**ASHRAE Guideline 44P**

## Public Review Draft

# Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events

**First Public Review (August 2023)**
**(Draft shows Proposed New Guideline)**

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**ASHRAE, 180 Technology Parkway, Peachtree Corners GA 30092**

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**(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)**

## FOREWORD

*In recent years, the incidences of wildland fires have increased in both the number of fires per year, the severity, and duration of each event. In some cases, smoke events have lasted several weeks to months. The smoke produced from wildland fires can have a significant negative impact on ambient air quality both local and distant, which in turn can negatively impact health. This guideline provides detailed information on the impacts of smoke on human health with best practices in both building design and building operation to reduce the impact of prolonged smoke events on indoor air quality. The overarching goal is to reduce exposure of occupants to wildland fire smoke thereby protecting their health and wellbeing.*

## 1 PURPOSE

The purpose of this guideline is to recommend building measures to minimize occupant health impacts from wildfire and prescribed burn smoke events.

## 2 SCOPE

**2.1** This guideline applies to commercial buildings; institutional buildings, including healthcare facilities; and multi-unit residential buildings, as well as dedicated spaces within these building types intended for temporary human occupancy during a wildfire or prescribed burn smoke event.

**2.2** This guideline addresses buildings expected to be occupied by potentially at-risk populations, including children and older adults.

**2.3** This guideline provides recommendations related to the design, installation, commissioning, operation, and maintenance of building envelope, ventilation, and air cleaning systems.

**2.4** This guideline and its measures do not apply to internally generated smoke (e.g., from internal fires or structure fires).

## 3 DEFINITIONS AND SYMBOLS

### 3.1 Definitions

***Actuator:*** device, either electrically, pneumatically, or hydraulically operated, that acts as a motor to change the position of movable devices such as valves or dampers.

***Air cleaning:*** the use of equipment that reduces the concentration of airborne contaminants, such as microorganisms, dusts, fumes, respirable particles, other particulate matter, gases, odors, and/or vapors in air.

***Air economizer:*** duct and dampers arrangement with an automatic control system that together allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather.

***Air intake:*** device or opening through which air is withdrawn from or discharged into a conditioned space (grilles, registers, diffusers, and slots may be used as air inlets).

***Air leakage:*** (a) the flow of air through the building envelope caused by a specified pressure difference; a measure of airtightness, cfm at fixed pressure (m3/s at fixed pressure). (b) undesirable or unwanted leakage of air from within a component within an air-distribution system that could include such items as ducts, air terminal devices, and air handling units (AHUs).

***Ambient air quality:*** attributes of the respirable air outdoors, including particulate matter, gases, and bioaerosols.

***As low as reasonably achievable (ALARA):*** recognition that absolute concentration thresholds may not be possible under some circumstance.

***Microbiological contaminants:*** Pollutants of biological origin including bacteria, molds, and viruses.

***Blower door:*** an assembly consisting of a fan/blower and a calibrated flow measuring station (orifice plate, flow nozzle(s), flow ring, etc.) used for pressurizing or depressurizing a building envelope.

***Building automation system (BAS):*** an energy management system, usually with additional capabilities, relating to the overall operation of the building in which it is installed, such as equipment monitoring, protection of equipment against power failure, and building security.

***Building envelope:*** outer elements of a building, including walls, windows, doors, roofs, and floors, including those in contact with earth.

***Building operator, or Operator:*** person responsible for operating building automation equipment or who is responsible for the overall operation of a building.

***Building pressure:*** relationship of pressure in a building relative to the pressure outdoors.

***Centrifugal fan surge:*** a phenomenon that can occur when a centrifugal fan is at maximum pressure and minimum airflow.

***Commercial air scrubber:*** system designed to purify the air by removing airborne contaminants through one or more stages of filtration.

***Commissioning process:*** a quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements.

***Conditioned space:*** that part of a building that is heated and/or cooled and/or humidity controlled for the comfort of occupants.

***Demand control ventilation (DCV):*** a feedback control method used to maintain indoor air quality by automatically adjusting the ventilation rate provided to a space in response to changes in conditions such as occupancy or indoor pollutant concentration.

***Direct expansion cooling:*** system in which the cooling effect is obtained directly from the phase change of the liquid refrigerant into a vapor.

***Direct fired unit:*** typically a heater, where the gas is fed directly to the burner while the airstream provides the needed oxygen for combustion.

***Electronically commutated motors (ECM):*** brushless electric motors designed with permanent magnets on the rotor and on-board electronics to control the voltage and current applied to the motor.

***Electrostatic precipitator:*** device for removing dust from the air by inducing an electric charge on the dust particles.

***Elemental carbon:*** formed by the complete combustion of organic matter, and used to describe the composition of particulate matter.

***Energy recovery ventilator (ERV):*** heat exchanger assembly for transferring heat between two isolated fluid sources. The recovery system may be of air-to-air design or a closed loop hydronic system design.

***Fan inlet:*** area of the fan or fan-equipment fitting provided for connection to attached ductwork.

***Filter bypass:*** unfiltered air that passes through the AHU filter installation but remains unfiltered because it bypasses the installed air filters.

***Filter:*** device to remove gases from a mixture of gases and/or to remove solid material from a fluid.

***Filtration:*** process of passing a fluid through a porous material in such a manner as to remove suspended matter from the fluid.

***Heat exchanger:*** device to transfer heat between two physically separated fluids. Common types are air-to-liquid coils, fixed plate, rotary wheels, heat pipes, runaround coil loops, and shell and tube.

***High-efficiency particulate air (HEPA) filter:*** Higher efficiency than a MERV 16 (see definition of minimum efficiency reporting value).

***Heating Ventilating and Air Conditioning (HVAC) system:*** the equipment, distribution systems, and terminals that provide, either collectively or individually, the processes of heating, ventilating, or air conditioning to a building or portion of a building.

***Indoor air quality (IAQ):*** attributes of the respirable air inside a building (indoor climate), including gaseous composition, humidity, temperature, and contaminants.

***Infiltration:*** uncontrolled inward air leakage to conditioned spaces through unintentional openings in ceilings, floors, and walls from unconditioned spaces or the outdoors, caused by the same pressure differences that induce exfiltration.

***Intake air vent:*** an open duct that goes from an outside vent that serves as a path for outdoor air (OA) to enter a structure.

***Maximum tip speed:*** the maximum allowable velocity of a fan or impeller blade tip to prevent structural failure.

***Means of egress:*** a continuous and unobstructed path of travel from any point in a building or structure to a public way.

***Mechanical ventilation:*** the active process of supplying or removing air to or from an indoor space by powered equipment such as motor-driven fans and blowers but not by devices such as wind-driven turbine ventilators and mechanically operated windows.

***Minimum efficiency reporting values (MERV):*** scaled rating of the effectiveness of air filters. The scale is designed to represent the worst-case performance of a filter when dealing with particles in the range of 0.3 to 10 micrometers. The MERV rating is from 1 to 16. Higher MERV ratings correspond to a greater percentage of particles captured on each pass, with a MERV rating of 16 filter capturing more than 95% of particles over the full range.

*Note: MERV is the ASHRAE rating scale for air filters. Europe uses different standards for filter classes; see https://www.emw.de/en/filter-campus/comparison-of-filter-classes.html to obtain the filter type that corresponds to the MERV ratings mentioned throughout the document. Other filter rating systems exist and equivalent filter performance for PM2.5 should be specified.*

***N95:*** a rating for face masks indicating 95% removal of 0.3 micron and greater particles that are not oil-based.

***Natural ventilation:*** movement of air into and out of a space primarily through intentionally provided openings (such as windows and doors), through nonpowered ventilators, or by infiltration.

***Negative air machine:*** a type of air scrubber that exhausts air to the outdoors at a rate faster than air is being supplied to the space, causing the space to become negatively pressurized.

***Outdoor air (OA):*** (a) air outside a building or taken from the external atmosphere and, therefore, not previously circulated through the system. (b) ambient air that enters a building through a mechanical ventilation system, through intentional openings for natural ventilation, or by infiltration.

***Particle sensor:*** a device used to sense and measure particles in the air.

***Particulate matter (PM):*** a mixture of solid particles and liquid droplets found in air. When the acronym PM is followed by a numerical subscript, it typically refers to the subset of particulate matter with an aerodynamic diameter less than or equal to that number in microns. For example, PM2.5 refers to particulate matter that is 2.5 microns or less in aerodynamic diameter.

***Personal protective equipment (PPE):*** equipment worn to minimize one's exposure to hazards that can cause injuries or illnesses.

***Photocatalytic oxidation (PCO):*** a purification process where UV light activates a catalyst to convert airborne contaminants into water and carbon dioxide.

***Portable air cleaner (PAC):*** a mobile device used to remove airborne impurities from air in a single room or space.

***Prescribed fire**:* any fire intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific land or resource management objectives; also referred to as planned fires, controlled burns, or prescribed burns.

***Pressure drop:*** difference in pressure between two points in a flow system, usually caused by frictional resistance to fluid flow in a conduit, filter, or other flow system.

***Recirculating air:*** air taken from a space and returned to that space, usually after being passed through a conditioning system. The part of the return air that is reused. Air removed from a space and reused as supply air.

***Recirculation filter:*** device to remove gases from a mixture of gases and/or to remove solid material from a fluid that is intended to be recirculated.

***Relief fan:*** a fan typically used during economizer operation that exhausts air at a predetermined rate, tracking with building pressure to offset the outdoor air that is introduced to the system to maintain the desired building pressure.

***Retrofit:*** modification of existing equipment, systems, or buildings to incorporate improved performance, updated operation, improved energy performance, or all three.

***Roof top packaged units:*** HVAC unit, typically mounted on a roof, containing coils, a compressor, and fan with the conditioned air being discharged directly into the rooms below or through a duct system.

***Sensor:*** device or instrument designed to detect and measure a variable.

***Smoke detector (duct mounted or area detector):*** a fire-protection device that automatically detects and gives a warning or alert signal in the presence of smoke.

***Smoke readiness plan:*** documentation of the preparatory steps and mitigation strategies that a facility will use before, during, and after a wildfire smoke event to maintain the quality of indoor air.

***Smoke:*** the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.

***Sorbent media air filters:*** device to remove gases from a mixture of gases and/or to remove solid material from a fluid via absorption, adsorption, or both.

***Static pressure:*** the resistance to airflow in ductwork or across an appurtenance such as a filter, damper, or grille.

***Test, adjust and balance (TAB) contractor:*** a person or organization certified to test, adjust, and balance HVAC systems to ensure optimal performance.

***Variable frequency drive (VFD) or variable speed drive (VSD):*** electronic device that varies its output frequency to vary the rotating speed of a motor, given a fixed input frequency. Used with fans or pumps to vary the flow in the system as a function of a maintained pressure.

***Ventilation:*** the process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, air pressure, or temperature within the space.

***Video Image Smoke and Fire Detection (VISD)*:** a digital video camera coupled with a computer running video analytic software which can recognize smoke and fire in the image.

***Volatile organic compounds (VOCs):*** organic compounds in the vapor state present in the ambient or indoor air.

***Wildfire***: any fire started by an unplanned ignition caused by lightning, volcanoes, or other acts of nature; unauthorized activity; accidental, human-caused actions; or a prescribed fire that has developed into a wildfire.

***Wildland fire***: generic term used to describe wildfires and prescribed fires.

***Wildland urban interface (WUI):*** the zone of transition between unoccupied land and human development. It is the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.

### 3.2 List of Acronyms

ALARA – As Low As Reasonably Achievable

AHU - Air Handling Unit

BAS - Building Automation System

CADR – Clean Air Delivery Rate

DCV – Demand Control Ventilation

ERV – Energy Recovery Ventilator

HRV – Heat Recovery Ventilator

HVAC - Heating Ventilation Air Conditioning

IAQ – Indoor Air Quality

HEPA – High-Efficiency Particulate Air

MERV – Minimum Efficiency Reporting Value

NAAQS - National Ambient Air Quality Standards

OA – Outdoor Air

PAC – Portable Air Cleaner

PCO – Photocatalytic Oxidation

PM – Particulate Matter

PPE – Personal Protective Equipment

TAB – Test Adjust and Balance

VAV - Variable Air Volume

VFD – Variable Frequency Drive

VISD – Video Image Smoke and Fire Detection

VOC – Volatile Organic Compound

WUI – Wildland Urban Interface

# 4 BACKGROUND

## 4.1 Wildland Fires

There are many different types of fire that can occur on the landscape, which are broadly classified into controlled fires and wildfires. Controlled fires include prescribed burning for ecological restoration or wildfire risk reduction, land clearing, pile burning of waste biomass, and agricultural fires. Wildfires, on the other hand, are unpredictable and can be caused by human activity or infrastructure, lightning strikes, or when controlled fires escape containment. Although many wildfires are suppressed when they are small, some cannot be suppressed when the weather conditions are unfavorable, and they grow very large.(1) When such fires occur at the interface of wildland and human habitation (referred to as wildland urban interface, or WUI), they can burn a vast amount of anthropogenic material in addition to natural biofuels. All fires generate smoke pollution, but large landscape and WUI wildfires often cause episodes of severely degraded air quality that lasts for days, weeks, or months. This guideline was primarily developed to address episodes of severe wildfire smoke, but it can be applied to smoke from all types of fires, including prescribed burns. As there are different terms used to describe landscape and wildfires and/or prescribed burns, this document will from herein use the term wildland fire smoke as a generic term unless a specific source is being addressed.

Wildfire risk is increasing across North America and worldwide, for complex and interrelated reasons.(2) Before colonization, Indigenous people in North America, Australia, and elsewhere practiced systematic controlled burning to shape the landscape and maintain ecological balance.(3) Settlers in these regions favored fire suppression to protect lives and property, thereby excluding fire from naturally flammable landscapes and causing fuels to accumulate.(4) Although forest management practices have been changing over the past decades, the accumulation of landscape fuels is now coinciding with a drier, hotter, and windier climate, which are all conditions that increase wildfire risk.(5) In addition, wildfire seasons are getting longer or disappearing in some areas where wildfires can occur at any time of year.(6) Overall, we can expect two important trends that will affect smoke pollution in the years ahead: (1) increased frequency, size, and intensity of wildfires; and (2) increased use of controlled, or prescribed fires to reduce wildfire risk.

## 4.2 Composition of Wildland Fire Smoke

Smoke from wildland fires is a complex and dynamic form of air pollution. Its composition depends on the fuels being burned, their moisture content, the temperature of the fire, the weather conditions, the distance the smoke has traveled, and other factors.(7) Most simply, smoke is composed of gases and particles. From a health perspective, the most important gases are oxides of nitrogen ($NO_X$), volatile organic compounds (VOCs), and secondary ground-level ozone ($O_3$) formed when $NO_X$ and VOCs interact with ultraviolet radiation from the sun. The particulate matter (PM) in smoke ranges in size from less than 0.1 micron in aerodynamic diameter ($PM_{0.1}$) to greater than 10 microns ($PM_{10}$) but is often characterized by particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$, or fine particulate matter). Most wildland fire smoke particles are less than 1.0 micron, though the size distribution changes as smoke ages in the atmosphere.(8) The composition of the particles is highly variable with respect to elemental carbon, organic carbon, and other substances such as heavy metals.(7) Smoke becomes even more complex when anthropogenic materials burn along with landscape fuels.

### 4.3 Ambient Air Quality Impacts of Wildland Fire Smoke

*Ambient air quality* is a term used to describe the status of outdoor air concerning the mix of air pollutants from all anthropogenic and natural sources. Many jurisdictions have regulatory standards that describe the legally allowable concentrations of different pollutants in ambient air. These concentrations are typically reduced slowly over time to ensure that air quality always improves. The pollutants for which such standards exist are known as *criteria air pollutants*, and they usually include $PM_{2.5}$ and/or $PM_{10}$, $O_3$, $NO_X$, oxides of sulfur ($SO_X$), and carbon monoxide (CO).(9) These pollutants are typically measured by a distributed network of regulatory monitoring stations using instruments that meet high standards for accuracy and precision. Concentrations are often logged at 1-minute intervals and reported as 1-hour averages. Many air quality monitoring programs also include measurements of some VOCs, polyaromatic hydrocarbons (PAH), lead, and other hazardous compounds known as *toxic air pollutants*.(9) Most of these compounds must be quantified by laboratory analysis of air samples, so a small number of measurements are made at a small number of locations compared with the criteria air pollutants. Toxic air pollutants are not regulated in the same way as criteria air pollutants. Whereas criteria air pollutants are measured in ambient air to assess compliance, emissions of toxic air pollutants are regulated at their source.

Wildland fire smoke could affect ambient concentrations of all criteria air pollutants, but its biggest impacts are on $PM_{2.5}$.(7) Under typical air quality conditions in most high-income countries, the 24-hour average mass concentration of $PM_{2.5}$ is less than 25 micrograms of particulate matter per cubic meter of air ($\mu g/m^3$) in dense urban environments and less than 10 $\mu g/m^3$ in many other locations. In comparison, days affected by moderate wildland fire smoke can have concentrations up to five times higher, and days affected by extreme wildfire smoke can have concentrations more than ten times higher. Wildfire smoke episodes can last for days, weeks, or months, and their day-to-day $PM_{2.5}$ concentrations tend to be highly variable because the fire dynamics change, and the winds shift. In comparison, the effects of smoke on concentrations of other criteria air pollutants are typically quite small (Figure 1).

The effects of wildland fire smoke on ambient concentrations of toxic air pollutants are poorly understood compared with the effects on criteria air pollutants. Because these pollutants are measured infrequently at a small number of locations, existing monitoring networks often do not capture the impacts of smoke. As international interest in smoke grows, there are more research studies designed to characterize its air quality impacts more completely by measuring criteria air pollutants, toxic air pollutants, and the composition of particulate matter.(10) Such studies have reported that wildfire smoke can include high concentrations of harmful VOCs, secondary $O_3$, PAH, metals, and other compounds, and that the air quality impacts are highly variable.(11–14) While smoke is a complex and dynamic mixture with many constituents that can affect human health, it is important to recognize that only a few can be easily measured in real-time.

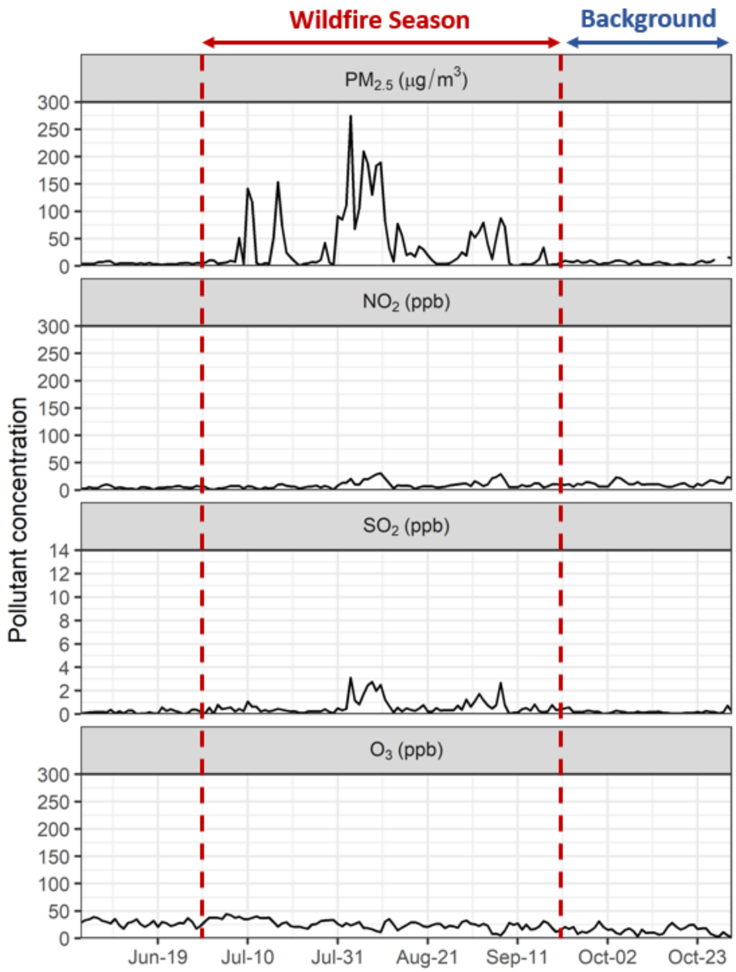


**Figure 1.** Daily concentrations (June-October) of fine particulate matter ($PM_{2.5}$), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), and ground-level ozone ($O_3$) in a community affected by severe wildfire smoke. The figure demonstrates how elevated $PM_{2.5}$ concentrations are during wildfire season compared with the typical background, and how much more elevated $PM_{2.5}$ concentrations are than concentrations of other criteria air pollutants.

### 4.4 Focus on Fine Particulate Matter ($PM_{2.5}$)

The mass concentration of $PM_{2.5}$ is often used as a proxy for the complex wildland fire smoke mixture, its air quality impacts, and its potential health effects. There are three key reasons for this. The first and most important is that $PM_{2.5}$ can penetrate deep into the human lungs, where the particles cause local irritation and systemic inflammation that can affect other organ systems.(15) Short-term and long-term exposure to ambient $PM_{2.5}$ has been conclusively linked to a wide range of acute and chronic health effects by a large body of scientific research.(16,17) While most of these studies have focused on $PM_{2.5}$ from sources other than wildland fire, the growing literature on the health effects of wildland fire smoke has been largely consistent with the broader health evidence on $PM_{2.5}$.(18–20) The co-pollutants in wildland fire smoke may cause health effects in addition to those of $PM_{2.5}$ exposure, but such health effects are likely to be smaller and more difficult to measure.

Second, the known health effects of ambient $PM_{2.5}$ have led to its regulation as a criteria air pollutant in most jurisdictions, meaning that it is routinely measured at 1-hour intervals across many locations, especially in high-income countries. Third, wildland fire smoke leads to larger and more consistent increases in ambient $PM_{2.5}$ than other criteria air pollutants (Figure 1).[7] In brief, $PM_{2.5}$ has well-established health effects, is routinely measured in many locations, and is more impacted by wildland fire smoke than other pollutants. This makes $PM_{2.5}$ the best information for assessing the air quality impacts of smoke and its potential health effects. Furthermore, $PM_{2.5}$ emissions from wildland fires are relatively easy to model and include in air quality forecasts that predict concentrations over the coming days. Many agencies now routinely produce smoke forecasts for the next 24-72 hours, which are valuable tools for short-term planning and response.[21–23]

The health effects associated with $PM_{2.5}$ are primarily due to the small size of the particles, though the composition of the particles also plays a role. Different constituents, such as elemental carbon, organic carbon, and heavy metals, have been associated with modified toxicity of $PM_{2.5}$ at the same mass concentration. The toxicity of $PM_{2.5}$ in wildland fire smoke is a very active area of research,[24–26] but the available evidence does not support distinguishing between different types of smoke based on fuels burned, fire intensity, or distance traveled. As such, this guideline focuses on reducing the mass concentration of $PM_{2.5}$ indoors whenever ambient air quality is affected by smoke from wildland fires.

### 4.5 Health Effects of Wildland Fire Smoke

Short-term exposure to $PM_{2.5}$ in wildland fire smoke has been associated with a comprehensive and growing range of acute health effects. There is consistent evidence that wildfire smoke exposure leads to higher rates of acute respiratory outcomes, including respiratory symptoms, use of rescue medications, lung function, outpatient physician visits, emergency department visits, ambulance dispatches, hospital admissions, and deaths.[18,19] Some of this evidence suggests that the respiratory effects of wildland fire smoke $PM_{2.5}$ may be greater than those of $PM_{2.5}$ from other sources, even at the same concentrations.[27,28] It is not yet clear whether these differences are due to differences in the $PM_{2.5}$ composition and toxicity between sources or unmeasured co-pollutants in wildland fire smoke.

Although wildland fire smoke makes first contact with the respiratory system, it can affect many other parts of the body due to the inflammation and oxidative stress it causes in the lungs. There is increasingly consistent evidence that short-term exposure to smoke $PM_{2.5}$ is associated with acute cardiovascular outcomes, including reduced heart rate variability, increased blood pressure, unstable angina, heart attacks, strokes, out-of-hospital cardiac arrest, and death.[20] In contrast with respiratory outcomes, the effects of wildland fire smoke $PM_{2.5}$ on cardiovascular outcomes may be smaller than or more consistent with the effects of $PM_{2.5}$ from other sources.

There is also a rapidly growing body of evidence indicating that wildfire smoke $PM_{2.5}$ has negative effects beyond the respiratory and cardiovascular system, including cognitive function[29], immune function[30], kidney disease[31], and blood sugar control among those who use insulin[32]. These types of effects associated with smoke exposure are consistent with the wider literature on the effects of $PM_{2.5}$ from other sources. Many acute respiratory, cardiovascular, and other health effects associated with short-term smoke exposures have now been reported within the first hours of increasing $PM_{2.5}$ concentrations,[29,32] highlighting the potential role of the indoor environment as a protective space.

Much less is currently known about the longer-term health effects associated with seasonal smoke exposures. It is plausible that extreme exposures during a severe wildfire season could cause health effects that do not resolve after the smoke has cleared, such as permanent detriments to lung function. It is also plausible that repeated seasonal exposures to wildland fire smoke can induce the onset of chronic diseases, consistent with the well-known effects of long-term exposure to urban air pollution from other sources. Indeed, two recent studies have shown an increased incidence of cancer after exposure to smoke from a coal mine fire (similar to wildland fire smoke[33]) and higher cancer rates in populations nearer to repeated wildfire activity.[34] The longer-term health effects associated with wildland fire smoke exposure are an active area of epidemiologic research.[35]

The longer-term effects of wildland fire smoke exposure on children, infants, pregnant people, and developing fetuses are all areas of particular concern. These groups are generally very sensitive to air pollution, and smoke exposure in early life may affect health throughout the life course.[36] For example, exposure to wildfire smoke $PM_{2.5}$ during gestation has been associated with adverse birth outcomes such as pre-term birth, low birth weight, and being small for gestational age.[37] In turn, all of these outcomes are associated with lifelong detriments to health. For example, a recent study found that adults who had been born pre-term were more affected by wildfire smoke exposure than those who had been born at full term.[38] Rhesus macaque studies have found associations between smoke from the severe 2018 Camp Fire wildfire and increased risk of pregnancy loss with exposure near conception[39], and biological and behavioral impacts of exposure specifically with exposure during the first third of pregnancy.[40] Other recent work on infant rhesus macaque monkeys exposed to wildfire smoke has found that they had smaller lung size and poorer immune function than unexposed infants and that some of these traits were passed down to their offspring.[30,41] Again, much of this research on wildland fire smoke $PM_{2.5}$ is consistent with the research on $PM_{2.5}$ from other sources.

All of this evidence supports the need to protect people from exposure to wildland fire smoke. Although most epidemiologic research has used outdoor concentrations of $PM_{2.5}$ to estimate smoke exposures, it must be acknowledged that most people in high-income countries spend at least 90% of their time indoors.[42] As such, the health effects associated with smoke $PM_{2.5}$ must be predominantly due to indoor exposures, and it follows that the burden of acute and chronic health effects can be reduced if the indoor impacts of outdoor smoke can be limited in places where people spend their time.

### 4.6 At-risk Populations

Some people are more susceptible to experiencing health effects due to smoke exposure. Anyone with a reactive respiratory condition such as asthma or chronic obstructive pulmonary disease (COPD) may be at risk of sudden airway closure and difficulty breathing, even after short exposures to relatively low $PM_{2.5}$ concentrations.[43] These individuals may also be at increased risk of longer-term health effects, especially those with conditions defined by degenerative lung function, such as COPD.[35] People with other chronic conditions such as heart disease, diabetes, neurological disease, mental illness, and dementia may also be at higher risk.[18,19] In general, people with conditions that compromise their daily health are more likely to be adversely affected by exposure to wildland fire smoke.

The effects of smoke exposure also vary by age. There is evidence that the developing fetus can be affected by maternal smoke exposure, and there may be critical developmental windows when exposures cause specific harm, such as birth defects. Newborn infants may be especially sensitive to smoke exposure in the first months of life when their lungs undergo rapid changes. Human lungs continue to grow and develop well into adolescence. Young children are at particular risk because they have a high baseline respiration rate, they tend to be more active than adults, and they often spend more time outdoors.[44,45] On the other end of the spectrum, there are natural decreases in lung function that occur with age, so older adults may be at higher risk from smoke exposure even if they are in good health.[46]

There are some indoor environments where people who are more susceptible to wildland fire smoke congregate. Inpatients at hospitals and other acute care facilities are in a state of compromised health, and smoke exposures in these environments may exacerbate their conditions and complicate care. Likewise, long-term care and assisted living facilities house individuals who are generally unable to care for themselves independently and may be at higher risk from smoke exposure. Although the populations of prisons may be younger than those in acute or residential care, the baseline health of incarcerated people is significantly lower than that of the general population.[47] In all of these cases, the populations at risk are congregated in the same setting for 24 hours per day, 7 days per week, so limiting smoke in these indoor environments is the only way to reduce their smoke exposure.

There should also be special attention paid to indoor environments where infants and children congregate, such as daycares, schools, and summer camps. In most cases, these spaces will be used by children during daytime hours only, and most of their exposures will occur in their homes and other environments. However, these hours will be the most active time of the day for most children, with higher respiration rates and deeper breaths during play. Once again, limiting smoke in these indoor environments is an important way to help protect the short- and long-term health of infants and children.[44,48]

## 4.7 Indoor Air Quality (IAQ)

Most people in high-income countries spend more than 90% of their time indoors,[42] where the built environment mediates their exposure to the outdoor air. Indoor air quality (IAQ) is a complex product of multiple factors, including outdoor air quality, indoor emissions, systems used for heating, ventilating, and air conditioning (HVAC), and other mechanisms such as deposition, chemical transformation, and air cleaning. The ASHRAE *Position Document on Indoor Air Quality* recognizes that IAQ affects human health, comfort, wellbeing, learning outcomes, and work performance.[49] It is the ASHRAE position that provision of acceptable IAQ is an essential building service and that all decisions about buildings and HVAC systems must consider the implications for IAQ. This guideline is written under the assumption that IAQ is generally well-managed in the buildings for which smoke readiness plans are being developed.

There are currently no federal government, non-occupational standards for $PM_{2.5}$ in indoor air environments. For informational purposes, US Environmental Protection Agency's (EPA's) primary (health-based) national ambient air quality standards (NAAQS) established under the Clean Air Act include both 24-hour and annual $PM_{2.5}$ standards which work together to protect the public from health effects associated with long- and short-term fine particle exposures. The annual $PM_{2.5}$ NAAQS is currently set at a level of 12.0 $\mu g/m^3$ (annual mean, averaged over 3 years) and the 24-hour $PM_{2.5}$ NAAQS is currently set at a level of 35 $\mu g/m^3$ (98 percentile, averaged over 3 years) at the time of publication of this guideline. The science upon which the NAAQS are based and the standards themselves are periodically reviewed and sometimes revised. Refer to the EPA website[50] for the most up-to-date standards. Refer to ASHRAE Standard 62.1-2022[51] Appendices E and N. (Consider occupant age, etc.), or standards published by other international environmental associations. The goal should be to keep indoor $PM_{2.5}$ concentrations as low as reasonably achievable (ALARA, see Background).

## 4.8 Indoor Infiltration of Fine Particulate Matter ($PM_{2.5}$) from Wildland Fire Smoke

Wildland fire smoke can enter the indoor environment through mechanical HVAC systems, natural ventilation systems, doors, windows, and any other openings in the building envelope. The proportion of outdoor smoke that gets indoors is often called the *coefficient of infiltration*, for which the theoretical range is 0% to 100%. Different constituents of the complex smoke mixture may infiltrate indoors with different efficiencies, depending on the physical and chemical properties that influence their behavior. Outdoor gases infiltrate the indoor environment at a range of different coefficients under typical ambient air quality conditions[52,53], and less is known about the infiltration of outdoor gases during episodes of landscape fire smoke.

Several studies have measured $PM_{2.5}$ infiltration during episodes of wildland fire smoke using simultaneous measurements of indoor and outdoor concentrations.[54–62] Many of these studies have been conducted in residential environments, often as part of trials testing the efficacy of air cleaning interventions. In the absence of any interventions, studies in residential environments have reported infiltration coefficients ranging from as low as 20% to as high as 100%, depending on the characteristics of the homes and occupant behaviors. Factors associated with higher residential infiltration coefficients include leakier building envelopes and more use of doors and windows by building inhabitants.

There are relatively fewer studies examining $PM_{2.5}$ infiltration into larger buildings during episodes of wildland fire smoke. In general, larger buildings have been more resilient to smoke than residential environments, with infiltration coefficients ranging from as low as 20% to as high as 80% in some cases(56). Factors associated with higher commercial infiltration coefficients include natural ventilation and the use of large doors such as loading bays.(55,62) Factors associated with lower infiltration coefficients include mechanical ventilation, closed windows, restricted use of entry doors, and distance from points of entry.

## 4.9 Indoor Fine Particulate Matter ($PM_{2.5}$) Should be as Low as Reasonably Achievable (ALARA)

Very few studies have reported $PM_{2.5}$ infiltration coefficients of less than 20% during wildfire smoke episodes, even when significant efforts were made to limit smoke infiltration and clean the indoor air.(54) This may represent a practicable lower threshold when considering the *as low as reasonably achievable* (ALARA) approach to indoor $PM_{2.5}$ control when the outdoor air is affected by wildland fire smoke.
Outdoor concentrations of $PM_{2.5}$ can vary widely during smoke episodes (Figure 1), with 24-hour measurements easily 300 $\mu g/m^3$ or higher in some areas. Such outdoor concentrations translate to indoor concentrations of 60 $\mu g/m^3$ or higher under the assumption of a 20% infiltration coefficient with no indoor $PM_{2.5}$ sources. This reduction in $PM_{2.5}$ constitutes *cleaner* indoor air compared with the outdoor environment, but not *clean* indoor air as it might be defined by existing guidelines and standards. For example, the EPA maintains a 24-hour average standard of less than 35 $\mu g/m^3$ of $PM_{2.5}$ in outdoor air on 98% or more of days, averaged over a three-year period. The equivalent Canadian standard was set at 28 $\mu g/m^3$ from 2015-2020 and 27 $\mu g/m^3$ from 2020-2025. This value may be further reduced in 2025, reflecting that there is no known safe threshold for $PM_{2.5}$ exposure. Recognizing this, the World Health Organization (WHO) recently revised its 24-hour $PM_{2.5}$ concentration guideline to 15 $\mu g/m^3$.(63)

There are currently no regulated limits for indoor concentrations of $PM_{2.5}$ in non-occupational settings. The ALARA principle is suggested referencing the most up to date sources of information such as but not limited to:

- ASHRAE 62.1-2022(51) appendices E and N
- EPA website(64)
- Websites for local health authorities which describe exposure considerations for $PM_{2.5}$

For any given building, the only way to understand the indoor infiltration of outdoor $PM_{2.5}$ is to measure indoor and outdoor concentrations simultaneously. There is now a proliferation of affordable technology for measuring $PM_{2.5}$ with reasonable accuracy and precision. Many studies on smoke infiltration have leveraged these devices to estimate infiltration coefficients and evaluate the effects of different interventions on those coefficients.(54,55,59) The best smoke readiness plans will include indoor and outdoor $PM_{2.5}$ measurements to ensure that indoor concentrations are truly ALARA for the building.

## 4.10 Emerging Technologies

Many existing technologies can reduce the indoor impacts of outdoor wildland fire smoke, and this guideline has been developed to provide information on their use. At the same time, rapid technological changes are occurring in the field of IAQ that will complement this guideline in years to come. The global COVID-19 pandemic has led to unprecedented interest in IAQ improvements as an intervention to control the transmission of infectious airborne disease. This paradigm shift has been compared to much earlier efforts to provide sanitation, clean drinking water, and safe food[65], and is likely to yield significant HVAC and air filtration innovations. At the same time, there are rapid advances in more reliable and low-cost sensors that can measure $PM_{2.5}$ and other constituents of wildland fire smoke.

Low-cost $PM_{2.5}$ sensors are increasing in availability so are highly recommended to be considered in new designs or added to existing buildings where practical. These sensors can act as one of the indicators of the effectiveness of any adaptations or design features of the HVAC system to reduce the impact of smoke on IAQ. They can also give information on when to trigger the Smoke Readiness Plan. In addition to measuring $PM_{2.5}$, some instruments include additional sensors such as for CO, $CO_2$, relative humidity (RH), or temperature.

**Note:** Devices intended for smoke detection from internal structural fires are not included in this section. Building fire suppression, detection, and control measures are not included in this guideline.

Given the breadth of air sensor technologies entering the market, the US EPA[66] has compiled information on the performance, operation, and best practices for effectively using these sensors, siting, and operation. The ideal application would be to monitor the space year-round and collect data on (IAQ) trends. These data can provide information on the "baseline" condition or the normal PM concentrations in the building. Since indoor activities can generate $PM_{2.5}$, it is critical to place the sensor at its projected location prior to a smoke event to understand how the background concentrations change as a function of occupancy and activities in the building. These data can then be used to inform the Smoke Readiness Plan. For example, a certain PM concentration or deviation from typical background concentration could trigger specific events such as increasing filtration or building pressurization setpoints.

Some sensors can send data to a cloud application which will increase resiliency in case the local storage is lost. These data can be made public or secure depending on the user's settings.

These low-cost sensors should not be used to report $PM_{2.5}$ concentrations for any regulatory requirements. They are only to be used as an indicator to compare existing conditions to baseline conditions and/or to monitor the effectiveness of adaptations made to the HVAC system. $PM_{2.5}$ sensors may not give the exact concentration of $PM_{2.5}$ in the air unless they are specifically calibrated or corrected. Raw sensor data can still be useful for understanding air quality, such as by examining trends over time or comparing air quality in different locations (e.g., indoors vs. outdoors). Avoid comparing very short-term (e.g., 1-minute) sensor readings directly to health-based advisories such as the Air Quality Index (AQI) for $PM_{2.5}$ which use much longer averaging times (e.g., 24-hours).

Another newer technology that could be used is Video Image Smoke and Fire Detection (VISD) which consists of a digital video camera coupled with a computer running video analytic software that can recognize smoke and fire in the image. VISD systems can monitor outside the building and look for visible indications of a fire or smoke to determine if the smoke is from outside the building or inside the building.

### 4.11 Need for this Guideline

Every building is different, but the principles of smoke infiltration are the same across all buildings. Smoke can be actively drawn indoors through the outdoor air intake of an HVAC system, and it can move passively indoors through doors, windows, and other openings in the building envelope. It follows that minimizing indoor smoke impacts requires two approaches: (1) preventing smoke from getting indoors and (2) removing smoke that does get indoors. The specifics of the Smoke Readiness Plan will depend on the characteristics of the building, including occupancy type, the HVAC system, building envelope, types and operation of doors and windows, and patterns of use. This guideline provides a general framework and best practices for creating a Smoke Readiness Plan for a building, within the scope of this guideline, including pre-season preparation, activation during smoke episodes, evaluation, deactivation once the smoke has cleared, and assessment of updates that may be needed to the smoke readiness plan.

# 5 DESIGN AND COMMISSIONING

## 5.1 Overview

This section is a guide for designers. The measures listed here are intended to protect indoor air quality (IAQ) during periods of wildland fire smoke and may be applied during initial design, or as a retrofit.

## 5.2 Definition of the Design Challenge

IAQ is protected from $PM_{2.5}$ in smoke by two means:

1. Reduction of $PM_{2.5}$ infiltration.
2. Removal of $PM_{2.5}$ in indoor air.

Smoke and related contaminants enter a building through various paths:

1. Intakes - outdoor air intakes at HVAC systems.
2. Doors - entrance and egress points into the building.
3. Envelope elements - windows, skylights, or other penetrations in the contiguous envelope.
4. Leakage through the contiguous envelope.
5. Emissions from contaminated clothing from occupants.

## 5.3 Selection of Design Outdoor and Indoor Contaminant Levels

To perform design calculations, the design team must select representative concentrations for both outdoor air and indoor air. Without indoor and outdoor concentrations, the design calculations in Section 5.4 cannot be performed. Design measures should be communicated to stakeholders in a Basis of Design, which articulates the design concentrations used for that design. The actual conditions faced by the system during an event will undoubtedly vary from the design concentrations.

### 5.3.1 Selection of an Outdoor Design Concentration of $PM_{2.5}$

Select outdoor design concentration of $PM_{2.5}$ based on Informative Annex B.

### 5.3.2 Selection of an Indoor Design Concentration of $PM_{2.5}$

This guideline recommends an indoor design strategy of ALARA; See Section 4.9. For general calculations, use 12 $\mu g/m^3$ or 15 $\mu g/m^3$. Adjust this value based on the vulnerability of the intended occupancy (e.g., usage of the space, occupant age, occupant susceptibility).

## 5.4 Design Calculations and Processes

### 5.4.1 Removal Need Calculation

The design calculations related to smoke protection (required flow rate and filtration efficiencies) are iterations of the conservation of mass of contaminants into the building that can be presented with the following equation for a given zone:

$$Cz = \frac{VifCo + Voz(1 - Ef)Co}{Voz + FrRVrEf}$$

Where
Cz is indoor contaminant concentration in the zone (µg/m$^3$)
Vif is the infiltration flow rate to the building (m$^3$/hr, cfm)
Co is the concentration of contaminants ($PM_{2.5}$) in the outdoor air (µg/m$^3$)
Voz is zone outdoor airflow (m$^3$/hr, cfm)
Ef is the filter removal efficiency (%)
Fr is the design flow reduction factor (=1 if the system is constant flow)
R is the recirculation flow factor (=1 if system is 100% recirculating)
Vr is the recirculating or return airflow (m$^3$/hr, cfm)

Notes: Zone air distribution effectiveness (Ez) is assumed to be 1.0. See Figure 2 for schematic.

The above equation can be programmed into a spreadsheet so that designers can determine the impact on indoor contaminant concentration with varying parameters such as filter removal efficiency.

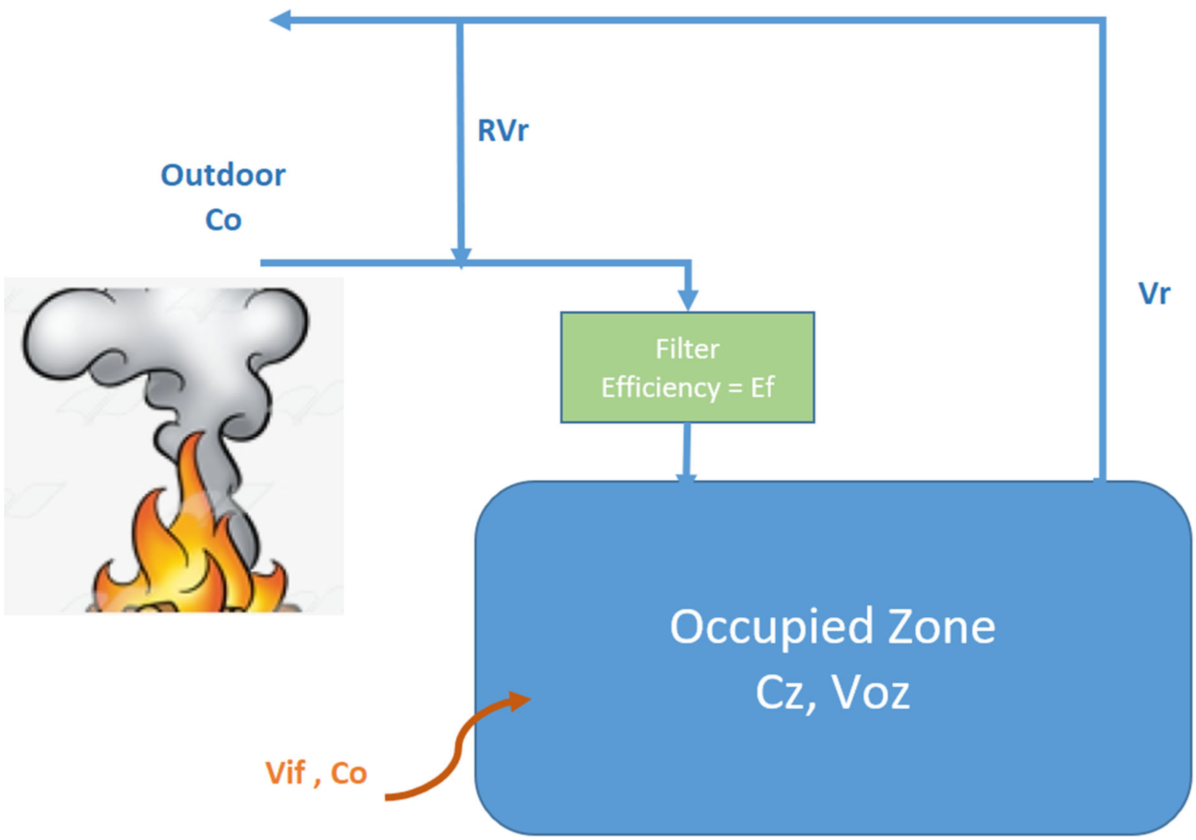


**Figure 2.** Schematic for single zone design equation

For more details on mass balance equations, including applications in different system configurations, see Appendix F of ASHRAE Standard 62.1-2022[51]

**Filter Removal Capabilities (Ef):** Table 1 indicates the $PM_{2.5}$ removal efficiency (Ef) for various MERV rated filters. This table represents a $PM_{2.5}$ *mass* removal efficiency, which is not to be confused with *particle* removal efficiencies. The removal efficiencies listed in ASHRAE Standard 52.2-2017(67) cannot be directly used in this equation, since they are based on particle count and not mass.

**Table 1** - $PM_{2.5}$ Removal Efficiency (Ef) for Various MERV Rated Filters.

| MERV | $PM_{2.5}$ Removal Efficiency (3) |
|---|---|
| 5 | 1.4% |
| 6 | 7.2% |
| 7 (#1) | 7.6% |
| 7 (#2) | 24.1% |
| 8 | 27.1% |
| 10 | 31.5% |
| 11 | 48.95% (1) |
| 12 (#1) | 27.2% |
| 12(#2) | 66.4% |
| 13 | 68.9% (2) |
| 14 | 71.4% |
| 16 | 96.3% |
| HEPA | 99.7% |

Table Note 1: Removal efficiency for MERV-11 has been extrapolated from MERV-10 and MERV-12 (high value)
Table Note 2: Removal efficiency for MERV 13 has been extrapolated from MERV-12 (high value) and MERV-14
Table Note 3: As stated in the reference(648), "Knowledge of MERV alone cannot always be used to predict UFP (Ultra Fine Particles) or $PM_{2.5}$ removal efficiency, as different makes and models can have very different UFP and $PM_{2.5}$ removal efficiencies depending on their actual size-resolved removal efficiencies." For this reason, removal efficiencies have been reported for multiple filter manufacturers having the same MERV. Users are encouraged to obtain removal efficiency values from the manufacturer whose filters they intend to use.

*Example:*

*During a wildfire, the $PM_{2.5}$ outdoor concentrations reached 300 µg/$m^3$. A building has an HVAC system with MERV-16 and the below characteristics. What will be the indoor $PM_{2.5}$ concentration?*

*HVAC System Characteristics*

| | *SI Units* | | *Imperial Units* | |
|---|---|---|---|---|
| *Voz* | *1000* | *$m^3$/h* | *588* | *Cfm* |
| *Co* | *300* | *µg/$m^3$* | *300* | *µg/$m^3$* |
| *R* | *0.8* | *(unitless)* | *0.8* | *(unitless)* |
| *Vr* | *5000* | *$m^3$/h* | *2940* | *Cfm* |
| *Ef* | *96.3* | *% removal* | *96.3* | *% removal* |
| *Vif* | *500* | *$m^3$/h* | *294* | *Cfm* |
| *Fr* | *0.6* | *(unitless)* | *0.6* | *(unitless)* |
| | | | | |
| *Cz* | *48.7* | | *48.7* | |

*Calculations and result (SI Units)*
*Cz = (500 x 300 + 1000 x (1-0.9) x 300) / (1000+0.6 x 0.8 x 5000 x 0.9)*
*Cz = 48.6 µg/$m^3$*

*Note: it is not necessary to convert µg/$m^3$ to µg/$ft^3$ while using imperial units.*

### 5.4.2 Estimation of infiltration

Use the ASHRAE Handbook Fundamentals Chapter 16[(69)] estimates of infiltration for commercial construction. These are:

0.6 cfm/$ft^2$ at 75 Pascals for leaky buildings

0.3 cfm/$ft^2$ at 75 Pascals for average buildings

0.1 cfm/$ft^2$ at 75 Pascals for tight buildings

Adjust these factors based on conditions at the site. See Section 4.8 of this document and Section 7 of the aforementioned chapter for more details on infiltration values in commercial buildings.

### 5.4.3 Filter loading calculation

In order to evaluate loading of a filter, using the PM removal efficiency values from ASHRAE Standard 52.2-2017, one would need to know the particle size, distribution, and mass in the incoming air.

Several points should be considered:

- Particle number concentration is the total number of particles per unit volume of air (for example particles/$cm^3$), whereas particle mass concentration is the total mass of particles per unit volume (for example μg/$m^3$). Mass concentrations are typically dominated by larger particles.
- Any mass shown as $PM_1$ is a subset of both $PM_{2.5}$ and $PM_{10}$ concentrations. Likewise, any mass shown as $PM_{2.5}$ is a subset of $PM_{10}$. Note: $PM_1$ is not an EPA defined value, but it is widely used to refer to particles less than or equal to 1 micron in aerodynamic diameter.
- Particles of different size ranges can have very different loading characteristics and methods.
- PM concentrations are generally reported as mass (e.g., μg/$m^3$) or particle number (e.g., particles/$m^3$).
- $PM_1$ particle number concentrations will typically be very high in high concentrations of smoke (i.e., large numbers, but very little mass). However, these particles can clog a filter very quickly if the media used in that filter does not load in depth allowing particles to penetrate deep into the media before capture. Most charged media products exemplify this expected result and can load very quickly with large concentrations of $PM_1$ particulate.

The chemistry and makeup of the particulate affects filter loading. If the particulate is dry and not "sticky" it will not readily agglomerate into larger particulate which will allow the filter to last longer in service. However, a slightly damp or "sticky" particulate is easier to catch, resulting in filters that reach final loading more quickly.

The protocol for loading a filter is defined in ASHRAE Standard 52.2-2017 resulting in a measurement of Dust Holding Capacity (DHC). The procedure involves loading the ASHRAE dust at a given rate into the filter while monitoring the resistance to airflow. When the final resistance is met, the test is stopped and DHC is calculated. The dust used is a mix of ISO fine, carbon black, and cotton linters. The ISO fine has a mean particle size of approximately 8 µm ($PM_{10}$ particles), but when combined with the "sticky" carbon black, the particles can agglomerate to much larger than 8 µm. This means ASHRAE Standard 52.2-2017 DHC is a mass loading from a particle size distribution that is very different from real life applications and especially under wildland fire smoke conditions. Thus, it is not unusual for a filter that holds 200 g of ASHRAE dust in the Standard 52.2-2017 test to hold several times more dust in "real life" to the same increase in resistance to airflow. However, if that same filter is subjected to a different outside air (OA) concentration/makeup, it might only hold 100 g until reaching the final resistance.

It is very difficult to predict how a filter will perform under wildland fire smoke conditions because of a number of variables involved in the problem including:

- accurate and complete testing information on the filters in the system
- accurate PM mass concentrations for particle size (PM 1, 2.5, and 10)
- knowledge of the particulate composition
- knowledge of the airflow rate
- knowledge of how the filter might load with different types of aerosol
- the amount of airflow bypassing the filter

If this information is not readily available, some assumptions can be made. Below is an example of how to calculate filter loading.

*Example*
*Assumptions:*
*$PM_{1}v$ = 65% of total mass*

*Efficiency performance (Typical for a MERV 14 filter with no electrostatic charge)*
*$ePM_1$ = 64%, $ePM_{2.5}$ = 77%, $ePM_{10}$ = 93%*
*Particulate is reasonably dry and not overly adhesive*
*Filter loads with depth loading and does not tend to mask off or face load*
*Filter will hold 2x the DHC of a ASHRAE 52.2 test*
*ASHRAE 52.2 DHC = 375g*
*Filter Flow rate 3400 $m^3$/hr (2000 cfm)*
*No airflow bypassed around the filter*
*Filter operation 24 hr/day, 7 days/wk*

*Mass capture rate (µg/min) = [($ePM_1$ * ($PM_1v$ * 200 µg/$m^3$) + ($ePM_{2.5}$ * 150 µg/$m^3$) + ($ePM_{10}$ * 200 µg/$m^3$)] * Filter Flow in $m^3$/hr / 60 min/hr*
*Mass capture rate = 8,222 µg/min = 0.008222 g/min*
*Filter Life = 0.008222 g/min * (375g * 2) = 1,520 hrs or 63 days*

Given the scarcity of information on actual filter mass removal efficiency, more research is encouraged.

## 5.5 Design measures

### 5.5.1 Monitoring

#### 5.5.1.1 $PM_{2.5}$ Sensors and Monitors

During a smoke event, $PM_{2.5}$ should be directly monitored. If permanent $PM_{2.5}$ sensors are not installed, use handheld monitors. Select $PM_{2.5}$ monitors with data logging capabilities, where possible. Not all monitors include on-board data logging, but data logging is widely available. Non-event $PM_{2.5}$ concentrations will establish a baseline $PM_{2.5}$ which will be used during smoke events (see Section 6.4.3).

For new designs and retrofits, consider permanent $PM_{2.5}$ monitors. Where building automation systems BASs are present, connect the $PM_{2.5}$ meters to the BAS to continuously monitor $PM_{2.5}$. Having $PM_{2.5}$ concentrations shown on the BAS user interface allows real-time management during an event.

This guideline is not recommending specific monitors or sensors for measuring $PM_{2.5}$. This technology is developing rapidly, with many new products or new versions regularly entering the market as noted in Section 4.10. In selecting a $PM_{2.5}$ sensor, the following resources may be useful:

- Testing and certification of sensors for $PM_{2.5}$ and other pollutants in commercial buildings, see RESET (70)
- Research evaluations involving laboratory or field studies, primarily focusing on outdoor pollutant measurements
  - South Coast Air Quality Management District Air Quality Sensor Performance Evaluation Center (71)
  - US Environmental Protection Agency Air Sensor Toolbox (72)
- Evaluation of PM sensors used indoors by researchers at Lawrence Berkeley National Laboratory (73)

#### 5.5.1.2 Considerations for Sensor Placement

Place sensors in the following locations:

- Occupied areas of the building: Place sensors in key locations in a building, such as those with most common occupancy, highest occupancy, or occupied by at-risk populations (See Section 4.6).
- Entryways: Placing a sensor in a hallway and corridor near a building entrance will help assess the smoke ingress in the buildings.
- Outside: Place sensors at secure outdoor locations to capture outdoor air concentrations in proximity to the building.

In lieu of outdoor sensors, data can be obtained online from an adjacent regional monitor. While a single system is more practical to operate, this may be a cost saving measure. For example, AirNow is a centralized data system that includes current and forecast U.S. air quality maps and data for more than 500 cities . AirNow's Fire and Smoke Map(74) includes current PM air quality information from regulatory-grade monitors and low-cost sensors.

Place sensors at a height representative of the occupants in the building. Take into consideration standing vs. seating positions or a mix. Sensors should be placed according to their manufacturer's instructions, in easily accessible locations, protected from tampering, and away from indoor sources such as cooking areas, printing, or other activities which produce $PM_{2.5}$. Sensors can be sensitive to swings in temperature and humidity; place them at some distance from supply registers.

Additionally, recommendations about how to site indoor sensors are provided by EPA's Air Sensor Toolbox; see Indoor Sampling Considerations.(75) The EPA Enhanced Air Sensor Guidebook also provides guidance on the selection and use of air sensors.(76)

#### 5.5.1.3 Building Pressure Sensors

Use differential pressure sensors to measure the pressure difference between the building interior and the outdoor air. Install sensors in such a manner as to protect the equipment from weather events and wind effects. In systems where no BAS exists, the pressure should be monitored in the control room or mechanical room.

#### 5.5.1.4 Building Smoke Detection Systems

Some smoke detection systems required by code are very sensitive to particle concentrations and can activate during a wildland fire smoke event from indoor particle concentrations caused by infiltration.

For buildings located in areas prone to wildland fire smoke events, this factor should be taken into consideration. The selection of a smoke detection system for structural fires should be selected based on the needs of the space.

Duct smoke detectors are typically either photoelectric or ionization type, both of which need smoke to trigger an alarm. Photoelectric detectors are generally considered less sensitive and need visible smoke to obscure the light source and trigger an alarm. It is unlikely that the amount of smoke that makes it through the filters would be enough to trigger a photoelectric sensor. If it was and the AHU remained operational, then the building would not be habitable after a short period of time.

Typically, commercial projects use dual detection – ionization and photoelectric for enhanced safety. Ionization detectors are more sensitive to air contaminants. Any air contaminant that will attract free electrons in the sensor will interrupt the flow of current and trigger an alarm.

When considering smoke detection, photoelectric sensors are recommended in areas where air handlers would need to be configured to handle OA during wildland fires.

### 5.5.2 Building Controls

#### 5.5.2.1 Building Control System

Manual control methods may be a cost-effective solution where smoke events are infrequent. For buildings in high-risk areas, with BAS systems, add specific smoke-limiting logic for wildland fire events to automatically reduce ventilation (outdoor air) rates. Smoke-limiting controls can be fully automated, manual, or a combination of both.

Include the following control actions:

a. Ventilation shutdown or reduction of airflow:
   1. Closure or reduction of airflow of outdoor air dampers for all systems equipped with automatic modulating control of the outdoor air dampers.
   2. Shutdown or reduction of airflow from outdoor air fans, Heat Recovery Ventilators (HRVs) and Dedicated Outdoor Air Systems (DOAS), and other systems that provide outdoor air ventilation.
   3. Shutdown or reduction of airflow for all exhaust systems to maintain a positive building pressure.

b. Economizer and Demand Control Ventilation (DCV) shutdown:
   1. Disable economizer function such that systems operate at minimum outdoor airflow.
   2. Disable the DCV function such that systems operate at minimum outdoor airflow.
   3. Use DCV associated $CO_2$ sensors to monitor IAQ. Reset the $CO_2$ setpoint up from its normal setting.
   4. Refer to Informative Appendix D Managing Air-Side Economizer and Demand Control Ventilation for Smoke

c. Increased indoor air filtration
   1. Where applicable, increase supply fan run times to include both occupied and unoccupied periods.

d. Manual control of wildfire smoke control logic
   1. Provide a one-button initiation with a timer-based reset to automatically restore normal operation after a user-adjustable period.
   2. Provide a screen or user interface with all relevant control points required to control and monitor HVAC operation during smoke events.

e. Automated control of wildfire smoke control logic
   1. Provide OA $PM_{2.5}$ sensor(s) with adjustable setpoints for initiation and return to normal operation.
   2. If a public $PM_{2.5}$ monitor is near the building, consider options for using these data to inform control inputs for initiation and return to normal operation.

Smoke-limiting controls could result in poorer IAQ from other contaminants than wildland fire smoke and increased energy usage. Systems should not be operated in a wildland fire smoke mode unless it is required.

Particularly, it is essential to ensure $CO_2$ does not build up beyond acceptable levels. This can occur if the outdoor airflow is reduced. $CO_2$ build up is more likely in areas where the occupancy includes physically active tasks, or in assembly areas. Some of those spaces may have $CO_2$ sensors which should be used as part of the smoke-limiting control sequence.

#### 5.5.2.2 Building Pressure

Design ventilation systems for a net exfiltration, including under all dynamic reset conditions (See ASHRAE 62.1-2022, Section 5.17). It is recommended to operate a building at +5 pa nominally as compared to the exterior of the building. Alternatively, balance the OA airflow to 10% greater than the exhaust airflow.

#### 5.5.2.3 Zonal Pressure Monitoring and Control

Smoke migration inside the building can be mitigated by establishing interzonal pressure differences. If a zone is provided with pressure control capabilities (e.g., a matching pair of supply and return air boxes), these can be used to monitor and control the pressure to mitigate the infiltration of wildland fire smoke.

Zone pressure control strategies include the following:

1. Make vestibules, lobbies, or entry spaces negative with respect to the rest of the building.
2. Make the inner zones positive with respect to the entryways and circulation spaces.
3. Protect sensitive areas in a building with positively pressurized zones.

Controlling interzonal pressure requires additional construction detailing.

1. Separation walls should be built from floor to structure.
2. All penetrations in the separation wall should be sealed. For retrofits of existing buildings, a survey should be completed to make sure penetrations through inter-zone separation walls and or the building envelope are properly sealed.
3. Pressurized zones should not share the same return air plenums or any common open spaces.
4. Pressurized zones typically require a ducted return air system.

In buildings where interzonal pressure difference is used to control smoke migration, pressure sensors should be used to monitor the pressure difference between zones.

### 5.5.3 Envelope Tightening

#### 5.5.3.1 Building Egress and Entrance Points

Entrance and exit points in a building are the most vulnerable to infiltration of smoke. The ideal designs will include features to prevent smoke ingress in all modes of operation (open and closed) such as:

- Vestibules – Where possible, a vestibule should be used on all building entrances used on a frequent basis. This structure allows for an extra barrier between the outside and inside of the building. The timing of automatic doors should be adjustable to allow for a staged entry program (only allowing 1 set of doors to be open at a time). This may not be ideal for occupant entrance but will reduce the chances of smoke entering the building during entry and egress. The vestibule space should allow for additional filtration or a high rate of air exchange to ensure any smoke that enters can be diluted or filtered rapidly. Alternatively, the vestibule could also allow for a portable air cleaner (PAC) to be used during peak smoke events, including having available power and/or space designed to accommodate the installation and use of a PAC.

- Dedicated entryway (lobby, reception area) – Where feasible, it is preferred to have a separate space dedicated for those entering the building. This area would have a physical separation from the main occupied areas of the building and should be designed to allow for a higher rate of air exchange and/or built-in air circulation/filtration systems. Where a dedicated receiving or entry area is not possible, doors should be designed and selected to operate under higher differential pressure. In these cases, the best way to reduce infiltration of smoke during door use is that the interior pressure is at least 5 pa above the outdoor pressure to reduce air infiltration during door use. See the cascading pressure description in Section 5.5.2.3.

- Note that for entry spaces (whether vestibule or entryway), simply disabling the economizer control function may not fully address pressure control, depending upon the logic used to maintain stable pressure in these areas during the normal switch over between economizer and non-economizer operation. In cases where special measures are taken to smooth or maintain relatively constant pressure relationships in vestibules or entryways as a system goes in and out of economizer mode, the control logic used for these actions must be examined to ensure that the disabling of economizer operation will not render the pressure control logic ineffective.

- Exterior features – Where possible, doors should be located in areas protected from the impact of wind pressure. Doors should not be placed facing the primary prevailing wind direction. Adding windbreaks is ideal such as landscaping/vegetation or engineered barriers.

- Air curtains – Air curtains are dedicated air streams meant to create a wall of air that occupants must pass through to enter the space. If vestibules are employed, an air curtain can be used as a means to increase air exchange rate, prevent outdoor smoke from entering, and reduce contaminant transfer from occupant clothing.

Doors of all types and uses should allow for a complete seal when closed. Some doors are not designed to operate under these conditions and may not seal properly when closed, such as sliding doors.

#### 5.5.3.2 Other Tightness Measures

The building envelope contains numerous penetrations for various purposes: plumbing, vents, exterior lighting, and exterior power outlets and security equipment are a few typical examples.

These penetrations are designed to be weatherproof; however, as noted above, smoke contaminants behave like gases and can infiltrate seals designed for water resistance /weatherproofing. Extra air sealing may be required to make those penetrations airtight.

A typical building practice is to seal any penetrations to exterior finishes which may not prevent smoke infiltration. It is recommended, where possible, to seal any penetrations directly to the building envelope air barrier.

Ducts located outside the building air barrier and under negative pressure where air is recirculated to the building should meet ASHRAE Standard 90.1-2022(77) Section 6.4.4.2 or an equivalent local duct leakage standard.

Dampers located outside the building air barrier should have a maximum leakage rate as indicated in ASHRAE Standard 90.1-2022 Section 6.4.3.4.3 when tested in accordance with AMCA Standard 500-D(78) or an equivalent local damper leakage standard.

### 5.5.4 Filters

The purpose of this section is to ensure that an adequate filtration level exists to protect building occupants from $PM_{2.5}$ present in wildland fire smoke. Depending on the design of the HVAC system, specific actions may involve outdoor air filters and/or recirculation filtration. It is advisable to request from the supplier, independent lab data to confirm filter performance expectations prior to purchasing or installing filters.

#### 5.5.4.1 Filters in New Construction

Designers are encouraged to use the removal need calculations outlined in Section 5.4.1 to determine the appropriate filter MERV rating. However, if calculations cannot be performed, the minimum filter efficiency for removing PM generated by a wildland fire event is MERV 13 where rated in accordance with ASHRAE Standard 52.2-2017, or not less than ePM1-50% where rated in accordance with ISO 16890[(79)]. The air handling unit (AHU)/HVAC equipment in new construction should be designed with a minimum of MERV 13 or ePM1-50% filters to filter both OA and recirculated air. The filter mounting system should include a gasket mounting surface and clips to hold the filter firmly on the gasket.

For new systems designed for a filter efficiency less than MERV 13 or less than ePM1-50%, it is recommended to design the system to accept a MERV 13 or ePM1-50% filter in the case of a wildland fire smoke event. This procedure is accomplished by making sure all new HVAC equipment is equipped with a filter rack sufficient to house a MERV 13 or ePM1-50% filter or better. The filter housing should be built in such a fashion as to hold a MERV 13 filter for the design airflow of the system. A pre-filter (MERV 8 or better) can extend the MERV 13 filter life and is most likely to be cost-effective for MERV 14 and higher rated filters (see ASHRAE Indoor Air Quality Guide,[(80)] Strategy 7.5). In this case, the system may be operated with a lower MERV rating filter during "normal" outdoor air conditions yet allow the use of a MERV 13 to be installed prior to the wildfire season or as part of the Smoke Readiness Plan. Note that smaller HVAC equipment such as small rooftop packaged units and ductless units may not have this feature. In this case, it is recommended to have the OA pass through a MERV 13 filter.

A low-pressure HEPA filter (greater than MERV 16) should be considered for buildings with at-risk populations (see Section 4.6), or if the building experiences frequent wildland fire smoke episodes.

The filter system should include equipment capable of continuous monitoring of the pressure drop across all filter housings.

Filtration capacity will vary depending on the concentration of smoke during any given event. During severe smoke events, filters will load rapidly, which will impact the system flow and possibly reduce overall air supply to the building. Detailed operational instructions should be developed to specify the pressure drop range and when to change filters. See Section 5.4.3 for calculations procedures to estimate filter loading time.

#### 5.5.4.2 Filters in Retrofits

Designers are encouraged to use the removal need calculations outlined in Section 5.4.1 to determine the appropriate filter MERV rating. However, if calculations cannot be performed, the minimum filter efficiency for removing PM generated by a wildland fire event is MERV 13 where rated in accordance with ASHRAE Standard 52.2-2017, or not less than ePM1-50% where rated in accordance with ISO 16890. The AHU/HVAC system in retrofits of existing buildings should be modified as practicable to accept a minimum of MERV 13 or ePM1-50% filters. A low-pressure HEPA filter should be considered if the building occupants have respiratory or heart disease conditions, or if the building experiences frequent wildland fire episodes.

Before upgrading the filter efficiency, the existing filter housing should be checked to to verify it can accept a MERV 13 or ePM1-50% filter, and the pressure drop rating for the new filter should not exceed the AHU design pressure drop. If a suitable MERV 13 or ePM1-50% filter cannot be matched to the system, consider the use of the highest MERV rating that the system can accept. Lower airflow is expected in these situations, but if the system has some reserve capacity, there may be minimal impact on the system's total air flow. If total airflow is reduced below the designed specification, the occupancy of the impacted areas should be reviewed.

Filters with a MERV rating lower than 11 are not effective to remove $PM_{2.5}$. In these cases, increasing interior filtration and circulation systems is recommended. See Section 5.5.5.

#### 5.5.4.3 Fan Sizing for Filter Loading

When designing a new fan system, the following measures are recommended to account for MERV 13 or ePM1-50% filters:

- Supply fans should be sized to ensure they can provide the design airflow through a loaded MERV 13 filter.
- The fans' operating point at the design airflow and the required total static pressure plus the pressure drop from a dirty MERV 13 filter should not be in the fan surge or 'do not select 'zone.
- The fan motor horsepower rating should be selected to handle the brake horsepower increase due to the added pressure drop from a dirty MERV 13 filter.
- The fans' motor starters or variable frequency drives (VFDs) should be selected so their rated current (amperage) is not below the required current (amperage) draw to handle the added pressure drop from a dirty MERV 13 filter at design airflow.
- With oversized fans and motors to account for the pressure drop of dirty MERV 13 filters, the designers should check if during normal operation the fans can still satisfactorily throttle down to the design minimum airflow (or as required by the energy code).

#### 5.5.4.4 All-water and Variable Refrigerant Flow (VRF) Systems

All-water and VRF systems are generally characterized by zone level units coupled with a Dedicated Outdoor Air System (DOAS). The zoned levels could be purely non-air base (like radiant panels) or have some recirculating air movement (like chilled beams, VRF indoor units, water-based fan coil units).

These systems present a challenge in filtering the air from wildland fire smoke contaminants in two aspects:

1. Some of them (like radiant panels) have no air movement at all except for the air for the DOAS which is minimal.
2. Many VRF indoor units cannot accept a MERV 13 filter, and some systems are not designed to accept any filter at all (like chilled beams).

For these systems, the following is recommended:

- Ensure the DOAS system is designed to use minimum MERV 13 filter, and ideally has a pre-filter rack or other means available to add lower efficiency pre-filters during smoke events to extend the operation of the MERV 13 filters.
- Consider using indoor PACs during wildland fire events.

#### 5.5.5 Portable Air Cleaners

PACs are most effective when airflow is unrestricted by furniture or architectural features. From a design perspective, spaces that may use PACs should be identified early in the design discussions and include the following aspects:

- Power outlets – ensure sufficient, ideally dedicated, power outlets for PACs. Consider emergency power outlets for special building occupancy types (see Section 5.7).
- No obstruction – interior layout of the space should allow for PAC placement such that desks or other furniture will not obstruct airflow from a PAC.
- Supply chain or storage – A source of PACs should be identified. If PACs will be purchased and stored on site, storage space should be planned.
    a. Replacement filters for the PACs should be kept on hand as well.

See Section 6.2.2.3 for additional information.

#### 5.5.6 Hybrid/Naturally Ventilated Buildings

In general, the design measures presented in this section apply to mechanically ventilated buildings. Buildings implementing a hybrid ventilation system (a system having a natural ventilation component with a mechanical ventilation backup system) should disable the natural ventilation component and solely rely on the mechanical ventilation backup system with appropriate filtration as described in this guideline during smoke events.

It is not recommended to design a building to use a solely natural ventilation system in areas prone to frequent wildland fires. Consider a hybrid system instead.

### 5.6 Commissioning

Any control system with a wildland fire-response design should be commissioned in the smoke-response or smoke limiting state. This will include any system from Section 5.5 of this guideline, which may include but is not limited to:

- Monitoring of $PM_{2.5}$
- Fan operation with any additional filtration
- Outdoor air damper diminishment or closure and return to normal operation
- Building and zone pressurization in all operational modes
- Economizer and DCV disable/enable control sequences

The commissioning steps noted below are specific to confirm intended building system operations for new builds and retrofits as they pertain to smoke mitigation strategies. The overall goal of these specific commissioning steps is to confirm the operational parameters needed to operate the building in a smoke readiness mode and develop specific protocols needed to convert the building to the smoke readiness mode and return it to its standard operating mode. In addition, it is recommended to perform building envelope commissioning described in Section 5.6.2 to ensure its air tightness.

### 5.6.1 Filter Challenge Testing (system filters)

At present, there are no established industry standards for on-site testing of particle removal efficiency in permanently installed HVAC equipment. There are established laboratory testing methods for air filters. There are also methods for testing of clean room filter panels. However, for the most common systems, there are no established methods for demonstrating filter/system effectiveness. The authors of this guideline recognize this issue as a need for future development. Particle removal effectiveness of installed filters as part of an HVAC system is a vital component of wildland fire management design, which should be supported by a field validation protocol.

### 5.6.2 Envelope Commissioning

Consider performing a full envelope commissioning for new buildings to ensure envelope tightness. The requirement for envelope commissioning should be included in the construction documents with special attention to the air barrier. As part of the envelope commissioning, the whole building and building elements should be tested per:

- ASTM E779-2019 - Standard Test Method for Determining Air Leakage Rate by Fan Pressurization(81)
- ASTM E3158-2018 – Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building(82)
- ASTM E283-2019 - Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors(93)
- ASTM E1186-2022 -Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems(84)

## 5.7 Special Building Occupancy Types

### 5.7.1 Healthcare Facilities

The following special points should be considered when analyzing wildland fire smoke mitigation measures for healthcare facilities:

- Hospitals may contain clean rooms (e.g., compounding pharmacies) or other spaces with enhanced filtration and airflows (e.g., operating and invasive procedure rooms, protective environments). Smoke could rapidly load the filters in these areas.
- Most hospitals are constructed with two-pass filtration, often containing a MERV 14 or MERV 16 as the final filter. Additionally, minimum ventilation rates in hospitals are high. As such, the removal capabilities of hospital HVAC systems are much higher than other building types. For smaller or less severe fire events, improvements will be unnecessary.
- Building and space level pressurization. Most, if not all, building codes require some spaces in healthcare facilities to maintain a certain pressure (positive or negative) with respect to adjoining spaces in order to help with infection control. Any modification to the buildings' OA or even the supply air to certain areas inside such healthcare facilities should be carefully reviewed with the facility infection control team. It is also recommended to include the impact of such changes in the Infection Control Risk Assessment (ICRA) report. Particular attention should be paid to the following areas:
    - Operating room suites, a location with persons undergoing invasive procedures, are much more susceptible to infectious agents.

    - Nurseries and pediatric care, an area occupied by the most at-risk patients, have newborns and infants who have not had the opportunity to develop the body's natural protection systems with regard to airborne contaminants. Many newborns spend their first days in an incubator that includes the highest level of contaminant protection, a HEPA filter.
    - Patient waiting and out-patient care areas, the typical first stop of those suffering from a variety of illnesses. These areas generally have the largest number of doors to the outside and hence are the most prone to smoke intrusion.
- Continuous operation under even severe wildland fire smoke. Hospital emergency departments near the fire must remain operational to treat firefighters and affected community residents. To deal with smoke risks, hospitals in fire-prone areas may be able to isolate emergency department ventilation systems and enable recirculated air during emergency conditions. In addition, portable air scrubbers or HEPA filters can be placed in various units to capture smoke, fumes, and airborne particles if outdoor ventilation systems must be shut down.
- Non-HVAC filters. In addition to HVAC equipment, healthcare facilities are encouraged to have adequate filtration on all outdoor air intakes to any equipment during wildland fires. A typical example is to make sure there is a HEPA filter on the medical air compressor intake and make sure it is changed frequently during a wildland fire event. Also, filters installed on medical equipment (e.g., the filter on a NICU incubator) may load up faster during a wildland fire event even if the equipment is indoors. The healthcare facility is encouraged to have a full inventory of filters in the facility (for HVAC and non-HVAC equipment) with a spare stock before the wildfire season starts. Continuous checking of the cleanliness of all filters on all equipment should be added to any smoke mitigation plan.
- 100% OA systems. Some hospitals are designed with 100% OA systems with which it will be challenging to mitigate the intake of large quantities of wildland fire smoke. The design team should consider adding bypass dampers on the HVAC system to allow the system to temporarily recirculate some air as long as infection control is not compromised.
- The deployment of PACs in healthcare facilities should be reviewed with the facility infection control team. Given the large areas in hospitals, the airflow from PACs may become large enough to compromise infection control. Placement of the unit(s) is critical.
- Hospitals should also pay special attention to the entryways, ambulance bays, and loading docks (See Section 6.2.7) because these areas may be large sources for smoke infiltration.[55]

### 5.7.2 Prison/Detention Centers

The following special points should be considered when analyzing wildland fire smoke mitigation measures for prisons/detention centers:

- Inability of residents to leave or evacuate at will. Prisons and detention centers are generally very difficult to evacuate and hence the smoke mitigation plan should consider a "shelter in place" strategy by considering higher efficiency filters, PACs, and pressure cascading to mitigate smoke infiltration as much as possible.

### 5.7.3 Applications

Table 2 includes a matrix representing a high-level assessment of the ease of incorporating the specific measures included in this section for various types of HVAC systems using a score from 1 to 3 as follows:

1. Easy to implement
2. Moderately difficult to implement

3. Hard to implement

**Table 2 - Application of measures to mitigate wildfire smoke**

| Measure / System | Large chilled water AHUs with supply VAVs | Large chilled water AHUs with supply VAV's <u>and</u> return airflow control | Large rooftop package units | Small roof top packed units | Radiant Systems with DOAS | Chilled Beams with DOAS | Ducted VRF with DOAS | Ductless VRF with DOAS |
|---|---|---|---|---|---|---|---|---|
| Add $PM_{2.5}$ sensors | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Add building pressure sensors | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Reduce / Shut-down OA | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| Disable economizers and/or DCV | 1 | 1 | 2 | 2 | N/A | N/A | N/A | N/A |
| Maintain positive pressure between building and outside | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Maintain positive pressure across zones inside building | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 |
| Vestibules/Entryways | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Add air curtains | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Tighten duct and dampers after leak test | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 |
| MERV 13 filters on recirculating and OA air | 1 | 1 | 1 | 2 | 3 | 3 | 2 | 3 |
| MERV 13 filters on OA air only | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| Fan sizing for filter loading | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 2 |
| Add Portable Air Cleaners (PACs) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

### 5.8 Communication of the Smoke-Readiness Plan to the Design and Operation Team

Communicate the building design elements of the Smoke Readiness Plan to both the building design team and the Operation and Maintenance (O&M) staff. In order to achieve the communication of the Smoke Readiness Plan, the below is recommended:

- For new designs, include the goals of the Smoke Readiness Plan (Section 6.1) in the Owner Project Requirements (OPRs).
- In the OPRs, clearly identify whether the building can or cannot be evacuated during a wildland fire event.
- Make sure the smoke mitigation goals of the OPRs are included in the project Basis of Design (BOD).
- Make sure the smoke mitigation measures in the BOD are implemented in the design. In particular, make sure the HVAC Sequence of Operations include a wildland fire smoke mode. In the event that unitary equipment is used, detail the procedure by which economizer operation will be circumvented to produce the smoke mode of operation.
- Make sure the wildland fire smoke mode is included in the commissioning scope and tested accordingly.
- Make sure the wildland fire smoke mode is included on the HVAC control interface for ease of reference to building operators.
- Make sure a hard copy of the Sequence of Operation is posted in each mechanical room or on each unit/system.
- Make sure there is a safe and convenient filter maintenance access. This includes a nearby filter storage area, hinged filter access doors, and adequate equipment clearance for filter replacement.

## 6 OPERATION DURING A WILDLAND FIRE EVENT

Facility managers should prepare for wildland fire smoke events in advance. It is important to realize that this planning and testing process will take considerable time and effort.

Any HVAC maintenance problems should be identified well in advance of wildfire season. Timely inspections will ensure that repairs can be made, and the system can be tested in the operating mode that will be implemented under smoke conditions.

This section provides guidance on:

- Elements to include in a Smoke Readiness Plan,
- Preparation and testing for smoke-ready operations,
- Operations and monitoring during a smoke event, and
- Returning to normal operations.

### 6.1 Developing a Smoke Readiness Plan

A Smoke Readiness Plan documents the preparatory steps and mitigation strategies that the facility will use before, during, and after a wildland fire smoke event to maintain indoor air quality (IAQ). Sections 6.2, 6.3, 6.4, and 6.5 provide guidance on elements to consider in a Smoke Readiness Plan. Each building and plan are specific to the type of building, the HVAC system, and the expected environmental condition.

The design and commissioning documentation discussed in Section 5 should include specific design elements for a wildland fire smoke event. This information should inform the Smoke Readiness Plan. The Smoke Readiness Plan will describe which control measures will be used and how they will be initiated.

In addition to the substantive actions, the development of the plan should also include:

- Specific building design elements for controlling smoke, when available;
- Roles and responsibilities of staff responsible for implementing the plan;
- Expected costs associated with implementing the plan so that any necessary approvals can be obtained beforehand; and
- Updates as lessons are learned with each smoke event.

**Table 3** Illustrates major elements that should be considered for inclusion in a Smoke Readiness Plan and indicates the sections and checklists or tables that can assist in the planning process.

**Table 3 - Elements to Consider in the Smoke-Readiness Plan**

| Preparing for Wildland Fire Smoke | |
|---|---|
| **Example Questions to Address in Planning Phase** | **Guidance in this Document** |
| What are any specific building design elements for controlling smoke? | Sec 5.5 Design Measures<br>Sec. 5.9 Communication of the Smoke Readiness Plan to the Design and Operation Team |
| Is the HVAC system in need of maintenance and repair? | Sec. 6.2.1 Mechanical Ventilation and Checklist 1 |
| Are the needed supplies on hand (including HVAC filters, personal protective equipment, portable air cleaners, etc.)? Where are they stored? | Sec. 6.2.2 Air Cleaning<br>Sec. 6.2.7 Administrative Controls |
| Do building automation systems display the controls and settings that will need to be adjusted for smoke? | Sec 5.5.1 Monitoring<br>Sec 5.5.2 Building 35controls<br>Sec. 6.2.3 Building Automation System, |
| Have the gaps in the building envelope been sealed? | Sec 5.5.3 Envelope Tightening<br>Sec. 6.2.4 Building Envelope |
| Do dedicated cleaner air spaces with portable air cleaners need to be set up? | Sec. 6.2.2 Air Cleaning<br>Sec. 6.2.5 Dedicated Cleaner Air Spaces |
| Are there concerns about maintaining space conditioning or reducing odors? | Sec. 6.2.6 Maintaining Space Conditioning and Reducing Odors |
| Can indoor sources of air pollutants be identified and either reduced or eliminated? | Sec. 6.2.7 Administrative Controls |
| Can smoke entry into the building be reduced by limiting use of certain entrances/exits? | Sec. 6.2.7 Administrative Controls |
| Are indoor $PM_{2.5}$ monitors available? What are the baseline $PM_{2.5}$ concentrations? | Sec 5.5.1 Monitoring<br>Sec 6.2.8 Indoor and Outdoor $PM_{2.5}$ Monitoring |
| Are there special circumstances to address? | Sec. 6.2.9 Special Considerations for Healthcare Facilities, Schools, and Other Institutions |
| What are the criteria for implementing the plan? | Sec. 6.4.1 When to Implement the Smoke-Readiness Plan |

| **Operational Testing** | **Implementing the Plan** | **Returning to Normal Operations** |
|---|---|---|
| Test any specific building smoke control measures | Take the steps in the plan.<br>Sec 6.4.2, Checklist 2 | Return HVAC to normal settings.<br>Sec. 6.5, Checklist 3 |
| Test outside air damper settings that may be used to limit smoke entry. Be sure that positive building pressure is maintained.<br>Sec. 6.2.1 | Take the steps in the plan.<br>Sec 6.4.2, Checklist 2 | Return HVAC to normal settings.<br>Sec. 6.5, Checklist 3 |
| Check that indoor $PM_{2.5}$ monitors are working<br>Sec. 6.2.8 | Check indoor $PM_{2.5}$ monitors to see if mitigation measures are working, make any adjustments.<br>Sec 6.4.3 | Clean indoor surfaces.<br>Sec. 6.2.7 |

Advanced planning for smoke events is critical for building operators, and some measures can be challenging or impossible to implement once smoke has already arrived. Many aspects of planning and implementation are complex. Professionals who can assist developing and implementing the plan include:

- HVAC service contractor
- Test, Adjust, and Balance (TAB) contractor
- Commissioning provider
- Controls contractor
- HVAC design professional

The building operator needs a complete understanding of the existing equipment and operating conditions. Resources for that understanding include:

- Observations
- Controls diagram
- Record drawings
- TAB Report
- Commissioning report

**Figure 3. Picture of a warped damper blade unable to close.**

Use **Checklist 1** to determine if the HVAC system is ready for smoke. For all components of the Smoke Readiness Plan, maintaining good documentation is recommended, as the personnel who carry out the actions to manage a smoke event may not be the same people who recommission the system afterwards. Detailed notes, checklists, and photos documenting any changes to the HVAC system(s) are essential**.** The Smoke Readiness Plan should also include documentation of original control settings (e.g., switches, damper positions, and control relays). Use notations, permanent markers on equipment, and photos to create a comprehensive record of normal operating conditions. **Table 4** shows an example of how these settings can be captured.

**Checklist 1: Determine if the HVAC System is Ready for Smoke**

1. Review and check the building's smoke control design features.
2. Do the outdoor air dampers function correctly? **Figure 3** shows a picture of a warped damper blade unable to close.
3. Are the damper blades, linkage, and edge seals in good condition?
4. Does the building have a commercial thermostat or control system that allows the outdoor air dampers to remain closed when the system is set for an unoccupied state?
5. Are there record drawings, blower door tests, commissioning reports, equipment installation, and service manuals or other information available?
6. Does the outdoor air economizer work correctly?
7. Can the minimum damper setpoint be changed and the economizer function be temporarily shut off? How is this accomplished for each air handler?
8. Is it possible to disable or reduce the relief fan airflow?
9. Does the demand control ventilation system work correctly?

10. Can the unit use MERV 13 or higher filters? If the system cannot use MERV 13, use the highest MERV-rated filter possible. There are alternative filtration technologies that allow filtration at a range of pressure drops. See the Upgrading and Improving Filtration section of the ASHRAE Epidemic Task Force Building Readiness guide for more information.
11. Has an HVAC or TAB technician evaluated whether installing MERV 13 filters will reduce airflow to an unsafe level? System characteristics such as the duct configuration and dirt on air coils can also affect airflow.
12. Are all filters properly seated and edges sealed? Air leakage around the filters will greatly reduce their ability to clean the air. **Figure 4** shows a filter that is not seated correctly.
13. Have the filter and fan access doors been checked to confirm that they are fastened and sealed?
14. Where are the exhaust fans and how are they controlled?
15. Which exhaust fans are critical for safety? Examples may include exhaust fans serving isolation rooms, commercial kitchen hoods (if cooking is occurring), and locations where hazardous materials are handled (e.g., laboratories).
16. Where are the locations of exhaust grilles? Can they be partially blocked to reduce the amount of filtered outdoor airflow?

**Figure 4. Picture of a filter that is not seated correctly.**

17. If the building has more than one air handler or rooftop AC unit, can some of them be set to recirculation and a small number used to provide filtered outdoor air?
18. Does the building have an air conditioning system or portable cooling units to prevent heat-related illness?

**Table 4 - Example of how to capture operational settings in normal operations and Smoke-Ready mode**.

| Setting | Value under Normal Operations | Value during Smoke-Ready Mode | Notes (such as date changed) |
|---|---|---|---|
| Outside air damper setting | | | |
| Operating time schedule of HVAC system | | | |
| Filter size | | | |
| Quantity needed per filter replacement | | | |
| MERV rating of main HVAC unit filters | | | |
| Critical breaker and switch positions and locations | | | |

## 6.2 Preparing for Smoke Events

### 6.2.1 Mechanical Ventilation

During wildland fire smoke events, the operational challenge will be to limit the amount of outdoor air brought into the building, consistent with maintaining positive building pressure relative to the outdoors, while maintaining adequate airflows that are protective of human health and equipment operation. Reduced ventilation may be acceptable for short periods to protect at-risk populations. Prior to wildfire season, determine an outdoor air intake level that controls odors, temperature, $CO_2$ concentrations, and maintains a positive building pressure consistent with building and HVAC system design during smoke-ready periods. Economizer and demand control ventilation (DCV) operation should be given high priority when developing a Smoke Readiness Plan (see Informative Appendix C). It is critical to repair broken dampers, actuators, and HVAC controls prior to wildfire season.

Finding effective work arounds to temporarily limit the amount of outdoor air and wildland fire smoke brought into the building may be difficult. Plan and investigate what actions are needed to limit economizer and DCV operation. This may include adding switches, control relays or implementing manual control for outdoor air damper to set the position for the minimum air required for positive building pressure. This will require testing, as outlined in Section 6.3.

Installing filters on the outdoor air intake is recommended (see Section 6.2.2.2).

Inspect energy recovery ventilators (ERVs) and evaluate how the projected changes to outside and ventilation airflows will impact building pressure.

### 6.2.2 Air Cleaning

Air cleaning to reduce $PM_{2.5}$ concentrations from wildland fire smoke in indoor air can be achieved through filtering recirculating air, incoming outdoor air, and using a portable air cleaner (PAC) in the room(s). Plan ahead, high efficiency filters frequently sell out during smoke events. The Smoke Readiness Plan should identify the size and number of replacement filers to have on hand and specify the storage location for these supplies. Section 5.4.3 details a loading estimation calculation that could be used to determine the lifespan of a particular filter to assist in supply and stock on hand decisions.

### 6.2.2.1 Cleaning Recirculating Air

HVAC system recirculation filter(s) can be upgraded. The particle removal calculation outlined in Section 5.4.1 is a method to select the appropriate filter MERV rating. If calculations cannot be performed, MERV 13 (or equivalent performance for $PM_{2.5}$ in other rating systems) filters are recommended. Before using filters with a higher MERV rating, check that the system can accommodate them (See Table 5 for more information). Wildland fire smoke can quickly load filters (see **Figure 5**) and they may need to be changed as frequently as daily during smoke events. Note, if the wildland fire smoke event lasts for multiple days, the recirculation system should be operated continuously for air cleaning.


**Figure 5. Comparison of a clean filter to a filter heavily loaded with wildfire smoke.**

When upgrading to higher-efficiency filters, there is concern the additional pressure drop will stress or harm the fan motor or other HVAC components. The airflow must be adequate to transfer heat in and out of the conditioned space within the design parameters of the equipment. Clean heat transfer coils and fan blades may provide additional capacity for air filtration. Note that as the filters load with smoke particles, airflow will be reduced. Most systems are not able to operate safely and effectively below 70-80% of nominal airflow.

Monitoring the fan motor operation and checking temperatures at a few key locations will provide information to determine safe operation or the inability to use higher MERV rated filters. To gain an understanding of important benchmark temperatures and pressures, reference the manufacturer's literature. Brief guidance related to upgrading filters is provided in **Table 5** for various HVAC components. For a more detailed discussion about evaluating the maximum MERV rating that the building HVAC system can accommodate, see the Upgrading and Improving Filtration section of the ASHRAE Epidemic Task Force's Building Readiness guidance.[85]

**Table 5 – Brief Guidance for Upgrading to Higher-Efficiency Filters**

<u>Centrifugal fan surge</u>

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

<u>ECM fans</u>

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

<u>VFD controlled fans</u>

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

<u>Other AC induction motors</u>

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

<u>Direct expansion cooling</u>

Low airflow can lead to loss of cooling and compressor failure. Air temperature measurements are a simple way to verify safe operation. The manufacturer's literature or the startup records will have a recommended air temperature difference (ΔT) across the evaporator coil. The rule of thumb is 20ºF (11ºC) ΔT with a minimum discharge temperature of 55ºF (13ºC) measured after 20 minutes of continuous running. If the discharge temperature is below 55ºF (<13ºC), visually check for frost or ice on the evaporator coil. Frost is an indication that there is inadequate airflow and the filters, or the level of dust loading, may have become too restrictive. Some fan motors may have the ability to increase speed by changing electrical connections or VFD settings. After adjusting the fan speed, re-check the temperatures.

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

<u>Heat pumps</u>

While cooling, follow the guidelines above. While heating, low airflow may cause the unit to shut down when the high-pressure safety trips. Review the manufacturer's instructions to determine the appropriate limits for the maximum discharge temperature and ΔT.

<u>Electric resistance heating</u>

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

<u>Combustion appliances</u>

Roof top units and air handlers with natural gas or propane heat need adequate supply airflow for heat transfer and to prevent damage to the heat exchanger. The unit label or manufacturer's literature will list a maximum discharge air temperature and a range of temperature differences that indicate acceptable operation. Rule of thumb is 160ºF (71ºC) maximum discharge temperature and 40 to 60ºF ΔT (22 to 33ºC) across the heat exchanger. Direct-fired units and oil-fired units have similar parameters. Always use the manufacturer's recommended settings to determine that safe operations are being met.

**6.2.2.2 Cleaning Outdoor Air Providing supplemental filtration of outdoor air entering the HVAC system is recommended.** A MERV 13 or higher filter on the outdoor air intakes will capture a large fraction of the $PM_{2.5}$. Figure 6 shows a MERV 13 filter temporarily installed on an intake air vent. Prior to wildfire season, inspect the air intake and make a list of filters (including the specific quantity and size of the filters), tape, temporary ducting materials, and other items needed to mount filters tightly to the air intake. Consider having a contractor install permanent filter racks on the outdoor air intake.

**Figures 6-a and 6-b. Picture of a MERV 13 filter installed on an outdoor air intake as supplemental filtration**

To help assess the useful life of these supplemental filters, add a port or pressure gauge to measure the filter pressure drop on at least one air handling unit (AHU). A rule of thumb is to replace the filter when pressure drop becomes twice the initial pressure drop. When outdoor $PM_{2.5}$ concentrations are high, supplemental filters may need to be changed daily.

**6.2.2.3 Use Portable Air Cleaners to filter the air in the room(s)**

Portable air cleaners (PACs), also known as air purifiers, can be used in appropriate spaces where cleaning the recirculating and incoming air is insufficient. PACs and replacement filters should be purchased in advance of the fire season. They may quickly become unavailable during wildfire events.

**6.2.2.3.1 Selection of Portable Air Cleaners**

PACs utilize different technologies to clean the air by filtering particles, reducing VOCs, or reducing micro-biological contaminants. Select a PAC that is matched to the target contaminant(s). For smoke from wildland fires, PACs should be selected primarily to reduce particles. Important tips for selecting a PAC include (Adapted from NIEHS Selection and Use of Portable Air Cleaners[86])

- Size – choose the correct size of air cleaner for the room where it will be used
- Noise – consider the noise rating. Air cleaners are usually most effective when run at high speed. Will the noise be disruptive in the room?
- Filter – select a unit with a HEPA or equivalent filter that will remove sub-micron particles
- Location - Place the air cleaner where it will be able to filter as much of the air in the room, as possible (not, for example, next to the wall or blocked by furniture)
- Avoid ozone generators or other disinfection features which may pose a health hazard

Some air cleaning devices include features which can produce ozone intentionally or as an unintentional by-product and hence are not recommended and may be prohibited in some jurisdictions. Air cleaning devices and systems that incorporate ultraviolet light or the creation of charged particles, ions, or free radicals should comply with Section 5.7 of ASHRAE 62.1-2022[51].

It is important to have a correctly sized air cleaner(s) for the space. PACs should be used in closed rooms to maximize effectiveness. PACs tested to the Association of Home Appliance Manufacturers (AHAM) standard are designed for room use in residential settings.

The AHAM smoke clean air delivery rate (CADR) is the rating for 0.09 to 1.0-micron particles and represents the amount of clean air delivered on the high-speed setting. AHAM tests and certifies CADRs of PACs following the ANSI/AHAM AC-1-2020 standard.[87] For wildland fire smoke, AHAM advises selecting an air cleaner with a smoke CADR equal to the size of the room in square feet, e.g., for a room of 120 $ft^2$, the CADR should be 120.[88] EPA and National Institute of Environmental Health Sciences (NIEHS) also provide additional information on the selection, use, (including room configuration), and maintenance of PACs.[77–79]

Another way to evaluate air cleaning is to calculate the equivalent amount of PAC air changes per hour (eACH) that are necessary to achieve the same reduction of pollutants as would be achieved with a MERV 13 filtration. This calculation can be done with a combination of air cleaning options. ASHRAE has developed a calculator to help with this method[92], as well as, AHAM has published a white paper on eACH for PACs. [93] Carefully read all information, examples, and instructions provided with the calculator prior to evaluation.

PACs tested to the AHAM standard have a maximum smoke CADR of 600. Multiple devices may be needed for larger rooms and those that have a ceiling height greater than 8 feet. Alternatively, commercial air scrubbers, which are similar to PACs, are specifically designed for use in larger spaces. They can be quite large and have high airflows and may be noisy. As with other equipment and supplies, larger air cleaners and replacement filters should be acquired by purchase or rental well in advance of the fire season.

There appears to be no standard method of testing the performance of commercial air scrubbers, and manufacturer performance data may not be readily available. Device specifications such as airflow, filtration efficiency, or a CADR are useful for selecting an appropriate device. Use caution when comparing the CADR to commercial air cleaners tested to the AHAM standard as the test methods may not be directly comparable. Many commercial air scrubbers can also be used as negative air machines by connecting a hose to the device that exhausts to the outdoors. Do not use this configuration during a wildland fire smoke event as it could draw in smoke via infiltration.

#### 6.2.2.3.2 Do-It-Yourself (DIY) Air Cleaners

Do-it-yourself (DIY) air cleaners using box fan(s) and MERV 13 filter(s) can provide air cleaning similar to commercial air cleaners. Advice on putting these together can be found online.[94] Studies have demonstrated that these DIY cleaners are an effective approach to achieve cleaner indoor air.[95, 96] Configurations with two or more filters will increase the filter area and lessen the pressure drop, reducing burden on the fan motor. In addition, DIY air cleaner designs with a cardboard shroud and multiple filters increase the cost effectiveness of DIY air cleaners.

To understand the risks around the possible fire and/or electrical hazards, testing was conducted by Underwriter's Laboratory (UL). The testing demonstrated that box fans with MERV 13 filters did not reach unsafe temperatures under the conditions measured in the testing (which included filters loaded with smoke).[8597]

To reduce the risk of fire and/or electrical hazards, it is recommended that only newer box fans manufactured since 2012, which have added safety features of fused plugs and thermal cutoffs, be used. Fans that have been verified to meet the UL 507-2022 safety standard for electric fans or equivalent can be identified by the UL or ETL safety marking.[98, 99] Use of extension cords is not recommended as the motor is working harder than designed. DIY air cleaners tend to be noisier than commercially available air cleaners, which may hinder use. These fans should not be placed near water. Users should read the fan's safety information and follow the fan's operating instructions. Users who construct a DIY air cleaner should ensure that fan manufacturers have stated in their use and care literature, labeling, or packaging that they support the application and have designed their products for this application.

#### 6.2.2.3.3 Portable Air Cleaner Operation and Maintenance

For any room air cleaner, plan to perform routine maintenance on the device as recommended by the manufacturer. An air cleaner that is used frequently in an area affected by wildland fire smoke may require more frequent filter changes. If the filter is changing color or if the level of airflow coming out of the air cleaner drops, it could mean the filter should be changed. DIY air cleaners can be almost completely ineffective with dirty filters, highlighting the need for frequent filter replacement during smoke events.[95] It is recommended to keep extra filters on hand, especially during wildfire season. Some air cleaners do not require filters, relying instead on an electrostatic precipitator (ESP), which charges particles and attracts them to a plate. The plate requires periodic cleaning according to the manufacturer's instructions.

Position PACs in the room such that airflow is unobstructed. Placement near any indoor sources of $PM_{2.5}$, or near where occupants spend time may be most effective. If the device causes uncomfortable drafts, redirect the airflow.

PACs can be operated at various fan speeds (airflows). The higher the flow, the more air will be moved through the filtration system. However, higher fan speeds often generate more noise, which may be disruptive to the intended use of the space. It is important that the air cleaner be operated in a manner to encourage its use. It may be helpful to inform occupants of the purpose and intended operation of the PAC to discourage tampering with it. Reducing the airflow setting will reduce the CADR.

Some PACs come with indicators that change color as the air quality changes. If the air cleaner does not come with an indicator function, it may be helpful to purchase a low-cost air monitor equipped with a $PM_{2.5}$ sensor to determine whether the air is being cleaned. If the monitor indicates that air quality is not improving, the PAC may not be large enough for the space. Doors, windows, or other openings may need to be closed, or the filter may need replacement. See Sections 4.10 and 6.2.8 for more information on indoor $PM_{2.5}$ monitoring.

Post wildfire season, the PAC should be checked, cleaned, and have the filters replaced if needed. If the units are stored seasonally, dedicated storage space will be needed.

### 6.2.3 Building Automation Systems (BAS)

The Smoke Readiness Plan defines what is needed for facility operations during wildland fire events. Initial steps for the building control systems will include evaluating current controls and settings and determining capabilities for smoke-limiting operation. Check for any BAS design features intended to control and monitor smoke as described in Sections 5.5.1 and 5.5.2.

HVAC controls range from simple single zone thermostats controlling a single HVAC unit's heating and cooling modes of operation, to complex BAS that integrate the controls from multiple units in large buildings. In addition, there are older HVAC systems and BAS that use electric and pneumatic controls. In the U.S., it is estimated that about 85% of small to medium-sized commercial buildings use thermostats exclusively. For these buildings, changes to HVAC system operation under smoke conditions need to be performed manually (see Section 6.2.1 Mechanical Ventilation).

An access, update, and testing policy should be developed in buildings with a BAS. A BAS policy not only facilitates operating the building HVAC system during wildland fire events, the policy is also useful for other incidents impacting IAQ (e.g., SARS CoV-2). **Below is** a list of essential elements that should be incorporated in this policy, including memorializing current settings and accessing new settings (adapted from the ASHRAE Epidemic Task Force's Building Readiness guidance).[74]

- Perform a full backup of all BAS software, databases, programs, graphics, trends, schedules, etc., and store off site either physically or in the cloud.
  - Consider printing them physically or to a pdf so that values can easily be returned when the wildland fire smoke event is over.
- Inspect or replace any batteries in building controllers such that databases are not lost during any extended power interruptions.
- If your building is not on a scheduled BAS inspection (either by a 3rd party or self-performed), consider performing a preventative maintenance inspection of all systems to ensure proper operation prior to any changes being made. Consider retaining the services of an independent 3rd party commissioning service provider (CxP) to help you review the scope of work for any control system modifications and who can verify the systems are functioning as intended.
- Review the access requirements with all parties that the owner wants to have remote access to control systems and company IT networks during the unoccupied or modified mode of operation period.
- Determine the level of access and permissions each person with access should have, such as full access to make changes in setpoints, schedules and system programming, schedule overrides only, alerts and notification access only, and view only access.
- Confirm with company IT departments what requirements may be in place to qualify, screen, and approve people for remote access to control systems and company IT networks.
- Set each person up as a unique user having unique usernames, passwords, and permission levels so that access and changes to the system can be monitored and documented.
- Have a trained and experienced operator review the existing system's remote access features and its interface with anyone who will be given remote access to the system.
- Review all alerts, notifications, event logs, and system and control point trend reports prior to making any modifications, and download those reports to create a baseline for comparing the effects of any changes that may be made in the future. If possible, walk the facility or facilities being controlled and managed by the BAS to become familiar with the location, size, and scale of the control network.
- At a minimum, review system graphics for all system types and buildings to become familiar with the system(s).
- Make note of any communication issues with components, sensors, controllers, buildings, etc., and develop a list of repairs that may need to be made before the system is placed in extended shut down, unoccupied, or partial occupancy modes of operation.
- Review system graphics or text-based reports to determine if temperatures, humidity, $CO_2$, airflows (supply, return, OA, exhaust), damper positions, control valve positions, motor speeds, and status are returning or reporting reasonable values.
- Use test instruments to verify any questionable information and to spot check a representative quantity of points. Start with verifying critical sensors, such as $CO_2$ or airflow measuring stations.
- Collaborate with the building owner, building users, and building operators and create a plan for modifications to sequences, setpoints, and system operations.

- Note who was in attendance, what was discussed, and any decisions made and implemented at meetings discussing control systems.
- Obtain buy-in and approval from key stakeholders before making any changes.
- Repairs to systems involved in this response should be considered essential as any new sequences may not be able to be implemented via the BAS.

HVAC and BASs may not be configured to easily access the controls needed for limiting indoor smoke. The graphical user interface (GUI) may need to be modified to show system components and settings needed during a smoke event. The facility operator should review the system's graphics and discuss with the controls contractor how to implement these BAS modifications if they are not readily apparent. This should include:

- Temporary override of the outside air (OA) dampers or fans to reduce amount of outdoor air entering the building;
- Temporary override of economizer operation to reduce reliance on outdoor air for cooling;
- Temporary override of DCV to maintain reduced intake of outdoor air;
- Temporary override of the exhaust airflows to reduce exhaust if less outdoor air is entering the building; and
- Adjust systems to maintain a positive building pressure during the override period.

In the future, more BAS may include $PM_{2.5}$ monitors, and the capacity to generate alerts in response to changes in $PM_{2.5}$ concentrations, as described in Section 5.5.1.2. These sensors could be placed near the OA intake to detect an increase in particle concentrations due to a wildland fire, and the building operator could adjust the dampers in response. A $PM_{2.5}$ monitor in the return air could provide an indication of whether particle concentrations in the indoor air are stable or changing, which can give an indication about whether interventions to reduce smoke concentrations are working. Consider placing $PM_{2.5}$ monitors in key indoor locations to provide representation of occupied areas of the building, in hallways and corridors leading to and from a building entrance to assess the smoke ingress in the building(s), and in an outdoor location to assess outdoor air concentrations near the building. See Section 6.2.8 for additional guidance.

Heavy episodes of wildland fire smoke may trigger the smoke detectors in the HVAC systems or occupied areas. When smoke is detected in the HVAC ductwork or occupied space, the smoke detector (duct mounted or area detector) sends a supervisory signal to the alarm control panel, which in many cases, will turn off the related AC unit(s). This is most likely to occur when no smoke mitigation effort has been made as MERV 8 and lower rated filters may not remove sufficient smoke from the indoor air. Management plans should include the possibility of a fire alarm from wildland fire smoke from outside the building and maintaining detection and notification of an internal fire. To minimize false alarm disruptions consider taking these measures:

- Schedule smoke detector cleaning and testing just before wildfire season.
- Implement the recommendations in the Smoke Readiness Plan to protect building occupants.
- Some larger fire alarm systems may be temporarily placed in test mode and a fire watch program implemented in the building. Discuss this option with the local fire department before wildfire season as it may create an unacceptable safety hazard if implemented improperly.

### 6.2.4 Building Envelope

Prior to wildfire season, weatherize the building envelope, doors, and windows to reduce smoke infiltration by sealing and caulking cracks. ANSI/ASHRAE/IES Standard 100-2018 describes at a high level the requirements for operations and maintenance related to the building envelope and energy efficiency, and elements of this standard have application to wildland fires.[49] Specifically, making a building energy efficient by doing things like replacing obviously broken or missing windows and repairing or replacing door closers on exterior doors also keeps out wildland fire smoke. Elements that can allow infiltration at the top of the building include skylights, hanging fixtures, roof vents, rooftop mounted HVAC equipment, security cameras, and roof access doors. Lower in the building, soffits, service penetrations, and doors may allow smoke infiltration. Check vertical shafts, plumbing stacks, conduits, hallway pressurization shafts, ventilation shafts, service shafts, and fire exit doors for outdoor air paths. Check the envelope: outside walls and openings, windowsills, baseboards, and electrical receptacles for air infiltration. Elements and renovations added post-construction that penetrate the building envelope are often poorly sealed.

To determine if these elements are well sealed, use the following methods:

- Visual inspection: Look for visible openings in the envelope. A thermal camera is useful to quickly find envelope problems.
- Physical inspection: Feel for drafts, cold spots, inconsistent temperatures, and window condensation (indicative of cold air leaking around windows). Also look for areas where outside noise is more prevalent. Lastly, use odor to identify areas to investigate for infiltration.
- Professional energy audits: Bring in a professional to conduct an air leakage site detection test following a standard such as ASTM 1186-17.[84] Thermographic scans and infrared photography can also be used. These images can determine leaks from examining where energy is being lost. It may be beneficial to conduct an initial audit, make repairs, and then conduct a second audit to ensure that problems have been adequately addressed.

ANSI/ASHRAE Standard 62.1-2022, provides minimum ventilation rates and other measures for acceptable IAQ for commercial buildings.[51] The standard specifies ventilation rates needed for different zones in the building depending on use, and the rates are calculated based on the expected number of persons and the size of the space.

Once leaks have been identified and ventilation is determined to be sufficient, seal the building in this order: top of building, bottom of building (meaning ground floor and any floors below grade), vertical shafts, and finally, outside walls. The following specific approaches can be used for sealing stationary elements[100]:

- Caulking around window and door frames and casings with silicone caulk.
- Caulking around glass panes in windows and doors with clear silicone caulk.
- Sealing areas around wall and ceiling penetrations. For smaller areas, this can be done with caulk. Larger areas might require that insulation or other material be fitted into the openings. Spray-foam insulation is effective for sealing medium-sized holes and gaps.
- Sealing or caulking around electrical outlets and switches.
- Making sure HVAC ductwork sections fit together tightly and connections are sealed with mastic or metal tape to stop leaks.

Movable building components should be sealed via weatherstripping. Important considerations when choosing a weatherstripping method include whether it can withstand weather changes, friction, and wear and tear when deployed in its specific location. It should provide a good seal when the door or window is closed but allow it to open freely. For further guidance, including best types of weatherstripping for each application, see the *US Department of Energy Guide to Air Sealing Your Home*.[101]

In addition to sealing the building envelope, it is important to keep the building at positive pressure during a wildland fire smoke incident. See Section 6.2.1 for a discussion on how to configure the HVAC system to have the building operate at positive pressure.

### 6.2.5 Dedicated Cleaner Air Spaces

In some situations, such as in older buildings or when HVAC systems cannot accommodate MERV 13 filters, it may not be possible to adequately reduce smoke throughout the building. Also, some at-risk individuals may require the air be as clean as possible. In those situations, determine how to create temporary cleaner air spaces within the building prior to the wildfire season using one or more PAC with a high-efficiency particulate air (HEPA) filter (or other high efficiency filter) in a closed room (see Section 6.2.2.3). As described in Sections 4.10 and 6.2.8, a low-cost air monitor may also help to verify that the $PM_{2.5}$ concentrations are in fact lower in the cleaner air space relative to other spaces in the building.

Consider how increased occupancy may affect air quality and comfort in the dedicated cleaner air space and plan to provide adequate cooling, dehumidification, and air cleaning for the size of the space and the expected number of occupants. Limit sources of indoor air pollutants in the space (see Section 6.2.7). Occupancy may need to be limited depending on how the space is intended to be used. For example, some public cleaner air spaces are intended to be used for a few hours at a time and may require less area while others may be occupied for several days or weeks by people displaced by smoke or fire. Those spaces may require more area per person or family and more amenities. Advanced planning for cleaner air shelters should address existing HVAC capabilities, the number and size of PACs that will be needed, and other factors to ensure the safety and comfort of those displaced (see Wildfire Smoke Guide, Appendix B).[102]

### 6.2.6 Maintaining Space Conditioning and Reducing Odors

Using a mitigation strategy of temporarily limiting outdoor air ventilation and exhaust airflows could affect indoor space conditions. Depending on the outdoor environment, reduced ventilation rates could cause building systems to struggle to maintain acceptable temperature and relative humidity. A qualified professional should evaluate the building systems to ensure that any modifications do not create concerns. As discussed in Section 6.2.7, attention should be paid to reducing indoor sources of air pollutants during wildland fire smoke events.

Odors are subjective, but steps can be taken to try to reduce VOCs that have infiltrated the building during a smoke event, which may be a source of odor. Adding a filter with activated carbon to the air intake vent may help control odors (see Section 6.2.2.2). However, the carbon impregnated within the filter may saturate quickly, and multiple filters may be needed. In addition, there are furnace filters and other duct-mounted air cleaning devices designed to either remove gases or convert them to harmless byproducts. Sorbent media air filters, photocatalytic oxidation, ionization, and intentional ozone generators sold as air cleaners (the latter should not be used in occupied spaces) are developed for this purpose. It is recommended to only use devices that meet Section 5.7 of ASHRAE Standard 62.1-2022[51].

ANSI/ASHRAE Standard 145.2-2016 can be used to evaluate the effectiveness of gas-phase filtration for some devices which can be installed in the ductwork of HVAC systems.[103] However, since gas-phase filtration is not widely used, little data exist on device effectiveness and there are concerns about toxic byproducts. EPA's *Residential Air Cleaners: A Technical Summary* provides additional information about these devices in the context of residential buildings.[91]

### 6.2.7 Administrative Controls

In addition to HVAC-related actions that are discussed in the following text, the Smoke Readiness Plan should include administrative steps to reduce smoke exposures within the facility. Concerns to be addressed will depend on the activities taking place in the building.

*Reduce Indoor Sources of Particulate Matter*. During wildland fire smoke events, it is critical to limit behaviors that result in the indoor generation of additional PM. One important focus is reducing indoor air pollution sources, e.g., avoiding activities that generate indoor pollutants. Cooking, vacuum cleaning (unless using appropriate equipment as described in *Indoor Cleaning*), use of printers or copiers, and smoking are examples of activities that increase indoor $PM_{2.5}$ concentrations.[91] Understanding potential sources of air pollution in the building can assist in the reduction of these sources during wildland fire events. In addition, when the percentage of outdoor air relative to recirculating air is lower, as would occur in smoke-ready mode, it is critical to reduce the generation of indoor air pollutants.

*Indoor Cleaning*. Vacuuming can be helpful to keep indoor surfaces and carpets clean and may be especially helpful for reducing particle resuspension if surfaces are thoroughly cleaned before a smoke event. If vacuuming during a smoke event, appropriate equipment should be used to avoid resuspending dust and other contaminants in the indoor air. A central vacuum cleaner system can be used, provided it is vented to the outside and the exhaust vents are at least 10 ft from ventilation system air inlets. HEPA-filter vacuum cleaners or HEPA-equivalent vacuum cleaners can also be used, preferably those which have been tested to ASTM F3150-18.[104]

*Limit Door Usage Where Possible*. During smoke events, plan to limit the use of allowable building entrances and exits to ones with a vestibule or airlock. If this is not possible, prepare to limit door use to only the doors on the least impacted side of the building during the smoke event (consider prevailing winds when selecting entrances that will be open). In advance, prepare signage to use on doors that will remain closed.

*Loading Docks and Other Frequently Used Entryways*. Loading docks can be major sources of smoke during a wildland fire.[55] Consider adding an air curtain, which produces a high velocity airstream that will help to prevent aerosols, like smoke, from entering the loading dock space. Air curtains can also be added to other frequently used doors and entryways. Consider retrofitting the most frequently used traditional doors with revolving doors, where possible, to reduce the amount of outdoor air, including smoke, coming into the building.

*Personal Protective Equipment May Be Needed*. If building personnel will conduct activities outdoors when there are high levels of smoke (for example, checking the rooftop HVAC units), they should be provided adequate personal protective equipment (PPE), specifically N95 or other NIOSH-approved particulate filtering facepiece respirators. Similarly, personnel in large, unconditioned spaces (such as warehouses) may need to use PPE, such as respirators. CDC NIOSH guidance provides recommendations for reducing smoke exposures for wildland firefighters and other outdoor workers, including the use of N95 or similar respirators.[105] The Occupational Safety and Health Administration (OSHA) has requirements employers must follow when respirators are required and recommendations for when respirators are used on a voluntary basis in occupational settings.[106] During wildfire season, N95 respirators may be in short supply. Consider purchasing anticipated supplies and implementing respiratory protection requirements prior to the start of the season.

### 6.2.8 Indoor and Outdoor $PM_{2.5}$ Monitoring

Indoor monitoring of $PM_{2.5}$ can help determine if outdoor smoke is penetrating the building. In Section 5.5.1, information about $PM_{2.5}$ sensors is provided, and considerations related to permanently installed $PM_{2.5}$ monitors are described. If the building does not have any installed monitors, consider purchasing one or more low-cost air monitors equipped with a $PM_{2.5}$ sensor prior to the wildfire season. Install the monitors in the facility, aiming to stay away from potential indoor sources of $PM_{2.5}$. Preferably, one or more monitors would be located in areas representative of general building use, and one monitor would be located in a planned temporary cleaner air space. If permanently installed monitors are not feasible, facilities operations personal should be equipped with handheld $PM_{2.5}$ monitors.

**Figure 7** illustrates outdoor concentrations of $PM_{2.5}$ during a wildfire smoke episode, and how indoor $PM_{2.5}$ declined after installation of HEPA filter air cleaners. As discussed in Sections 4.10 and 5.5.1.2, $PM_{2.5}$ sensors will not be as accurate as high-quality regulatory monitors, but they can show whether interventions are reducing indoor $PM_{2.5}$ concentrations. For example, upward trends in $PM_{2.5}$ concentrations might indicate that doors or windows are open, HVAC air filters are degrading, PACs should be turned on, or that there is an indoor source of $PM_{2.5}$ that should be addressed (especially when outdoor $PM_{2.5}$ concentrations are not showing the same upward trend). Since indoor activities can generate $PM_{2.5}$, it is critical to place the sensor at its projected location prior to a smoke event to understand how the background concentrations change as a function of occupancy and activities in the building. For example, it may be typical that indoor $PM_{2.5}$ concentrations increase somewhat during the day when the building is occupied. In the Smoke Readiness Plan, document typical $PM_{2.5}$ concentrations and include procedures for how data from both temporary and permanent monitors will be accessed and evaluated.

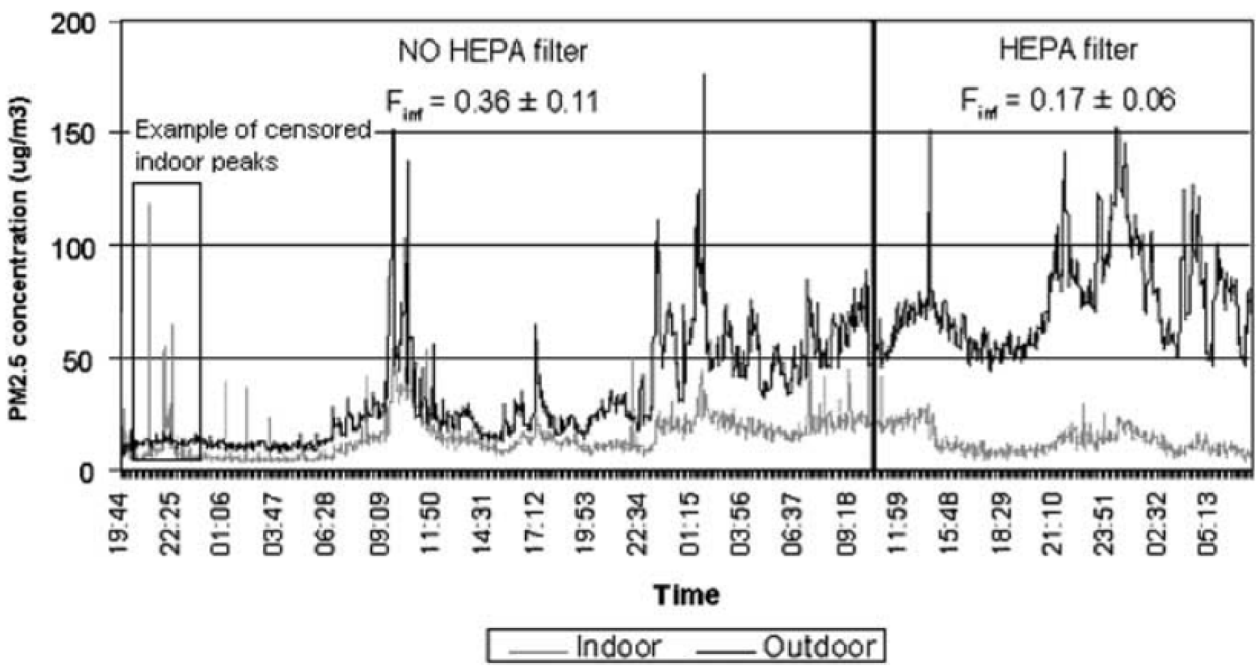


**Figure 7.** Indoor and outdoor $PM_{2.5}$ concentrations in a home measured with and without use of an air cleaner with a HEPA filter.[107]

For outdoor $PM_{2.5}$ concentrations, check local air quality conditions on AirNow.gov, including the Fire and Smoke Map [74] for more detailed information on air quality in areas impacted by wildland fire smoke, and state websites[108]. If adequate public information on air quality is available in the area, it is not necessary to install a dedicated outdoor $PM_{2.5}$ monitor for the building. If there is not adequate information for the area, consider installing an outdoor monitor as well (see US EPA Air Sensor Toolbox, Outdoor Sampling Considerations [72]).

### 6.2.9 Special Considerations for Healthcare Facilities, Schools, and Other Institutions

#### 6.2.9.1 Hospitals

See Section 5.7.1.

### 6.2.9.2 Schools

Schools should follow the guidelines in this document to prepare for smoke, keeping in mind that they house at-risk populations. As described in Section 4.6, children are potentially at-risk of experiencing health effects related to exposure to wildland fire smoke, and advance planning is needed to minimize smoke exposure. A school's Smoke Readiness Plan should carefully address issues such as:

- **School cancellation**. During a wildfire, the biggest issue is whether to cancel school. Although it may appear that closing a school is the best option during a smoke event, there are health and safety, equity, and instructional time considerations. See guidance from California school and air pollution agencies for a discussion of these considerations.[109] This guidance also suggests how to modify student activities as the outdoor air quality changes.
- **HVAC preparation.** In the planning phase, school facility managers should consult with HVAC professionals to understand the usual settings for their system (e.g., often, ventilation rates are high) and how those settings can be controlled during a smoke event. The steps to make changes in the settings should be clearly identified. Additionally, smoke entering the building can be reduced by limiting the intake of outdoor air during unoccupied hours and in unoccupied parts of the building. If smoke arrives and the intake of outdoor air is reduced to limit smoke coming into the building, the air intake should be returned to normal as soon as possible after smoke clears (see Section 6.5).
- **Indoor $PM_{2.5}$ monitoring**. An indoor or handheld $PM_{2.5}$ monitor can provide immediate information on IAQ, which is critical for protecting at-risk populations (see Sections 4.10 and 6.2.8). Consider purchasing one or more $PM_{2.5}$ monitors so that changes in indoor $PM_{2.5}$ concentrations can be detected when a smoke event occurs. The Smoke Readiness Plan should define what steps should be taken if $PM_{2.5}$ concentrations begin to rise.
- **Schools that rely on natural ventilation.** Schools in northern climates may not have central air systems. To the extent feasible, these schools could prepare for smoke by purchasing PACs and one or more $PM_{2.5}$ monitors. If a smoke event occurs, windows and doors should be closed, and PACs deployed and turned on. Indoor temperatures should be monitored in buildings with no air conditioners, closing doors and windows may increase indoor temperatures, potentially increasing the risk of heat-related health effects. When outdoor smoke clears, window and doors should be opened promptly to help in clearing the indoor air and providing cooling.

### 6.2.9.3 Restaurants, Hospitals, Schools, and Other Buildings with Commercial Kitchens

Restaurants, hospitals, schools, and other buildings with commercial kitchens will have large vent hoods with exhaust fans over the cooking range. These vent hoods are designed to ensure proper removal of combustion gases and other odors formed during cooking and use of gas burning appliances. Because these fans pull a lot of air out of the kitchen, the ventilation system is typically designed to bring enough OA into the kitchen to maintain the kitchen at slightly negative pressure (just enough to keep the kitchen odors and other possible combustion products from spreading to other spaces). In many cases, the OA coming in will have an inadequate filter or no filter at all. To avoid bringing in smoky air, the cooking appliances and vent hood exhaust should remain off; plan ahead for cold food choices or alternative cooking methods which will not produce combustion products, such as microwave ovens or induction hotplates. Other options to consider include adding supplemental filtration to the make-up air and providing N95 masks to protect kitchen workers. Note that adding filtration may impact airflow. It is essential to confirm proper function of exhaust systems prior to implementation.

### 6.2.9.4 Prisons/Detention Centers

Prisons and detention centers should consider how implementation of the Smoke Readiness plan impacts their security practices. See Section 5.7.2.

### 6.2.9.5 Multi-unit Residential Buildings

It is important to investigate and understand the HVAC equipment serving common areas and dwelling areas of multi-unit residential buildings. Most of the considerations in Section 6 also apply to common areas in multi-unit residential buildings.

If dwelling units have independent heating and cooling systems, occupants may need to take action to reduce smoke exposure within their unit. In appropriate settings, the building manager may need to provide a large number of filters and supplemental PACs to protect occupants. In many cases, residents may be asked to provide their own equipment and supplies for air filtration and/or adjust ventilation controls and behaviors to reduce smoke entry into individual units.

Building managers should consider distributing outreach and educational materials to assist residents with these actions. Existing materials and information may be available from federal, state, or local health or environmental authorities. Some examples include:

- AirNow Wildfire Smoke Factsheets(110)
- British Columbia Centre for Disease Control Wildfire Smoke webpage and factsheets(111)
- California Air Resources Board Protecting Yourself from Wildfire Smoke(112)
- EPA Wildfires and Indoor Air Quality webpage(113)

## 6.3 Operational Testing

When the Smoke Readiness Plan is prepared and before the start of wildfire season, test the HVAC system with the additional filtration and adjusted flow settings. There may be several non-functioning items that will take more time to fix than emergency conditions allow**. It is important to test the Smoke Readiness Plan every year**. Syncing this test with the required testing of the building's fire and life safety systems every year (e.g., sprinklers) will help make this testing become a regular part of building operations and maintenance.

*Indoor Air Quality Monitor Failures.* Sections 4.10 and 6.2.8 provides recommendations for using monitors to observe changes in $PM_{2.5}$ concentrations. Sometimes it is difficult to tell when a sensor has stopped working. Most sensors do not have a status indicator and may fail in ways that are not immediately obvious, so routine data review is critical to identify problems. Some ways to identify invalid sensor data include:

- Sensors reporting a constant value (e.g., zero)
- Sudden, frequent jumps in the data or sudden, very erratic data
- Divergent data from redundant or repeated sensor measurements in sensors equipped with more than one sensor.

In addition to these more obvious malfunctions, sensor data may also "drift" over time; that is, the sensor's response may gradually change the longer it has been in use. Drift may manifest as overall declines in measured values that may not reflect what is known about activities near the sensor. It is important not to confuse very low concentrations, which may occur during low-occupancy periods, with a sensor malfunction. Likewise, a malfunctioning sensor may report consistently low concentrations when air quality is in fact poor. A simple check that the sensor is responding to $PM_{2.5}$ can be accomplished by, for example, safely lighting a match or candle or kicking up some dust near the sensor. Periodic collocation of the sensor with a portable reference monitor, if available, can help to determine if the sensor is still working correctly.

## 6.4 Maintenance and Monitoring During a Smoke Event

### 6.4.1 Roles and responsibilities

Responsibilities for plan implementation should be clearly defined: For example,

- Who checks with reliable sources on current and forecasted outdoor air quality?
- Who decides when and what HVAC changes need to be made in response?
- Who implements the changes and returns the system to normal operations?
- Careful judgement is needed to determine when it is necessary to close dampers or otherwise restrict the outdoor air intakes, with consideration of the minimum level needed for ventilation.

### 6.4.2 When to Implement the Smoke-Readiness Plan

The Smoke Readiness Plan should include the information sources to consult in determining when to implement smoke mitigation measures. When wildland fires occur, state and local health departments may issue air quality notifications and guidelines when actions are needed to protect the public from smoke. Local air quality conditions can be found on AirNow.gov and state websites. The US Air Quality Index (AQI), available on AirNow.gov for locations across the US, has six color-coded categories indicating levels of health concern as a function of $PM_{2.5}$ concentrations and other criteria air pollutants. The AirNow Fire and Smoke Map[74] provides information on $PM_{2.5}$ concentrations from both regulatory-grade monitors (operated by air quality agencies and temporary monitors deployed by agencies for smoke events) and low-cost sensors (owned and operated by individuals, organizations, or agencies); fires; and smoke plumes. Building managers should use these sources of information to understand when to initiate the Smoke Readiness Plan. See Table 6 for guidance on when to implement the plan.

**Table 6 - Decision Matrix for Implementation of Smoke Readiness Plan**

| Smoke Conditions | Action |
|---|---|
| No current smoke, and no smoke forecast | Carry on with normal operations. Have Smoke Readiness Plan prepared and ready. |
| Current smoke OR smoke forecast in coming days | Consider implementing Smoke Readiness Plan. For example, if at-risk populations are likely to be impacted. |
| Current smoke AND smoke forecast for coming day(s) | Implement Smoke Readiness Plan. |

### 6.4.2 Placing the Building in Smoke-Ready Mode

Implement the Smoke Readiness Plan. **Checklist 2** provides an example for placing a building in smoke-ready mode. A building-specific plan should include a similar checklist, with modifications appropriate for that building. Use the information in Table 4 (Section 6.2.1) to provide building specific parameters.

**Checklist 2: Placing Building in Smoke-Ready Mode**

1. Note the $PM_{2.5}$ concentrations from the indoor or handheld sensor(s) and the outdoor $PM_{2.5}$ concentrations from an appropriate source (e.g., AQI or a nearby outdoor $PM_{2.5}$ monitor).
2. Install the higher-rated HVAC recirculation filter.

3. Set BAS controls to unoccupied state to close outdoor air dampers or manually set.
4. Make additional changes to BAS controls (if applicable).
5. Disable or reduce relief fan airflow.
6. Adjust exhaust fans and block exhaust grills.
7. Put filters on the OA intake.
8. Set some of the air handlers or rooftop AC unit to recirculation mode.
9. Make sure that spaces are conditioned adequately (e.g., turn on air conditioning system if hot).
10. Set up cleaner air spaces, making sure to properly place the PACs inside the spaces and turn to the correct setting; the highest setting is typically the most effective for air cleaning.
11. Implement administrative controls (e.g., reduce indoor sources of air pollution and restrict number of building entrances).
12. Implement odor controls, if part of the plan.
13. Monitor data from indoor $PM_{2.5}$ monitor(s), outdoor $PM_{2.5}$ monitors, and other instruments to determine if mitigation measures are working (see Section 6.4.3).

### 6.4.3 Determining if Mitigation Measures are Working

Once the plan is implemented, use the data from the indoor and outdoor $PM_{2.5}$ monitors to determine whether the actions taken have reduced the $PM_{2.5}$ concentrations. Specifically, examine current sensor data versus baseline sensor data for times when occupancy in the space is similar. In addition, consider how trends in outdoor $PM_{2.5}$ concentrations may be affecting indoor $PM_{2.5}$ concentrations. If a plateau and/or upward trend in indoor $PM_{2.5}$ concentrations is observed, check filters, and replace as needed; look for cracks in the building envelope and seal them; ensure that the building remains at a positive pressure; and reduce indoor PM sources. If needed, set up PACs in designated cleaner air spaces. Consider the outdoor $PM_{2.5}$ concentrations when examining the data. If the outdoor concentrations are trending up, the indoor concentrations may still trend up even if the mitigation measures are effective.

Temporarily reducing the amount of ventilation air may create unexpected conditions. Track important information with handheld devices or a BAS. Knowing the $PM_{2.5}$ concentrations, temperature, relative humidity, $CO_2$ concentrations, and number of occupants will allow problems to be addressed as they arise.

### 6.4.4 What to Do if the Plan Does Not Work

If the plan and the adjustments do not work, consider relocating occupants to another building. Prior to wildfire season, determine building conditions that are no longer acceptable and who will make the decision regarding relocation. If forced to relocate, close air intakes, and shut off the HVAC system to minimize smoke particles getting into the system.

## 6.5 Returning to Normal Operations

As soon as outdoor smoke clears, the building should return to normal operation. Normal HVAC operation will help to remove any smoke lingering indoors and will improve IAQ. The Smoke Readiness Plan should include a checklist for resuming normal operations, and **Checklist 3** provides an example of the topics to address. This list will largely involve reversing the changes made during the smoke event, relying on the documentation developed for normal operations and any additional notations made during the event. Dirty filters should be changed to avoid circulation of odors that may remain from the smoke.

In addition to reversing building HVAC system settings and removing filters, ash may need to be removed from building surfaces. Wear appropriate PPE when cleaning up ash. Avoid actions that kick ash particles up into the air, such as dry sweeping or leaf blowers. Before sweeping indoor and outdoor hard surfaces, mist them with water to keep dust down, and follow with wet mopping. For areas lightly dusted with ash, use a damp cloth or wet mop to wet down ash. Whenever using water, use as little water as possible and do not rinse ash into drains. Commercial cleaning may be needed for carpet, upholstery, and window treatments. Clean and sanitize food contact areas and any items that may facilitate ash ingestion. Collected ash may be disposed of in the regular trash and should be stored in plastic bags or other containers to prevent it from being stirred up. [(102)]

**Checklist 3: Returning the building to normal operations**

1. Refer to documentation and photos of the original settings and follow in reverse order.
2. Re-connect and/or re-enable OA dampers.
3. Return thermostat and control setting to pre-smoke settings.
4. Remove outdoor intake temporary filters.
5. Inspect and change return air filters to the type used for normal operation.
6. Re-enable economizer and DCV systems.
7. Verify operation of system after returning to normal.
8. Clean indoor surfaces to remove ash deposited from the smoke.

Review and, as appropriate, update the Smoke Readiness Plan and/or the normal operating procedures based on lessons learned during the wildland fire smoke event.

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**(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)**

# INFORMATIVE APPENDIX A – ANALYSIS OF PARTICULATE MATTER CONCENTRATIONS DURING RECENT U.S. WESTERN WILDFIRES

## A.1 Background

To better understand the possible particulate matter (PM) concentrations which may occur during wildland fires (i.e., wildfires and prescribed fires), ambient air quality data during three recent wildfire events in the western U.S. were evaluated. Concentrations of fine particles ($PM_{2.5}$) reported to the Air Quality System (AQS)[114] were analyzed. The range of 24-hour $PM_{2.5}$ concentrations observed, and the relative timeframes concentrations can persist at unhealthy levels based on the U.S. Air Quality Index (AQI)[115] were summarized. These data are included in this appendix to inform building designers as they consider the filtration performance of air handling systems. In addition, this information can be useful for those developing wildland fire response plans to provide an idea on timeframes for actions.

It is important to understand that $PM_{2.5}$ concentrations related to wildland fire smoke can be highly variable and are greatly dependent on meteorological, topographical, and fire conditions. The data provided here are meant to be informative and illustrative of $PM_{2.5}$ concentrations observed during actual smoke events.

## A.2 Approach

For the analysis, the EPA AQS 24-hour $PM_{2.5}$ data for three wildfire events was explored using both 24-hour average Federal Equivalent Method (FEM) and Federal Reference Method (FRM) measurements. Monitoring data were evaluated for six states: California, Oregon, Washington, Nevada, Montana, and Idaho and three events: (1) Labor Day fires (9/7/2020-9/24/2020, 243 monitoring sites); (2) Summer 2018 fires (7/24/2018-8/29/2018, 235 monitoring sites); and (3) Camp Fire (11/8/2018-11/25/2018, 233 monitoring sites). Tools for communicating air quality information to the public vary from country to country. For example, the U.S. AQI uses color-coded categories with health-based descriptors for six pollutants ($PM_{2.5}$, $PM_{10}$, ozone, $NO_2$, $SO_2$, and CO). The highest AQI value is reported, and the responsible pollutant is identified. The reader is encouraged to review resources in their country or jurisdiction. For this analysis, a simplified version of the $PM_{2.5}$ AQI breakpoints was used as summarized in Table A-1. More detailed information on the AQI breakpoints and guidance for reporting the daily air quality in the US are available in US[116]. For each event, data analyzed from all monitoring stations in the six states are summarized below. More detailed information is available[117].

| Air Quality Index (AQI) Category | AQI Range | $PM_{2.5}$ Range |
|---|---|---|
| **Good/Moderate** | 0-100 | 0-35 ug/m$^3$ |
| **Unhealthy for sensitive groups** | 100-150 | 35-55 ug/m$^3$ |
| **Unhealthy** | 151-200 | 55-150 ug/m$^3$ |
| **Very Unhealthy** | 201-300 | 150-250 ug/m$^3$ |
| **Hazardous** | 301 and higher | 250-500 ug/m$^3$ |

| | | |
|---|---|---|
| **Above the AQI** | | 500+ ug/m$^3$ |

**Table A-1:** Simplified version of the US AQI breakpoints used in analysis

A.3 Results

For each of the three events, the $PM_{2.5}$ concentrations across multiple stations in a subset of the six states are shown in Figures A-1 and A-2. Elevated 24-hour $PM_{2.5}$ concentrations were observed across wide spatial extents during all three events. The highest 24-hour $PM_{2.5}$ concentrations were observed during the Labor Day fires, with peaks around 600-800 µg/m$^3$ (Figure A-1a, c). Elevated 24-hour $PM_{2.5}$ concentrations during the Labor Day fires and the Camp Fire were observed at many monitoring stations for multiple, consecutive days (Figure A-1a, c, Figure A-2c). The Labor Day fires consisted of multiple fires burning at the same time, leading to smoke from these multiple events impacting the same sites. Spatially, during the Summer 2018 fires, 24-hour $PM_{2.5}$ peak concentrations were observed in California before Oregon and Washington, indicating smoke transport across long distances and additional fires burning in Oregon. However, the $PM_{2.5}$ concentrations across all three states were similar in magnitude and duration (Figure A-2a).

Overall, these three events resulted in elevated $PM_{2.5}$ concentrations for extended time periods. A summary of the air quality during these events is provided in Table B-2. Concentrations above 35 µg/m$^3$, the lower end of the range of $PM_{2.5}$ concentrations for EPA's AQI category characterized as air quality that is *unhealthy for sensitive groups*, were observed during all three events lasting at least one consecutive week across ten or more monitoring stations. Additionally, concentrations above 55 µg/m$^3$, the lower end of the range of $PM_{2.5}$ concentrations for the AQI category characterized as *unhealthy* air quality, were observed across dozens of monitoring stations for up to 15 consecutive days. Concentrations above 150 µg/m$^3$, the lower end of the range of $PM_{2.5}$ concentrations for the AQI category characterized as *very unhealthy* air quality, were observed at a limited number of monitoring stations for up to 12 consecutive days.

The peak 24-hour $PM_{2.5}$ concentrations for the three events varied as well. The highest concentrations were observed during the Labor Day fires with 36 monitoring stations reporting 24-hour $PM_{2.5}$ concentrations above 250 µg/m$^3$, the lower end of the range of $PM_{2.5}$ concentrations for the AQI category characterized as *hazardous* air quality, and a maximum observed 24-hour $PM_{2.5}$ concentration of 824.1 µg/m$^3$, which is beyond the AQI scale. During the Camp Fire, 28 monitoring stations observed peak 24-hour $PM_{2.5}$ concentrations above 150 µg/m$^3$ (AQI category – *very unhealthy)* and two stations reported concentrations above 250 µg/m$^3$ (AQI category – *hazardous*). Lower peak 24-hour concentrations were observed during the Summer 2018 fires at fewer monitoring stations, with seven monitoring stations reporting concentrations above 150 µg/m$^3$ (AQI category – *very unhealthy*).

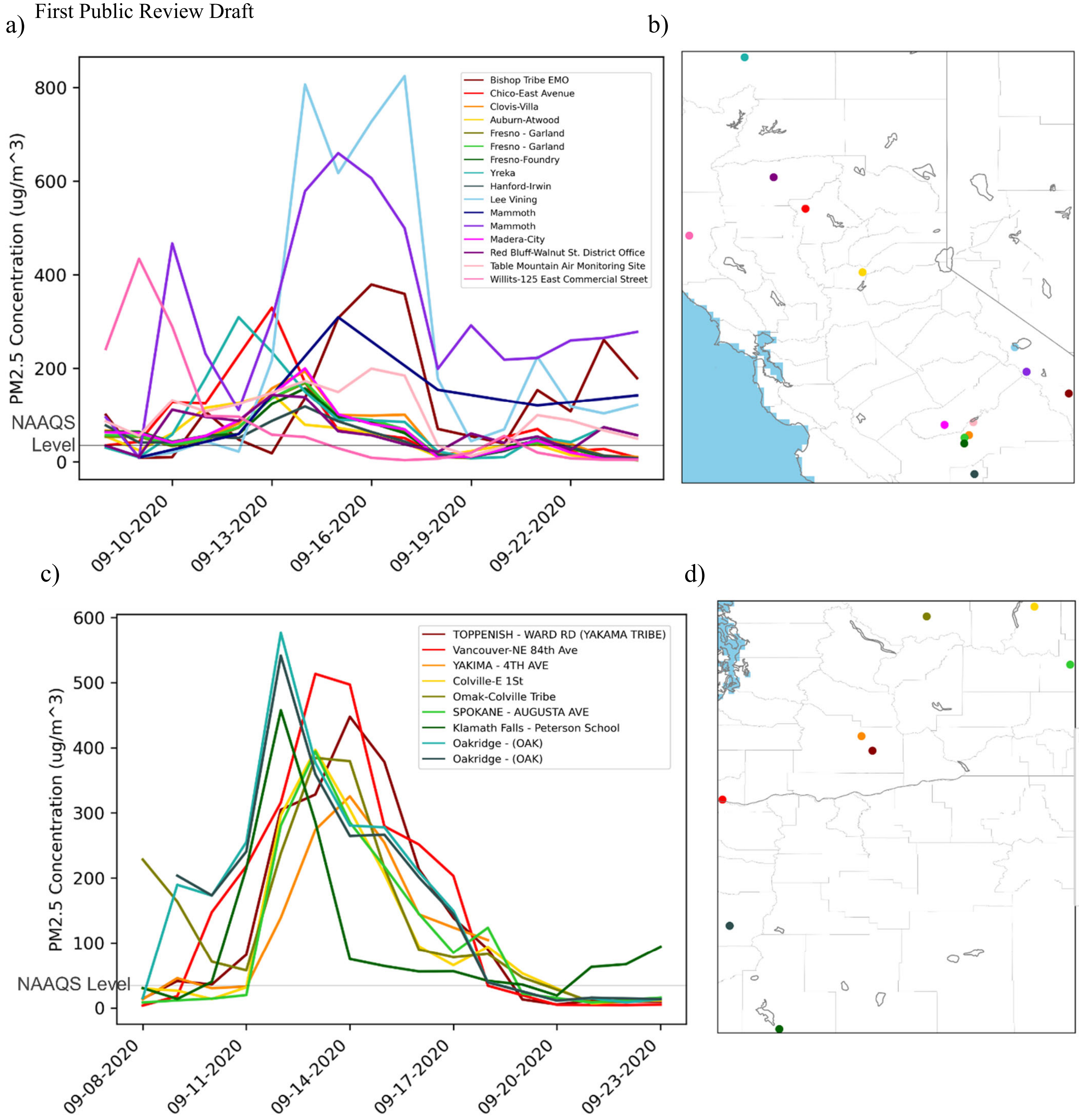


**Figure A-1:** 24-hour $PM_{2.5}$ concentrations reported at multiple stations in a) California and c) Oregon and Washington during the 2020 Labor Day fires. Station locations for b) California and d) Oregon and Washington are also shown.

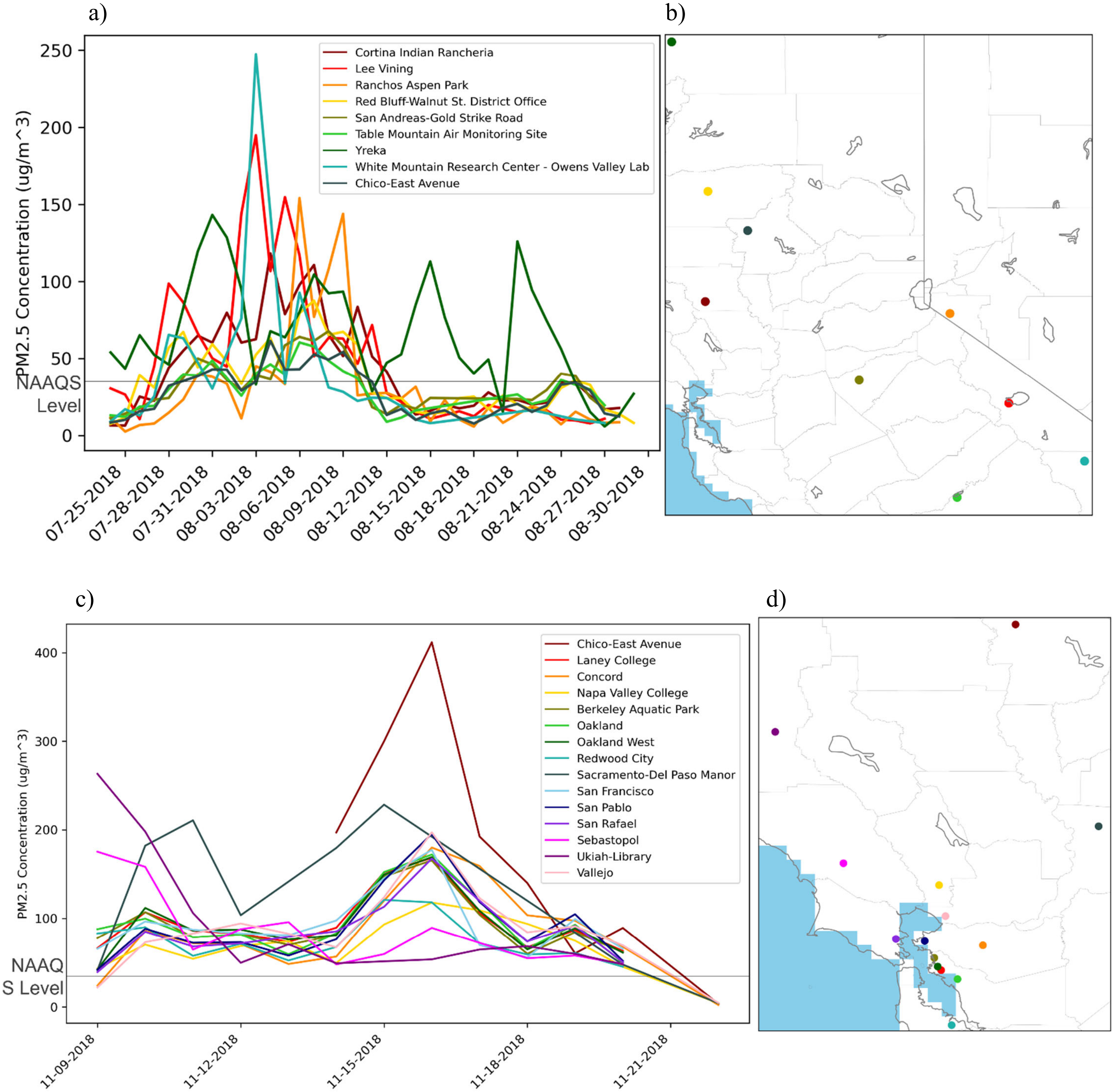


**Figure A-2:** 24-hour $PM_{2.5}$ concentrations reported at monitoring stations in California, Oregon, and Washington during a) the Summer 2018 fires and c) the 2018 Camp Fire. Station locations for b) the Summer 2018 fires and d) the 2018 Camp Fire are also shown.

| | Labor Day Fires (2020, 18 days) | Summer Fires (2018, 37 days) | Camp Fire (2018, 18 days) |
|---|---|---|---|
| **1. How long did the smoke event last?** | | | |
| Days above 35 ug/m$^3$ : | 10-17 days (34 stations) | 7-28 days (39 stations, 8 stations 2+ weeks) | 10-13 days (31 stations) |
| Consecutive days > 35 ug/m$^3$: | 10-15 days (18 stations) | 7-17 days (10 stations) | 10-13 days (28 stations) |
| **2. During the smoke event, what was the average concentration?** | | | |
| Mean > 35 ug/m$^3$: | 150-315 ug/m$^3$ (12 stations, very unhealthy)<br>55-150 ug/m$^3$ (93 stations, unhealthy) | 55-101 ug/m$^3$ (27 stations, unhealthy) | 55-179 ug/m$^3$ (41 stations, unhealthy and very unhealthy) |
| **3. How long were PM2.5 concentrations at unhealthy levels?** | | | |
| Consecutive days > 55 ug/m$^3$ (unhealthy): | 1-15 days (33 stations for one week or more) | 1-13 days (4 stations for one week or more, 24 stations for 3 days or more) | 1-12 days (20 stations for one week or more) |
| Consecutive days > 150 ug/m$^3$ (very unhealthy): | 1-12 days (4 stations for one week or more) | 1-2 days (7 stations) | 1-4 days (9 stations > 1 day) |
| **4. What was the peak concentration?** | | | |
| Maximum: | 824.1 ug/m$^3$ (36 stations > 250, hazardous) | 261 ug/m^3 (7 stations > 150, very unhealthy) | 411 ug/m$^3$ (28 stations > 150, very unhealthy, 2 stations > 250, hazardous) |

**Table A-2:** Summary of ambient 24-hour $PM_{2.5}$ concentrations during three wildfire events in the western U.S.

Examples of additional resources for $PM_{2.5}$ breakpoints:

British Columbia Centre for Disease Control *Air Quality Health Index and Wildfire Smoke* Fact Sheet(118)

Environment Protection Authority Victoria *PM2.5 particles in the air*(119)

British Columbia Center for Disease Control

# INFORMATIVE APPENDIX B – MANAGING AIR-SIDE ECONOMIZER AND DEMAND CONTROL VENTILATION FOR SMOKE

Economizer and demand control ventilation (DCV) are control techniques to provide energy savings and maintain indoor air quality (IAQ) by changing the amount of outdoor airflow in occupied buildings. While they are separate systems, they are often combined to control outdoor and return air dampers, relief air dampers, and fans. During wildfire smoke events, normal functioning of these systems can cause unhealthy indoor conditions. Up to 100% of the system airflow can be outdoor air used for cooling or ventilation.

Air-side economizers save energy by keeping the mechanical cooling system off when outdoor air is cool and dry enough to meet the HVAC's cooling requirements. Most roof top HVAC units above 5 tons capacity are equipped with air-side economizers. (ASHRAE 90.1-2022[77] requires economizers on systems above 54,000 btuh (4.5 tons) except in hot humid climates where using outdoor air for cooling is not advisable.) The economizer control also maintains a minimum outdoor air damper position for adequate ventilation, controls relief fans, and may close the outside damper when the building is unoccupied

There are many equipment and control variations used to provide the air-side economization. Figure B-1 is a typical air handler layout.

Determining what's happening and how it is happening in a particular HVAC unit may be challenging. Research and testing are needed to understand how these systems function at a specific building or within specific units. Gathering the manufacturer's installation and testing instructions will most likely be necessary. Some economizer controls can be a stand-alone controller typically mounted on the air handler or included as part of the control logic in an HVAC controller.

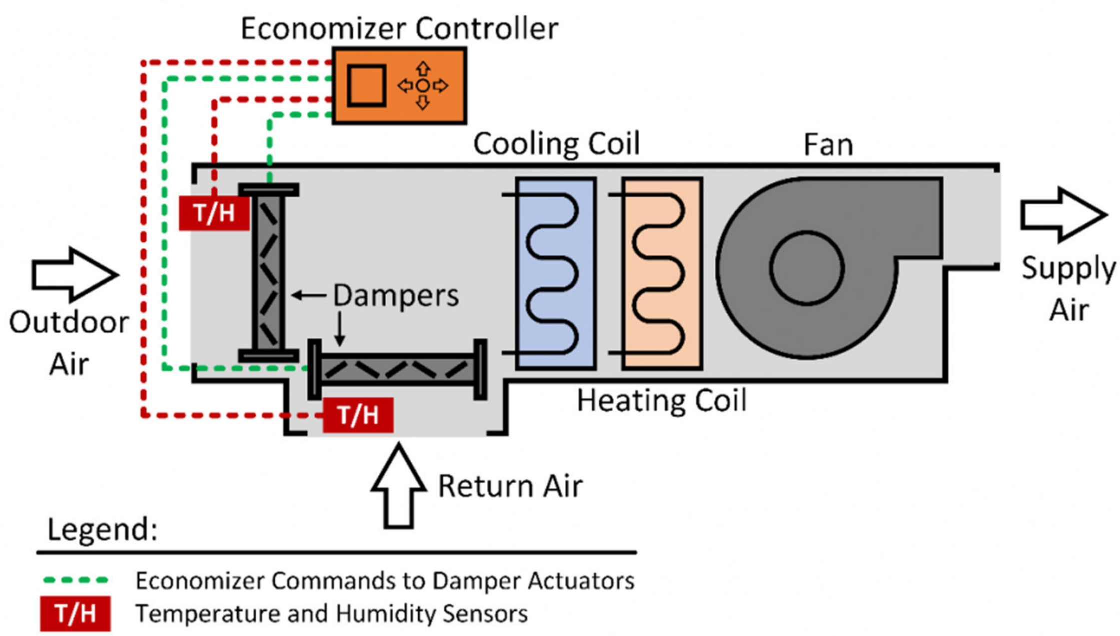


**Figure B-1.** Schematic of an air-side economizer in a unitary HVAC system. The economizer controller may be a stand-alone hardware module or be integrated into the HVAC control. (*From https://www.pnnl.gov/projects/best-practices/air-side-economizers*)

There are at least four common types of economizer controls in use. They are:

*Dry Bulb High Limit*: Sensors detect outdoor air temperature and adjust dampers to allow up to 100% outdoor air to be used for cooling. The high-limit setting acts to enable or disable the economizer function.

*Enthalpy High Limit:* Sensors detect outdoor air temperature and humidity to calculate the total heat of the air also known as enthalpy, then determine if outdoor air can be used to cool a building. The high-limit setting acts as to enable or disable the economizer function.

*Differential Enthalpy Economizer:* Two sensors measure return air and outdoor air enthalpy and adjust dampers to select the air stream providing the lowest enthalpy for cooling.

*Integrated Differential Enthalpy Economizer:* Sensors track return and outdoor air enthalpy and are integrated as the first stage cooling with a multi-stage indoor thermostat or controller. If the outdoor air's temperature and enthalpy are low enough, multi-stage cooling will start with the economizer and mechanical cooling will be activated as additional stages of cooling to meet the cooling demand.

In cooler, dryer climates dry bulb temperature control economizers are generally used. In warmer humid climates, enthalpy control is commonly used. Unfortunately, it is common for economizers to be set up incorrectly or fail as sensors lose calibration, system components age, and maintenance is deferred. As a response to the high failure rate, fault detection and diagnostics (FDD) for economizers have been required since 2018. The FDD reporting systems monitor and report problems with temperature sensors, dampers, operations at inappropriate times, and excess outdoor air. These faults may be displayed on zone thermostats or via a building automation system.

Air-side economizers can also be configured to provide "night cooling" or "night purge" functions depending on building usage and location. These functions should also be temporarily suspended to protect building occupants for the duration of wildfire smoke events.

DCV is a system that provides an automatic increase or reduction of outdoor air intake based on the actual occupancy of spaces. DCV controls use $CO_2$ sensors as a proxy to monitor building occupancy. (A common example is movie theatres, where outdoor air needs are normally low, except for crowded evening showings. The DCV sequence increases outdoor air in response to a rise in $CO_2$ indicating high occupancy.)

Temporary disabling of these systems requires research and making a plan for every air handler providing outdoor air. Solutions may be simple or complex. Listed below are a few considerations.

1. The specific technique to limit or increase the outdoor airflow to the minimum setting is dependent on the unique systems and conditions encountered. Professional assistance may be required.
2. The odds are good that the system's economizer is not working properly. The outdoor air damper may be failed closed or open. Sensors or damper actuators may have failed, lost calibration, or been disconnected. See the sample maintenance checklist for air-side economizers at https://www.pnnl.gov/projects/best-practices/air-side-economizers for guidance. If the damper has failed closed, leave it closed or block the damper partially open. Check the building pressure and adjust exhaust fans or OA damper until the internal pressure is positive to the outdoor pressure.
3. If the location has a building automation system (BAS), it may be possible to set and override for the outdoor air damper position. Verify the override holds when the economizer is active.
4. If the location has a BAS, it may be possible to simply raise the DCV setpoint, such that less outside air (OA) is demanded by the sequence.

5. Some BAS allow an override of OA temperature sensor. Temporarily setting the temperature to above the economizer high limit may prevent economizer operation.
6. If the building has a commercial thermostat with separated Occupied and Unoccupied times and setpoints, use the unoccupied function.
    a. Verify the outdoor air damper is closed when the system is operating during the unoccupied setting.
    b. Temporarily set the unoccupied time and temperature setpoints to include times the building is occupied.
7. It may be possible to temporarily disconnect the OA sensor used by the economizer controls. This will disable the economizer operation. This should be done by a qualified HVAC technician to verify no other systems are disabled and safety is maintained.
8. It may be possible to temporarily disconnect the OA damper actuator. This should be done by a qualified HVAC technician.

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