BC Centre for Disease Control
An agency of the Provincial Health Services Authority

Environmental Health Services
655 12th Ave W
Vancouver BC   V5Z 4R4

Tel 604.707.2443
Fax 607.707.2441

www.bccdc.ca

Evidence Review:

Filtration in institutional settings during wildfire smoke events

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Author: Anya Keefe

Reviewers: Ed Chessor
Nima Atabaki
Peggy Jenkins

Editors: Catherine Elliott
Karen Rideout

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Key Points

- Smoke from unanticipated wildfire events can create hazardous conditions for both workers and vulnerable patient populations in hospitals and other institutional settings.
- The effectiveness of the existing filtration system may be enhanced with the use of pre-filters or higher MERV rated filters, more frequent change-out of the filters, as well as portable air cleaning devices equipped with HEPA filters.
- In US health care settings, filters with a Minimum Efficiency Reporting Value (MERV) between 8 and 15 are required for normal operating conditions. In locations where frequent wildfire episodes are likely or for buildings with occupants having respiratory or cardiac conditions, the State of California recommends that a filter with a rating of MERV 17 be used.
- According to the technical literature, the loading rate of air filters is determined by the total concentration of suspended particulate matter in the atmosphere. Because of its episodic nature, smoke from wildfires can quickly overload filters and adversely impact on an air cleaner's ability to function properly.
- Increasing the efficiency of a filtration system is not as simple as replacing a low efficiency filter with a high efficiency filter because higher MERV filters have higher pressure loss than lower MERV filters. The air handling system must be capable of handling the additional power load, the potential for filter bypass must be minimized and protocols must be developed and implemented to ensure that filters are changed out in a timely fashion.
- Modification of HVAC systems must be done carefully to avoid unintended effects (e.g., potential for reduction in airflow and heating/cooling capacity, likelihood of filter bypass, life-cycle cost, building envelope and infiltration).
- Rooms designed to prevent infectious and airborne contaminants from entering the room either through the supply air or through doors (e.g., operating rooms) may provide a safe location for workers and vulnerable patients should the need arise. These rooms have existing filtration systems and are operated under positive pressure with HEPA-filtered supply air.
- The effectiveness of portable air cleaning units is highly variable and is dependent on the size of the room in which it is to be used and the air exchange rates within the room. More than one air cleaner may be required to filter air in a large space or in a space with high air exchange rates.

Evidence Gaps

- There is a dearth of evidence on the effectiveness of filtration to reduce wildfire smoke exposures in institutional settings.
- While there is a large body of knowledge about ventilation and filtration, much of the research focuses on infiltration of different sized particles into buildings. There is no literature specifically examining the issue of infiltration of wildfire smoke particles into institutional settings.
- It is not clear how best to use existing filtration capacity within institutions' HVAC systems to create clean air shelters.
- It not clear how to use portable filtration to establish clean air shelters within institutions.

Considerations

- The loading rate of air filters is determined by the total concentration of suspended particulate matter in the atmosphere. Because of its episodic nature, smoke from wildfires can quickly overload filters and adversely impact on an air cleaner's ability to function properly.
- Capacity of institutional filtration systems to handle higher efficiency filters (as described in key points) must be carefully assessed prior increasing filter efficiency. Ideally this is done prior to a wildfire event, for example in regions frequently affected by wildfire smoke.
- A qualified professional, with expertise in ventilation engineering, can help assess a building's vulnerability to smoke infiltration, as well as determine airflow patterns within the building and recommend strategies to manage the risk of exposure.
- It is theoretically possible to set up clean air shelters in areas of institutions with positive pressure and higher filtration efficiency (e.g. operating rooms); however, it is not clear how the necessary alterations in the HVAC system may affect air flow and filtration in other areas of the hospital. Therefore each such alteration should be individually designed, with the assistance of a qualified professional, to ensure important HVAC functions, including infection control, are maintained.
- In the absence of adequate in-duct filtration in an institution, the development of clean air shelters using portable HEPA filters is a reasonable approach. Considerations for setting up clean air shelters are summarized in the review *Air Shelters*.
- A systems approach for hospital preparedness for wildfire events involves pre-planning measures, reactionary measures and long-term planning (Appendix 3). This approach is intended to provide some high level guidance to owners of institutional buildings on how to assess where their HVAC system may be vulnerable to infiltration from wildfire smoke. It is not intended to replace the advice of a trained ventilation engineer or technician.

1. Objective

The objective of this project was to review the evidence for air filtration in institutional settings as a public health intervention during wildfire smoke events. In the context of this review, institutional settings included: hospitals, nursing homes, retirement homes, daycares, and, long-term care facilities. Filtration is the removal of particulate matter (PM) from air using an air-handling system and a filter (or a bank of filters). The complexity and capacity of the air handling system, as well as the extent of filtration, will depend on the size of the institution (i.e., single story building with a simple air supply and exhaust system *vs*. a multi-level high rise building with a multi-zone heating, ventilation and air conditioning system). Facilities with little or no system in place may be advised to develop a temporary shelter-in-place with portable air handling units. This is covered in the evidence review *Air Shelters*.

2. Background

Wildfires are sudden unanticipated events that can cause extreme degradation of air quality and risk of physical harm. During wildfires, public health practitioners and emergency managers are faced with the task of protecting the public from the threat of smoke - and fire-related illness. Institutional settings - such as hospitals, nursing homes, retirement homes, long-term care facilities, and schools –

present a unique public health challenge when it comes to wildfires and related illnesses. Not only do hospitals become triage or treatment centres for surges of patients seeking emergency care, but they also house vulnerable[1] populations requiring treatment on a short-term or a long-term basis. In addition, they are workplaces in which the employer has a duty to protect their workers from exposures that may cause illness or disease. Some of these workers may also fall into the category of 'vulnerable population'.

3. Literature Search

A series of literature searches across various databases were undertaken to identify both published and unpublished papers, as well as any reference texts, that might inform the review. Standard search engines (e.g., Medline and PubMed) and online databases (e.g., Google Scholar) were used to search both the peer-reviewed and the grey literature.

Search terms included: wildfire, forest fire, smoke, exposure, infiltration, control, intervention, hospitals, long-term care, nursing homes, schools, mitigation, case study, healthcare workers, air cleaners, filtration, effectiveness, infection control[2], hospital preparedness, hospital emergency planning. These terms were used in varying combinations, with results filtered by publication year (date range from January 2000 to February 2014). In each search, the first 250 hits were scanned by title and abstract to identify key papers and other related publications. Articles and book chapters were selected by review of abstracts and full text (if available). The reference lists of each paper were also hand searched for additional relevant publications. In total, 85 publications were downloaded for review, but only 20 were deemed to be of particular relevance.

Many of articles and books cited in this report were identified using the "Indexes and Databases" electronic search engine provided by the University of British Columbia Library. This search tool yielded articles from scholarly journals, newspapers, conference proceedings, as well as book chapters. A list of additional resources that public health practitioners may find useful is found in Appendix 1.

4. Results

This section of the report summarizes what is known about the composition of wildfire smoke, about how smoke enters a building, about filtration and filter effectiveness in general, and about the effectiveness of filtration during wildfire events in particular. No research has been undertaken to specifically evaluate the effectiveness of filtration for controlling wildfire smoke exposure in institutional settings and there are no case studies or formal evaluations offering guidance on measures to take to minimize infiltration in these settings. As a result, much of what is presented in this evidence review comes from the technical literature, as well as from guidance documents published by governmental agencies.

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[1] For example, individuals with asthma or other acute respiratory disease (such as airway hyper-responsiveness), individuals with chronic lung or heart diseases (such as chronic obstructive pulmonary disease, COPD), the elderly, smokers, children, and unborn children (3, California wildfire doc). The health impacts of exposure to wildfire smoke on vulnerable populations are addressed in Section 3 of this review.

[2] As the evidence base on the effectiveness of filtration to prevent penetration of wildfire smoke into institutional settings was limited, a secondary literature search was conducted to identify intervention studies in the area of infection control.

Of the articles reviewed in this project, only one reported on the challenges faced by health care providers during a wildfire event – namely, having to adapt medical care to respond to the surge in emergency room visits, as well as the number of staff requiring treatment for smoke inhalation; preparing a large-scale evacuation of special needs patients; and striking a balance between being emergency providers of health care and potentially being a wildfire victim at the same time (i.e., requiring treatment for smoke inhalation, being unable to get to work due to poor visibility and road congestion, and preparing to evacuate their own homes) (1).

4.1 What is known about smoke from wildfires

Smoke from wildfires is a complex mixture produced by the incomplete combustion of wood and other carbonaceous materials. It is comprised of numerous substances, including solid particulate matter (PM), water vapour, inorganic gases (such as carbon dioxide, carbon monoxide, nitrogen oxides), polycyclic aromatic hydrocarbons and other volatile organic chemicals (such as benzene, acrolein and formaldehyde), trace minerals, and levoglucosan (2, 3). The spatial and temporal factors affecting the composition of wildfire smoke, as well as the health impacts of exposure, are covered evidence reviews *Wildfire Smoke* and *Health Effects of Smoke*.

Carbon monoxide levels tend to be highest during the smoldering stages of a fire and are hazardous primarily for those in very close proximity. Because particulates from smoke tend to fall in the size range[3] that can be inhaled deeply into the lungs and that can be transported over long distances (4, 3, 5), the remainder of this evidence review focuses on filtration as a measure for controlling exposure to particulate matter.

4.2 What is known about how smoke enters a building

Smoke from a wildfire can enter a building through infiltration or air leakage. The Association of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) defines infiltration as the “flow of air into a building through cracks and other unintentional openings and through normal use of exterior doors for entrance or egress” (6). Building walls and roofs have many openings through which outside air can enter. Doors and windows, whether open or closed, usually allow some air to leak in[4]. There are openings in building roofs and walls designed to admit fresh air for ventilation and to allow air to escape from exhaust systems and sanitary sewer systems. In addition, there are joints in wall and roof systems that allow unintentional leakage.

Infiltration is driven by a natural or artificial pressure differential across the building envelope. Wind often drives air through building openings[5]. The degree to which wind impacts the ventilation rate of a

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[3] Particulate matter (PM) is classified on the basis of particle size. Fine particles have a median diameter of 2.5 micrometres (aka, microns) or less and are referred to as PM2.5. Large particles have a median diameter of 10 microns or less and are referred to as PM10. The concentration of particulate matter in air is measured and reported as “micrograms of particles per cubic metre of air”.

[4] Because they tend to stay open longer, automatic doors (e.g., sliding, swinging, rotating, or overhead) are a major source of air leakage in buildings (6).

[5] These may include: windows, doors, dormer openings, skylights, roof ventilators, stacks and specially designed inlets or outlets (6).

building is affected by such factors as average wind speed, prevailing wind direction, seasonal and daily variation in both speed and direction, local obstructions, and how much air leakage there is into the building. If the temperature inside the building is higher than outside, a force (called the stack effect) pulls air in near ground level and helps it escape from the roof or upper floor walls. The strength of the stack effect depends on the height of the building – the taller the building, the higher the stack effect.

In many buildings, the fans that discharge the air have more capacity than the fans bringing in replacement air. This creates a negative pressure difference across the building envelope and results in air being drawn in through many of the openings in the walls and roof. If a building is under negative pressure, air may also be drawn in through inactive exhaust fans and sanitary sewer vents. The implication of this during a wildfire event is that smoke outside the building will enter with the air coming though all leakage points.

When considering infiltration of smoke into a large building, it is important to not only take into account the potential for leakage *into* the building, but also the potential for air leakage *within* the building. That is, it is important to know what the patterns of air movement are between different rooms and public spaces, as well as across internal partitions (such as floors, elevator shafts and stairwells). The leakage characteristics of these internal partitions and how air moves through the building will determine smoke movement patterns during an unanticipated wildfire event (e.g., the likelihood that smoke will leak into “clean” sections of the building such as operating rooms, cancer or transplant wards, laboratories). A qualified professional, with expertise in ventilation engineering, can help assess a building’s vulnerability to smoke infiltration, as well as determine airflow patterns within the building and recommend strategies to manage the risk of exposure to smoke and other infectious or chemical agents present within the institutional setting.

4.3 What is known about filtration, in general

(a) Definition of Filtration

It is important to be aware of the distinction between air filtration and air cleaning as these methods are not interchangeable. Air filtration is the removal of particulate matter (PM) from air using an air-handling system and a porous (or semi-porous) media filter (or a bank of filters). Filtration is effective at removal of particulate matter, but not gases and vapours (such as carbon monoxide). Filtration systems can be “in-duct” (i.e., part of the building’s heating, ventilation and air conditioning (HVAC) system) or they can be portable (i.e., they clean the air from one room in the building). Air cleaning is the removal of gaseous contaminants from air using an air-handling system and sorbent filters (such as granular activated carbon, potassium permanganate impregnated alumina and impregnated carbon). Air cleaning sorbents are effective at collecting gases and vapours, but not aerosols and particulates(7). This review focuses on filtration. Since HVAC systems that are already in place and operational in many institutions they can be adapted for enhanced filtration in wildfire smoke situations.

(b) Filter Efficiency

Filters are characterized by their ability to capture particles. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) rates filters according to their Minimum Efficiency Reporting Value (MERV). MERV, which ranges from 1 to 20, is a measure of a filter's ability to capture particles between 0.3 and 10 microns (µm). If the particle size of the contaminant is known, an appropriate filter that has the desired PSE (particle size efficiency) for that particular particle size can be selected. Particle size efficiencies corresponding to specific MERV ratings are shown in Table 1, below.

Table 1: Particle size efficiency of MERV rated filters

MERV	Particle Size Range, µm			Applications
	3–10	1–3	0.3–1	
1	<20%	--	--	residential, light pollen, dust mites
2	<20%	--	--	
3	<20%	--	--	
4	<20%	--	--	
5	20– 35%	--	--	industrial, dust, moulds, spores
6	35–50%	--	--	
7	50–70%	--	--	
8	>70%	--	--	
9	>85%	<50%	--	industrial, Legionella, dust
10	>85%	50–65%	--	
11	>85%	65–80%	--	
12	>90%	>80%	--	
13	>90%	>90%	<75%	hospitals, smoke removal, bacteria
14	>90%	>90%	75–85%	
15	>90%	>90%	85–95%	
16	>95%	>95%	>95%	
17	--	--	≥99.97%	clean rooms, surgery, viruses
18	--	--	≥99.99%	
19	--	--	≥99.999%	
20	--	--	≥99.9999%	

Source: Adapted from NIOSH (7)

The higher the MERV rating, the more efficient the filter is at removing more and smaller-sized particles. High-efficiency particle air (HEPA) filters, which remove more than 99.97% of small particles 0.3 microns or larger (so long as there is no leakage around the filter and no damage to the pleated media), are equivalent to filters rated between MERV 17 and 20.

It is unlikely that MERV 13 or lower efficiency filters would provide effective protection from wildfire smoke. A higher degree of protection will be offered with increasing MERV rating, up to MERV 17.

(c) Factors Affecting Filter Performance

A number of factors influence the overall effectiveness of a filtration system. These include: the concentration and size of the particles, the type of filter used, and HVAC operating conditions (e.g., the rate of airflow through the filter, the efficiency of the filter, the extent of air leakage around the filter (also known as 'bypass'), the location of filters, the filter housing, and the filter maintenance schedule). In selecting an appropriate filter, it is important to know the size of the particles being removed (6, 8). The proportion of particles removed will depend on the filter media, the depth of the filter, and the pore size.

Bypass, or leakage of unfiltered air around filters, can have a significant impact on the efficiency of a filtration system (8). Ward and Siegel (9) developed a general model to estimate impact of bypass on the effectiveness of nine typical commercial and residential filters in a range of configurations (clean and dust-loaded, with bypass gaps typical of those found in real filter installations). Their simulations found that bypass can dramatically affect filter performance. For example, they found that a small gap (of approximately 1 mm) caused the rating of a MERV 15 filter to drop by 1 point, resulting in an effective MERV rating of 14. A large gap of 10 mm decreased the rating of the MERV 15 filter by 7 points, the MERV 11 filter by 3 points, and the MERV 6 filter by 1 point, resulting in effective MERV ratings of 8, 8, and 5 respectively. This is illustrated in Table 2, below. They found that respirable particles were more likely to bypass the filter and, as a result, they concluded that an HVAC system equipped with high efficiency filters may fail to perform as intended due to bypass. This finding could have implications for institutional settings during wildfire events with high $PM_{2.5}$ concentrations. The authors noted the importance that their findings be replicated in controlled experiments and in real HVAC systems.

Table 2: The Impact of Bypass on Filter Performance

Filter	Effective MERV Rating			
	1 mm gap, 2 bends	1 mm gap, 0 bends	0 mm gap, 2 bends	10 mm gap, 0 bends
MERV 6	6	6	5	<5
MERV 11	11	11	8	8
MERV 15	14	14	8	8

Source: Ward and Siegel (9)

4.4 What is known about the effectiveness of filtration in institutional settings

(a) Filtration Requirements in Healthcare Settings

Pressurization and filtration are two of the primary tools used in hospitals to minimize the migration of airborne infectious aerosols from one part of the building to another. Some isolation rooms are kept under negative pressure to prevent the spread of contaminants from the isolation room to other areas of the hospital, while others (such as “clean” rooms or surgical suites) are maintained under positive pressure to prevent the spread of contaminants into the clean room. In-duct HEPA filters are used, for example, in the supply air distribution side of protective rooms and the return air of infectious isolation rooms if the air is re-circulated to other parts of the facility.

In the United States, filtration requirements within healthcare facilities are published by the American Institute of Architects and are based on a consensus of authorities having jurisdiction, governmental regulatory agencies for public and workplace health, healthcare professionals, professional organizations such as ASHRAE, and accrediting organizations such as the Joint Commission on Accreditation of Healthcare Organizations. Health Canada and the Canadian Standards Association publish similar guidelines in Canada.

The minimum filtration requirements for US health care facilities are shown in Appendix 2. Under normal operating conditions, filters between MERV 8 and 15 are required. However, as noted in Table 1, above, filters with higher ratings (i.e., more efficient removal capacity) will be required under very dusty or very smoky conditions.

In a 2006 report on improving HVAC system performance to reduce exposure to aerosolized infectious agents, a working group of the Center for Biosecurity at the University of Pittsburgh Medical Center recommended that the effectiveness of filtration could be improved with pre-filters. That is, using one or more lower MERV filters in series with MERV 13 (or higher) filters. They note that while the use of a pre-filter can increase the life cycle of the final filters, this strategy should only be considered under heavy contaminant load conditions and after evaluating operating costs (e.g., filter and life cycle costs) (10).

(b) Effectiveness of Filtration in Institutional Settings During Wildfire Events

Despite the large number of wildfires around the world each year, there is a lack of literature on the effectiveness of filtration as a specific measure to prevent smoke from entering institutional settings during wildfire events. No well-designed intervention studies have been conducted to address this question. Given the unanticipated nature of these events, this is not surprising. The majority of published investigations into the impact of wildfires focus on hospital admissions, community exposures and interventions (e.g., the use of portable air cleaning devices in homes), exposure of fire suppression crews, wildfire management and disaster planning for capacity surges. While some studies have been published on the effectiveness of community interventions during wildfire events (e.g., the use of high-efficiency particulate air (HEPA) portable air cleaners in residential settings, the issuing of face masks (11, 12)), they yield little information that is transferable to an institutional setting.

In the absence of evidence from studies designed to evaluate this question, the best source of information to guide public health practitioners is the technical literature and government guidelines. What is known from the technical literature is that the loading rate of air filters is determined by the total concentration of suspended particulate matter in the atmosphere (6, 7). Therefore, it is possible to calculate the length of time to filter breakthrough if the airflow rate of the system is known and the concentration of smoke in air is either known or can be estimated.

Research conducted in a number of jurisdictions during various wildfire events has shown that the levels of particulate measured in the ambient air is many times higher than local air quality objectives[6]. For example, Henderson et al. (13) reported 24-hour PM_{10} levels ranging from 5.1 to 248.4 µg/m^3 in the southeastern corner of British Columbia during the fires of 2003. Wegesser et al. (14) reported a peak $PM_{2.5\text{-}10}$ value of 381 µg/m^3, with values between 200 and 380 µg/m^3 logged over a period of several hours during one day of the California wildfires of 2008. Reisen et al. (5) reported daily-averaged PM2.5 concentrations ranging from 0.6 µg/m^3 to 76.5 µg/m^3 and hourly $PM_{2.5}$ concentrations ranging from 0.6 µg/m^3 to 319 µg/m^3 in one rural location of southern Australia between 2006 and 2008.

In areas without continuous particulate matter monitoring stations or in situations where the concentration of smoke appears to be changing rapidly, it is possible to use visibility as a surrogate of particulate matter concentration, as shown in Table 3 (15).

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[6] For purposes of comparison, the 24-hour guidelines[6] for PM10 and PM2.5 in British Columbia, Canada and Australia are 50 µg/m^3 and 25 µg/m^3, respectively. The 24-hour PM10 guideline for California is 50 µg/m^3.

Table 3: Estimated Particulate Matter Levels (µg/m^3) from Visibility Index

Categories	Visibility, in		Particulate Matter Levels (1 hour average, µg/m^3)
	Miles	Kilometres	
Good	11 and up	17.6 and up	0 – 38
Moderate	6 – 10	9.6 – 16	39 – 88
Unhealthy for sensitive groups	3 – 5	4.8 – 8	89 – 138
Unhealthy	1.5 – 2.75	2.4 – 4.4	139 – 350
Very Unhealthy	1 – 1.25	1.6 – 2	351 – 526
Hazardous	less than 1	less than 1.6	over 526

Source: Adapted from http://www.arb.ca.gov/carpa/toolkit/data-to-mes/wildfire-smoke-guide.pdf (California Environmental Protection Agency, Air Resources Board)

Because concentrations of particulate matter may be quite episodic (i.e., levels of PM can be very high for short periods of time), smoke from wildfires can quickly overload filters and adversely impact on an air cleaner's ability to function properly. Therefore, it is important that filters with appropriate MERV ratings be selected, that the air handling system be capable of handling the additional power load, and that protocols be developed and implemented to ensure that they are changed out in a timely fashion.

In its wildfire smoke guide for public health officials[7] (15), the State of California recommends that employers consider a filter with a rating of MERV 17 or higher if the building occupants have respiratory or cardiac conditions or if the building experiences frequent wildfire episodes.

The advantage of filtration as a measure to control exposure to wildfire smoke is that increasing filter efficiencies is one of the few measures that can be taken in advance of a wildfire event. However, because switching to a more efficient filter (e.g., a MERV 17 filter in place of a MERV 13 filter) will have significant impacts on power requirements and operating costs, it is important that building owners have an understanding of their building and how their HVAC system works[8] *before* an unanticipated event, like a wildfire, occurs (16). Field studies conducted by NIOSH show that unless specific measures are taken to reduce infiltration, as much air may enter a building through air leakage as through the filtration system (7). A qualified professional, with expertise in ventilation engineering, can help assess a building's vulnerability to smoke infiltration, as well as determine airflow patterns within the building and recommend strategies to manage the risk of exposure.

(c) Effectiveness of Portable Air Cleaning Devices in Institutional Settings

Studies have been carried out to examine the effectiveness of portable air cleaners to reduce the transmission of infectious agents in hospital settings. For example, Rutala et al. (17) tested the efficiency of four portable high-efficiency air filtration units, (three HEPA, one 95% filter efficiency), for their ability to remove aerosolized particles in the 0.3 to 5.0 micron range. Portable units were placed in a non-ventilated test chamber and in a hospital isolation room that met tuberculosis control guidelines set by the US Centers for Disease Control. Tests were then carried out to measure the time required to remove 50%, 90% and 100% of the aerosolized particles. Results were compared to the time it took to achieve

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[7] This document was prepared by representatives of a number of state agencies with responsibility for public and environmental health, as well as internationally respected environmental health researchers.

[8] For example, it is important to consider such issues as filter bypass, life-cycle cost, building envelope and filtration.

the same reduction in concentration in a “control” room (i.e., one with no filtration units). They found that the time required to remove 90% of the aerosolized particles ranged from a low of 5-6 minutes to a high of 18-31 minutes in the non-ventilated room (compared to more than 171 minutes in the “control” room) and from a low of 5-8 minutes to a high of 9-12 minutes (compared to 12 to 16 minutes in the “control” room). They found that placing the unit in the centre of the room versus the corner of the room did not appreciably affect the results. Airflow rates through the unit were thought to be the most important factor affecting the rate of particle clearance, but this could not be evaluated in this experiment. The authors concluded that the units were effective in removing aerosolized submicron particles.

In a 2005 review of the literature (18), the Medical Advisory Secretariat of the Ontario Ministry of Health and Long-Term Care identified the following as factors that influence the effectiveness of an in-room air cleaner in hospitals: the single-pass efficiency of the filter, the airflow rate through the filter, the airflow patterns in the room, the positioning of the units within the room and the relative positions of the source of contamination and the receptor to the air cleaner. They noted that the effectiveness of these units is highly variable and recommended that placement and set-up of these units, whether fixed or portable, should be done in consultation with a qualified professional.

(d) Effectiveness of Portable Air Cleaning Devices in Non-Institutional Settings

Some studies have investigated the use of portable air cleaning units to reduce infiltration of air pollutants in residential settings, schools and retirement homes. Ward et al. (19) examined the effectiveness of stand-alone air cleaners at reducing bio-aerosol concentrations for shelter-in-place strategies in residential dwellings. Through a modeling exercise, they found maximum reductions in concentrations as high as 90% (relative to outdoor air) when one to three portable HEPA air cleaners were used.

This issue is looked at in more detail in the evidence review *Air Shelters*, which examined the effectiveness of portable air cleaners at reducing exposure to wood smoke and other indoor air pollutants in residential settings. As noted in that section, the effectiveness of these units is highly variable. The most important determinant of effectiveness was appropriate sizing of the unit. Sizing should take into account not only the size of the room in which it is to be used, but also the air exchange rates within the room and the home. In general, higher reductions in concentration are seen in rooms with lower air exchange rates. As a result, more than one air cleaner may be required to filter air in a large space or in a space with high air exchange rates.

5. Summary and Conclusions

To date, there have been no well-designed studies evaluating the evidence of filtration as an effective measure to control fire smoke exposure in institutional settings. As a result, the most useful sources of information for developing strategic recommendations for public health practitioners to reduce the potential for infiltration in institutional settings are the following: the technical literature on ventilation and filtration (which is informed from the results of controlled experiments in laboratory settings and upon which regulatory standards or ventilation requirements are based), guidance documents published by governmental agencies such as NIOSH and Cal/OSHA (which are informed by the technical literature, as well as available scientific evidence, and are developed through consensus of technical experts, policymakers, and scientists), and recently published books on hospital preparedness for bioterrorism attacks and other unanticipated events (see, for example, references 8, 16, 20).

Key points, evidence gaps and considerations for filtration in institutional settings are summarized at the beginning of this evidence review. A systems approach for hospital preparedness for wildfire events is provided in Appendix 3. This approach is intended to provide some high level guidance to owners of institutional buildings on how to assess where their HVAC system may be vulnerable to infiltration from wildfire smoke. It is not intended to replace the advice of a trained ventilation engineer or technician.

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Appendix 1: Additional Resources for Public Health Practitioners

- 2009 Victorian Bushfires Royal Commission: http://www.royalcommission.vic.gov.au/
- ASHRAE. Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning. 2009. To download the guide: http://iaq.ashrae.org/
- BC Air Quality website. http://www.bcairquality.ca/index.html
- California Environmental Protection Agency, Air Resources Board: http://www.arb.ca.gov/carpa/toolkit/data-to-mes/wildfire-smoke-guide.pdf
- Global Fire Monitoring Center: http://www.fire.uni-freiburg.de/
- Insurance Institute for Business and Home Safety: http://www.disastersafety.org/wildfire/
- International Journal of Wildland Fire: http://www.publish.csiro.au/nid/114/paper/WF12010.htm
- Lawrence Berkeley National Laboratory – Indoor Air Quality Scientific Resources Data Bank: http://energy.lbl.gov/ied/sfrb/vent-illness.html
- Lawrence Berkeley National Laboratory – Secure Buildings: http://securebuildings.lbl.gov/links.html
- National Center for Disaster Medicine and Public Health: http://ncdmph.usuhs.edu/KnowledgeLearning/2013-Wildfires.htm
- National Fire Protection Association: http://www.nfpa.org/safety-information/for-consumers/outdoors/wildland-fires
- McIsaac, Joseph H. Hospital Preparation for Bioterror: A Medical and Biomedical Systems Approach. Academic Press, Burlington, MA, USA. 2006. 461pp. (See Chapters 7, 10, 12, 14, 16, 18, and 22; and, Appendices A, C, D, F.)
- State Compensation Fund of California: http://www.statefundca.com/safety/losscontrol/LossControlArticle.aspx?ArticleID=518
- US Centers for Disease Control and Prevention: http://www.cdc.gov/Features/Wildfires/
- US Federal Emergency Management Agency: https://www.llis.dhs.gov/content/wildland-fires-1
- UPMC Center for Health Security – Protecting Building Occupants from Biological Threats: http://www.upmchealthsecurity.org/website/resources/multimedia/2008-protecting_building_occupants/index.html
- WorkSafeBC. Indoor Air Quality: A Guide for Building Owners, Managers and Occupants. 2005. http://www.worksafebc.com/publications/health_and_safety/by_topic/assets/pdf/indoor_air_bk89.pdf

Appendix 2: US Health Care Facility Filtration Requirements

Area Designation	Number of Filter Beds	Filter Bed # 1 Efficiency	Filter Bed # 2 Efficiency
All areas for inpatient care, treatment, and diagnosis, and those areas providing direct service or clean supplies such as sterile and clean processing, etc.	2	MERV 8	MERV 14
Protective environment room	2	MERV 8	99.97 (MERV 15)
Laboratories	1	MERV 13	
Administrative, Bulk storage, Food preparation areas, Laundries, Soiled holding areas	1	MERV 8	

Source: Guidelines for Design & Construction of Hospital & Health Care Facilities, The American Institute of Architects Academy of Architecture for Health, US Department of Health & Human Services

Appendix 3: A Systems Approach for Hospital Preparedness for Wildfire Events

The following has been adapted from the literature on enhancing the resistance of buildings to security threats. Sources include: Hospital Preparation for Bioterror by JH McIsaac; Development of Assessment Protocols for Security Measures – A Scoping Study by W Bahnfleth et al., and Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks by NIOSH.

This Appendix is intended to provide some high level guidance to owners of institutional buildings on how to assess where their HVAC system may be vulnerable to infiltration from wildfire smoke. It is not intended to replace the advice of a trained ventilation engineer or technician.

Information is organized into three distinct sections: pre-planning for an unanticipated wildfire event, immediate or reactionary measures during the event, and long-term planning.

1. Pre-Planning Measures

The following are recommended steps that building owners and employers should take before a wildfire event occurs. Many of these are good practice to ensure the proper functioning of the building's HVAC system, as well as to document compliance with appropriate regulatory requirements.

1. Have a trained technician and/or engineer conduct a complete inspection of the building's HVAC system to ensure that the system has been appropriately designed and is in good working order.
    - The inspection should document that the appropriate high-efficiency filters have been installed (i.e., that they do not exceed the static pressure limits of the system and that they have particle removal ratings consistent with their purpose) and that the filters are in good working order (i.e., they are clean, undamaged, in their proper place and not leaking around the edges). Depending on the indoor air pollutants present in the facility and their proximity to vulnerable patients, filters with a MERV[9] rating of 6 to 11 may be appropriate under normal operating conditions. However, filters with higher ratings (i.e., more efficient removal capacity) will be required under very dusty or very smoky conditions. In its guidelines to workers, CAL/OSHA recommends that employers consider a filter with a rating of MERV 17 plus if the building occupants have respiratory or cardiac conditions or if the building experiences frequent wildfire episodes.
    - If the inspection identifies deficiencies, immediately replace and/or repair any damaged or leaking or inappropriately sized/rated filter. Guidance and sample checklists are found in the indoor air quality guides published by AHSRAE and WorkSafeBC (see the Resource List in Appendix 2).
    - The inspection should determine and document the amount of outside air required to prevent a negative pressure differential across the building and to sufficiently ventilate areas of the building housing hazardous processes (e.g., laboratories) or vulnerable populations (for

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[9] MERV is an acronym for Minimum Efficiency Reporting Value. It is a measure of a filter's ability to capture larger particles between 0.3 and 10 microns (µm) and is derived from a test method developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).

example, patients with respiratory, cardiac or immune-compromised conditions). The inspection should factor in such issues as areas, such as the emergency room where the doors open frequently and operating rooms where there is a need for sterile conditions.

2. Conduct a walk-through inspection of each department, to ensure that all indoor sources of pollution (and the methods of controlling them) are appropriately identified and documented. This information must be factored into any decisions made regarding if and when to shut off systems or reduce the amount of outdoor air in certain parts of the building (for example, the proper storing of reagents in laboratories must be considered before cutting off a lab's ventilation system). Sample checklists for conducting such an inspection are found in WorkSafeBC's Indoor Air Quality Guide (see the Resource List in Appendix 2).
3. The employer should purchase an adequate supply of appropriately rated filters in the event that smoke overloads the filters. In addition, the employer should ensure that systems are in place to ensure that filters are checked regularly before, throughout and after the fire event to verify that they are functioning properly. The employer should invest in and install pressure gauges across the filters to provide an objective indicator of when the filter needs to be replaced.
4. The employer should invest in equipment to monitor levels of indoor particulate, carbon dioxide and carbon monoxide, and consider standby or portable air cleaning devices for situations where they have to reduce general ventilation rates.
5. The employer should identify a shelter-in-space that is isolated from the rest of the building to provide a safe location for employees and vulnerable patients that cannot be evacuated, should the need arise. Important considerations for selecting an appropriate space include: adequate filtration efficiency, adequate airflow, adequate training and preparation of staff, as well as the identification of sufficiently safe paths for staff and patients to travel from their normal locations to the shelter.
6. The employer should develop a written protocol outlining the procedures to be followed during an unanticipated event and ensure that all workers are adequately trained. The protocol should consider all possible scenarios, like having the turn off the ventilation system and/or sealing up openings in the buildings, and the possible impacts on both workers and vulnerable patient populations. Local regulatory requirements (such as the number of fire exits required under the local fire code and the control of hazardous indoor air pollutants under the local occupational health and safety regulations) must be factored in.

2. Immediate/Reactionary Measures

The following are steps that building owners and employers can take to minimize the risk of exposure to workers and vulnerable patient populations during a wildfire event.

1. Pay regular attention to the local wildfire smoke advisories[10].
2. Keep all doors and windows closed as much as possible.
3. Use entrances with vestibules and ensure only one door is open at a time

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[10] For example, in Canada, wildfire smoke forecasts can be found here for Western Canada: http://www.bcairquality.ca/bluesky/west/index.html and here for Eastern Canada: http://www.bcairquality.ca/bluesky/east/index.html.

4. Seal up other openings to the extent possible, factoring in what is safe and legal. If a shelter-in-place has been created, ensure that the paths to the shelter are not sealed up.
5. Turn off exhaust fans, where possible, to maximize positive pressure in the building. Shut down equipment that requires exhaust, wherever practical.
6. Turn off HVAC or air supply units that have poor air filtration (e.g., MERV 12 or lower).
7. Adjust the HVAC system to control fresh air intake, to recirculate indoor air and to isolate zones that are not essential.
8. Monitor indoor air quality (especially particulates, carbon dioxide and carbon monoxide) to guide decisions about HVAC system adjustments.
9. Monitor outdoor air quality data (if possible) or pay attention to local air quality advisories to guide operation of outdoor air dampers or HVAC units. Do not bring in air that contains more than 20 ppm carbon monoxide or more carbon dioxide than indoor air.

3. Long-term Planning

The following are steps building owners and employers could consider in the long-term to minimize the impact of an unanticipated event like a wildfire. Either option is likely to require consider significant capital expenditures.

1. If the pre-planning inspection identifies serious deficiencies in the design of the HVAC system, the building owner should consider retrofitting the building with a system designed to handle not only the day-to-day operational needs of the building, but also unanticipated events that could potentially overload the system’s capacity. When retrofitting HVAC systems, it is important that the modifications be designed to accommodate the increase in pressure that will accompany the use of higher efficiency filtration. This may necessitate changes in the physical size of the unit. Other retrofitting options include: relocation of air intakes and isolation of the more vulnerable spaces.
2. In designing new buildings, the architects and engineers should collaborate to design an HVAC system that not only meets its day-to-day operational requirements (for heating, cooling, humidification, dehumidification, and contaminant removal) but also can be adapted to respond to unanticipated events that might make the system vulnerable. For example, are there advantages to a recirculating vs. a once-through system, and how can the air supply and return systems be designed to minimize leakage and cross-contamination.