the childcare area. (**Gym facilities manager**)
- ☐ Review sensor data and adjust plan as needed. (**Gym facilities manager**)
    - If outdoor air is clean, consider opening door to allow fresh air indoors.
- ☐ If smoke persists indoors, re-inspect the building interior and exterior and apply quick fixes as needed (e.g., new weather stripping, caulking). (**Gym facilities manager**)
- ☐ If smoke mode is not sufficient to keep indoor air clean, consider acquiring additional PACs and distribute in day care and then in gym areas. (**Gym facilities manager**)
- ☐ If a smoke event has been extended, request building manager to contact HVAC contractor to inspect HVAC filters and replace as needed. (**Gym facilities manager**)

Exit Smoke-Mode

- ☐ Adjust thermostat programming back to normal settings. (**Gym facilities manager**)
- ☐ Consider airing the building out if outdoor air is clean. (**Gym facilities manager**)
- ☐ Check the building pressure is back to normal. (**Gym facilities manager**)
- ☐ Inspect PAC filters – identify if replacement filters are needed – store until next smoke event. (**Gym facilities manager**)
- ☐ May leave PM sensor to identify indoor air pollution events. (**Gym facilities manager**)
- ☐ Replace filters as needed. For short smoke duration events and continued fire season you may leave lightly loaded filters in place. At the end of fire season request the HVAC contractor return to re-install our normal MERV 8 filters. (**Building manager**)

Appendix 2: Resources for Indoor Air Quality

Indoor Air Quality & Airborne Viruses

For additional information about indoor air quality measures, including guidance on infectious aerosol particles, such as COVID-19 please see:

- https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-building-readiness.pdf
- https://www.epa.gov/indoor-air-quality-iaq
- https://www.epa.gov/indoor-air-quality-iaq/preventing-spread-respiratory-viruses-public-indoor-spaces
- https://www.epa.gov/coronavirus/indoor-air-and-coronavirus-covid-19

Smoke Resources

For additional information on smoke, health effects of smoke, and current air quality conditions, please see:

- Current Air Quality Information via AirNow: https://www.airnow.gov/. Additional links on this page include
  - AirNow Fire and Smoke Map (under Fires)
  - Be Smoke-Ready Resources (under Fires – Wildfires)
  - Air Quality Index Basics
  - Wildfire Smoke, a Guide for Public Health Officials (Fires-Wildfires)
- Particulate matter general information via U.S. EPA https://www.epa.gov/pm-pollution/. Additional links on this page include
  - PM Basics
  - How Smoke from Fires can Affect Your Health
- Preparing for Wildland Fire Smoke Webinar Archive: https://www.epa.gov/research-states/preparing-wildland-fire-smoke-webinar-archive

HVAC Resources

For further resources and more information on HVAC topics, please see:

- Protecting Commercial Building Occupants From Smoke During Wildfire Events: https://www.ashrae.org/File%20Library/Technical%20Resources/COVID-19/Planning-Framework-for-Protecting-Commercial-Building-Occupants-from-Smoke-During-Wildfire-Events.pdf
- ASHRAE Guideline 44 - Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events: https://store.accuristech.com/ashrae/standards/guideline-44-2024-protecting-building-occupants-from-smoke-during-wildfire-and-prescribed-burn-events?product_id=2923808

Portable Air Cleaners Resources

For further resources and more information on PAC topics, please see:

- Wildfire smoke factsheet on indoor air filtration: https://www.epa.gov/sites/default/files/2018-11/documents/indoor_air_filtration_factsheet-508.pdf
- Air Cleaners and Air Filters in the Home (despite being a resource for residences, this resource may prove useful in some circumstances for commercial establishments). https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home
- Determining an appropriate air cleaner for your space: https://www.ahamdir.com/room-aircleaners
- Create a Clean Room to Protect Indoor Air Quality During a Wildfire: https://www.epa.gov/indoor-air-quality-iaq/create-clean-room-protect-indoor-air-quality-during-wildfire#how
- California Air Resources Board-certified air cleaners list: https://ww2.arb.ca.gov/list-carb-certified-air-cleaning-devices
- DIY air cleaner safety report: https://chemicalinsights.org/wp-content/uploads/2021/07/DIY-Box-Fan-Report-2021.pdf
- EPA's research on safety and efficiency of PACs: https://www.epa.gov/air-research/research-diy-air-cleaners-reduce-wildfire-smoke-indoors

Air Sensor Resources

For further resources and more information on Air Sensor topics, please see:

- U.S. EPA Air Sensor Toolbox: https://www.epa.gov/air-sensor-toolbox/. Additional links and information on this page include
    - Air Sensor Guidebook
    - A Guide to Siting and Installing Air Sensors
    - Sensor operation and data interpretation
    - EPA Sensor Evaluation Results
    - EPA sensor loan programs
- Community in Action: A Comprehensive Guidebook on Air Quality Sensors: http://www.aqmd.gov/docs/default-source/aq-spec/star-grant/community-in-action-a-comprehensive-guidebook-on-air-quality-sensors.pdf?sfvrsn=10
- How to Evaluate Air Sensors for Smoke Monitoring: https://www.epa.gov/research-states/how-evaluate-air-sensors-smoke-monitoring-webinar-archive
- Sensor evaluation and performance via AQ-SPEC: http://www.aqmd.gov/aq-spec
- The Enhanced Air Sensor Guidebook: https://www.epa.gov/research-states/enhanced-air-sensor-guidebook-webinar-archive
- EPA's Air Sensor Loan Pilot Programs: Successes, New Resources, and Lessons Learned: https://www.epa.gov/research-states/epas-air-sensor-loan-pilot-programs-successes-new-resources-and-lessons-learned
- Children's Health and Wildfire Smoke Exposure Work: https://www.airnow.gov/sites/default/files/2022-01/childrens-health-wildfire-smoke-workshop-recommendations.pdf

- EPA Air Sensor Technology and Indoor Air Quality: https://www.epa.gov/indoor-air-quality-iaq/air-sensor-technology-and-indoor-air-quality
- EPA Low–Cost Air Pollution Monitors and Indoor Air Quality: https://www.epa.gov/indoor-air-quality-iaq/low-cost-air-pollution-monitors-and-indoor-air-quality

Building Usage and Weatherization Resources

For more information on identifying leaks in buildings, visit:

- The Department of Energy: https://www.energy.gov/energysaver/detecting-air-leaks

Additional Resources for Indoor Air Quality

EPA's Indoor Environments Division (IED) provides guidance and programs to help build community capacity to understand and avoid indoor and outdoor health impacts. Resources available through https://www.epa.gov/indoor-air-quality-iaq/ include:

- Indoor Particulate Matter (includes information about National Academies of Science, Engineering, and Medicine [NASEM] on Indoor PM)
- Air Cleaners and Air Filters in the Home
- Learn About Wildfires and Indoor Air Quality**:** https://www.epa.gov/emergencies-iaq/learn-about-wildfires-and-indoor-air-quality
    - Wildfires and Indoor Air Quality
    - Schools as Cleaner Air and Cooling Centers fact sheets
    - Create a Clean Room to Protect Indoor Air Quality During a Wildfire
    - Wildfires and Indoor Air Quality in Schools and Commercial Buildings
- Webinar Recordings:
    - An Introduction to ASHRAE Guideline 44: Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events, presented by Greg Nilsson, Sarah Henderson, Abdel Darwich, Mike Gallagher and Randy Cooper. (February 25, 2025) https://www.youtube.com/watch?v=VLRqqB4RM2M
    - Safety and Efficacy of DIY Air Cleaners for Wildfire Smoke Reduction (February 14, 2023) https://www.youtube.com/watch?v=5v6tDspQLXI
    - Health Risks of Indoor Exposure to Fine Particulate Matter and Practical Mitigation Solutions presented by Richard Corsi and Meredith McCormack (April 4, 2024)

National Academies of Sciences, Engineering, and Medicine Resources:

- Consensus Study: Health Risks of Indoor Exposures to Fine Particulate Matter and Practical Mitigation Solutions: https://www.nationalacademies.org/our-work/health-risks-of-indoor-exposures-to-fine-particulate-matter-and-practical-mitigation-solutions
- Indoor Exposure to Fine Particulate Matter and Practical Mitigation Approaches: Proceedings of a Workshop (2022): https://nap.nationalacademies.org/catalog/26331/indoor-exposure-to-fine-particulate-matter-and-practical-mitigation-approaches
- Health Risks of Indoor Exposure to Particulate Matter: Workshop Summary (2016): https://nap.nationalacademies.org/catalog/23531/health-risks-of-indoor-exposure-to-particulate-matter-workshop-summary

Environmental Law Institute Resources:

- Wildfire Smoke: State Policies for Reducing Indoor Exposure (2024): https://www.eli.org/research-report/wildfire-smoke-state-policies-reducing-indoor-exposure
- Reducing Indoor Exposure to Particle Pollution from Outdoor Sources: Policies and Programs for Improving Air Quality in Homes (2020): https://www.eli.org/research-report/reducing-indoor-exposure-particle-pollution-outdoor-sources-policies-and-programs

ASHRAE Resources:

- Guideline 44-2024 – Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events
- Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events

Appendix 3: Glossary of Terms

Term	Definition
Activated Carbon	Porous carbon that adsorbs some types of odors, gases, and vapors.
ACH	Air Changes per Hour. A measure of how many times the air within a room is replaced each hour.
AHAM	Association of Home Appliance Manufacturers. A professional organization that represents the producers of household appliances including air cleaners.
Air Curtain	A controlled stream of air moving across the height and width of an opening with sufficient velocity and volume to reduce the transfer of air from one side of the opening to the other and to inhibit insects, dust, and debris from passing through.
Air Handler	Also called an air handling unit (AHU). This is the part of an HVAC system that is responsible for regulating and circulating air. It can include an evaporator coil, blower motor, electric heater package, and other components. In many cases, it also houses the HVAC filter racks or a filter chamber.
Air Duct	Conduit used to distribute air in a building.
Air Intake	Device or opening through which outside air is drawn into a building's HVAC system.
Airflow	Movement of air, usually within boundaries (such as ducts)
Ambient Air	Outdoor air.
ASHRAE	Professional organization dedicated to advancing the arts and sciences of heating, ventilation, air conditioning and refrigeration; formerly, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
Building Envelope	Elements of a building that separate the outdoors from the indoors including walls, windows, doors, roofs, and floors, and the semi-exterior portions of a building (e.g. unconditioned space).
Clean Air Delivery Rate	CADR; The amount of clean air an air cleaner can deliver to a room per minute. This is often reported in units of cubic feet per minute.

Cleaner Air Space	An designated space within a building that is set up with air cleaning equipment to provide cleaner air during a smoke event. May also have cooling equipment to provide heat relief, which may be called a cleaner air and cooling center.
CO_2	Carbon dioxide. Can be used as an indicator of ventilation.
Conditioned Space	Part of a building that is temperature and/or humidity controlled for the comfort of occupants and/or to protect the condition of the space.
Damper	A component of an HVAC system that modifies or shuts off airflow.
DIY Air Cleaner	Sometimes called "box fan filters". DIY air cleaners are made by attaching one or more HVAC air filters to a box fan using tape, brackets, clamps, or bungee cords.
Ductwork	System of ducts for distribution of air.
Economizer	Technology that saves energy by bringing in cooler outdoor air to replace warm indoor air when the outside air is cooler.
Electrostatic Filter	Also called electret filters, the filter material is electrostatically charged. This charged surface attracts charged particles to the surface, like a magnet, removing them from the air.
FPR	Filter Performance Rating – a proprietary system similar to MERV developed by manufacturers to rate filter efficiency.
Heat Recovery Unit	A device that allows for heat recovery ventilation, where residual heat from an exhaust gas flow is used as a heat source.
HEPA Filter	High Efficiency Particulate Air filter; a mechanical filter that traps particles by passing air through a fine, pleated, mesh material. HEPA filters are typically more efficient that MERV 16 filters.
HVAC	Heating, ventilation, and air conditioning.
IAQ	Indoor air quality.
Infiltration	The unintended movement of air from outside of a building inside through openings in the building envelope.

MERV	Minimum Efficiency Reporting Value- scale used to rate how well a filter removes particles from the air. Higher ratings indicate a greater percentage of particles are captured each time air passes through the filter. Based on a consensus standard developed by ASHRAE.
Mechanical Filter	In mechanical filters, air is forced through filter material causing particles to stick to the filter surface.
MPR	Micro-particle Performance Rating – a proprietary system similar to MERV developed by manufacturers to rate filter efficiency.
Negative building pressure	This occurs when the air pressure inside a building is **lower** than the air pressure outside the building. This causes air to flow from outside to inside through open doors and windows, and through cracks and gaps in the building structure.
PAC	Portable Air Cleaner.
Positive Building Pressure	This occurs when the air pressure inside a building is **higher** than the air pressure outside the building. This causes air to flow from inside to outside through open doors and windows, and through cracks and gaps in the building structure.
PM	Particulate matter.
$PM_{2.5}$	Fine particulate matter, which are particles with an aerodynamic diameter generally less than or equal to a nominal 2.5 μm and are capable of depositing deep in the lungs.
Prescribed Fire	A planned fire intentionally ignited to meet land management objectives such as reducing fuel buildup or managing the spread of pests and disease.
Pressure Drop	Difference in pressure between two points in a flow system, usually caused by resistance to air passing through a filter.
Recirculating Air	Air taken from a space and returned to that space, usually after being passed through a conditioning system.
Register	Combination grille and damper assembly over an air opening
Return Air	Device or opening through which air is withdrawn from a conditioned space (e.g., grills, registers, diffusers, and slots may be used as air inlets).

South Coast Air Quality Management District	(South Coast AQMD) The regulatory agency responsible for improving air quality for large areas of Los Angeles, Orange, Riverside and San Bernardino counties, including the Coachella Valley.
SD Card	Secure Digital (SD) Card – a memory card used to store data in portable devices, including some types of air sensors.
TAB	Testing, Adjusting, and Balancing. A TAB evaluation is performed on HVAC systems during/after installation to ensure optimized conditions for occupant comfort, energy efficiency, and indoor air quality. The process involves measuring and adjusting air flows using test instruments, sensors, and monitors to ensure appropriate temperatures, airflow, and other characteristics within the HVAC system.
Thermostat	Automatic control device used to maintain temperature at a fixed or adjustable setpoint.
VAV	Variable Air Volume System – A type of HVAC system that varies the air flow in response to the heating and cooling needs of the space.
Ventilation	(1) The process of supplying air to or removing air from a space to control air contaminant levels, humidity, or temperature within the space. (2) The process of supplying or removing air by natural or mechanical means to or from any space. Such air may or may not have been conditioned.
Vestibule	An enclosed space between the inside and outside of a building.
VOCs	Volatile organic compounds. Carbon-containing gases present in the air.
VRF	Variable Refrigeration Flow System – A type of HVAC system where heating and cooling is accomplished with a variable flow of refrigerant transferring heat to or from the inside to the outside.
Wildland Fire	An umbrella term for wildfires and prescribed fires.
Wildfire	An unplanned fire caused by lightning or other natural causes, by accidental (or arson-caused) human ignitions, or by an escaped prescribed fire.
WUI	Wildland urban interface. This is the space where urban development meets undeveloped wildlands.

Appendix 4: How to Perform an Air Sensor Precision Check

As noted in the main text, if you plan to use multiple sensors, it is recommended that you run a precision check before installing them in their dedicated locations to make sure they are all performing similarly. This collocation will ensure that when the sensors are measuring the same air, no one sensor is measuring higher or lower values than expected (i.e., bias). Only sensors measuring the same pollutant should be precision checked. For example, if you have selected different sensors to measure PM and VOCs, then PM sensors should only be compared to PM sensors, and VOC sensors should only be compared to VOC sensors. Multiple sensors of the same model from the same manufacturer are expected to vary slightly in reported concentrations and response times to changes in pollutant concentrations, but large differences indicate a problem.

Guidance on collocation and data interpretation is provided in other documents including these listed in **Appendix 2**:

- U.S. EPA Air Sensor Toolbox: https://www.epa.gov/air-sensor-toolbox/.
- Community in Action: A Comprehensive Guidebook on Air Quality Sensors: http://www.aqmd.gov/docs/default-source/aq-spec/star-grant/community-in-action-a-comprehensive-guidebook-on-air-quality-sensors.pdf?sfvrsn=10

Choosing Your Location

Upon receiving the sensors, choose a location indoors where you can temporarily run them side by side. For this test, the sensors should be placed about 1 ft apart. See **Figure A4-1** for an example setup.

Preparation

Prior to the precision check test, make sure that power is available for the sensors (or the battery is fully charged); review the users guide or manual on how to start, run, and troubleshoot the sensors; know (or set) the time interval/reporting frequency of your sensor (1 to 5 minutes is advisable); know your sensor IDs or names and label them so you can tell the data and sensors apart later; and know where the data are reported, how to access the data, and how much data is retained.

Run the Precision Test

You should plan to run all sensors simultaneously for at least one day, but longer if possible. This will allow you to see how the sensors perform under normal operation conditions in your building. You may wish to introduce a PM source to check that the sensors perform as expected to elevated levels of PM. Sources might include bringing an extinguished match into the room, or spraying hairspray, for example.

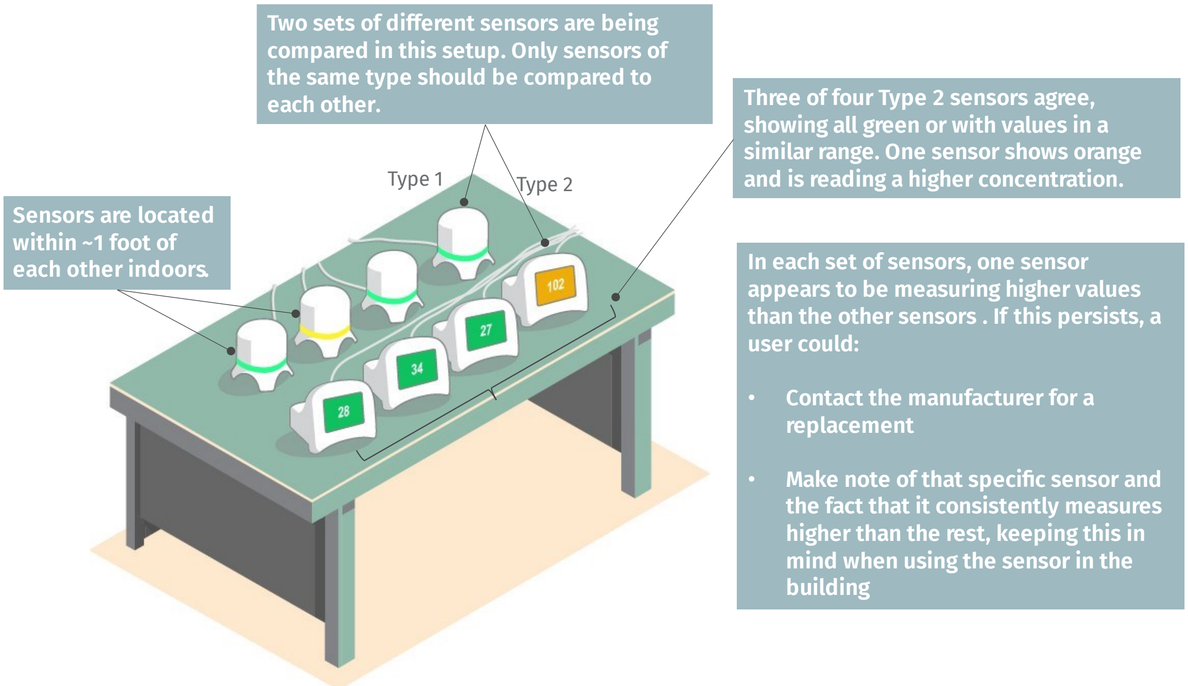


Figure A4-1. An example set up for how to perform a sensor "precision check" prior to deploying multiple sensors in a space.

<u>Gather the Data</u>

After your precision test, access the sensor data to evaluate how well the sensors performed. When reviewing the data, it will be most helpful to look at a time series of the data. A time series shows the concentration on the y-axis and time on the x-axis. If possible, try to look at all sensor data in one plot as this will help show whether or not the sensors capture the same variation in pollutant concentrations.

An example time series from a PurpleAir $PM_{2.5}$ sensor is shown in **Figure A4-2**. If your chosen sensor does not provide a time series of the data but instead gives you a list of times and measurements, you can take the data and create a time series using a program such as Microsoft Excel or Google Sheets. Tools and data visualizations are discussed the EPA Sensor Toolbox and the South Coast AQMD Sensor Guidebook.

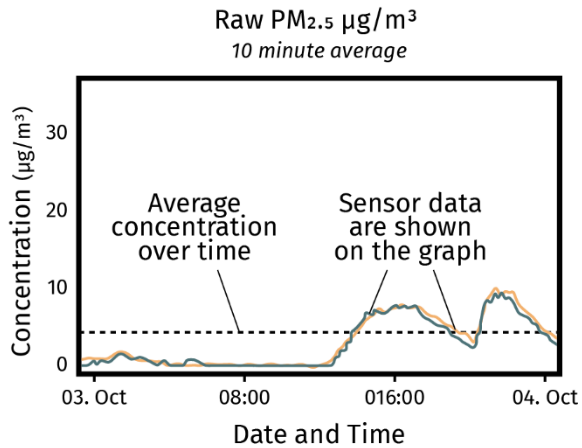


Figure A4-2. An example of a time series for comparing sensor data.

<u>How to Evaluate the Data</u>

In your evaluation of the data, there are a few things to look out for such as:

1. **Errors**: Did any of the sensors fail to report data or report error codes? If so, check the user manual and/or contact the manufacturer as the sensor may need to be serviced or replaced.

2. **Trends:** Do the sensors all track concentration in the same way? Is there one sensor that acts differently than the others? If there is, evaluate why that might be the case; for example, was that sensor located closer to a door where people frequently come in and out of the room? Was it located closer to an HVAC vent than the other sensors? If you think a source may have played a role, try to repeat the precision check test in another location.

   - If there are no apparent reasons why the sensor was reporting concentrations differently than the other sensors, you may wish to contact the manufacturer for further assistance.

   - It is important to remember that multiple sensors will not track perfectly and there will be variations in the data; however, all sensors should track in the same way. **Figure A4-3** shows examples of good and questionable sensor data.

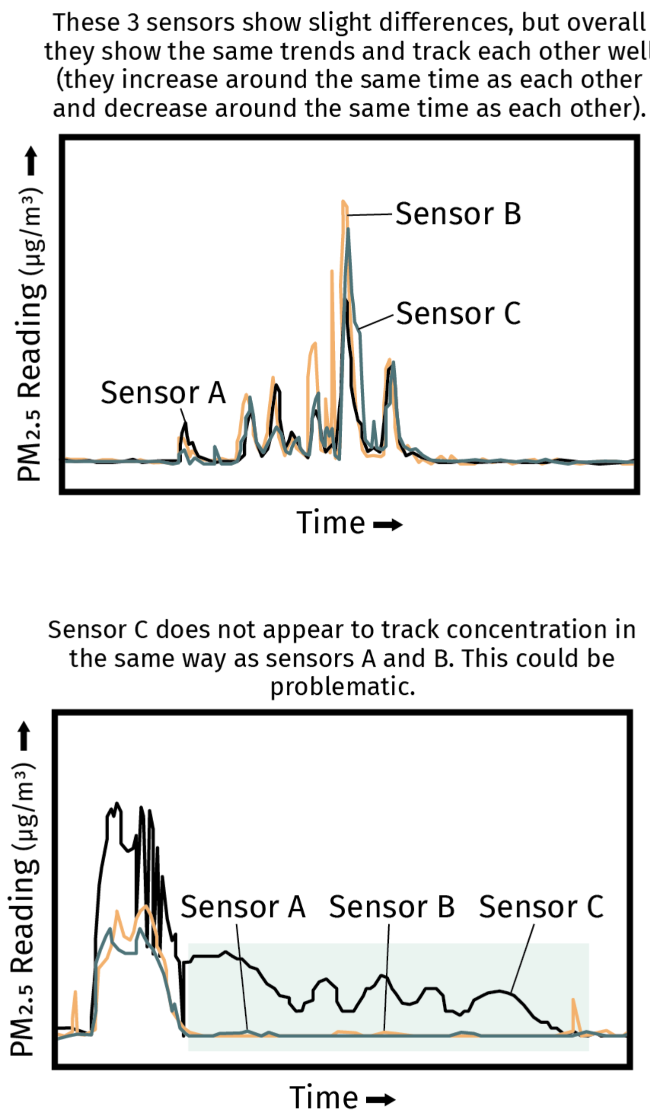


Figure A4-3. An example of sensor data that track appropriately (top), and an example where one sensor is exhibiting problematic behavior (bottom).

3. **Bias:** Are there any sensors that consistently report higher or lower concentrations than the other sensors? This is referred to as bias. **Figure A4-4** shows an example of sensor bias. If you find a sensor is biased, there are two options you could explore. The advised option is to contact the manufacturer for next steps (they may be able to help you correct the bias or they may suggest an exchange). Another option is to make note of the sensor exhibiting a bias and to keep in mind that this one (in the example) is consistently higher than the others. You will need to be mindful of bias during a smoke event so as not to interpret the space where a biased sensor is as being more or less polluted than the other spaces. This option is less advisable because real changes in pollutant concentration will be harder to decipher.

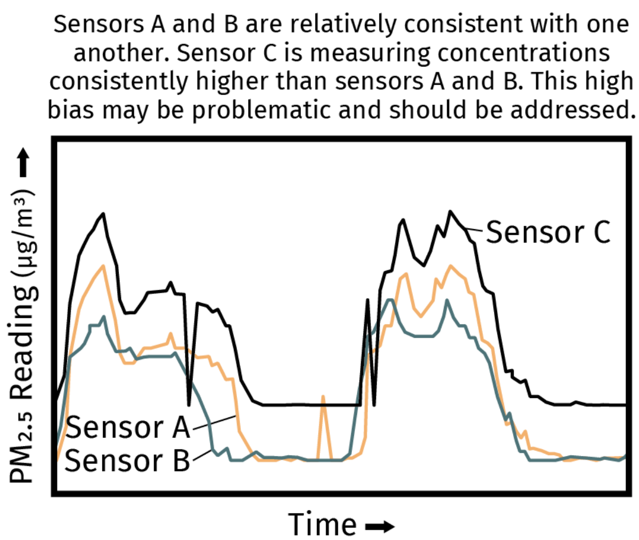


Figure A4-4. Example showing a sensor reporting data that appear to be biased high.

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