Effectiveness of personal interventions regarding air pollution as caused by wildfires

Wildfire in Yosemite National Park in 2009. Image source: Kip Evans/Alamy Stock Photo

Literature review
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Layman's Summary

Wildfires are events during which parts of the natural landscape are burning, thereby releasing smoke and radiating heat. Wildfire smoke consists of several types of very small particles which are able to penetrate into the airways and cause damage. In the short term, this may lead to symptoms such as coughing and sneezing. When someone is regularly exposed to wildfire smoke over the long term, more serious illness such as heart disease and cancer can potentially develop. Aside from reducing the frequency of wildfire events through means such as forest management, there are methods that people can use to reduce the extent to which they are exposed to wildfire smoke. Such methods include the use of face masks, modifying their habits during wildfire episode by closing windows and staying inside, and using specially designed devices in their home that filter the inside air that reduce the number of dangerous particles. However, there is not yet a lot of evidence available on exactly how effective these methods are at reducing the exposure to wildfire smoke particles. This is important to know, due to the increasing occurrence of wildfires through climate change and the desire to protect as many people as possible from the dangerous effects of wildfire smoke exposure. In this review, existing literature on the effectiveness of exposure reducing methods was sought out and evaluated. This resulted in 15 articles being found that all show beneficiary effects of different exposure reducing methods. The most effective methods were the use of air cleaning devices as well as the use of mechanical ventilation units installed in buildings. However, the effectiveness of these methods greatly varies due to different factors, such as using filtration devices with low quality filters. Low quality filters might be used due to a lack of budget to replace the often very expensive filters, or due to a lack of knowledge about the necessity of filter replacement. This means more resources should be dedicated to developing protective methods that are accessible to the whole population. In addition, 15 studies is a low number to draw conclusions about the definitive effectiveness of a method, especially considering that each article uses a slightly different building type, population and location to test protective methods. For each specific combination of circumstances, multiple studies confirming each other's results are needed to prove in a reliable and scientifically correct way that the results are indeed correct. This is not the case in this literature review, due to a lack of available studies. As a result, a larger amount and more reliable evidence is needed to prove without a doubt that all these methods are as effective as they seem to be. In addition, there are some problems with the way some of the reviewed studies were designed, which caused some important data to be missing. For example, it is important to know whether or not windows were open when an air cleaning device was operated, which is not reported in each study on this intervention type. This could have led to incorrect reports on the effectiveness of certain interventions. In the future, more research of a high-quality level into combining the most effective methods with wide accessibility to these methods is needed to protect everyone from smoke exposure, and vulnerable groups in particular.

Abstract

Wildfires poses a great threat to the environment both through the burning fire itself and the smoke that is released. Particles such as $PM_{2.5}$ that are released in the air through wildfire events have been found to cause detrimental effects on multiple aspects of human health and mortality. Besides implementation of policies in an attempt to reduce the frequency of wildfires, personal interventions are available for individuals to protect themselves and their household against smoke exposure. However, there is little evidence available to establish how effective these personal interventions are. Due to the expectation that wildfire occurrence will increase as a result of climate change, it is important to properly investigate protective measures that can be taken. This report aimed to investigate the effectiveness of personal interventions in wildfire situations by means of a systematic literature review. 1794 papers were identified in the initial search with 15 primary research articles being included in the final review. The amount and quality of evidence for the effectiveness of personal interventions is relatively low. Due to the small amount of studies available and highly variable experimental conditions and results, it is hard to form a final conclusion about the effectiveness of any particular intervention. In addition, all of the studies reviewed have some level of bias or issues. Most importantly, sample sizes are very small across all included studies, and at least six studies are missing some type of data related to air quality measurements or occupant behavior that could have affected the reported results on intervention effectiveness. The use of portable air cleaners and mechanical ventilation systems with high-efficiency filters combined with occupant behavior that keeps the building as sealed off as possible seems to be the most effective intervention currently available. However, these interventions might be particularly costly to purchase and use, leaving vulnerable groups that cannot afford these devices at risk. Future research should focus on better establishing the effectiveness of all types of interventions through high-quality, large scale clinical trials and observational studies. In addition, it should focus on developing low-cost, highly-efficient interventions that are easily accessible for everyone, and groups at risk in particular.

Chapter 1: Introduction

Wildfires can be defined as burning events occurring in a variety of landscapes including savannahs, peat bog, grass, heath and forests (Knorr, Dentener, Lamarque, Jiang, & Arneth, 2017). Wildfires do not only pose a risk to environmental health through its flames and their radiating heat, but also by the resulting smoke (Finlay, Moffat, Gazzard, Baker, & Murray, 2012). Wildfire smoke is a main source of air pollution, as it consists of particulate matter (PM) as well as other gaseous emissions. The main components of wildfire smoke that have been studied in regard to adverse health effects are PM with a diameter of less than 2.5 µm ($PM_{2.5}$) and PM_{10}.

A diversity of adverse health effects has been linked to wildfire smoke exposure. Some acute effects that are reported are increases in asthma diagnoses, asthma-related outpatient visits and asthma medication prescription refills (Gan et al., 2020). It was found that a 5 µg/m^3 increase in daily, as well as three-daily $PM_{2.5}$ levels lead to a 6.1% increase in asthma-related hospital visits (Kiser et al., 2020). Interestingly, this effect was not observed when an increase in $PM_{2.5}$ coming from a non-wildfire related source was present (Kiser et al., 2020). This is pointing towards specific conditions being present during wildfires that exacerbate health problems more so than air pollution from other sources. Exposure to particulate matter in wildfire smoke can also increase survival and spread rates of different types of aerosols, including viruses and bacteria (Kiser, et al., 2021). This is a particularly worrying implication given the current COVID-19 pandemic. Indeed, one study found that a 10 µg/m^3 increase in the $PM_{2.5}$ weekly average lead to a 6.3% relative increase of positive COVID-19 tests (Kiser et al., 2021). Longer-term effects such as cardiovascular disease and respiratory disease have also been attributed to wildfire smoke exposure (Liu, Pereira, Uhl, Bravo, & Bell, 2015). These diseases lead to an increase in hospital admissions, physician visits and mortality rate. As a result, the effects of wildfire smoke exposure cause a great economic burden. Between 2008 and 2012, the annual healthcare costs of wildfire smoke in the USA was estimated to be 13-24 billion $ for short-term exposure, and 90-154 billion $ for long-term exposure (Fann et al., 2018).

Due to this immense burden on the economy and human health, it is imperative that effective intervention strategies are available for use in the event of wildfires. As a result of climate change, the frequency of wildfire occurrence has risen. In addition, wildfires have started occurring more frequently in geographical areas that were previously unaffected or less affected (Finlay et al., 2012; Flannigan A, Krawchuk B, de Groot A, Mike Wotton, & Gowman A, 2009). This means that over the next years, it is likely that an increasing amount of people will be at risk for wildfire smoke exposure and resulting adverse outcomes. A study on forest fire danger in Europe revealed that between 1980 and 2012 a significant increase in forest fire danger through weather changes could be established, where none could be found between 1960 and 1999 (Venäläinen et al., 2014). The weather circumstances that facilitate forest fires, presented in the articles through the fire weather index, increased with a mean gradient of 0.078 to 0.391 depending on the specific location in Europe. This means that over the years, the weather circumstances that pose the most danger for facilitating a forest fire have become increasingly more extreme (Venäläinen et al., 2014). This trend in wildfire facilitating weather stimulated by climate change is expected to increase even further in the years to come (Venäläinen et al., 2014).

Aside from control strategies trying to reduce the frequency of forest fires and smoke exposure, such as land management regulations, there are personal intervention strategies that individuals can use in the event of a wildfire. While it is most effective to limit the potentially hazardous effects of wildfire smoke inhalation closest to the source, a complete elimination of wildfire occurrence is currently impossible especially due to the aforementioned effects of climate change. As a result, personal interventions are useful tools at household, individual and community levels in order to reduce risk (Laumbach, 2019).

Some of these possible intervention strategies that prevent or reduce wildfire smoke exposure include mechanical ventilation (MV), use of portable air cleaners (PACs), behavioral changes such as staying indoors, and usage of masks (Laumbach, 2019). All these interventions aim to reduce exposure to air pollutants through the process of filtering out hazardous smoke particles and/or putting up a certain type of physical barrier between an individual and the polluted air. Even though these tools seem promising in reducing exposure and adverse health effects resulting from wildfire smoke inhalation, there is relatively little and weak evidence available to confidently prove the effectiveness of the different types of interventions. There are no large-scale clinical trials or observational studies available that have researched the effectiveness of personal interventions (Laumbach, 2019). The research that does exist on this topic is often very small-scale and performed in specific experimental circumstances (Laumbach, 2019). This begs the question: what is the current state of evidence on effectiveness of personal interventions for use during wildfire episodes, and what do we still need to uncover?

In this review, the effectiveness of prevention strategies regarding air pollution resulting from wildfires will be explored by means of a literature review. The aim is to assess what the current state of evidence is on how effective personal intervention strategies are at mitigating exposure and reducing adverse health outcomes. Articles selected for inclusion in this review will be analyzed based on the evidence they provide for the effectiveness of personal interventions and the quality of this evidence. Lastly, these results will be discussed, and a conclusion will be given on personal intervention effectiveness based on the currently available evidence. Current knowledge gaps, ideas for future research, problems with and feasibility of intervention use will also be addressed.

Chapter 2: Methods

In order to establish the effectiveness of prevention strategies regarding air pollution as caused by wildfires, a literature search was performed to find relevant articles. A systemic literature review approach was used with the aim to identify all articles published around this topic, as this was deemed the most effective strategy to answer the research question. Before the start of the review, eligibility criteria, search strategy, results analysis and analysis of bias were defined.

Eligibility criteria

Articles published on the topic of studying interventions for air pollution caused by wildfires were included. 'Interventions' were defined as personal and household level interventions, in other words: any method a member of the general public may use to reduce their and their household's exposure to wildfire smoke in order to mitigate adverse health outcomes. This includes methods such as use of air cleaners, home air filtration units and masks but also behavioral changes such as staying indoor and closing windows. Only articles written in the English language (abstract and full article) were included, regardless of publication date. Studies using controlled or artificial conditions regarding either the intervention or the source of the wildfire were included. Studies were included regardless of outcome measurement type, participant characteristic, or geographical area.

Studies on interventions for indoor or outdoor sources of air pollution other than wildfires in particular were excluded. Articles studying interventions specifically for occupational exposure (e.g. fire fighters and agricultural workers) were excluded, as this review focuses on interventions for the broader public. As a result of the aforementioned definition, interventions that are not part of what a member of the general public can control themselves were also excluded, for example: improving wildfire smoke forecasting or trying to reduce wildfire occurrence by better forest management. Studies regarding compliance to and effectiveness of communication strategies during wildfire events were excluded, as this was not deemed to fall under the 'intervention' definition of this review. Individual or household level studies only investigating the effectiveness of air quality monitoring, but not using them to measure during an intervention situation were excluded.

Search strategy

The databases that were used were PubMed, Scopus and Web of Science. Search strings can be found in the appendix in table A.1. Articles were then analyzed using rayyan.ai software. First, this software was used to filter out duplicate articles across databases. The software identified articles with large amounts of overlap and presented these to the author to be manually defined as a duplicate or original text. Next, articles not relevant to the research question (e.g. studying only health effects and not focusing on interventions) or otherwise not fulfilling the aforementioned eligibility criteria were excluded based on title and/or abstract alone. Lastly, irrelevant articles were excluded based on an analysis of the full text. If any literature reviews included in the final results included primary research articles relevant to the present research question that were not identified through the used search strategies, these articles were also evaluated for inclusion in the final results following the eligibility criteria.

Analysis of results

Results were analyzed by means of reading through the full text and analyzing the positive and/or negative outcomes of the use of the studied intervention type. Outcomes were directly taken from the article and compared to other similar outcomes while taking into account the context of the results regarding variables such as location and sample size. Bias of each article was ascertained by following the Cochran Handbook guidelines for bias assessment in systematic reviews ("Cochrane Handbook for Systematic Reviews of Interventions | Cochrane Training," version 6.2, 2021).

Chapter 3: Results

The literature search identified 1794 papers published between 1974 and 2021, of which 1291 were unique. A further 1168 articles were excluded due to not meeting the eligibility criteria after review of title and/or abstract. 103 more articles were eliminated as they did not fulfil the inclusion criteria after a study of the full text. A final selection for this review was made consisting of 20 articles. Of these, 15 primary research articles presented data that was included in this review, and five additional review articles were used as additional source for information for further context. An overview of these articles is presented in table 3.1. Across all 15 articles included in the final review, a variety of intervention types, study sizes and locations are represented. Results will be discussed further through sorting them by intervention type.

Study	**Location**	**Population size**	**Intervention type(s)**	**Main outcome(s)**	**Study time period**
(Shrestha et al., 2019)	Denver, Colorado, USA	28 homes	MV with low efficiency filters	I/O ratio of $PM_{2.5}$ 18% higher in homes with MV using low-efficiency filters active during wildfire episodes	2016-2017
(Stauffer, Autenrieth, …, & 2020, 2020)	Pacific Northwest region, USA	2 single-occupant university campus offices	PAC	Reduced indoor fine PM by 73-92% depending on time of day and occupation	August - September 2018
(Fisk & Chan, 2017)	Southern California, USA (simulation of actual events)	~17,4 million individuals (simulation based on census data)	MV, PAC	Prevent 11-63% of wildfire-related hospital admissions and 7-39% of wildfire-related deaths	2003 (simulation of actual events)
(Pantelic, Dawe, & Licina, 2019)	Berkeley, California, USA	2 office buildings with a total of 570 full-	MV with high efficiency MERV filters	Higher indoor air quality in mechanically ventilated	November 2018

		time occupants		building (I/O 0.27 vs 0.67 in naturally ventilated building)	
(P. Barn et al., 2007)	Southern British Columbia, Canada	17 homes	PAC with HEPA filter	Lower indoor infiltration and reduced $PM_{2.5}$ exposure	2004-2005
(Reisen, Powell, Dennekamp, Johnston, & Wheeler, 2019)	Yarra Valley and Gippsland, southeastern Victoria, Australia	21 homes	Behavior: remaining indoors, shutting doors/windows during wildfire episodes	12-76% level of protection form peak outdoor $PM_{2.5}$ concentrations	2013-2015
(Mott et al., 2002)	Hoopa Valley, California, USA	289 participants residing on the Hoopa Valley Indian Reservation	PAC with HEPA filters, N95 masks, temporary evacuation	Increased duration of HEPA filtered PAC use associated with decreased odds of reporting worsening symptoms (Odds Ratio= OR = 0.54)	October 1999
(Henderson, Milford, & Miller, 2012)	Near Deckers and Bailey, Colorado, USA	Two homes per wildfire episodes (8 total)	PAC	$PM_{2.5}$ decrease of 63-88% in homes with a running PAC	3 distinct wildfire events and 1 prescribed burn event in October 2001, April, May, and June 2002
(Wheeler, Allen, …, & 2021)	Port Macquarie, New South Wales, Australia	Individual public library (as a clean indoor air shelter)	PAC with HEPA filters	70-83% reduced $PM_{2.5}$ concentration indoor vs outside	August 2019 – February 2020

(Künzli et al., 2006)	Southern California, USA	6434 high school and elementary school children, aged 17-18 and 6-7	Mask	Among those who reported a fire smell, mask users were less likely to report wheezing and sneezing than those who did not use a mask	October 2003
(Luo et al., 2019)	Simulation based on northern California, USA	Individual office building (simulation)	Ventilation, behavior (opening windows, turning on ventilation, walking in and out of rooms)	Opening windows and walking around rooms leads to higher levels of indoor air pollution	2019
(May, Dixon, & Jaffe, 2021)	Western US	Two rooms (200 m^3 and 50 m^3) in one home	MV (FFU with high efficiency MERV filters)	Lower I/O and indoor penetration of $PM_{2.5}$ with active FFU, with a minimum $PM_{2.5}$ concentration reduction of 45% compared to outdoors in the largest room, and a reduction of nearly 100% in the smallest room	September 2020
(Tham, Parshetti, Balasubramanian, Sekhar, & Cheong, 2018)	Singapore	Two same-sized rooms in one individual apartment on the 3rd	MV (FFU with high efficiency MERV filters)	Exposure reduction efficiency to $PM_{2.5}$ of 80.4% compared to outside in the	October 2015

		floor of a hostel building		FFU-operated room, reduced by 43.3% in the control room compared to outside	
(Sharma, 2017)	Singapore	Individual residential building (20th floor) on National University campus	PAC	Exposure to $PM_{2.5}$ reduced by 62%	2015
(Chen et al., 2016)	Western Singapore	Individual office building on the Nanyang Technologi cal University Campus	MV with MERV 7 filters and air conditionin g	Lower I/O ratios with a combination of mechanical ventilation and air conditioning vs. mechanical ventilation only	June and August 2013

Table 3.1: Overview of all articles included in the final results of this review. The author, publication year, study year and location, type of intervention, study size and general remarks about the most important outcomes for each article are shown. There were also five reviews identified through the literature search that were not used as primary data sources, but used as additional source of information and analyzed for the inclusion of studies that could potentially be included in this review according to the used eligibility criteria. These reviews are referred to as (P. K. Barn et al., 2016), (Laumbach, 2019), (Cheek, Guercio, Shrubsole, & Dimitroulopoulou, 2021), (Rajagopalan, Climate, 2021), Zhu et al., 2021). Abbreviations used: PAC = portable air cleaner, FFU = fan filter unit MV = mechanical ventilation, HEPA = high efficiency particulate air, MERV = minimum efficiency reporting value

Portable air cleaners with HEPA filters

Portable air cleaners (PACs) represent the intervention type that was most studied across all articles included in the final results, with 7 primary studies being on PACs available in the articles included in this review. All studies researching the effectiveness of PAC report a positive effect. Different effectiveness outcomes are reported, with most studies stating a reduction of the indoor exposure to $PM_{2.5}$ as caused by wildfires. The effects that are reported vary, as different outcome measurements are used. The effectiveness depends on factors such as the type, size and occupancy of the studied building and the amount of time during which the PAC is turned on. An overview of all primary studies and results on the effectiveness of PACs is shown in figure 3.2.

One simulation type study by Fisk & Chan reports less expected hospital admissions and deaths attributable to wildfire exposures, and another study reports lesser odds of worsening symptoms over a long-term wildfire episode when a PAC is in use. Most of the studies involving PACs explicitly report using HEPA filters integrated in the PACs, while other studies report no specific filter type. A review article by Zhu *et al*. also reports studying specific different types of filter, namely HECA filters and filtrete air filters. However, only one primary study included in this review by Stauffer *et al.* used an alternative filter type, and one study by Henderson *et al*. used an electrostatic air cleaner that had no specific particle filters. Both studies show a positive effect of the used non-HEPA filtered PACs. It should be noted that the sample size of non-HEPA filters in this review is too small to state with confidence whether or non-HEPA filters are more or less effective than HEPA filters.

Study	**Filter type**	**Room type and size**	**Occupancy**	**Result**
(Stauffer et al., 2020)	Filtrete	Campus office, 12.2 m^2	Occupied as normal during 8-hr workday, doors open and visitors coming in and out, unoccupied at night	Mean reduction of $PM_{2.5}$ concentrations of 72% during the day, 92% during the night (compared to same-size office on the same campus without a running PAC)
(Fisk & Chan, 2017)	Calculations based on HEPA filter	Calculations based on southern California home characteristics (no specifics stated)	Normal occupancy, calculations based on a PAC that may not always be in the same room as the home occupants spend time in, windows closed	Calculated reduction of $PM_{2.5}$ concentration of 45% (compared to calculations of homes in the same study without any type of intervention implemented)
(P. Barn et al., 2007)	HEPA	Main bedroom of the house (various sizes, different homes were studied)	Homes occupied as normal, windows/doors could be opened, activities were kept in a diary by occupants	Mean air cleaner efficiency of 65% (comparing $PM_{2.5}$ infiltration rates of the same homes with and without a HEPA filter installed in the PAC)
(Mott et al., 2002)	HEPA	PACs distributed to participants for use according to their own	Not reported, normal home occupancy is assumed except	Those who ran HEPA for the longest time periods had an OR of 0.54 of reporting worsening symptoms,

		discretion, no data on location of PAC in the home or home size available	for participants who may have combined PAC use in their own home with evacuation to another location (no data on amount of participants who may have combined these two interventions is available)	compared to those who ran the PAC for the shortest time period (table with exact timeframes missing from article)
(Henderson et al., 2012)	Electrostatic air purifier without HEPA or similar filter, only a large dust and carbon filter	Home volumes ranging from 396 m^3 to 1415 m^3. Homes supplied with 2 or 3 PACs according to home size.	Homes occupied as normal, activity diary was kept by participants, windows were not opened in 6 out of 8 homes, and opened in 5% and 10% of the time in the other two homes	24-hr average indoor $PM_{2.5}$ was ≤3 μg/m^3 in homes with PAC running. For homes without PAC running, the concentration was 5.2 to 21.8 μg/m^3
(Wheeler, Allen, …, & 2021)	HEPA	Public library, PACs placed in the 22 m^2 media room to account for limited air cleaning capacity	Library was open and occupied during measurement period, but no specific data on occupation levels and opening of doors was collected	Infiltration efficiency of $PM2_{.5}$ in the main library was 30% compared to outdoors, infiltration into the media room where PACs were operating was 17% compared to outdoors
(Sharma, 2017)	HEPA	Living room of 20th-storey appartment	Living room windows were closed for the whole measurement period, no data on occupancy available from article	Air cleaner effectiveness of 73% for PM_{10} and 54% for $PM_{2.5}$

Table 3.2: Overview of all primary research articles studying the effectiveness of PACs that were included in this review. For each article, the type of filter (if any) used in the PAC, the

room and/or building size the PAC was used in, the occupation status and occupant behavior and the most important results are presented.

The study by Stauffer *et al*. operated a PAC with a filtrate filter in a single campus office room throughout the day and night, with normal occupancy status and behavior. During working hours, indoor $PM_{2.5}$ concentrations were 72% reduced compared to a similar office room on campus without a PAC. During the night, when the office was not occupied, there was an even higher reduction of 92%. The computer model study by Fisk & Chan calculated an estimated reduction of indoor PM2.5 of 45% compared to calculation of homes within the study without implemented interventions based on a PAC equipped with a HEPA filter.

Barn *et al*. reported air cleaner efficiency as their outcome, with an efficiency level of 65% when comparing $PM_{2.5}$ infiltration rates to the same room over a period of time when the PAC was inactive. The PAC was installed in the main bedroom of the house, which was the room in which the occupants would spend the most amount of time per day. Occupant behavior during the measurement period was as normal. Mott *et al*. also reported a different outcome type, stating the OR of reporting worsening symptoms. There was a negative association between running the PAC for the longest amount of time as measured within the study and reporting worsening symptoms, with the reference group being those who operated the PAC for the shortest amount of time as measured within the study. The length of these 'long' and 'short' timeframes of operating the PAC are not stated within the article. Data on other occupant behaviors during the time the PAC was operated were not collected in this study.

Henderson *et al.* reported on a type of PAC not used in any other article in this review, using an electrostatic air purifier without any additional HEPA or other highly efficient filter other than a dust and carbon filter. During the study, 2 or 3 PACs were used in the homes depending on their size, and occupancy behavior was as normal with activities by occupants being tracked. This study found a 24-hr average indoor $PM_{2.5}$ of ≤3 $\mu g/m^3$ in homes with PAC running. For homes without PAC running, the concentration was 5.2 to 21.8 $\mu g/m^3$.

Wheeler *et al.* studied the use of a library as a public clean air shelter. Two PACs were placed in the media room within the library. The library was open and occupied as normal during the measurement period, although occupancy levels and behavior were not tracked. Infiltration efficiency of $PM2_{.5}$ in the main library was 30% compared to outdoors, infiltration into the media room when the PACs were operating was 17% compared to outdoors. Sharma *et al*. studied air cleaner effectiveness after operating a PAC in a living room with the ceiling fan on and all windows closed. No further details on occupancy status are given. The article reports an air cleaner effectiveness of 73% for PM_{10} and 54% for $PM_{2.5}$, stating that the PAC becomes less effective the smaller the particle size, being ineffective for ultrafine particles.

Behavioral changes

Four out of the 15 included articles report studying the effect of behavioral changes during wildfire episodes with varying results. The specific behaviors that were studied in these articles are (temporary) relocation, opening of windows or manual operation of ventilation systems, walking in and out of the room that is being studied and remaining indoors during wildfire episodes. Remaining indoors was studied by one article by Reisen *et al*. reports a 12-76% protection from peak PM2.5 levels during the wildfire episode, depending on length and intensity of the wildfire as well as the leakiness of the building. Temporary evacuation from the wildfire smoke site was studied by Mott *et al*. in relation to the odds of reporting worsening symptoms up to two weeks after complete clearance of smoke exposure. No association between these two factors was reported. In the article by *Luo et al.*, behaviors such as opening windows and moving between different rooms (thereby opening doors) led to a higher level of indoor air pollution than when these behaviors were restricted.

Masks

Out of the 15 final results, three articles report an effect of the use of face masks during wildfire events, of which two are primary studies. The effectiveness of masks was reported to be greatly variable, the lowest being an estimated 0% effectiveness when masks are ill-fitting as stated by Laumbach's review. Künzli *et al.* report an OR for presence of airway-related symptoms among individuals who reported a fire smell for more than six days, with the reference group being individuals who reported a fire smell for a period of time shorter than six days. Mask wearers had an OR of reporting such symptoms of 2.23 versus an OR of 3.47 for non-wearers. Mott *et al*. studied mask-wearing in relation to the odds of reporting worsening symptoms up to two weeks after complete clearance of smoke exposure. Different types of masks were used, namely N95 filtered masks, nonfiltered masks and bandanas. No association, whether negative or positive, was reported between wearing of masks and worsening of symptoms.

Mechanical ventilation

Mechanical ventilation (MV) is another often-studied intervention, reported in six primary research articles included in the results of this review. Different types of MV are studied, including FFUs (fan filtration units) MV with or without use of additional filters of different types, and HVAC systems which combine mechanical ventilation with the possibility of heating and air conditioning a certain space. An overview of all the results on MV effectiveness from the primary studies included in this review is shown in table 3.3. MV is reported to be an effective intervention, with a lower indoor/outdoor (I/O) ratio, reductions in MV-operated building $PM_{2.5}$ concentrations between 11% and 47% and an exposure reduction efficiency of 80.9% being reported. Only one of the included articles shows a negative effect on air quality as a result of using MV; the study by Shresta *et al.* reported a worsening effect due to the use of low-efficiency filtered MV usage compared to no MV usage at all, stating an 18% increased I/O $PM_{2.5}$ ratio.

Study	MV type	Room type and size	Occupancy conditions	Result
(Shrestha et al., 2019)	Low-efficiency filters (not designed for air	Different housing situations, no	Normal occupancy, activity diary	I/O ratio of $PM_{2.5}$ 18% higher in homes with MV using low-

	cleaning) in continuously running exhaust fans and heat recovery ventilation systems	further sizes stated	completed by participants	efficiency filters active during wildfire episodes
(Fisk & Chan, 2017)	Calculations based on HVAC with no filters, low efficiency filters, and high efficiency filters separately; and the system used either intermittently or continuously	Calculations based on southern California home characteristics (no specifics stated)	Normal occupancy, calculations based on a PAC that may not always be in the same room as the home occupants spend time in, windows closed	Calculated reduction of $PM_{2.5}$ concentration of 24% (continuous use, low-efficiency filter), 47% (continuous use, high efficiency filter) and 11% (intermittent use, high-efficiency filter) (compared to calculations of homes in the same study without any type of intervention implemented)
(Pantelic et al., 2019)	HVAC with high-efficiency MERV filters	Office building	Occupied as normal, ~ 270 daily occupants	Higher indoor air quality in mechanically ventilated building (I/O 0.27 vs 0.67 in naturally ventilated building)
(May et al., 2021)	High-efficiency MERV filters attatched to FFU	Two rooms (200 m^3 and 50 m^3) in a home	Unoccupied during measurement period, windows and doors shut	Lower I/O and indoor penetration of $PM_{2.5}$ with active FFU, with a minimum $PM_{2.5}$ concentration reduction of 45% compared to outdoors in the largest room, and a reduction of nearly 100% in the smallest room
(Tham et al., 2018)	FFU with high-efficiency MERV filters	Two rooms, both 24 m^3, in the same 3rd-storey apartment that normally serves as a hostel	Unoccupied during measurement period, windows and doors closed after initial period of letting smoke enter, ceiling fan running continuously	Exposure reduction efficiency to $PM_{2.5}$ of 80.4% compared to outside in the FFU-operated room, reduction of 43.3% compared to outside in the control room
(Chen et al., 2016)	ACMV with high-efficiency MERV filters	19 m^2 room within an office	Unoccupied during measurement period and up to	Lower I/O ratios with a combination of mechanical ventilation and air conditioning vs. mechanical ventilation only, removal

			one year before measurements	efficiency of less than 30% for particles sized 0.01 -1.0 µm with air conditioning and ventilation on

Table 3.3: Overview of all primary research articles including data on MV that were included in this review. An overview of the type of MV and filters, the room and/or building size the MV was used in, the occupation status and occupant behavior and the most important results are presented for each study.

The article by Fisk & Chan reports the lowest computer calculated reduction of just 11% in indoor $PM_{2.5}$ compared to indoor measurements a baseline home with no interventions. This is for a computer model simulated situation in which the MV is not operated continuously, even though high-efficiency filters are placed. The same article reports a calculated reduction of 24% in a situation in which the MV is operated continuously, despite the filter being of low efficiency. The highest reduction was calculated as 47% in a situation in which the MV is operated continuously with high-efficiency filters.

Pantelic *et al*. report their MV effectiveness outcome as an I/O ratio. A lower I/O ratio suggests lower penetration of $PM_{2.5}$ indoors. They compared an office building equipped with MV to a similar office building that is naturally ventilated in similar occupancy situations, with the MV-equipped office building having a lower I/O ratio. May et al. also reported a lower I/O ratio for the rooms they studied. In addition, they reported a $PM_{2.5}$ reduction as compared to outside concentrations, with a reduction of 45% in a large size room (200 m^3) they studied and a near 100% reduction in a small size room (50 m^3) they studied. The study by May *et al.* used unoccupied, sealed off rooms. Both studies used high-efficiency filters within their MV units.

Tham *et al* compared two rooms with the same layout situated within the same hostel building. One room was equipped with a FFU including high-efficiency filters, and one room was used as a control. Both rooms were sealed off and not occupied during the wildfire measurement period, after an initial period of letting polluted air in. Indoor PM2.5 concentrations were compared to outside levels, with an exposure reduction efficiency of 80.4% being reported for the FFU-equipped room, whereas only a 43.3% exposure reduction efficiency was reported for the control room. Chen *et al*. studied one room within an office building, comparing a situation with only the MV on and a situation with the MV and AC on. The inclusion of an operating AC in addition to an operating MV resulted in lower I/O concentrations across different particle sizes, with a level of 0.59 with the AC on and a ratio of 0.64 with only the MV on for particles sized 0.3 µm.

Risk of bias

The potential bias of each of the 15 primary studies was evaluated using the Cochrane handbook guidelines for assessing bias (“Cochrane Handbook for Systematic Reviews of Interventions | Cochrane Training,” version 6.2, 2021). The studies included in this review consist of non-randomized types of research. An overview of the identified potential biases and problems for each study is shown in table 3.4.

Study	Biases & Problems		
(Shrestha et al., 2019)	Small sample size	Variation in types of homes studied (layout, number of doors/windows)	Incomplete data due to failing equipment during measurement periods
(Stauffer et al., 2020)	Small sample size	No source apportionment	Outdoor PM measured not directly outside building, but 3 miles away
(Fisk & Chan, 2017)	Digital model simulation relies completely on averages and estimates		
(Pantelic et al., 2019)	Small sample size	No source apportionment (only estimates)	
(P. Barn et al., 2007)	No source apportionment	<24 hr sampling periods	
(Reisen et al., 2019)	Reporting bias	Missing data on ventilation status of homes	
(Mott et al., 2002)	Confounding of interventions with preexisting symptoms	Recall bias, reporting bias	Not reporting on other occupant behavior that occurred while operating a PAC
(Henderson et al., 2012)	Small sample size	Selection bias	
(Wheeler, Allen, …, & 2021)	Missing data on occupancy levels and behavior of occupants	No measurements during most smoke-heavy period of the wildfire event during the study	
(Künzli et al., 2006)	Interrelated reporting, recall bias, selection bias	Estimated PM values instead of measured	Confounding of interventions with preexisting symptoms
(Luo et al., 2019)	Building airtightness not taken into account in establishing air infiltration rates	Methodology focused only on commercial buildings, not residential	Digital model simulation relies completely on averages and estimates
(May et al., 2021)	Small sample size	Selection bias	
(Tham et al., 2018)	Small sample size	No occupancy behavior data	
(Sharma, 2017)	Small sample size	Short measurement period	No occupancy behavior data

(Chen et al., 2016)	Small sample size	No source apportionment (only estimates are present)	

Table 3.4: Overview of the different types of bias and other issues with study design and data that were identified for each primary research article included in this review.

Two studies reported themselves that they are missing some data. The study by Reisen *et al.* is missing some data on the ventilation status of a few homes on certain timepoints, a metric that should have been reported by a member of the participating household. The study by Shresta *et al*. reports missing some emission measurements. The researchers report that this happened due to failure of the used equipment. In other studies, data deemed important for full analysis of the results is missing. In the articles by Wheeler *et al*., Mott *et al,* Sharma *et al* and Tham *et al*, occupant behavior was not or not completely tracked or mentioned. This measure could potentially affect the effectiveness of interventions found in the studies, and as a result its absence is deemed as problematic here.

A selection bias is deemed to be present in two studies, the articles by Henderson *et al.* and May et al. For the article by Henderson et al, four homes were selected through contacting the local fire chief. No further characteristics of the participants are stated, but since they were recruited via the local fire chief, the selection was not random and may have included individuals with high risk awareness concerning wildfires leading to different behavior than occupants of a randomly selected home. If this is the case, it may have affected some data. For the article by May *et al*, participants were selected from a pool of individuals already participating in an air sensor study. As a result, the selection of these participants was not random, and the participants may not be representative of the general population.

Two of the studies, by Luo *et al* and by Fisk and Chan, did not include actual live measured data, but were based on computer models. Such study types might be prone to bias, as they rely heavily on estimations and averages. For example, Fisk & Chan did not take spatial variability in outdoor PM2.5 into account and relied on steady state mass balance models as well as on the assumption that the indoor air was well mixed. In the bigger 'sample size' of Fisk & Chan's study this might lead to appropriate averages in the final analysis, but small to moderate errors could potentially be present in the final results.

Overall, missing source apportionment for $PM_{2.5}$ is identified as a problem in many of the included studies. As all studies took place during a wildfire event as established by the inclusion criteria, it is assumed in all studies that the wildfire was the main source of the $PM_{2.5}$ during the studies, but this cannot be known for sure. Other outdoor sources for $PM_{2.5}$ might have been present, such as living near high traffic roads. Indoor sources of $PM_{2.5}$ also exist, such as use of cooking stoves. As stated in the above paragraph, occupant behavior data was not included in some studies, and its effects on spikes in $PM_{2.5}$ levels could not be measured in these studies as a result, which is seen as an issue as this might affect the reported intervention effectiveness.

Similar to missing source apportionment, small sample sizes are a problem in almost all of the included studies. Many studies, like Wheeler *et al*, Pantelic *et al*, and Stauffer *et al,* only compare 1 or 2 rooms/buildings to each other in terms of air quality, with either the outdoor measurements or the other room/building without an intervention being used as a control. Such small sample sizes are not representative for the general population and cannot be confidently used to determine intervention effectiveness for a broader public.

Chapter 4: Discussion

In this report, a systematic literature review approach was used to study the effectiveness of interventions available for use in the event of wildfires. Out of 1794 papers initially identified, 15 primary articles were included in the final review. The articles studied a variety of interventions which were almost all effective to some extent. The only ineffective methods that are reported were ill-fitting facial masks and usage of MV units without highly efficient filters.

Following the results from the included articles, MV and PACs were the most widely studied interventions, and were overall reported to be the most effective. The amount of evidence in this review is too small and too diverse to state confidently which of these two types is most effective as an intervention, and in real life this may vary according to an individual's personal situation for example regarding their behavior and home size. When comparing the effectiveness of MV usage between the studies that researched this type of intervention, high-efficiency filters, continuous use of the MV system, and the room being unoccupied or (mostly) sealed off appear to be factors positively associated with a higher measured efficiency of the MV system. It is interesting to note that MV only seems to be effective if high-efficiency filters are installed in the unit, instead of merely using a forced flow between indoor and outdoor air without additional particle filtering. The article by Shresta *et al.* even reported a worsening effect resulting from the use of a MV system without efficient filters, as the indoor air was more highly polluted in homes with MV systems containing low-efficiency filters than in homes without MV. Such a low-efficiency MV system only ensures that the highly polluted outdoor air during a wildfire episode is able to penetrate indoors more quickly, resulting in a higher indoor air pollution within a shorter amount of time. However, the computer model study by Fisk & Chan did report a positive effect even in a situation where low-efficiency filters were used. In fact, an MV with a low-efficiency filter was found to be more effective than a high-efficiency filter if the low-efficiency filtered MV system is operated continuously and the high-efficiency filter MV system is only operated intermittently. This difference in study outcome might have resulted from the assumptions made by the computer model in Fisk & Chan's study, or a difference in the specific type of low-efficiency filter used in each separate study which was not clearly stated.

Compared to MVs, PACs have the added benefit that they can be constantly put in close proximity to an individual, wherever they may be in their home. As a result, the home occupant can constantly benefit from being in a zone with clean air, especially if multiple PACs are installed throughout larger homes. With PACs, it is indeed important that the appropriate type of PAC is used for a certain home and/or room, as PACs have a maximum limit to the area (in m^2 or m^3) they can effectively clean air in. This was addressed in the reviewed studies, as for example the articles by Henderson *et al*. and by Wheeler *et al*. placed two or three PACs in the buildings they studied to ensure a proper level of air cleaning effectiveness. In real life situations, it should be noted that people might not have the means to purchase and operate the appropriate types or amounts of PACs. This potential issue will be further addressed under the header 'Socioeconomic status and interventions' in this discussion section.

It is important to note that not all individuals might be aware about the efficiency of filter units installed in their home MVs or in the PACs they use, and the correct way of using them to ensure maximum efficacy. If public safety announcements focus on stimulating a community at risk of wildfire smoke exposure to take action, for example by switching on their ventilation systems during the wildfire episode, this might potentially lead to more adverse effects if the filters an individual uses are inadequate. Future research could aim to investigate whether or not PAC and MV users are aware of correct and efficient filter usage and maintenance, whether or not they are able to replace filters periodically and how current public health messages help make people aware of the correct use of these interventions.

Masks were a type of intervention that was only barely studied, with highly variable results that are hard to compare or evaluate. An issue with masks is that they have to be properly fitting. When a mask does not have a perfect fit, the efficiency rapidly drops as smoke particles will be able to infiltrate past gaps in the fitting and penetrate the airways (Laumbach, 2019). The material of the mask may be important as well. Home-made masks or use of items of clothing such as shawls and bandanas to function as a mask might not be efficient either, as not all types of cloth are designed to protect against smoke particle infiltration (Holm, Miller, & Balmes, 2020).

The most worrying implication from mask use is that it could lead to a false sense of protection for the wearer. The wearer may assume they are properly protected from smoke inhalation and its dangerous health effects (Holm et al., 2020). As a result, the wearer might resume their daily activities or may not be as worried about also running an air cleaner or staying inside as much as possible during wildfire episodes. However, when the mask is not as effective as the wearer assumes, this behavior might lead to adverse health effects after all (Holm et al., 2020). Unfortunately, no metric relating to the wearer's sense of security while wearing the mask was reported in any of the studies included in this review that looked at the effectiveness of masks. In future studies addressing mask effectiveness, it would be good to assess the wearer's behavior during mask-wearing periods in order to investigate whether or not wearers are more likely to participate in other activities that might increase smoke inhalation. In addition, wearers could be asked to report on their feelings of protection as a result of mask-wearing to investigate whether or not behavior and (potentially false) feelings of security might be related. If this is indeed the case, public health advise could be modified to inform people about the most effective ways to use masks during wildfire events. Masks may also be subject to inconsistent wearing, as wearers might temporarily remove the mask to due to discomfort or in order to carry out activities such as talking or eating. This further reduces the effectiveness of masks (Holm et al., 2020). On balance, masks are quite possibly not the most effective personal intervention method to be used in the event of wildfires due to their potential to lose effectiveness rather quickly and weak evidence found in this review supporting the idea that mask wearing reduces exposure to and symptoms resulting from wildfire smoke.

Socioeconomic status and interventions

One particularly important group is individuals with low socioeconomic status. Individuals belonging to minority groups and those with lower socioeconomic status might be more susceptible to living in areas where exposure to wildfire smoke is more prevalent (Davies, Haugo, Robertson, & Levin, 2018). In addition, many of the widely-used interventions to reduce exposure that are discussed in this review might not be as accessible to those with lower socioeconomic status. MV with implemented filters as well as PACs are devices that cost a significant sum of money to purchase and install (Cheek et al., 2021). The website 'Consumer Reports' states the prices of five high-rated models of air purifiers as varying between 250 and 600 USD as of October 25, 2019 (P. Santanachote, consumerreports.org, 2019). The rooms these purifiers can clean effectively range in size from about $45m^2$ to $102m^2$. This either leads to added costs if a larger sized house needs to be purified, or less overall effectiveness because the house occupant(s) move the purifier around from room to room in an attempt to get better air quality throughout the house without purchasing additional units. In addition, these devices might need to have their filters replaced every few months and they run on electricity which is not always energy efficient, leading to lifelong usage costs during wildfire episodes aside from the initial purchasing (Tham et al., 2018). The website 'Consumer Reports' also made a calculation of these additional costs for the aforementioned five top-rated PAC models. Yearly energy costs ranged from 31 to 87 USD, whereas replacement filters cost between 90 and 175 USD depending on the specific type of PAC as of October 25, 2019 (P. Santanachote, consumerreports.org, 2019). As a result, these interventions are costly and might not be accessible for all (P. K. Barn et al., 2016; Cheek et al., 2021). Sometimes, MV without proper filters is used, leading to a high rate of air exchange between the indoor and outdoor environment without particle filtration. During a wildfire episode, this potentially only results in a higher indoor pollution level over a shorter amount of time, as was established in the article by Shresta *et al*. Not all behavioral changes might be accessible either, as staying indoors during wildfire episodes or temporary relocation might not be feasible. For example, this might be due to economic hardships of undocumented workers, who might not be able to afford to stay home from their job or book a short stay in a hotel away from the fire site, or due to minorities facing language barriers which means public health messages are not understood and followed up (Masri, Scaduto, Jin, 2021). Interestingly, one article by Wheeler *et al.* investigated the use of PACs in a public library with the aim of using this building as a clean air shelter during wildfire episodes. Such a public shelter might be more accessible to those who are unable to implement interventions in their own home. However, the use of such a public shelter needs to be investigated further, as the article by Wheeler *et al*. has some limitations, such as not investigating the effect of occupant behavior during the period in which the effectiveness of the PACs in the library were measured. However, occupant behavior and the effect this has on the effectiveness of the PAC are extremely important to know in a public shelter situation. People are expected to be walking in and out of the shelter throughout the day, and the related opening of doors probably effects the air quality in the shelter as it allows for more polluted air to flow inside. The willingness to use such shelters and the time that individuals would be committed to spending in such a public shelter, as well as the facilities people would like to be able to use within the shelter should be investigated in order to determine if clean air shelters are an effective public health intervention and how they should be set up.

Effectiveness of personal interventions

This review aimed to answer the question whether or not currently available personal interventions used to protect against wildfire smoke are effective. Like other similar reviews have stated, there is a small amount of evidence stating positive effects of personal intervention, and the quality of this evidence is rather weak. This is mostly caused by the small sample sizes in all studies included in this review, and the small amount of total studies available which makes comparison to a large base of evidence impossible. Most importantly, potentially important data is missing in at least six of the 15 included studies in this review. As a result of the above, it cannot be stated with high confidence whether or not any particular intervention is effective for use in the general population. Likewise, it cannot be stated with high confidence whether or not certain interventions are definitely more effective than others. This is the reason why any such remarks in this discussion, for example about masks potentially being less effective, are made cautiously. What can be concluded from the data however is that personal interventions, especially PACs and MV combined with appropriate occupant behavior in the homes in which they are operated, show promising effects when it comes to reducing exposure to air pollution as caused by wildfires. The most effective intervention may vary from individual to individual and from situation to situation. In order to make more confident claims about which interventions are more effective in which situations, more high-quality and large-scale research is needed.

There are many more articles focusing on different types of interventions not included in the scope of this article, such as reducing the effects of climate change, forest management, and studying the effectiveness of communication strategies during wildfire episodes. This review must be seen as a small part in the bigger context of intervention and prevention strategies regarding wildfires and resulting health effects. However, this does mean that there is a limited amount of studies concerning the *specific* effectiveness of personal interventions in the *specific* event of wildfires. As wildfires are still becoming more prevalent, personal interventions are of high value to populations that are particularly vulnerable to the effects of wildfire smoke exposures and/or groups that are often exposed to wildfire smoke. Individuals may not have much control over policy, regulations and grand-scale changes attempting to reduce wildfire occurrence, but they are very much in control of using personal measures in an attempt to reduce their personal exposure. As of such, personal interventions are very important to ensure an individual's level of protection, as this might be the only option they have. A false sense of security resulting from ineffective methods or usage of ineffective methods due to inaccessibility to more effective means might result in a greater societal cost.

Strengths and limitations

The validity of a literature review is highly dependent on any potential bias introduced during the process of reviewing. Some types of bias may have been introduced in the present review. A high risk of bias is present regarding the selection of results in this review. Since this process was carried out by one person only, bias may have been introduced due to there not being a second control step being carried out by another person. This might have resulted in accidental exclusion of articles that would be valid for this review according to the used eligibility criteria. For future literature reviews concerning this topic, a selection committee of at least two (but preferably more) individuals should be used. Each should individually sort the articles in 'inclusion' and 'exclusion' categories after which final results should be compared and any disputes should be resolved following a group discussion.

Another limitation of this study arises from potentially having missed relevant results due to having missed important keywords in the search string. This might also be introduced due to some relevant articles not being included in any of the databases that were searched in this review. The tree main databases Scopus, Web of Science and PubMed were used for this literature review, as it was assumed that those databases are extensive enough to cover almost all relevant articles to be found in existing literature. However, it cannot be excluded that there are articles relevant to the research question that are not present in any of the used databases, although the risk of having missed a significant number of relevant articles is considered low due to the extensive search string and the expected coverage of the used databases.

Some remarks about limitations can also be made on the risk of bias of the included results. Trials studying personal interventions for wildfire smoke are mostly non-randomized trials due to the nature of the interventions. Some of the studies that were reviewed made use of questionnaires and asked about the behavior of participants during a certain wildfire event sometime after the event ended. Such study setups are susceptible to recall bias and reporting bias. Other study setups that took PM measurements in- and outside homes took their outside measurement at a location further away from the home instead of directly outside of it, sometimes more than 10 kilometers away. When presenting the effectiveness of the studied intervention by means of comparing indoor air quality versus the outdoor air quality measured a greater distance away, there might be issues with the reliability of this data, as outdoor air quality measurements can vary greatly over relatively small distances based on other ambient sources of pollution as well as weather circumstances, as wind can cause wildfire smoke clouds to drift only over particular areas. From the results on the risks of bias involved in the reviewed studies, it becomes clear that the most used study designs in this type of intervention research are quite susceptible to bias. All of the included studies have at least a minor issue with bias or other problems with reliability of the presented data, meaning the overall base of evidence this literature review aims to draw a conclusion on is relatively weak. However, this is a limitation that is not specific to this literature review, as the literature search was very extensive and as a result, other literature reviews concerning this topic will have to use the same base of evidence since there is simply no great amount of high-quality research available on this subject.

A strength of this literature review is the specificity of the research question. This review only included studies that specifically looked at interventions during wildfire episodes, whereas other review articles often include other ambient sources of air pollution. As an article by Kiser et al. suggested, air pollution specifically caused by wildfires might cause effects that are not seen when the air pollution originates from other sources. In this article, a 6.1% increase in asthma-related hospital visits was seen only when high $PM_{2.}$ levels directly attributable to a wildfire were present (Kiser et al., 2020). Another strength related to the specificity is the particular focus this review puts on interventions for the general public. There are many more reviews on interventions for use in occupational situations, mostly studying firefighters and/or agricultural workers. It is true that people involved in these occupations are a great risk for wildfire smoke exposure and potential adverse health effects, and that specific effectiveness related to their situation needs to be studied. However, their situation does not reflect the hazard that members of the general public are exposed to during wildfire episodes. For example, some intervention types might not be feasible in an occupational situation, and those who are exposed to wildfire smoke through their occupation might be more aware of the risk posed by wildfires leading to some interventions being potentially more effective in an occupational situation. However, this review only looks at the effectiveness for the broader public and interventions that are applicable in that situation.

Concluding remarks

All in all, there appears to be a relatively small amount of evidence regarding the effectiveness of personal interventions in the event of wildfires. A wide net was cast during literature research, but only 1.1% of initially identified articles was used in the final review. Despite this, the small base of available evidence showed largely consistent evidence regarding effectiveness per intervention type. Due to the small number of studies and each study investigating a slightly different setup and outcome, the exact percentages of effectiveness vary from study to study. The low absolute number of included articles might be due to the narrow scope and strict inclusion criteria of this review, as many more research regarding personal interventions is available that specifically focusses on outdoor and indoor sources of air pollution other than wildfires. Other than the low absolute number of evidence, the quality of the studies is relatively on the lower side due to small sample sizes in almost all studies, and experimental setups being used instead of conducting grand-scale observational studies or clinical trials that would be less biased based on that inherent study design. However, the fact that personal interventions are effective in certain situations cannot be dismissed, as many of the studies agreed on the relative effectiveness of specific interventions. In conclusion, personal interventions are probably effective, with MV and PAC devices combined with occupant behavior that does not allow for great penetration of polluted air indoors being the most effective. To further back up this argument and provide a larger amount of evidence on which interventions are the most effective in which particular situations, more research is needed. This future research should primarily focus on creating a greater base of reliable evidence for the effectiveness of personal interventions, but it should also put a great focus on the accessibility of interventions that are deemed highly effective. This might be in the form of researching how interventions can be produced in a low-cost way. It might also take shape in identifying particular populations that are at risk and providing them with the most effective interventions for their situation, thereby creating a high cost-effectiveness by reducing deaths and hospital admissions due to wildfire events.

Appendix

A.1: Search terms used to identify articles that were used in this literature review.

((forest fire OR wildfire OR bushfire OR bush fire) AND (intervention OR prevention OR air filtration OR filtration OR mitigation OR communication OR ventilation OR air purifier OR respirator OR mask OR masks OR control strategies OR control OR portable air cleaner)) AND (air pollution OR air quality OR air pollutants OR indoor air exposure OR indoor air concentration OR particulate matter)

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