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School of Nursing

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Rapid Review: What is the effectiveness of public health interventions on reducing the direct and indirect health impacts of wildfires?

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Executive Summary

Background

Exposure to wildfires and their smoke has a well-established impact on the health of populations, from direct physical and mental health implications to more indirect environmental and socioeconomic consequences (Hadley et al. 2022; Liu et al. 2015; Reid et al. 2016). The role of public health in responding to and mitigating these risks varies across jurisdictions, but typically involves multi-sectoral collaboration, community engagement, and the use of diverse sources of evidence.

Public health's role in the emergency management of wildfires falls within the components of prevention and mitigation, preparedness, response, and recovery (Government of Canada 2023). Smoke forecasting and air quality assessment may be used to identify risks and inform public health's decision making in issuing recommendations; effective public messaging is then critical for communicating these risks and recommendations, leading to intended behaviour change (Yao 2014; Fish et al. 2017).

Specific actions and interventions to respond to and reduce the negative impacts of wildfire smoke events have included establishing air quality monitoring systems and cleaner air shelters (i.e., indoor areas where the concentration of contaminants from outdoor smoke is reduced due to limited infiltration and by using air filtration devices), providing masks or recommending their use, issuing evacuation orders, and offering mental health and socioeconomic supports and resources (Government of Canada 2023; Maguet 2018). The evidence on the effectiveness of these interventions, however, is less understood (Cascio 2018).

As the frequency, severity, and duration of wildfire events increases worldwide (WHO 2023), the burden on public health organizations to implement interventions and measures to mitigate impacts will undoubtedly increase. This rapid review seeks to identify, appraise, and summarize available research evidence to support evidence-informed decision making in public health. It was produced through a collaboration between the National Collaborating Centre for Methods and Tools (NCCMT) and the National Collaborating Centre for Environmental Health (NCCEH).

This rapid review includes evidence available up to July 27, 2023 to answer the question:

What is the evidence for the effectiveness of public health interventions, and their potential unintended consequences, to reduce the direct and indirect health impacts of exposure to wildfires, including wildfire smoke and combined heat-wildfire smoke events?

Key Points

- Interventions for reducing the health impacts of wildfires and wildfire smoke included in this review comprise executing evacuation orders, staying indoors and improving indoor air quality, and communicating about outdoor air quality. The effectiveness of these interventions was assessed using both direct health (e.g., physical, mental) and indirect (e.g., smoke exposure reduction) outcomes.

- Community-wide evacuation orders may negatively impact mental health, including stress, anxiety, and depression. Access to care (e.g., healthcare, prescription medications, mental health supports) and information about the wildfires and evacuation orders may also be negatively impacted, potentially resulting in greater unmet need and uncertainty among evacuees. The certainty of evidence is very low (GRADE, see Methods for details); findings are likely to change as new evidence emerges.

- Evacuation orders have had varied impacts on different individuals: female evacuees may experience higher rates of anxiety and depression, and female evacuees and those with mental illnesses may have more confusion around and difficulty finding information related to the evacuation. The evacuation destination may also have a differential impact on anxiety. The certainty of evidence is very low (GRADE); findings are likely to change as new evidence emerges.

- The findings from qualitative studies corroborate the quantitative results. Negative consequences of evacuation experiences (e.g., fear, uncertainty/confusion, anxiety, financial losses) are reported more frequently than positive outcomes. These consequences may have enduring and varied impacts on different populations, stressing the importance of communication and preparedness. Relocating evacuees together may offer opportunities to strengthen cohesion, altruism, and support within the community. The confidence of evidence is moderate (GRADE-CERQual); findings are likely a reasonable representation of the phenomenon of interest.

- Most of the studies reporting on indoor air quality included air filtration interventions, highlighting findings for both unfiltered and filtered conditions. Indoor air quality is likely impacted by outdoor air quality: when outdoor air quality is poor, unfiltered indoor air quality is also likely poor. The amount of infiltration may depend on factors related to the indoor environment (e.g., building type, number of windows, air exchange rate, occupant behaviours). Remaining indoors, without air filtration, likely does not provide sufficient protection during smoke events, particularly for high-risk populations. The certainty of evidence is low (GRADE); findings may change as new evidence becomes available.

- Filtering, or cleaning the air (e.g., by using filters on central heating, ventilation, and air conditioning (HVAC) systems or portable air cleaners), likely reduces indoor particulate matter ($PM_{2.5}$) concentrations. There is some evidence that high-efficiency particulate air (HEPA) filter use may have a greater impact on reduction. The certainty of evidence is low (GRADE); findings may change as new evidence emerges.

- Wildfire smoke forecasting and air quality health indices may be predictive of respiratory health indicators, with implications for use as an early warning system and indicator for other interventions (e.g., evacuations). The certainty of evidence is very low (GRADE); findings are likely to change as new evidence emerges.

- The evidence is very uncertain about the impacts of other interventions on respiratory symptoms. In one multicomponent intervention – involving HEPA use, mask provision, public health messaging, and evacuation support – only HEPA use and recalling a public service announcement related to wildfire risk were associated with decreased odds of reporting worsening respiratory symptoms. In another mobile app intervention, combining air quality, smoke, wildfire, and symptom monitoring, it was unclear whether app use was more effective than control in improving asthma outcomes. The certainty of evidence is very low (GRADE); findings are likely to change as more evidence becomes available.

Overview of Evidence and Knowledge Gaps

- Despite wildfire smoke events being a well-established and growing concern, there is limited quantitative evidence that rigorously evaluates the effectiveness or unintended harms of public health interventions to reduce the impacts of exposure. More research is required, taking a realist approach (i.e., paired with expert opinion, evaluation studies), to establish which interventions are most effective, under which circumstances.

- This review includes 19 single studies of moderate to high quality, describing the effectiveness of public health interventions to reduce the health impacts of wildfires and their smoke. The evaluated interventions were related to **executing evacuation orders** (n=7), **improving indoor air quality** (n=7), and **communicating outdoor air quality** (n=4), with one study evaluating a **multicomponent intervention** (e.g., masking, evacuation, air filtration, and public service announcements).

- There is considerable variation across studies with respect to the setting, population, and outcomes - even within similar intervention groupings – as well as inconsistency in the level of detail provided for each. These inconsistencies may limit the generalizability of any findings, highlighting further the importance of context.

- A limited number of studies provide evidence for the experiences of populations who live with social and structural inequities, such as Indigenous, racialized, or rural communities, and those for whom gender and/or mental health considerations apply. These factors were mainly addressed by studies evaluating the impact of evacuation interventions. Further research is required to ensure representation of these populations for decision making related to all interventions.

- While the search was comprehensive (i.e., databases, reference lists, subject matter expert), it is limited in that a jurisdictional or grey literature scan (e.g., program evaluation data, regional data) was not conducted.

Methods

A description of the development of the NCCMT's Rapid Evidence Service, including an overview of the rapid review process and rationale for methodological decisions, has been published (Neil-Sztramko et al., 2021).

Research Question

What is the evidence for the effectiveness of public health interventions, and their potential unintended consequences, to reduce the direct and indirect health impacts of exposure to wildfires, including wildfire smoke and combined heat-wildfire smoke events?

Search

On July 27, 2023, the following databases were searched using key terms wildfire* OR "forest fire*" OR "bush fire*" OR "wildland fire*" OR "smoke event*" OR "wild fire" OR "brush fire*" OR conflagration OR "rural fire*":

- MEDLINE database
- Global Health Database
- Political Science Database
- MedRxiv preprint server
- Web of Science

A copy of the full search strategy is available in Appendix 1.

In addition to the databases searched above, the reference lists of included studies were searched, as well as the reference lists of reviews and reports that did not meet all inclusion criteria themselves but were relevant to the general topic. A subject matter expert from the NCCEH, with air quality and wildfire smoke expertise, was also consulted to identify additional studies for consideration and confirm study inclusion/exclusion criteria.

Study Selection Criteria

The search results were first screened for recent guidelines and syntheses. When available, findings from syntheses and clinical practice guidelines are presented first, as these consider the available body of evidence and, therefore, can be applied broadly to populations and settings.

Single studies were included if, 1) no (or only low quality) syntheses were available; 2) they were published after the search was conducted in any included syntheses; or 3) the synthesis in its entirety was not relevant to this rapid review's question (i.e., relevant single studies from syntheses were included, but not the synthesis itself).

Peer-reviewed sources and sources published ahead-of-print before peer review were included. Surveillance sources and mathematical modelling studies that exclusively used estimated data were excluded.

	Inclusion Criteria	Exclusion Criteria
Population	Public health units Policy makers (all levels) Decision makers (all levels) Communities	Non-OECD countries
Intervention	Interventions to mitigate the effects of wildfires, wildfire smoke, and combined heat-wildfire smoke events on the community Interventions include both policies for mitigating effects and provision of protective items, including, but not limited to: - Providing filtration devices and masks - Establishing cleaner air shelters - Recommending reduced time spent outdoors - Surveillance of wildfires, smoke and/or poor air quality - Issuing evacuation orders	Laboratory studies (e.g., effectiveness of masks at removing fine particulate matter) Interventions to prevent wildfires Interventions for resource reallocation in response to wildfires
Comparisons	N/A	
Outcomes	Direct (e.g., respiratory, cardiovascular, burns, mental health, etc.) or indirect (e.g., environmental, economic, etc.) health impacts	
Study design		Modelling studies, editorials, opinion pieces, dissertations

Data Extraction and Synthesis

Data relevant to the research question (including study design, setting, location, population characteristics, interventions, and outcomes) were extracted when reported in the included studies. The results were synthesized narratively due to the variation in methodology and outcomes for the included studies. A subject matter expert from the NCCEH reviewed and provided feedback on the synthesized results; these considerations were incorporated into the final review.

Appraisal of Evidence Quality

The quality of included evidence was evaluated using critical appraisal tools, as indicated by the study design below. Quality assessment was completed by one reviewer and verified by a second; conflicts were resolved through discussion.

Study Design	Critical Appraisal Tool
Cohort	Joanna Briggs Institute (JBI) Checklist for Cohort Studies
Cross-sectional	Joanna Briggs Institute (JBI) Checklist for Analytical Cross Sectional Studies
Diagnostic	Joanna Briggs Institute (JBI) Checklist for Diagnostic Test Accuracy Studies
Qualitative	Joanna Briggs Institute (JBI Checklist for Qualitative Research
Quasi-experimental	Joanna Briggs Institute (JBI) Checklist for Quasi-Experimental Studies
Randomized Controlled Trial	Joanna Briggs Institute (JBI) Checklist for Randomized Controlled Trials

Completed quality assessments for each included study are available on request.

This review includes both quantitative and qualitative research evidence. The approach to assessing the certainty and confidence in the quantitative and qualitative findings, respectively, is described below and the results of the assessments are summarized in the Summary of Evidence Certainty and Confidence table.

The Grading of Recommendations, Assessment, Development and Evaluations (GRADE) (Schünemann *et al.*, 2013) approach was used to assess the **certainty in the findings** in **quantitative research** based on eight key domains.

In the GRADE approach to quality of evidence, **observational** and **experimental studies** (e.g., randomized controlled trials)**,** as included in this review, provide **low** and **moderate certainty** evidence, respectively, and this assessment can be further reduced based on:

- High risk of bias
- Inconsistency in effects
- Indirectness of interventions/outcomes
- Imprecision in effect estimate
- Publication bias

and can be upgraded based on:

- Large effect
- Dose-response relationship
- Accounting for confounding.

The overall certainty in the evidence for each outcome was determined, considering the characteristics of the available evidence (observational studies, some not peer-reviewed, unaccounted-for potential confounding factors, different tests and testing protocols, lack of valid comparison groups). A judgement of 'overall certainty is very low' means that the findings are very likely to change as more evidence accumulates.

The Grading of Recommendations, Assessment, Development and Evaluations - Confidence in Evidence from Reviews of Qualitative Research (GRADE-CERQual) approach was used to assess the confidence in the findings in **qualitative research** based on four key domains.

In the GRADE-CERQual approach to quality of evidence, **qualitative research**, as included in this review, provides **high confidence** evidence, and this assessment can be reduced by one or more levels based on:

- Methodological limitations
- Relevance
- Coherence
- Adequacy

The overall confidence in the evidence (expressed as either high, moderate, low, or very low) for each prominent theme was determined considering the characteristics of the available evidence. A judgement of 'overall confidence is moderate' means that it is likely that the finding is a reasonable representation of the phenomenon of interest (Lewin *et al.*, 2018).

Findings

Summary of Evidence Certainty and Confidence

This review includes 19 single studies.

What is the evidence for the effectiveness of public health interventions, and their potential unintended consequences, to reduce the direct and indirect health impacts of exposure to wildfires, including wildfire smoke and combined heat-wildfire smoke events?

Key Finding	**Quantitative** studies included (n, type)	Overall certainty in **quantitative** evidence (GRADE)	**Qualitative** studies included (n)	Overall confidence in **qualitative** evidence (GRADE-CERQual)
Community-wide **evacuation** likely has significant negative impacts on mental health, including increased stress, anxiety, and depression among evacuees.	2 (observational)	⊕◯◯◯ VERY LOW[1]	3	Moderate[2]
Evacuation orders likely have varied impacts on individuals, depending on factors such as gender, health and mental health status, place of residence, and ethnic identity.	2 (observational)	⊕◯◯◯ VERY LOW[1]	1	Moderate[2]
Limited access to health care and prescription medications may lead to perceived unmet need among **evacuees**.	2 (observational)	⊕◯◯◯ VERY LOW[1]	-	-
Negative consequences of **evacuation** experiences are reported more frequently than positive outcomes.	3 (observational)	⊕◯◯◯ VERY LOW[1]	3	Moderate[2]
Evacuation experiences where positive impacts are highlighted focus on opportunities for community cohesion, altruism, and support.	-	-	2	Moderate[2]
Staying indoors, without air filtration, does not likely provide sufficient protection when outdoor air quality is poor.	5 (experimental) 1 (observational)	⊕⊕◯◯ LOW[3]	-	-
The amount of **$PM_{2.5}$ infiltration** is dependent on type of indoor environment (e.g., building type, number of windows, air exchange rate).	2 (experimental) 1 (observational)	⊕⊕◯◯ LOW[3]	-	-
Air cleaning systems – particularly the use of HEPA filters – are likely to reduce $PM_{2.5}$ to improve indoor air quality.	4 (experimental) 1 (observational)	⊕⊕◯◯ LOW[3]	-	-

Wildfire smoke **monitoring** and **forecasting** may be predictive of respiratory health indicators, with implications for use as an early warning system.	5 (observational)	⊕◯◯◯ VERY LOW[1]	-	-
The evidence is very uncertain about the impacts of multicomponent interventions and mobile apps for symptom and air quality monitoring on worsening respiratory symptoms.	1 (experimental) 1 (observational)	⊕◯◯ VERY LOW[4]	-	-

[1] In the GRADE approach to certainty of evidence, observational studies, as included in this review, provide low certainty evidence; this was downgraded to **very low** due to inconsistency and imprecision in effect estimates.

[2] In the GRADE-CERQual approach to confidence of evidence, qualitative studies, as included in this review, provide high confidence evidence; this was downgraded to **moderate** due to concerns with data adequacy and coherence.

[3] In the GRADE approach to certainty of evidence, experimental and observational studies, as included in this review, provide moderate and low certainty evidence, respectively; the overall certainty here is **low** due to inconsistency.

[4] In the GRADE approach to certainty of evidence, experimental and observational studies, as included in this review, provide moderate and low certainty evidence, respectively; this was downgraded to **very low** due to risk of bias, inconsistency, and imprecisions in effect estimates.

*Values exceed the total number of studies (n=19) as some studies involved multiple outcomes.

Table 1: Summary of findings

Reference	Date Released	Study Design	Setting and/or Event	Population	Intervention Details	Data Collection Methods	Type of Impact	Summary of Findings	Quality Rating
Evacuation (n=7)									
Cherry, N., & Haynes, W. (2017). Effects of the Fort McMurray wildfires on the health of evacuated workers: follow-up of 2 cohorts. *CMAJ open*, *5*(3), E638–E645.	Aug 15, 2017	Cohort	Fort McMurray / Wood Buffalo, Alberta, Canada 2016 Fort McMurray Fires	n=130 workers (i.e., non-residents working in the area, who had been recruited before the fire for an occupational health study)	A mandatory city-wide evacuation order was issued; workers were relocated to work camps, motels, or reception centres.	Data were collected on respiratory and mental health and evacuation experiences via telephone or online survey (3 – 26 weeks post-evacuation) and compared to demographic and health data collected pre-fire.	Direct	109/130 workers were in Fort McMurray at the time of the fire; 103 were evacuated. Evacuated workers had higher mean anxiety (6.3 ± 4.5 vs. 3.4 ± 2.9, p=0.01) and depression (4.1 ± 4.0 vs. 2.3 ± 2.5, p=0.04) scores, compared to those not evacuated. Mean anxiety (7.8 ± 5.2 vs. 5.3 ± 4.4, p=0.01) and depression (5.2 ± 5.2 vs. 3.4 ± 3.7, p=0.04) scores were higher among women vs. men; mean anxiety (8.2 ± 5.5 vs. 5.6 ± 3.9, p=0.02) scores were higher in those evacuated to a motel vs. evacuated elsewhere. There was no difference in alcohol, cigarette, recreational drug, or medication use in evacuated workers after the fire.	Moderate
Jenkins, J.L., Hsu, E.B., Sauer, L.M., Hsieh, Y.H., & Kirsch, T.D. (2009). Prevalence of Unmet Health Care needs and description of health care-seeking behavior among displaced people after the 2007 California	Apr 8, 2013	Cross-sectional	San Diego and Riverside, California, United States 2007 southern California wildfires	n=175 heads of households at 3 shelters and 7 local assistance centers	State and federal disaster declarations, leading to statewide evacuation and establishment of shelters and local assistance centers.	Data were collected on unmet medical needs, health care-seeking patterns, and health status via in-person survey.	Direct	161/175 heads of households agreed to participate, representing 520 household members. 47/161 (29.2%) reported needing health care at some point during their evacuation; 13/47 (27.7%) perceived these needs to be unmet. 47/161 (29.2%) reported needing prescription medication; 20/47 (42.6%) perceived these needs to be unmet. 14/161 (8.7%) reported mental health needs; 7/14 (50%) perceived these needs to be unmet. 46/161 (28.6%) reported at least 1 family member leaving prescription medication behind during evacuation; by post- evacuation day 10, 30/46 (65.2%) had replaced their medication.	Moderate

wildfires. *Disaster medicine and public health preparedness*, *3*(2 Suppl), S24–S28.								48/161 (29.8%) reported that at least 1 family member saw a health care provider since their evacuation; 50% visited a clinic, 22.9% a private doctor, 12.5% the emergency department. 15/161 (9.3%) believed their access to health care had worsened after the wildfires; 127/161 (78.9%) reported no change and 11/161 (6.8%) had better access.	
Krstic, N., Henderson, S.B. (2015). Use of MODIS data to assess atmospheric aerosol before, during, and after community evacuations related to wildfire smoke. *Remote Sensing of Environment,* (11), 1-7.	Sep 2015	Cohort	Canada Smoke-related evacuations from 2000-2007	n=41 smoke-related evacuations, impacting 10,597 evacuees; 32/41 evacuations were in First Nations communities	Community evacuation events that occurred as a result of wildfire smoke; all but one were mandatory.	Daily mean aerosol optical depth (AOD) measurements (i.e., representing smoke levels) were collected 4 days prior to, on, and 4 days after evacuations from objective remote sensing data (i.e., Moderate Resolution Imaging Spectroradiometer (MODIS)), adjusted for daily cloud mask (AOD*). Criteria for optimally-timed evacuation, according to AOD scenarios: 1. mean AOD higher post-evacuation 2. AOD values over risk	Indirect	Mean differences between pre- and post-evacuation AOD and AOD* across the 41 cases were 35% and 49%, respectively. Post-evacuation mean AOD and AOD* were higher than pre-evacuation in 22 (54%) and 21 (51%) cases, with mean increases of 105% and 135%, respectively. Risk threshold for sensitive populations (i.e., AOD >0.53) was exceeded in 8 (20%) cases for AOD and 21 (51%) of cases for AOD*; risk threshold for general population (i.e., AOD >0.85) was exceeded in 3 (7%) and 9 (22%) of cases, respectively. Peak AOD occurred before (n=17, 41%), on (n=6, 15%), and after (n=18, 44%) evacuation day; peak AOD* were similar (before: n=15, 37%; on: n=6, 15%; after: n=20, 49%). 16 (39%) (AOD) and 11 (27%) (AOD*) evacuations did not meet any of the three criteria for optimally-timed evacuations.	High

						threshold post-evacuation peak AOD exposure post-evacuation			
Tally, S., Levack, A., Sarkin, A.J., Gilmer, T., & Groessl, E.J. (2013). The impact of the San Diego wildfires on a general mental health population residing in evacuation areas. *Administration and policy in mental health*, *40*(5), 348–354.	Jun 5, 2013	Cross-sectional	San Diego, California, United States 2007 southern California wildfires	n=754 San Diego County Mental Health system clients	A mandatory evacuation order was issued for an area of 500,000 residents.	Data were collected on impact of evacuation on mental health status and service use via online survey (1-month post-evacuation, fall 2007).	Direct	72/754 (9.5%) of respondents lived in an evacuation area and evacuated; 51/754 (6.8%) lived in an evacuation area but did not evacuate; 631/754 (83.7%) lived in a non-evacuation area. 18.1% of evacuees sought additional mental health services due to the fire, compared to 8% of those in an evacuation area who did not evacuate and 2.1% of those in non-evacuation areas. Evacuees reported more negative impact for overall impact of fires, stress/anxiety/fear caused by fires, depression/sadness caused by fires, and confusion about knowing when and whether to evacuate ($p<0.05$). Evacuees and those in an evacuation area who did not evacuate reported more negative impact for trouble finding adequate information about fires and difficulty obtaining and taking medications regularly due to fire ($p<0.05$). Female evacuees reported more trouble finding information about the fires ($p=0.01$); females in an evacuation area who did not evacuate reported more difficulty taking their medications due to fire ($p=0.01$). Evacuees with a diagnosis of bi-polar disorder reported greater confusion about knowing when and whether to evacuate compared to evacuees with other mental health diagnoses (e.g., schizophrenia, major depressive disorder) ($p=0.02$).	High
Thériault, L., Belleville, G., Ouellet, M.C., & Morin, C.M.	Nov 11, 2021	Qualitative	Fort McMurray / Wood Buffalo, Alberta, Canada	n=393 evacuees (aged 18 and older) at 3	A mandatory city-wide evacuation order was issued.	Data were collected on perceived consequences of	Direct and indirect	Preparedness was identified as an important step of evacuation; lack of preparedness (i.e., limited time/warning) resulted in increased stress, uncertainty.	High

(2021). The Experience and Perceived Consequences of the 2016 Fort McMurray Fires and Evacuation. *Frontiers in public health*, *9*, 641151.			2016 Fort McMurray Fires	months post-evacuation; n=31 / 393 evacuees at 3 years post-evacuation		the evacuation via an online survey (3 months post-evacuation, Jul 25 - Aug 16, 2016) and telephone interview (3 years post-evacuation, Jun - Sep 2019).		Problems encountered while evacuating (e.g., heavy traffic, closed roads, separation from family, lack of communication with authorities) were also identified as sources of stress, particularly when compounded with a lack of preparedness. The evacuation was perceived as a frightening, unpredictable, stressful, and traumatic event, leading to many negative consequences. The most frequently mentioned negative consequences were related to material and financial loss/worries and emotional/mental health (i.e., anxiety, uncertainty). Negative consequences were reported more often than positive consequences; the latter, however, included opportunities for posttraumatic growth, resilience and adoption of adaptive coping strategies, altruism (e.g., helping others evacuate), and community cohesion (i.e., shared experience, strengthened relationships and sense of community). These observations were all provided at 3 months post-evacuation and still present / perceived at 3 years.	
Christianson, A.C., McGee, T.K. & Whitefish Lake First Nation 459. (2019). Wildfire evacuation experiences of band members of Whitefish Lake First Nation 459, Alberta, Canada. *Natural Hazards (98),* 9–29.	Jan 11, 2019	Qualitative	Whitefish Lake First Nation 459, Alberta, Canada 2011 Utikuma complex fire	n=45 band members	A mandatory evacuation order was issued by the First Nations Chief and Council; residents were evacuated to reception centres in host communities for up to 3 weeks.	Data were collected during two site visits (Jul, Sep 2014) via semi-structured interviews with 3 groups of band members, including those who: 1) evacuated to reception centres; 2) evacuated elsewhere; and 3) did not evacuate.	Direct and indirect	Short warning times, lack of information, separation of families, uncertainty (e.g., unknown damage to homes), and lack of control were identified as factors that increased stress during the evacuation process. The impact of the evacuation on community Elders and those with pre-existing health and mental health issues was of particular concern to many. Returning home, after the evacuation, many faced financial losses (e.g., spoiled food, ruined appliances), ongoing mental health impacts (e.g., difficulty returning to “normal”, anxiety, fear of being evacuated again), and reluctance to evacuate in future. The band experienced financial losses, as well, with a complicated provincial reimbursement process for costs associated with the evacuation.	High

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian journal of public health*, *109*(3), 327–337.	May 25, 2018	Qualitative	Yellowknife, N'Dilo, Detah, and Kakisa, Northwest Territories, Canada 2014 Northwest Territories wildfires	n=30	A voluntary evacuation recommendation was issued for residents of Kakisa; residents were evacuated to the local community hall in a neighboring community for 1.5 weeks.	Data were collected on lived experiences via semi-structured interviews (Oct-Dec 2015).	Direct and indirect	Evacuees reported that their experience with evacuation was a source of acute and ongoing fear, uncertainty, and anxiety, and a source of ongoing concern (e.g., fear of future evacuations). The experience also fostered opportunities for community members to support and care for each other (e.g., residents primarily relocated together).	High
Indoor air quality (n=7; reporting results for filtered (n=6) and unfiltered air (n=1))									
Barn, P., Larson, T., Noullett, M., Kennedy, S., Copes, R., & Brauer, M. (2008). Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. *Journal of exposure science & environmental*	Dec 5, 2007	Randomized-controlled trial	British Columbia, Canada 2004-05 southern British Columbia forest fire	n=17 homes (summer), n=21 homes (winter)	A portable HEPA filter was added to the main bedroom of each home; the filter itself was installed for 1 of the 2 sampling days, assigned randomly.	$PM_{2.5}$ concentrations[1] were measured for 48 hours in homes affected by forest fire (summer) or residential wood (winter) smoke.	Indirect	Valid samples were collected from 13 homes in summer and 19 homes in winter. Infiltration was lower when HEPA filters were in place in summer (mean F_{inf} (SD) = 0.19 (0.20) vs. 0.61 (0.27), $p<0.05$) and winter (0.10 (0.08) vs. 0.28 (0.18), $p<0.05$). There was no difference in air cleaner efficiency between summer and winter. When seasonal data were combined, increasing number of windows and the summer season were significantly related to increased infiltration ($R^2=0.41$, $p<0.0001$).	High

[1] Particulate matter (PM) is a type of air pollutant, consisting of airborne particles of varying sizes. Particles less than 2.5 micrometers in diameter ($PM_{2.5}$) are considered harmful to human health (CCME 2023).

epidemiology, *18*(5), 503–511.									
Wheeler, A.J., Allen, R.W., Lawrence, K., Roulston, C.T., Powell, J., Williamson, G.J., ... Johnston, F.H. (2021). Can Public Spaces Effectively Be Used as Cleaner Indoor Air Shelters during Extreme Smoke Events?. *International journal of environmental research and public health*, *18*(8), 4085.	Apr 13, 2021	Quasi-experimental	Port Macquarie, New South Wales, Australia 2019-20 local peat and bushfires	n=1 public library	A portable HEPA filter was added to a public library with a central HVAC system, serving as a cleaner indoor air shelter.	$PM_{2.5}$ concentrations were measured using low-cost sensors in 2 indoor (1 HVAC-only room, 1 HVAC + HEPA filter room) and 2 outdoor locations from Aug 2019 – Feb 2020.	Indirect	The median [5th-95th percentile] outdoor $PM_{2.5}$ concentration was 31 [2-113] $\mu g/m^3$; outdoor air quality was poorest during November bushfires and peaked at 600 $\mu g/m^3$. Median indoor $PM_{2.5}$ concentrations over the study period were lower in the HVAC-only room (15.0 $\mu g/m^3$ (9.8-21.2) and HVAC + HEPA room (5.7 $\mu g/m^3$ (5.5-8.5), vs. median outdoor $PM_{2.5}$ concentrations (23.3 $\mu g/m^3$ (12.0-49.1), with infiltration efficiencies (F_{inf}) of 0.45 (i.e., 55% reduction) and 0.17 (i.e., 83% reduction), respectively. During dates within the study period when the HEPA filter was not operating (median outdoor $PM_{2.5}$ = 30.7 $\mu g/m^3$ (12.2-85.9)), the indoor $PM_{2.5}$ concentrations and infiltration efficiencies were similar in both rooms (19.6 $\mu g/m^3$ (9.8-36.2) vs. 20.0 $\mu g/m^3$ (10.5-39.0), F_{inf}= 0.31 and 0.32 (i.e., ~ 70% reduction).	High
Stauffer, D.A., Autenrieth, D.A., Hart, J.F., & Capoccia, S. (2020). Control of wildfire-sourced $PM_{2.5}$ in an office setting using a commercially available portable air cleaner. *Journal of occupational*	Mar 11, 2020	Quasi-experimental	United States 2018 Pacific Northwest wildfire season	n=2 single-occupancy university campus offices	A commercially available portable air cleaner was installed in one office.	$PM_{2.5}$ concentrations were measured in 2 office locations (6 sampling sessions during the day, 8 during the night) and 1 outdoor location from Aug-Sep 2018 (i.e., peak wildfire season).	Indirect	During the day, mean (SD) indoor $PM_{2.5}$ concentrations were lower in an office with a portable air cleaner (2.95 $\mu g/m^3$ (2.39)) vs. an office without (11.09 $\mu g/m^3$ (9.70), mean concentration percent change reduction of 73%, $p<0.001$); the same was true during the night (0.50 $\mu g/m^3$ (0.39) vs. 6.55 $\mu g/m^3$ (7.10), 92% reduction, $p<0.001$). Mean (SD) 1-hour average $PM_{2.5}$ concentrations in an office without a portable air cleaner were lower indoors vs. outdoors (10.44 $\mu g/m^3$ (9.07) vs. 17.47 $\mu g/m^3$ (13.07), $p<0.001$). There was a strong correlation between indoor and outdoor $PM_{2.5}$ concentrations (Spearman rho = 0.91, $p < 0.001$).	High

and environmental hygiene, *17*(4), 109–120.									
Xiang, J., Huang, C.H., Shirai, J., Liu, Y., Carmona, N., Zuidema, C., ... & Seto, E. (2021). Field measurements of PM2.5 infiltration factor and portable air cleaner effectiveness during wildfire episodes in US residences. *The Science of the total environment, 773*, 145642.	Feb 5, 2021	Quasi-experimental	Seattle, Washington, United States 2020 wildfire event	n=7 residences	A HEPA-based portable air cleaner was installed in each residence. All residences kept their windows closed for an 18-to-24 h period without filtration; 5/7 residences then ran their HEPA for an 18-to-24 hr period with filtration.	$PM_{2.5}$ concentrations were measured during a wildfire event (Sep).	Indirect	Outdoor $PM_{2.5}$ levels ranged from 33 to 111 µg/m^3, with a mean (SD) of 64 µg/m^3 (17). (During non-wildfire seasons, mean outdoor $PM_{2.5}$ levels are < 10 µg/m^3). Mean (SD) indoor $PM_{2.5}$ levels with and without portable air cleaners were 14 µg/m^3 (7) and 47 µg/m^3 (24), respectively. Mean (SD) $PM_{2.5}$ infiltration factor ranged from 0.33 (0.06) to 0.76 (0.05), with a mean of 0.56 (0.13) across all residences. Mean (SD) $PM_{2.5}$ infiltration factor was significantly reduced in all 5 residences with air filters, ranging from 0.09 (0.02) to 0.29 (0.05), with a mean of 0.19 (0.09) (p value not reported). The use of a portable air cleaner decreased indoor $PM_{2.5}$ levels by 48 – 78%.	High
May, N.W., Dixon, C., Jaffe, D.A. (2021). Impact of Wildfire Smoke Events on Indoor Air Quality and Evaluation of a Low-cost Filtration Method. *Aerosol and Air Quality*	May 12, 2021	Quasi-experimental	United States 2020 western United States wildfire season	n=42 sites (26 residential, 6 school, 10 commercial)	Air quality was measured across all sites; low-cost air filters were added to 4 residential sites.	Indoor and outdoor $PM_{2.5}$ concentrations were obtained from publicly available PurpleAir sensor network during a period of heavy wildfire smoke (Sep 2020).	Indirect	Median (range) $PM_{2.5}$ infiltration (F_{inf}): residential, 0.21 (0.01-0.87); commercial, 0.45 (0.30-0.71); school, 0.68 (0.41-0.80). Ratio of indoor/outdoor (I/O) $PM_{2.5}$: residential, 0.33; commercial, 0.58; school, 0.73. Percentage of $PM_{2.5}$ indoors due to infiltration: residential, 0.77; commercial, 0.90; school, 0.93. Continuous HEPA filter use, with windows and doors closed, reduced indoor $PM_{2.5}$ concentrations in two residences by 99% (F_{inf} = 0.04 and 0.09); a third residence used a furnace fan with MERV-12 (i.e., low-cost filtration method) and HEPA filter at night (F_{inf} =	Moderate

*Research, (21)*7.								0.31); a fourth residence used HEPA and HVAC in 2019 vs. only HVAC in 2018 (F_{inf} = 0.18 vs. 0.38).	
Henderson, D.E., Milford, J.B., & Miller, S.L. (2005). Prescribed burns and wildfires in Colorado: impacts of mitigation measures on indoor air particulate matter. *Journal of the Air & Waste Management Association*, *55* (10), 1516–1526.	Mar 1, 2022	Cohort	Deckers, Colorado, United States 1) Oct 2001 Polhemus prescribed burn; 2) Apr 2002 Snaking fire; 3) May 2002 Schoonover fire; and 4) Jun 2002 Hayman fire	n=8 homes (i.e., 2 per burn event)	Paired homes were instructed to keep windows and doors closed; a portable air cleaner was added to 1 home per pair and operated continuously during the burn event.	$PM_{2.5}$ concentrations were measured indoors and outdoors for 24-hr periods at each home.	Indirect	24-hr average $PM_{2.5}$ indoor concentrations, in homes without air cleaners, ranged from 5.2 - 21.8 µg/m^3, 58 - 100% of outdoor levels; $PM_{2.5}$ concentrations in homes with air cleaners ranged from 1.43 – 3.02 µg/m^3. The effectiveness of air cleaners was estimated to be 63-88%. Indoor/Outdoor (I/O) ratios (i.e., estimate of effect of sheltering indoors with windows closed) were highest in homes with highest average air exchange rates (AER[2]); homes with low AER provided more protection than those with high AER.	High
Nguyen, P.D.M., Martinussen, N., Mallach, G., Ebrahimi, G., Jones, K., Zimmerman, N., & Henderson, S.B. (2021). Using Low-Cost Sensors to Assess Fine Particulate Matter Infiltration (PM2.5) during	Sep 17, 2021	Quasi-experimental	Vancouver, British Columbia, Canada Sep 2020 wildfire smoke event	n=1 rehabilitation facility	Air quality was monitored during a wildfire smoke event.	$PM_{2.5}$ concentrations were measured by low-cost sensors in 2 outdoor and 7 indoor locations from Aug-Oct 2020.	Indirect	Mean (range) outdoor 24-h $PM_{2.5}$ concentrations were higher during the smoke episode (72.0 µg/m3 (7.7-141.6) vs. on typical days (7.5 µg/m3 (0.0-46.8). Mean (range) indoor concentrations were higher during the smoke episode (29.6 µg/m3) vs. on typical days (2.4 µg/m3). Mean (range) infiltration of outdoor $PM_{2.5}$ concentrations indoors were 19% (3-41%) higher during the smoke episode (0.37 µg/m3 (0.31-0.47)) vs. on typical days (0.32 µg/m3 (0.22-0.39)).	High

[2] Air Exchange Rate (AER) refers to the number of times total air volume in a space is completely removed and replaced in an hour.

a Wildfire Smoke Episode at a Large Inpatient Healthcare Facility. *International journal of environmental research and public health*, *18*(18), 9811.									
Communication about outdoor air quality (n=4)									
Postma, J.M., Odom-Maryon, T., Rappold, A.G., Haverkamp, H., Amiri, S., Bindler, R., ... Walden, V. (2022). Promoting risk reduction among young adults with asthma during wildfire smoke: A feasibility study. *Public health nursing (Boston, Mass.)*, *39*(2), 405–414.	Mar 1, 2023	Randomized-controlled trial	Washington and Oregon, United States 2020 summer wildfire season (Aug-Sep)	n=67 young adults aged 18-26 with asthma	A mobile app for reducing risks from breathing wildfire smoke was tested. Participants were divided into 3 groups: Smoke Sense Urbanov (SSU)*, SSU-Plus**, and control. *Features of SSU: - symptom, smoke, fire, and air quality observations **Additional features of SSU-Plus: - daily spirometry - air quality index advisories,	Asthma outcomes (e.g., Asthma Control Test, ACT; forced expiratory volume, FEV) were assessed at baseline, 4- and 8-weeks.	Direct	Participants' exposure periods averaged 78.2 (SD 14.2) days; the level of $PM_{2.5}$ was deemed "unhealthy for sensitive groups" (e.g., ≥35.5 µg/m^3) for 0-17.2% of days; 35.3% of days were "moderate" ($PM_{2.5}$ ≥12.1 µg/m^3). 37 (7 SSU, 17 SSU-Plus, 13 control) recorded ACT and FEV measures. Participants in the SSU-Plus group reported an increase in ACT at week 8 (mean (SD)= 21.5 (2.3)) vs. baseline (20.0 (2.4), p=0.0008) and a decrease in percent predicted FEV (88.6% (17.2) vs. 94.9% (16.2), p=0.0172). Participants in the SSU group reported no differences in either measure. Participants in the control group reported an increase in ACT (22.4 (1.9) vs. 20.2 (3.7), p=0.0320), but no change in percent predicted FEV.	Moderate

					mapped to lung function - preventive tips - message board				
Yao, J., Brauer, M., & Henderson, S.B. (2013). Evaluation of a wildfire smoke forecasting system as a tool for public health protection. *Environmental health perspectives*, *121*(10), 1142–1147.	Oct 1, 2013	Diagnostic test	British Columbia, Canada 2010 British Columbia wildfire season	n=89 local health areas	A wildfire smoke forecasting system (BlueSky) for public health protection was evaluated.	BlueSky $PM_{2.5}$ and smoke plume forecasts were compared with air quality monitor and remote sensing data; daily counts of salbutamol dispensations and asthma-related physician visits were aggregated (Jul – Aug).	Direct	There was modest agreement between BlueSky and monitored $PM_{2.5}$ levels (global correlation, 0.4). Mean areas of BlueSky and remote sensing data plumes were 153,200 and 334,500 km^2; the mean FMS score (i.e., area of intersection and union of BlueSky and remote sensing data) (range) was 0.21 (0-0.52), with higher FMS scores during major fire event periods. BlueSky forecasts were predictive of respiratory health indicators including (RR (95% CI)): - Salbutamol dispensations: ○ 1.08 (1.06, 1.10) BlueSky $PM_{2.5}$ vs. 1.12 (1.07, 1.17) monitored $PM_{2.5}$ ○ 1.05 (1.02, 1.09) BlueSky plumes vs. 1.05 (1.01, 1.09) remote sensing data plumes - Asthma-related physician visits: ○ 1.05 (1.01, 1.09) BlueSky $PM_{2.5}$ vs. 1.10 (1.00, 1.21) monitored $PM_{2.5}$ ○ 1.06 (0.99, 1.15) BlueSky plumes vs. 1.09 (1.02, 1.18) remote sensing data plumes	High
McLean, K.E., Yao, J., & Henderson, S.B. (2015). An evaluation of the British Columbia asthma monitoring system (BCAMS) and PM2.5 exposure metrics during the 2014 forest	Jun 12, 2015	Diagnostic test	British Columbia, Canada 2014 British Columba wildfire season	n=16 provincial health service delivery areas	The British Columbia Asthma Monitoring System (BCAMS), which tracks smoke exposure (i.e., monitoring stations, smoke exposure modelling, and BlueSky and FireWork forecasting) and asthma-related	Excursions for asthma-related physician visits and salbutamol dispensations were identified and compared to smoke exposure (Jul – Aug).	Direct	35 and 48 excursions for asthma-related physician visits and salbutamol dispensations occurred, respectively. 55.8% and 69.8% of smoky days (i.e., $PM_{2.5} \geq 25$ µg/m^3) were associated with at least one excursion for physician visits and salbutamol dispensations, respectively. 57-71% excursions were associated with measured or modelled $PM_{2.5}$ concentrations of ≥ 10 µg/m^3; majority of excursions were associated with forecasted $PM_{2.5} \leq$ 10 µg/m^3.	High

fire season. *International journal of environmental research and public health, 12*(6), 6710–6724.					health outcomes, was evaluated.				
Yao, J., Stieb, D.M., Taylor, E., & Henderson, S.B. (2020). Assessment of the Air Quality Health Index (AQHI) and four alternate AQHI-Plus amendments for wildfire seasons in British Columbia. *Can adian journal of public health*, *111*(1), 96–106.	Jul 8, 2019	Cohort	British Columbia, Canada	n=32 local health areas	The ability of four alternate Air Quality Health Index (AQHI)-Plus amendments (1) Trump & Hold; 2) 1-h $PM_{2.5}$ Only; 3) AQHI with 1.4*$PM_{2.5}$; 4) AQHI with 2*$PM_{2.5}$] to predict adverse population health effects from wildfire smoke was compared with the original AQHI.		Direct	Increases in the AQHI and all four AQHI-Plus amendments were associated with increased risk of all health outcomes (e.g., all-cause mortality, physician visits for circulatory and respiratory causes, salbutamol dispensations) (p=0.05). The AQHI and Trump & Hold AQHI-Plus had the largest effect estimates. The AQHI is most indicative of the mortality and circulatory risks during periods affected by wildfire smoke. The 1-h $PM_{2.5}$Only AQHI-Plus is most indicative of the respiratory risks during high-intensity fire periods, particularly for people with asthma.	Moderate
Multicomponent interventions (n=1)									
Mott, J.A., Meyer, P., Mannino, D., Redd, S.C., Smith, E.M., Gotway-Crawford, C., & Chase, E. (2002). Wildland forest fire smoke: health effects	May 2002	Cross-sectional	Humboldt County, California, United States 1999 Hoopa Valley National Indian Reservation Fire	n=289 reservation residents	During the fires, medical center staff and other tribal organizations distributed free masks, vouchers for hotel services (to facilitate evacuation), and portable HEPA cleaners	Data on intervention participation and lower respiratory tract symptoms before, during (Aug 23 - Oct 26), and after (Oct 27 - Nov 15) the smoke episode were collected via survey.	Direct	140/287 people who answered this question on the survey (48.8%) evacuated, 100/286 (35.0%) wore masks, 98/287 (34.1%) ran a HEPA filter, and 238/289 (82.4%) correctly recalled a PSA (of which, 66.0% reported acting as a result of a PSA); 92/289 (31.8%) had preexisting cardiopulmonary conditions. 178/289 (61.6%) reported increased respiratory symptoms during the smoke; 65/289 (22.5%) continued to report increased respiratory symptoms two weeks after the smoke cleared.	Moderate

and intervention evaluation, Hoopa, California, 1999. *The Western journal of medicine*, *176*(3), 157–162.					(prioritized to persons with adverse or pre-existing health conditions); local media outlets released public service announcements (PSA).			Increased duration of HEPA use was associated with decreased odds of reporting worsening respiratory symptoms (OR=0.54), which followed a dose-response relation (e.g., highest duration users were significantly less likely than lowest duration users to report worsening symptoms). Respondents recalling a PSA were less likely to report worsening respiratory symptoms (OR=0.25) vs. those who could not recall a PSA, which followed a dose-response relation (e.g., more PSAs recalled associated with fewer reported symptoms). Duration of evacuation and mask use were not associated with the odds of reporting worsening lower respiratory tract symptoms.	

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