

Examining the effectiveness of public health interventions to address wildfire smoke, combined heat-smoke events and pollutants

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Context

- Wildfires are increasing in size and frequency worldwide, due in part to hotter and drier conditions caused by global climate change.
- Canada is experiencing an unprecedented wildfire season that has so far affected 12 provinces and territories across the country, and it is expected that conditions conducive to wildfires will continue posing prolonged impacts.
- In addition to the destruction of property and risk of injury from exposure to fire, wildfire smoke contains components known to be harmful to human health, including carbon monoxide, fine particulate matter and other hazardous air pollutants.
- Short or repeated exposure to these components may impact individuals' physical health, including reductions in lung capacity and acute bronchitis, as well as result in mental health and socio-economic consequences due to evacuations and displacement associated with fires and smoke.
- The issue is particularly complex as wildfire smoke can significantly impact the air quality and introduce dangerous pollutants in areas far from where wildfires are taking place.
- Identifying different mitigation measures and their effectiveness is important to reduce the effects (and unintended consequences) of exposure to wildfire smoke, combined heat-smoke events and associated pollutants.
- This rapid evidence profile provides an overview of relevant evidence syntheses and primary studies as well as experiences in relation to the question and framework below.
- The profile provides high-level findings from the included evidence but is not a fulsome synthesis and does not include quality assessments for included single studies, though AMSTAR ratings are provided for included evidence syntheses.

Questions

- What is the evidence for the effectiveness and potential unintended consequences of public health interventions that can be used to reduce the direct and indirect health impacts of exposure to wildfires, including wildfire smoke, combined heat-smoke events and other pollutants associated with wildfires?

High-level summary of key findings

- We identified five evidence syntheses and 25 single studies relevant to the question, of which three evidence syntheses and 15 single studies were determined to be highly relevant.
- Significant gaps in the literature from the past five years were identified, including:
 - an uneven distribution of evidence across mitigation strategies, with many evidence documents pertaining to the use of enhanced heating, ventilation and air conditioning (HVAC) systems and risk communication strategies
 - very limited evidence (findings from three single studies) that examines the health, mental health or socio-economic outcomes resulting from public-health measures

- almost no evidence that considers the relative effectiveness of these measures on equity-deserving populations.
- Across each of the five mitigation interventions, we found:
 - risk communication was primarily focused on expanding reach and compliance, and emphasized the importance of short plain-language content tailored to specific populations (e.g., those who do not speak English, those who are unable to adhere to advice for the general population)
 - respirators, including N95 masks, were found to be effective in three studies at capturing wildfire smoke and pollutants
 - high-efficiency air filters could be used to transform public spaces such as libraries into cleaner air spaces
 - increasing the minimum filter efficiency and using portable air cleaners with high-efficiency particulate air filters can be effective in reducing indoor PM2.5 levels, but additional measures may be needed in cities with sustained or severe transient exposure
 - significant mental health outcomes and socio-economic effects were reported as a result of wildfire evacuations, including anxiety, depression and post-traumatic stress disorder, as well as material and financial losses and displacement of communities; stress from evacuations had concerning effects on pregnant women and new mothers (e.g., intrauterine growth restriction, small gestational age and a reduction in breast feeding).
- We also identified guidance from six Canadian provinces and territories and the U.S. that noted many of the same interventions, including monitoring air quality using the Air Quality Health Index, weather forecast and nationally issued advisories, and basing public health advice on levels of smoke and particulate matter.

Framework to organize what we looked for

- Type of exposure
 - Wildfire smoke

Box 1: Approach and supporting materials

We identified evidence over the past five years addressing the question by searching [Health Systems Evidence](#), [Social Systems Evidence](#), [Health Evidence](#), [PubMed](#) and [Scopus](#) (note that the first three are one-stop shops that identify and index evidence syntheses from many sources). All searches were conducted on 25 July 2023. The search strategies used are included in Appendix 1. We also hand searched government and stakeholder websites of Canadian provinces and territories and select countries (Australia, France, Italy, California in the U.S.) to identify any guidelines or guidance relevant to the question.

In contrast to synthesis methods that provide an in-depth understanding of the evidence, this profile focuses on providing an overview and key insights from relevant documents.

We searched for full evidence syntheses (or synthesis-derived products such as overviews of evidence syntheses), protocols for evidence syntheses and single studies (using targeted searches).

We appraised the methodological quality of evidence syntheses that were deemed to be highly relevant using AMSTAR. AMSTAR rates overall quality on a scale of 0 to 11, where 11/11 represents a review of the highest quality. The AMSTAR tool was developed to assess reviews focused on clinical interventions, so not all criteria apply to evidence syntheses pertaining to delivery or financial or governance arrangements within health systems or to broader social systems.

We assess all documents using the PROGRESS+ framework to identify those that provide equity-relevant findings.

A separate appendix document includes:

- 1) methodological details (Appendix 1)
- 2) details about each identified synthesis (Appendix 2)
- 3) details about each identified single study (Appendix 3)
- 4) evidence-based guidelines identified through a jurisdictional scan (Appendix 4)
- 5) documents that were excluded in the final stages of review (Appendix 5).

This rapid evidence profile was prepared in the equivalent of three days with a ‘full-court press’ by all involved staff.

- Combined wildfire smoke and heat
- Pollutants
 - Particulate matter (e.g., PM2.5 or smaller)
 - Other chemicals (e.g., polycyclic aromatic hydrocarbons, nitrogen oxides, benzene, acid gases)
- Duration of exposure
 - Short term/immediate
 - Repeated short term
 - Long term
- Mitigation interventions
 - Risk communication
 - Assess risk using Air Quality Health Index (AQHI)
 - Determine when to reschedule outdoor activities
 - Protect indoor air quality (e.g., keep windows and doors closed)
 - Understand how and when to use cleaner air spaces
 - Identify what is needed for evacuation preparation
 - Protect and promote mental health
 - Masks
 - Respirators, including N95 masks
 - Surgical, with valves
 - Surgical, without valves
 - Other
 - Cleaner air spaces
 - Public cleaner air spaces
 - Private cleaner air spaces
 - Enhanced HVAC
 - Evacuation
- Interventions for mitigating unintended consequences of public health interventions on equity-seeking populations
- Settings
 - Community settings
 - Community centres
 - Schools
 - Parks and outdoor recreational sites
 - Healthcare settings
 - Community care centres
 - Hospitals
 - Long-term care homes
- Populations
 - Children
 - Indigenous people
 - People living in areas directly affected by wildfires
 - Occupations directly affected by wildfires
 - Healthcare workers
 - Individuals with pre-existing conditions (e.g., respiratory or cardiac conditions)
 - Pregnant women
 - Older adults
- Outcomes
 - Physical health outcomes
 - Injuries and burns
 - Effects on pre-existing conditions (e.g., cardiovascular and respiratory diseases)

- Obstetric outcomes (e.g., low birthweight, pre-term birth)
- Respiratory conditions (e.g., bronchitis, chronic obstructive pulmonary disease, asthma)
- Mental health outcomes
 - Anxiety
 - Depression
 - Post-traumatic stress disorder
 - Personal and community isolation
 - Substance use
- Socio-economic effects
 - Displacement of individuals and communities
 - Employment and labour challenges
 - Economic hardship
 - Property destruction

What we found

Our searches of the literature from the last five years identified 30 evidence documents relevant to the question. This included five evidence syntheses conducted between 2020 to 2022 and 25 single studies conducted between 2019 and 2023 (except one highly relevant older study from 2015 identified by requestors). Of these, three evidence synthesis and 15 single studies were considered highly relevant. Normally, we would not classify modelling studies as highly relevant (as their results may be difficult to extrapolate to the real world), but given the lack of identified findings from evidence syntheses and other studies, we have done so for this profile.

Gaps in existing evidence syntheses and single studies

We identified very few high-quality, recent-evidence syntheses to answer the question, which means that many of the included findings come from single studies, including modelling studies. While the 20 highly relevant evidence documents include insights about each of the five mitigation interventions outlined in the above framework, most covered the use of enhanced HVAC systems (as well as portable air cleaners with high-efficiency particulate air filters) or risk communication strategies.

We found a significant gap in the evidence examining the health, mental health or socio-economic outcomes resulting from public-health measures. Mask wearing was the only intervention with evidence related to the effectiveness of mitigating the health risks from exposure to smoke or pollutants. However, even this evidence was limited as it comes from three single studies, one of which was included in a high-quality evidence synthesis.

There was also a considerable gap in the literature related to the effectiveness of these measures on equity-deserving populations.

We provide key insight below about each of the five interventions with additional details related to the findings and gaps in the identified evidence in Table 1.

Key findings from highly relevant evidence documents

The evidence on risk communication was primarily focused on expanding reach and compliance. This evidence pointed to the need for short plain-language content that is tailored to populations, notably those who do not speak English and those who are unable to adhere to advice for the general population (e.g., individuals who are homeless or precariously housed).(1-4)

We found three single studies that provided evidence about effects of respirators. In these studies, respirators, including N95 masks, were found to be the most effective as compared to those not wearing respiratory protection

(5; 6) or wearing natural fibre masks (7) at capturing wildfire smoke and pollutants. In the third study, which was included in a high-quality evidence synthesis, masks were found to be effective at improving skin hygiene and possibly reducing respiratory conditions caused by wildfire pollutants for occupationally exposed individuals.(5)

A single study focused on public cleaner air spaces, but did not examine the effectiveness of these spaces at mitigating the health effects of wildfire smoke. Instead, it provided insight about the extent to which high-efficiency air filters could be used to transform public spaces such as libraries into cleaner air spaces.(8)

Evidence related to enhanced HVAC systems focused on the effectiveness of interventions to reduce smoke or pollutants on PM2.5 levels, but none provided evidence related to health, mental health or socio-economic outcomes. One simulation study found that increasing the minimum filter efficiency may be effective in moderate exposure cities, but additional measures may be needed to reduce indoor PM2.5 levels in cities with sustained or transient severe exposure.(9) Three single studies, including one simulation study, found that portable air cleaners with high-efficiency particulate air filters can help to reduce indoor PM2.5 levels.(9-11) A fourth study found that lower-cost methods made from a MERV-13 filter attached to a box fan can help to reduce indoor exposure to PM2.5 during wildfire events.(12)

Lastly, four studies were identified related to evacuation due to wildfires (13-15) and wildfire smoke.(16) One of the studies examined aerosol concentration before and after evacuation due to wildfire smoke (16), while the three other studies focused on the unintended consequences of evacuations.(13-15)

The evidence related to evacuation due to wildfires included experiences from Fort McMurray, Alberta, where a large proportion of the population was evacuated. However, it does not include a comparison to any individuals who were able to or chose to stay and therefore self-reported effects cannot be solely attributed to the experience of evacuation. Findings from the included studies identified significant self-reported impacts of evacuation on mental health and socio-economic outcomes at three months and three years after evacuation. Self-reported impacts included increased levels of emotional and mental health disorders, including post-traumatic stress disorder, anxiety and depression, cognitive impairments following the evacuation, material and financial losses, and changes to individuals' physical conditions including sleep problems and weight changes.(13) In addition, findings from qualitative evidence noted that stress from evacuations had concerning effects on pregnant women and new mothers, with participants reporting intrauterine growth restriction, small gestational age and a reduction in breast feeding.(14; 15)

The single study examining evacuations in Canada due to smoke found that between 27 and 39% of evacuations that took place between 2000 and 2007 were ineffective or suboptimal to protecting individual's health.(16) This was a result of either post-evacuation aerosol concentration being higher than pre-evacuation (which occurred in approximately half of the ineffective evacuations) or in select cases where the threat of unhealthy levels of exposure had already passed when evacuation orders were made.(16) The study did not directly examine the effects of evacuations on health, mental health or socio-economic outcomes.

Key findings from a jurisdictional scan of guidance documents to reduce the direct and indirect health impacts of exposure to wildfires

In addition, we identified guidance from six Canadian provinces ([BC 1](#); [BC 2](#); [BC 3](#); [AB](#); [MB](#); [NFL](#)) and territories ([NWT](#); [YK](#)), one state in Australia ([AU](#)), and the U.S. ([US 1](#); [US 2](#); [US 3](#)). Guidance was included if it provided a reference list that demonstrated a clear grounding in evidence. Many other jurisdictions had developed reports, fact sheets and frequently asked questions pages related to public health interventions during wildfires, but these did not demonstrate sufficient grounding in evidence to be included. They are included alongside other excluded documents in Appendix 5.

In Canada, the most recent and extensive guidelines were from British Columbia and the Yukon, while several recent guidelines were also identified from the U.S. In general, guidelines noted many of the same interventions, including:

- monitoring air quality using the Air Quality Health Index, weather forecast and nationally issued advisories
- basing public health advice on levels of smoke and particulate matter, which may include
 - cancelling or rescheduling outdoor activities and avoiding strenuous exercise
 - staying indoors and closing windows and doors
 - using high-efficiency filters in HVAC systems to reduce particle concentration indoors
 - opening community cleaner air spaces in libraries, community centres and other spaces
 - reducing other sources of indoor air pollution including from smoking, woodburning or frying or broiling
 - evacuating after consideration of contextual factors (see below) and when other interventions have been found to be ineffective.

For evacuation, the [Yukon wildfire smoke response guideline](#) indicated that contextual factors that support evacuation include high levels of smoke concentration that is expected to last several days, smoke that is of high toxicity (e.g., due to the nature of materials burning, such as fuel) and identification of smoke-related impacts. The same guideline also notes several factors that improve evacuation success, which include early evacuation of vulnerable people who require the most care, addressing barriers to evacuation for some people (e.g., financial, evacuation of pets or livestock), planning for and ensuring capacity and funding to execute a timely evacuation, and a coordination plan for smoke and fire-related evacuation.

In addition to the guidance, we identified [a review of public health guidance](#) in Canada, which identifies planning considerations, forecasting systems and lessons learned from public health practitioners related to public-health decision-making in the context of wildfires.

Table 1. Key findings on the effectiveness of public health interventions for mitigating the effects of smoke, combined heat-smoke events and pollutants due to wildfires*

Intervention	Key findings	Key gaps
Risk communication	<ul style="list-style-type: none"> • Short health-alert-style messages with plain-language content warning of the effects of smoke were found to be more likely to be recalled and complied with than longer, more technical content (1; 2) <ul style="list-style-type: none"> ○ Guidance, timeframe, geographic location and specific hazards were noted as critical factors to include (2) ○ Using directive language such as ‘evacuate,’ ‘now’ and ‘update’ increased public participation and uptake of messages (2) • Television, online and smart-phone based (e.g., mobile apps) communications for smoke warnings were preferred sources of information, and were effective for particular populations (e.g., children with asthma), with exception of older adults who preferred radio and television communications (1; 4) • Tailored, translated and more frequent messaging warning before wildfire season and during periods of smoke were found to be effective approaches at increasing the reach of communications (3) 	<ul style="list-style-type: none"> • None of the identified evidence addressed effectiveness on health, mental health, or socio-economic outcomes • Very little of the identified evidence provided a comparative perspective (e.g., evaluating different approaches to risk communication) • Additional research is needed to identify the most effective ways to target risk communication for populations at the highest risk of smoke exposure and those who cannot adhere to general advice (e.g., individuals who are homeless or those who are precariously housed)
Masks	<ul style="list-style-type: none"> • Particulate/organic vapor/formaldehyde filter masks reduced respiratory symptoms compared to either particulate only or particulate/organic vapor masks for those with occupational exposure to wildfire smoke (5) • Respirator masks were found to provide efficient protection for all particle types, followed by surgical masks and then cloth masks, with surgical and cloth masks capturing wildfire smoke at an efficiency of between 30 and 100% (6) 	<ul style="list-style-type: none"> • Very little (one study included in a high-quality evidence synthesis and two single studies) addressed the effectiveness of mask wearing during wildfires on health, mental health or socio-economic outcomes
N95	<ul style="list-style-type: none"> • N95 masks improved skin hygiene on polycyclic aromatic hydrocarbons exposure in field settings for those with occupation exposure to wildfire smoke (5) • N95 mask usage protected against the negative effects of pollutants during wildfires and may reduce the risk of respiratory health conditions caused by wildfire pollutants (7) 	<ul style="list-style-type: none"> • Most of the literature addressed mask wearing among those that are occupationally affected by wildfires rather than the general public or particularly vulnerable individuals
Cleaner air spaces	<ul style="list-style-type: none"> • High-efficiency particulate air filters can be used to transform indoor community spaces such as libraries into public cleaner air spaces, including reducing PM2.5 concentrations by up to 70% compared to outside (8) 	<ul style="list-style-type: none"> • None of the identified evidence examined the extent to which spaces were used • None of the identified evidence addressed the effectiveness on health, mental health or socio-economic outcomes
Enhanced HVAC	<ul style="list-style-type: none"> • A simulation of the effects of ventilation systems on wildfire smoke and pollutants in four Canadian cities that varied in proximity to wildfires found that existing recommendations for minimum filters for indoor residential spaces are insufficient when increased outdoor PM2.5 levels are present 	<ul style="list-style-type: none"> • None of the identified evidence addressed its effectiveness on health, mental health, or socio-economic outcomes

	<ul style="list-style-type: none"> ○ In moderate exposure cities, a single MERV 16 air filter or multiple MERV 13 filters were sufficient to reduce the indoor 24-hour peak exposure to below the exposure limit ○ However, in cities with sustained or transient severe exposure other techniques are required in addition to using multi-filter mechanical ventilation models and upgrading the minimum filter efficiency (9) ● Portable air cleaners with high-efficiency particulate air filters have been identified as an approach in both simulation and real-world studies to reduce indoor PM2.5 levels (9-12; 17) <ul style="list-style-type: none"> ○ One single study noted that high-efficiency particulate air filters are particularly useful in residential facilities with low-air exchange that are exposed to repeated short-term wildfire smoke (10) ● Closed and non-ventilated buildings as well as positively pressurizing building can be effective in reducing exposure to particulate matter during wildfires (17; 18) ● Low efficiency filters that are frequently used in residential buildings are not sufficient to control the infiltration of smaller smoke particles (18) ● DIY air cleaners (made out of a box fan and a furnace filter) were found to be a cost-effective alternative to commercial air cleaners and showed comparable performance during wildfire smoke events to commercially available air cleaners (19) 	
Evacuations	<ul style="list-style-type: none"> ● Significant mental health outcomes and socio-economic effects were reported by some participants as a result of evacuating due to wildfires including emotional and mental health disorders such as anxiety, depression and post-traumatic stress disorder, as well as material and financial losses and displacement of communities (13; 16) <ul style="list-style-type: none"> ○ Early preparation and early evacuation were reported by some participants to have been helpful to reduce some anxiety, while others reported the adoption of new adaptive coping strategies and healthy living habits ● Stress from evacuations due to wildfires were reported to have had an effect on obstetric outcomes from pregnant women including intrauterine growth restriction and small gestational age, as well as resulting in a reduction in breast feeding and a larger reliance on formula (14; 15) 	<ul style="list-style-type: none"> ● Evidence comes predominantly from qualitative single studies
Other	<ul style="list-style-type: none"> ● Paper filter windows made from Hanji paper (from the bark of a mulberry tree) significantly reduced PM2.5 particles as well as CO₂ concentrations in homes due to smoke during wildfires (20) 	

* Typically, we would include findings by the outcomes in the organizing framework, but so few were identified that we instead focused on the high-level findings from effects of interventions identified and any key gaps within the literature. Where possible, we do link interventions to identified outcomes.

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References

1. Keegan SA, Rahman KM. Health protection messaging for populations susceptible to air pollution during landscape fire smoke events: an integrative review. *Reviews on Environmental Health* 2021; 36(4): 599-609.
2. Heaney E, Hunter L, Clulow A, Bowles D, Vardoulakis S. Efficacy of communication techniques and health outcomes of bushfire smoke exposure: A scoping review. *International Journal of Environmental Research and Public Health* 2021; 18(20): 10889.
3. Shellington EM, Nguyen PDM, Rideout K, et al. Public health messaging for wildfire smoke: Cast a wide net. *Frontiers in Public Health* 2022; 10: 773428.
4. Postma JM, Odom-Maryon T, Rappold AG, et al. Promoting risk reduction among young adults with asthma during wildfire smoke: A feasibility study. *Public Health Nursing* 2022; 39(2): 405-14.
5. Koopmans E, Cornish K, Fyfe TM, Bailey K, Pelletier CA. Health risks and mitigation strategies from occupational exposure to wildland fire: a scoping review. *Journal of Occupational Medicine and Toxicology* 2022; 17(1): 2.
6. Wagner J, Macher JM, Chen W, Kumagai K. Comparative mask protection against inhaling wildfire smoke, allergenic bioaerosols, and infectious particles. *International Journal of Environmental Research and Public Health* 2022; 19(23): 15555.
7. Kodros JK, O'Dell K, Samet JM, L'Orange C, Pierce JR, Volckens J. Quantifying the health benefits of face masks and respirators to mitigate exposure to severe air pollution. *Geohealth* 2021; 5(9): e2021GH000482.
8. Wheeler AJ, Allen RW, Lawrence K, et al. Can public spaces effectively be used as cleaner indoor air shelters during extreme smoke events? *International Journal of Environmental Research and Public Health* 2021; 18(8): 4085.
9. Shum C, Zhong L. Wildfire-resilient mechanical ventilation systems for single-detached homes in cities of Western Canada. *Sustainable Cities and Society* 2022; 79: 103668.
10. Xiang J, Huang C-H, Shirai J, et al. Field measurements of PM2.5 infiltration factor and portable air cleaner effectiveness during wildfire episodes in US residences. *Science of The Total Environment* 2021; 773: 145642.
11. Stauffer DA, Autenrieth DA, Hart JF, Capoccia S. Control of wildfire-sourced PM2.5 in an office setting using a commercially available portable air cleaner. *Journal of Occupational and Environmental Hygiene* 2020; 17(4): 109-120.
12. May NW, Dixon C, Jaffe DA. Impact of wildfire smoke events on indoor air quality and evaluation of a low-cost filtration method. *Aerosol and Air Quality Research* 2021; 21(7): 210046.
13. Thériault L, Belleville G, Ouellet MC, Morin CM. The experience and perceived consequences of the 2016 Fort McMurray fires and evacuation. *Frontiers in Public Health* 2021; 9: 641151.
14. Pike A, Mikolas C, Tompkins K, Olson J, Olson DM, Brémault-Phillips S. New life through disaster: A thematic analysis of women's experiences of pregnancy and the 2016 Fort McMurray wildfire. *Frontiers in Public Health* 2022; 10: 725256.
15. DeYoung SE, Chase J, Branco MP, Park B. The effect of mass evacuation on infant feeding: The case of the 2016 Fort McMurray wildfire. *Maternal and Child Health Journal* 2018; 22(12): 1826-1833.
16. Belleville G, Ouellet MC, Morin CM. Post-traumatic stress among evacuees from the 2016 Fort McMurray Wildfires: Exploration of psychological and sleep symptoms three months after the evacuation. *International Journal of Environmental Research and Public Health* 2019; 16(9): 1604.
17. Davison G, Barkjohn KK, Hagler GSW, et al. Creating clean air spaces during wildland fire smoke episodes: Web summit summary. *Frontiers in Public Health* 2021; 9: 508971.
18. Dev S, Barnes D, Kadir A, Betha R, Aggarwal S. Outdoor and indoor concentrations of size-resolved particulate matter during a wildfire episode in interior Alaska and the impact of ventilation. *Air Quality, Atmosphere & Health* 2022; 15(1): 149-58.
19. Holder AL, Halliday HS, Virtaranta L. Impact of do-it-yourself air cleaner design on the reduction of simulated wildfire smoke in a controlled chamber environment. *Indoor Air* 2022; 32(11): e13163.
20. Yee S, Spitzack J, Swanson J, Jung H, Rim D. Effect of paper filter windows on indoor exposure to particles of outdoor origin. *Environmental Pollution* 2023; 333: 121996.