World Health Organization

European Region

Personal-level actions to reduce air pollution exposure in the WHO European Region

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Abstract

This report summarizes evidence and information and formulates practical advice on personal-level actions to reduce exposure to ambient air pollution. It covers personal actions such as reducing the amount of time spent in polluted outdoor environments, adjusting the location and timing of physical activity, using air cleaners, wearing face coverings, and mobility options (transport, active transportation, routes, driving style and vehicle settings). Each topic is evaluated according to a uniform set of criteria, ranging from effectiveness to personal costs and social factors. Most of the evidence available to inform the advice derives from western European and North American studies. Although evidence on effectiveness and on health risks/harms can be considered applicable across settings, evidence on economic, social or feasibility factors is less so. Consequently, the applicability of the advice presented in this report should be carefully considered at national level, especially in settings outside western Europe.

Keywords

AIR POLLUTION, PROTECTIVE FACTORS, EXERCISE, PERSONAL PROTECTIVE EQUIPMENT, AIR FILTERS, EUROPE

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Abbreviations

CO	carbon monoxide
CO_2-eq	carbon dioxide equivalent
COVID-19	coronavirus disease
EU	European Union
FFP2/3	filtering facepiece class 2/3
HEPA	high-efficiency particulate air (filter)
HVAC	heating, ventilation and air conditioning
MERV	minimum efficiency reporting value
NO_2	nitrogen dioxide
O_3	ozone
PAC	portable air cleaner
PM	particulate matter
$PM_{2.5}$	particulate matter, where particles have an aerodynamic diameter equal to or less than 2.5 µm
PM_{10}	particulate matter, where particles have an aerodynamic diameter equal to or less than 10 µm
SKAPHIE	Sharing Knowledge on Air Pollution and Health in Europe (project)
TRAP	traffic-related air pollution
UFP	ultrafine particles

Introduction

Clean air, that is, ambient (outdoor) air free from harmful levels of air pollutants, is a human right *(1)*. Even so, air pollution is the single largest environmental health risk in the WHO European Region, with significant impacts on the health of the European population *(2,3)*. Air pollution increases the disease and mortality risk, and cardiovascular and respiratory illnesses are the major causes of mortality in the WHO European Region *(4)*. It also increases the burden of lower respiratory tract infections, as well as of preterm birth and other causes of death in infants and children *(4)*. Air pollution has considerable economic impacts through reducing life expectancy, increasing medical costs and reducing productivity through lost working days across different economic sectors *(2)*.

Most European citizens consider the health impacts of air pollution to be a serious problem *(5)*. In 2019 more than 90% of the urban population in the European Union (EU) was exposed to health-damaging levels of key air pollutants *(2)*. In particular, 97% of the urban population was exposed to concentrations of fine particulate matter ($PM_{2.5}$)[1] above the new WHO guideline level of 5 µg/m³ *(2)*. In 2019 in the EU, 307 000 premature deaths were attributed to $PM_{2.5}$ exposure, 40 400 to nitrogen dioxide (NO_2) exposure and 16 800 to ozone (O_3) exposure *(2)*. According to WHO, approximately 570 000 premature deaths were attributed to ambient $PM_{2.5}$ in the WHO European Region in the same year *(6)*.

In 2019 residential, commercial and institutional energy generation and consumption were the principal sources of particulate matter (PM), that is $PM_{2.5}$ and PM_{10}.[2] Road transport and the manufacturing and extractive industries were also significant sources of both pollutants, and agriculture was an important source of secondary $PM_{2.5}$. $PM_{2.5}$ and PM_{10} emissions fell by 29% and 27%, respectively, between 2005 and 2021 *(2)*. Anthropogenic emissions of air pollutants are the key drivers of ambient concentrations of PM, NO_2 and O_3 *(2)*.

In the EU, total emissions of all air pollutants declined between 2005 and 2019. During this period, there was also a significant level of absolute decoupling between pollutant emissions and economic activity, which is desirable for environmental protection and productivity gains. Absolute decoupling indicates that a variable remains stable or decreases while the growth rate of the economic driving force increases. Emissions may become decoupled from economic activity for a combination of reasons, such as increased regulation and policy implementation, fuel switching, technological improvements, and improvements in energy or process efficiencies. In the EU, the consumption of goods produced outside the EU also contributes to the global economic activity and emission trends *(2)*. Climate change also represents a challenge to air quality in Europe, especially for future concentrations of PM and O_3 *(7)*.

Under the European Green Deal's Zero Pollution Action Plan, the European Commission set the 2030 goal of reducing $PM_{2.5}$-related premature deaths by at least 55% compared with 2005 levels *(8)*. To this end, the European Commission initiated a revision of the ambient air quality directives in order to align the air quality standards more closely with WHO recommendations *(2,4)*. In parallel, stricter

[1] PM where particles have an aerodynamic diameter equal to or less than 2.5 µm.
[2] PM where particles have an aerodynamic diameter equal to or less than 10 µm.

requirements are also expected for tackling air pollution from sources such as agriculture, industry, transport, buildings and energy production *(2)*.

Several key WHO documents outline actions that are needed to better protect health from air pollution through measures to be taken by Member States, including the importance of disseminating evidence-informed practices on air quality actions related to health. World Health Assembly resolution WHA68.8, Health and the environment: addressing the health impacts from air pollution *(9)* highlights as key activities providing information to policy-makers and the public about the health impacts of air pollution and taking action to reduce it. Similarly, the WHO Global Strategy on Health, Environment and Climate Change recognizes the potential of increasing citizens' awareness of promoting adaptive actions and pro-environment behaviours. Health professionals have an important role in promoting behavioural change towards healthy and more sustainable ways of living *(10)*. Lastly, the European Programme of Work 2020–2025 promotes as a flagship initiative the use of behavioural, social and cultural insights into decision-making to build a culture of health in which everyone is enabled to make healthy choices *(11)*.

Whereas primary prevention requires that political attention remains firmly focused on reducing emissions of air pollution at source, at personal level some actions can be implemented to reduce personal exposure to air pollution, particularly during high pollution episodes *(12)*. Although limited evidence exists in this area, some provisional advice can be drawn from the existing literature. It is also important to highlight the need for public education on air pollution as a key health risk factor and for public communication and air quality information to support the prevention of air pollution exposures. An equity approach should be used to support and facilitate access to personal-level actions and provide the necessary resources to implement them.

Furthermore, personal-level actions should be seen as complementary to and not as a substitute for long-term planning and multisectoral interventions by government authorities and society to reduce air pollution emissions *(3)*. Multisectoral interventions might involve the active participation of individuals, for example, in replacing polluting household appliances with cleaner ones or choosing less-polluting transportation modes. However, such interventions are outside of the scope of this report.

Scope of this report

Building upon ongoing efforts to enhance and promote evidence-informed practices, the provisional advice in this report contextualizes and expands the work on the topic presented in the expert consultation report, *Personal Interventions and Risk Communication on Air Pollution (3)*, and the *WHO Global Air Quality Guidelines (4)*. The advice is intended to help the general public to minimize personal exposure to air pollution in the WHO European Region. Other stakeholders who will also benefit from this advice include health professionals, community leaders and journalists. Since the format of this report might be too complex for easy communication, WHO will publish a set of accompanying communication materials. National public health authorities or specialists can use the report as the basis for locally relevant communication materials.

This report was produced in the framework of the Sharing Knowledge on Air Pollution and Health in Europe (SKAPHIE) project, led by the WHO European Centre for Environment and Health and in collaboration with experts from European universities, agencies and organizations.

It has five main sections that correspond to the main categories of personal-level action identified in the earlier WHO expert consultation report (3) and the suggestions of experts who attended a virtual scoping meeting:

- Reducing time spent in polluted outdoor environments
- Physical activity: location and timing
- Air cleaners
- Face coverings
- Transport, active transportation, routes, driving style and vehicle settings.

Each section provides a formal definition and then evaluates the type of personal-level action according to a uniform set of criteria:

- effectiveness in reducing exposure to air pollution
- effectiveness in improving health
- health risk or harms
- negative environmental impacts
- personal costs
- social factors
- barriers and facilitators to implementation
- practical advice for general and vulnerable populations.

For each criterion, the evidence provided by a narrative review[3] of the literature is summarized. The narrative review is based on recent systematic reviews, institutional reviews and expert appraisals.

A panel of experts discussed and made further input to the narrative review in three virtual meetings and through email exchanges. The "Practical advice for general and vulnerable populations" sections highlight key messages for both general and vulnerable populations related to each personal-level action to reduce exposure to air pollution. However, owing to the limited evidence available in some areas and the evolving nature of this evidence, the key messages give only provisional advice. Evidence from future studies will help to improve the strength of evidence and guide future advice.

This report is intended to guide and facilitate the rational use of the most widely recognized or viable approaches to reduce personal exposure to air pollution (both day to day and during high air pollution episodes). It focuses on personal-level actions to reduce exposure to air pollution and is not intended to guide infectious disease prevention and management approaches, such as those related to coronavirus disease (COVID-19), seasonal influenza or other communicable respiratory diseases. Separate reports by the WHO Regional Office for Europe focus on other topics covered by the SKAPHIE project such risk communication in air quality indexes and the relationships between air pollution and COVID-19 *(14–16)*.

This report was intended to meet the needs of the European Commission in the context of EU air quality policy, but in principle is also applicable to other subregions of the WHO European Region

[3] A narrative review is a literature review that describes and appraises published articles but does not include a specific search strategy or database *(13)*.

other than the EU (e.g. central Asia, western Balkans, Caucasus). Most of the evidence available to inform the advice derives from western European and North American studies. Although evidence on effectiveness and health risks/harms can be considered applicable across settings, evidence related to economic, social or feasibility factors is less so. Consequently, the applicability of the advice presented in this report should be carefully considered at national level. Further activities in specific subregions of the WHO European Region may enable this advice to be further contextualized. As an example of this approach, Poland convened a panel of experts to adapt the 2020 WHO global advice on air pollution risks and actions to the local context *(17)*.

Personal-level actions to reduce air pollution exposure

Reducing time spent in polluted outdoor environments

Definition

Avoiding outdoor environments during high air pollution episodes is an action based on public advice to reduce exposure to outdoor air pollution by staying indoors. The impact of this action depends on the amount of time spent indoors, outdoor air pollution levels, the amount of air pollution able to infiltrate the building and indoor sources of air pollution (e.g. mould, dust, emissions from heating/cooking). High air pollution episodes are defined based on local or national air quality standards and policies.

Effectiveness in reducing exposure to air pollution

A common piece of precautionary public health advice is to avoid harmful outdoor environments when outdoor air pollution levels are high. The evidence shows that during high air pollution episodes the concentrations of allergenic particles, biogenic particles, PM and other air pollutants are lower indoors than outdoors *(18–20)*. However, infiltration (that is air leakage) efficiencies vary widely: compared with outdoor air pollutant levels, indoor levels can be reduced by > 60% through mechanical ventilation and by < 20% through natural ventilation only (i.e. open windows) *(21)*. O_3 concentrations are generally lower (by 30–70%) indoors than outdoors, primarily because O_3 is removed from indoor air through chemical reactions that occur in the air and on surfaces *(22)*. The effectiveness of avoiding outdoor environments on reducing air pollution exposure depends on factors such as the outdoor–indoor penetration of air pollution, type of ventilation, season, climate and type of housing *(3)*. Closing windows combined with the use of air conditioning can reduce the outdoor–indoor penetration of $PM_{2.5}$ *(23)*. Reducing household energy consumption and using cleaner fuels and more-efficient, less-polluting household appliances may also help to improve indoor air quality.

Effectiveness in improving health

Where outdoor–indoor penetration of air pollution is high, closing windows can attenuate the increased levels of inflammatory biomarkers, such as plasma C-reactive protein and fibrinogen, and decrease heart rate variability *(23,24)*.

Health risk or harms

In households with sources that emit high levels of indoor pollutants, the advice to stay indoors may unintentionally lead to higher exposure to air pollution *(3)*. Household energy sources such as natural gas and liquid petroleum gas may also increase the risk of gas leakage, fire, explosion and suffocation. Thermal insulation without ventilation may reduce the dilution of indoor air pollutants by air leakage and so increase the risk of mould and dampness. Avoiding outdoor environments by spending time indoors with closed windows may also increase the risk of exposure to high temperatures *(3)*. Staying indoors could also reduce quality of life and mental well-being. For example, when indoor ventilation is limited, the presence of indoor air pollution sources (from cooking and heating) may reduce comfort levels in the home. Avoiding outdoor environments can also increase social isolation, reduce physical fitness and impair mental health *(25,26)*. However, despite these risks, appropriate measures for avoiding outdoor environments may help to reduce pollutant exposure in environments with high ambient $PM_{2.5}$ levels *(23)*.

Negative environmental impacts

Avoiding outdoor environments may indirectly reduce air pollution emissions by reducing motorized transportation needs, but may also have negative environmental impacts resulting from increased household energy consumption for ventilation, air conditioning, using household appliances, or burning fossil fuels for heating and cooking. Furthermore, avoiding outdoor environments may indirectly increase air pollution emissions related to the delivery of takeaway food and online shopping *(27)*.

Personal costs

In general, avoiding polluted outdoor environments is not expected to have a direct cost to individuals. However, the societal costs of work absences by population subgroups could impact the local economy *(28)*. Furthermore, maintaining a clean indoor environment could involve costs related to the purchase and use of high-efficiency appliances, clean fuels, ventilation and air cleaners with high-efficiency particulate air (HEPA) filters, and the maintenance of building structures that minimize air pollution and air leakage *(29)*.

Social factors

Owing to the low personal cost and ease of implementation, avoiding outdoor environments when air pollution levels are high may be an acceptable action to reduce personal-level exposure to air pollution. However, not everyone has access to indoor facilities (e.g. transient and homeless people) or to quality housing or buildings (i.e. with proper ventilation, thermal comfort, air conditioning and electrical appliances) or can decide when to stay at home (e.g. essential workers) *(30)*. This is particularly relevant because essential workers are often members of a vulnerable group (e.g. low income or ethnic minority). Other equity considerations related to avoiding outdoor environments include communication barriers *(31,32)* such as barriers to the communication channels used by different community groups (e.g. young, elderly, deaf or visually impaired people), language skills, or access to the internet or electricity *(32)*. Another barrier may relate to how the advice is interpreted, for example, how community members interpret air quality thresholds, measurements or indexes when deciding to avoid outdoor environments *(31,32)*.

Barriers and facilitators to implementation

Avoiding outdoor environments in order to reduce high air pollution exposure may be insufficient in the absence of additional measures to reduce the infiltration of outdoor air pollution *(33)*. Indoor sources of pollutants such as cooking, heating, cleaning and tobacco smoking should also be considered and, if possible, reduced to improve indoor air quality when a recommendation to avoid outdoor environments is in place *(3)*. To effectively reduce air pollution exposure, avoiding outdoor environments should be combined with closing windows, increasing indoor ventilation, reducing indoor air pollution emissions, and maintaining building structures that minimize air pollution penetration and air leakage. These considerations should be combined with actions to reduce emissions from outdoor air pollution sources. Based on the criteria discussed in this section, avoiding outdoor environments during high air pollution episodes could be considered a feasible personal-level action. The effectiveness of this action will vary based on the implementation of measures to improve indoor air quality (e.g. ventilation, emissions), levels of outdoor emissions and social factors.

Practical advice for general and vulnerable populations

- Reduce the amount of time spent outside during high air pollution episodes to reduce exposure.
- Combine avoiding outdoor environments with closing windows, using indoor ventilation with air cleaners with HEPA filters, adopting measures to reduce indoor air pollution emissions, and ensuring that building structures minimize air pollution penetration and air leakage.
- Consult local air quality indexes/forecasts when planning outdoor activities.

An important enabler of these personal-level actions is to provide clean indoor facilities (e.g. public shelters, schools) for homeless people and those who do not have access to a clean indoor space. This can be achieved by organizing local response teams, as well as through tailored public advice communication and dissemination strategies that consider the needs of vulnerable communities (e.g. elderly, deaf or visual impaired people, ethnic minorities).

Physical activity: location and timing

Definition

This section focuses on the avoidance of physical activity in areas and during times of the day when air pollution levels are high. WHO defines physical activity as any bodily movement produced by skeletal muscles that requires energy expenditure *(34)*. This refers to all movement, including leisure activities (e.g. running, jogging) and activities conducted for transportation or as part of work *(35)*.

Effectiveness in reducing exposure to air pollution

Since physical activity can increase the breathing rate and, thus, air pollution inhalation, choosing a cleaner air environment for physical activity can significantly reduce exposure. Studies have shown that exercising outdoors can increase the inhalation of harmful air pollutants *(26,36,37)*. In addition, vigorous exercise may impair the body's natural defences against air pollution, such as nasal mucociliary clearance, thereby increasing the potential for health risks *(38)*. However, strategically choosing locations with lower air pollution levels, such as green spaces or indoor facilities with air filtration systems, as well as the timing of physical activity can effectively mitigate these risks *(37,39,40)*. Therefore, incorporating air quality considerations into physical activity routines is crucial to maximize the health benefits and minimize exposure to harmful air pollutants.

Effectiveness in improving health

Despite the possibility of increasing exposure to air pollution, physical activity can play a significant role in protecting healthy adults against the adverse effects of traffic-related air pollution (TRAP). Health modelling studies suggest that the overall health benefits of regular aerobic exercise outweigh the risks associated with increased air pollution exposure for healthy adults across a range of pollution concentrations and even for long exercise durations *(26,36,38,41)*.

However, it is still unclear how much physical activity is needed to offset the detrimental health effects of air pollution; this is likely to vary depending on individual factors such as age, health status and underlying disease. Evidence is also lacking on health effects in children, pregnant women, unhealthy populations, and populations of low- and middle-income countries (where there may be higher exposure to air pollution and different mixtures of pollutants). Furthermore, most evidence relates to $PM_{2.5}$ and long-term health effects and does not support precise advice regarding the short-term effects of multiple pollutants. Despite this, consideration of O_3 and temperature levels, especially in warmer climates, is suggested *(3)*. Nevertheless, studies suggest that people with pre-existing conditions such as cardiovascular diseases, hypertension, and respiratory illnesses are more susceptible to the harmful effects of air pollution and may experience diminished benefits from physical activity when exposed to high pollution levels *(3,41,42)*. Similarly, children are considered a vulnerable population because their developing lungs and immune systems makes them more susceptible to air pollution-related health risks *(43,44)*. In particular, people with underlying health conditions or who belong to susceptible groups are suggested to consult their health-care providers to determine appropriate physical activity levels and strategies to minimize their air pollution risks.

Health risk or harms

Although engaging in physical activity poses no known risks in locations and times without harmful levels of air pollutants, studies show a clear association between air pollution and reduced levels of physical activity overall *(26,38)*. This is probably because concerns about air pollution exposure discourage people from exercising outdoors. However, avoiding physical activity altogether because of air pollution can have detrimental health consequences resulting from physical inactivity. Therefore, it is crucial to find ways to mitigate air pollution exposure while maximizing opportunities for regular physical activity.

Negative environmental impacts

Although selecting a location or time with cleaner air to perform physical activity may not have a direct impact on the environment, any additional activities required to enable this action, such as traveling in a motorized vehicle, could indirectly generate negative effects such as air and noise pollution.

Personal costs

No direct costs are known to be associated with conducting physical activity in environments or at times with cleaner air. Indirect costs may be associated with transportation to such environments or if the only location with reduced air pollution that is available for physical activity is an indoor site that charges a fee for its use.

Social factors

Access to indoor and outdoor areas with cleaner air can be a social limitation. Type of work (e.g. essential worker, night shift) can also limit a person's capacity to choose when and where to conduct physical activity. Furthermore, lack of access to or a lack of understanding of air quality data could influence levels of air pollution exposure.

Barriers and facilitators to implementation

Not all people can perform physical activity in clean air or indoor settings. Some people may lack the physical space at home or the flexibility to choose a specific time for physical activity. During high air pollution episodes, physical activity should be conducted in a clean air environment, such as an indoor setting with good ventilation and air filtration. Outdoor physical activity should also be planned according to the air pollution levels in order to avoid times when these are expected to be high: this could be done by consulting real-time air quality information and forecasts. Changing the location and timing of physical activity is feasible as long as people have access to locations with cleaner air areas.

Practical advice for general and vulnerable populations

- In general, regular physical activity is beneficial except under conditions of extreme air pollution or in the case of underlying health conditions, such as cardiovascular diseases, that increase the risk associated with air pollution.
- If possible, perform physical activity in outdoor green spaces and away from air pollution sources, such as motorized traffic.
- Consult local air quality indexes/forecasts when planning outdoor activities.
- Decrease the intensity or stop exercising if you experience symptoms such as coughing, chest tightness or wheezing.

Air cleaners

Portable air cleaners

Definition

Portable air cleaners (PACs) are small mobile electric air cleaning units used in living spaces (bedroom, offices) to reduce the concentration of airborne particles and, sometimes, of vapours and gases *(45,46)*. PACs use different methods to separate airborne contaminants from ambient air, such as air filters (e.g. HEPA filters) that capture particles on fibrous materials and electronic air cleaners (e.g. ionizers or electrostatic precipitators) that remove airborne particles via electrostatic force *(45,47,48)*.

Effectiveness in reducing exposure to air pollution

PACs are suggested to lower indoor air pollution from cooking, cigarette smoking, other indoor sources and outdoor pollutants that have infiltrated indoors. They may provide the additional benefit of reducing the levels of volatile organic compounds associated with household chemicals or levels of pollen, which is associated with allergies *(38,48)*. The efficiency is reported as the minimum efficiency reporting value (MERV), which can range from 1 to 16. The MERV reports a filter's ability to capture larger particles of 0.3–10 µm in diameter *(38)*. The effectiveness is indicated by the clean air delivery rate (expressed in m^3/min): the higher the value, the larger the room size the PAC can serve *(47)*.

The use of HEPA filtration (typically equivalent to MERV 16) in living rooms or bedrooms has been shown to reduce indoor residential $PM_{2.5}$ concentrations to 40–72% of baseline, control or outdoor levels *(38,49)*. However, since the efficiency of filtration decreases over time, HEPA filters should be replaced on average every 6 months *(38,49)*. Studies in schools have reported that PACs can reduce indoor $PM_{2.5}$ concentrations by 49% *(50)*, but their efficacy may be reduced in buildings that are not airtight, if windows are kept open or if placed in a heavily polluted location *(22)*. In addition to lowering indoor PM levels in the room where they are located, evidence from personal monitors has shown that PACs can reduce the average PM exposure in household members by > 40% over a 24-hour period *(23,51)*. It is also essential to position the PAC in the room where people spend most of their time, such as the bedroom *(52)*. Few studies have investigated the benefits of incorporating activated carbon within a HEPA-based PAC to reduce gaseous pollutant concentrations. However, the efficacy appears poor: one study demonstrated reductions in NO_2 concentration of approximately 20% versus baseline that diminished over time *(53)*.

Effectiveness in improving health

Several intervention studies found statistically significant associations between PAC use in the home and improved health outcomes (e.g. symptoms or biomarkers) (23,38,47,50,54). However, most reported health improvements were relatively small and when multiple outcomes were measured, only a fraction of health outcomes or biomarkers were typically improved *(47,50)*. Several studies have explored the effects of PACs on respiratory symptoms, blood pressure, heart rate variability, endothelial function, plasma oxidative stress and inflammatory markers *(54)*. However, few have focused on cardiorespiratory outcomes or adverse fetal outcomes *(23,50)*. Some reports indicate that the effects are not always consistent in terms of the direction, magnitude and timing of the response; this may reflect differences in study populations, the study design and potential confounders *(38)*. The main limitations are reliance on a small number of volunteers and low statistical power *(54)*. Health impact modelling studies have estimated that during wildfires PACs may provide cost-effective mortality-related benefits, which could be improved by targeting elderly people *(55)*. Evidence is scarce on the benefits of using PACs with non-filter technologies (e.g. ionizer air cleaners) in homes or other buildings – findings range from improved biomarker levels to no effect *(23,47)*.

Health risk or harms

Electronic PACs that ionize incoming streams of particles, which are then deposited onto a charged plate, may also generate O_3 *(23)*. PACs have also been linked to noise exposure, which may have multiple health impacts. The effects of PAC-related noise should be especially considered for susceptible groups (e.g. with hypertension or cardiovascular diseases). However, risk–benefit analyses that consider the benefits of reducing air pollution versus the risks of noise exposure are not available.

Negative environmental impacts

The environmental impacts of PACs relate to all parts of the life cycle (production, use and disposal) of both PACs and filters. Specifically, a PAC will produce waste related to regular filter replacement and the device's end of life and will consume electricity when in use.

Personal costs[4]

PAC costs include the initial purchase price, along with maintenance (cleaning or replacing filters and other parts) and operating costs (electricity) *(47)*. Market research conducted in France in 2015 found that stand-alone devices cost €315 on average, but prices varied widely from less than €50 (for small or non-HEPA-filter PACs) to more than €2000 (for PACs for larger rooms and with additional functions such as heating and internet connectivity). The high costs may explain their low market penetration *(48)*. Operating cost is another important factor to consider because air cleaning is an ongoing process and units require filter replacement or cleaning and other maintenance to remain effective *(37)*. The cost of filters varies widely depending on the type, size and brand of PAC. On average, filters should be replaced every 6–12 months at a cost ranging from €20 to more than €150 *(56)*. In the United States of America in 2018 the estimated average annual electricity cost of running a portable HEPA PAC for 24 hours per day was less than €170 per year, with individual units ranging from just over €80 to nearly €200 per year (approximate electricity use: 850–2000 kWh (3.0–7.2 GJ)) *(47)*. Studies that modelled the use of PACs for reducing indoor air pollutant concentrations suggest a very favourable cost–benefit ratio: each year in the United States PACs prevent around 64 000 premature deaths, with the economic benefits exceeding €800 per person per year *(57)*.

[4] In this report, personal costs originally reported in United States dollars were converted into euros using 2021 currency exchange rates.

Social factors
Owing to the initial cost, low market penetration and lack of awareness, only a small proportion of the world's population uses PACs, and an even smaller proportion uses them regularly *(23)*. Operating noise may also affect the acceptability and use of PACs. Even when people own PACs, noise may be a barrier to their effectiveness (because higher operating speeds increase both effectiveness and noise), so users may tend to use PACs at lower operating speeds, less frequently and away from the main living areas.

Vulnerable groups (e.g. people with low incomes, migrants) may be less aware of the availability and efficacy of PACs. Even for those who are aware of PACs, the purchase and running costs may limit their access and use. Furthermore, vulnerable groups may live or work in areas with high environmental noise levels, making PACs less desirable because of noise emissions. Susceptible groups (e.g. elderly people, children, people with underlying health issues) may benefit the most from reductions in indoor air pollution. The use of PACs in living areas should be a priority for these groups despite related noise levels. Furthermore, people with specific health conditions (e.g. hearing problems, mental health issues) may be more sensitive to noise, making them less likely to consider using PACs.

As discussed in the section "Reducing time spent in polluted outdoor environments", not everyone has access to indoor facilities (e.g. transient and homeless people), good quality housing or workplaces (e.g. with proper ventilation, air conditioning, electrical appliances), or can decide when to stay at home (e.g. essential workers); these factors can increase environmental health inequities. Moreover, not everyone is able to buy and maintain these devices properly, which can create additional inequities. Inclusive communication and information strategies to increase awareness and knowledge about the types and effectiveness of PACs should be considered as tools for reducing inequities and increasing the benefits derived from PAC use. Such strategies should include a clear description and comparison of PAC types and their effectiveness, noise emissions, costs (maintenance and use) and environmental impacts (e.g. life-cycle analysis).

Barriers and facilitators to implementation
The efficacy of PACs in reducing indoor $PM_{2.5}$ levels is likely to be lower (i) in residences and buildings that are not airtight (e.g. many windows, draughty) or are located in hot environments (without air conditioning), where windows may remain open; (ii) if PACs are placed in rooms that are too large for the clean air delivery rate; (iii) if PACs are located near objects that reduce the airflow; or (iv) if the filters are not changed as often as recommended by the manufacturer *(21,48,50,54)*. Operating noise can also limit their use. PAC performance ratings are determined at maximum airflow, which typically corresponds to maximum noise levels *(47)*. At lower airflow settings, PACs may have lower operating noise but will also be less effective at pollutant removal *(47)*. Uncomfortable noise levels can discourage the placement of air cleaners in bedrooms, where people spend a large percentage of time. Since PAC noise levels are seldom quantified or are not reported in a standardized and accessible manner on consumer packaging, comparing devices based on the noise rating can be challenging.

To reduce indoor air pollution, HEPA-filter PACs are the preferred option. PACs should be located in the main living areas (especially bedrooms) and used at the highest operating speed possible or in automatic mode. Rooms occupied by susceptible people (e.g. children, elderly, those with underlying diseases) should be prioritized. The clean air delivery rate (effectiveness, rated in m^3/min) based on the room volume should correspond to the room size: a higher clean air delivery rate will increase effectiveness for the same room size. Furthermore, the manufacturer's instructions should be followed (e.g. PACs should be located a certain distance from objects that might obstruct airflow, filters should be changed regularly). To effectively reduce air pollution exposure, PAC use should be combined with closing windows, reducing indoor air pollution emissions, and maintaining building structures that minimize air pollution penetration and air leakage. These actions should be combined with interventions to reduce emissions from outdoor air pollution sources.

Based on the criteria discussed in this section, PAC use is a feasible option to reduce air pollution exposure. However, owing to their considerable cost, health and social care systems should assess these devices and consider including them in benefit packages, especially for vulnerable people. The effectiveness of PACs will vary based on their characteristics and pattern of use, indoor and outdoor emission levels, characteristics of the building, and social factors. Some intervention studies found that after an initial period of use, PACs are often incorrectly maintained and may be used less often, turned off completely or put into storage, often because of annoyance related to operating noise or other factors *(47)*.

Practical advice for general and vulnerable populations

If affordable or if the costs are met by health and social care systems:

- Consider the use of indoor PACs, especially for people with underlying health conditions who live in heavily polluted locations or during high air pollution episodes.
- Use PACs with a HEPA filter.
- Select PACs with an appropriate clean air delivery rate (m^3/min) for the room size.
- Use PACs at the highest operating speed possible when the room is occupied and position them close to occupants.
- If the PAC is too small to cover the entire living space, then prioritize the bedroom or living room.
- Locate PACs away from objects that can reduce airflow.
- Change filters according to the manufacturer's recommendation.
- Avoid PACs that may produce O_3 (e.g. electrostatic and ionizing air cleaners).
- Combine PAC use with closing windows, reducing indoor air pollution emissions and maintaining building structures that minimize air pollution penetration and air leakage.

Bear in mind that the cost of PACs includes the initial purchase price, maintenance costs and operating costs. The total cost may not be affordable for all people who are likely to benefit from PAC use in a variety of settings in the WHO European Region, which may promote inequities. National public health authorities are well positioned to evaluate the use of PACs through cost–benefit analysis that considers the impact on equity.

Central air cleaners/heating, ventilation and air conditioning

Definition

Central air cleaners include heating, ventilation and air conditioning (HVAC) filters (also called furnace filters) and other duct-mounted air cleaners that are installed in the home or in a building's central HVAC system *(23,47)*. Such duct-mounted air cleaners are installed either at the base of the air-handling unit or upstream in return grilles, and filter the air whenever the fan of the HVAC system is operating *(47)*.

Effectiveness in reducing exposure to air pollution

Studies have shown that high-efficiency furnace filters (e.g. rated as M6 and above, in accordance with the ISO 16890 standard), duct-mounted air cleaners and PACs with a high clean air delivery rate can substantially reduce levels of airborne particles and, in some cases, gaseous pollutants in the home *(23,47)*. In general, the higher the filter rating, the higher the removal efficiency for particles of at least one size range. Although standards also exist for testing the removal efficiency of gas-phase, in-duct air cleaners, they are not widely used or reported *(47)*. The United States Environmental Protection Agency recommends that people who are concerned about small particles should choose central air cleaner filters with a rating of at least MERV 13 (or the equivalent M6 rating) or as high a MERV or ISO 16890 rating as the system can accommodate *(47)*.

Effectiveness in improving health

There is no clear evidence for the health benefits of filters in central air cleaners in homes *(23)*. One modelling study into the potential benefits of HVAC systems during wildfires found that they are likely to be less effective than other methods such as PACs *(55)*.

Health risk or harms

Depending on the building structure and location of the HVAC system, central air cleaners have been linked to increased noise exposure, which is associated with multiple health impacts. HVAC-related noise should be particularly considered for susceptible groups (e.g. people with hearing problems or cardiovascular disease). However, risk–benefit analyses of the benefits of air pollution reduction versus the risk of noise exposure are not available.

Negative environmental impacts

The environmental impacts of HVAC systems can relate to all parts of their life cycle (production, use and disposal). The use of HVAC systems produces waste related to filter replacement (around every 12 months). Furthermore, their energy consumption is an important environmental concern.

Personal costs

The costs of HVAC systems include the initial purchase price, along with maintenance (e.g. cleaning or replacing filters and parts) and operating (e.g. electricity) costs *(47)*. Moreover, the cost of the professional installation of an upgraded media filter or electronic air filter in an HVAC system must also be considered. The most effective air cleaners have high airflow rates and efficient pollutant capture systems, but are generally the most expensive *(47)*. Maintenance and operating costs vary depending on the device: these are essential considerations because air cleaning is an ongoing process and units require regular filter replacement or cleaning and other maintenance to remain effective. Although central HVAC systems can distribute filtered air to multiple places in the home, they cost approximately twice as much to operate as portable HEPA-filter PACs for the same operating time *(47)*. As with PACs, the considerable cost of these devices may cause inequity.

Social factors

For people with access to HVAC systems in their building or home, ease of use may make these systems an acceptable option to reduce personal-level exposure to air pollution. However, less than 5% of all European households have air conditioning *(58)*, and installation and maintenance costs may be barriers to the acceptability and implementation of HVAC systems. Furthermore, vulnerable groups (e.g. people with low incomes) may have less access to the resources needed to integrate HVAC systems into their homes and may be less aware of the availability and efficacy of HVAC systems. Susceptible groups (e.g. elderly people or those with an underlying health condition) may benefit the most from reducing indoor air pollution with an HVAC system. However, people with specific health conditions (e.g. hearing problems, mental health issues) may be more sensitive to noise, making the use of HVAC systems less attractive. In addition, not everyone has access to indoor facilities (e.g. transient and homeless people) or can decide when to stay at home (e.g. essential workers).

Barriers and facilitators to implementation

HVAC systems are expected to have lower efficacy in reducing indoor air pollution levels (i) in homes or buildings that are not airtight (e.g. with many windows, draughts), (ii) if the HVAC filters have a MERV rating of less than 13, (iii) if the filters are not changed as often as the manufacturer recommends, or (iv) if the HVAC system is not properly maintained. Operating noise can also limit the use of HVAC systems. The effectiveness of furnace filters and other duct-mounted air cleaners is limited by the operating hours of the fans in the HVAC system in which they are installed and whether they are adequately maintained *(47)*. People who are concerned about small particles should choose furnace filters with a rating of M6 or higher (ISO 16890). However, a higher-efficiency furnace filter can only be used if it is compatible with the existing ducted HVAC system. Furnace filters and duct-mounted air cleaners must be easily accessible to enable regular replacement, inspection and maintenance. The installation of some furnace filters and duct-mounted air cleaners may also require modifications to the HVAC system, such as a fitting a wider filter track or providing additional electrical power. Furthermore, the manufacturer's recommendations on how often to replace, clean or otherwise service the filters should be followed to ensure optimal performance. To effectively reduce air pollution exposure, the use of HVAC systems should be combined with closing windows, reducing indoor air pollution emissions and maintaining building structures that minimize air pollution penetration and air leakage. These actions should be combined with interventions to reduce emissions from outdoor air pollution sources. Based on the criteria discussed in this section and the costs, HVAC systems may be considered a less feasible option for people who do not live or work in a building with a HVAC system or have the resources to install one. Moreover, the effectiveness of HVAC systems will vary based on their characteristics and pattern of use, the level of indoor and outdoor emissions, and characteristics of the building.

Practical advice for general and vulnerable populations

If affordable or if the costs are met by health and social care systems:

- consider using an indoor HVAC system, especially for people with underlying health conditions living in heavily polluted locations or during high air pollution episodes;
- use an HVAC system with filters rated at M6 or higher;
- change filters and maintain the HVAC system according to the manufacturer's recommendations; and
- combine the use of an HVAC system with other actions, such as closing windows, reducing indoor air pollution emissions and maintaining building structures that minimize air pollution penetration and air leakage.

Bear in mind that the overall costs of HVAC systems include the initial purchase price, along with the maintenance and operating costs. This may not be affordable for all people who are likely to benefit from the use of HVAC systems in various settings across the WHO European Region, and may promote inequities. National public health authorities are well positioned to undertake a cost–benefit analysis of HVAC use that considers the impact on equity.

Face coverings

Both respirators and face masks are types of face covering. Face masks differ from respirators in that respirators are designed to reduce the inhalation of $PM_{2.5}$ and other particles under certain conditions, and face masks are not.

Respirators

Definition

Respirators (also known as air-purifying respirators) are personal protective devices that cover the nose and mouth and reduce the inhalation of $PM_{2.5}$ and other particles with an efficiency that depends on the rating *(23)*. In the WHO European Region, the filtering facepiece class 2 (FFP2) removes over 95% of inhaled particles of 0.3 µm in diameter, and the filtering facepiece class 3 (FFP3) removes over 99% of inhaled particles of the same size *(21,59)*. United States and Chinese respirators can be also found on the European market, with N95 or KN95 respirators equivalent to FFP2 devices, and N99 or KN99 respirators equivalent to FFP3 devices *(3)*.

Effectiveness in reducing exposure to air pollution

Use of an appropriate respirator reduces exposure to inhalation hazards *(3)*. Scientific evidence and operational experience support the use of respirators in workplaces, but mainly relates to healthy adult populations and not to the most vulnerable subgroups *(3)*. Although a respirator fit test can demonstrate the expected level of protection, no studies have measured the actual reduction in exposure from respirator use in the general public *(3)*. Furthermore, trials on respirators have been small, of short duration and focused on a range of physiological measurements rather than relevant health outcomes such as hospitalization, disease incidence and mortality. These trials have limited applicability to the European population, including groups with existing respiratory and cardiovascular diseases *(60)*. However, a United States modelling study of respirator use related to wildfire smoke found that N95 respirators offer protection against PM: they reduced PM exposure by more than a factor of 14 when worn with a leak rate of 5% *(61)*. Respirator efficiency depends on the rating (e.g. FFP2 vs FFP3) *(23)*. Respirators lacking special adsorbent material (e.g. activated charcoal, silica gel) generally do not provide protection against gaseous pollutants *(21)*. The effectiveness of respirators also depends on how well they fit the face. Some studies found that particle filtration may be affected by the presence of diesel emissions, suggesting that gases may influence the performance of respirators *(59)*. Advice on respirator use in the workplace could be adapted for use by the general public to provide interim guidance for protection against air pollutants during wildfires, volcanic eruptions, desert dust episodes or clean-up after disasters *(3)*. FFP2 respirators can also offer protection against heavy pollen counts during outdoor activities *(62)*.

Effectiveness in improving health

Limited evidence is available on the effectiveness of respirators to reduce health outcomes. Studies suggest that use of an N95 respirator for 2 hours in an air-polluted urban environment can reduce particle-associated airway inflammation and improve measures of autonomic nervous function and blood pressure compared with no respirator use *(38,54,63)*. A modelling study found that N95 respirators offered protection against wildfire smoke inhalation and reduced the respiratory hospitalization rate by 30% *(61)*.

Health risk or harms

Respirators can trap warm, moist air, leading to rashes or overheating and, potentially, to pathogen retention *(38,64)*. Perioral dermatitis or flare-up of inflammatory facial skin diseases has also been reported among workers who are required to constantly wear respirators *(65,66)*. Respirators may also increase resistance to breathing, which could have adverse cardiovascular effects. People with respiratory and cardiovascular disease who may most benefit from reductions in exposure to ambient air pollution are also the group most likely to be at risk of adverse health effects from wearing respirators *(21)*. One study suggested that respirator use may cause an acute increase in blood pressure *(67)*. In particular, people who may be susceptible to the mild increase in cardiovascular and respiratory stress caused by respirator use are advised to consult a physician before using such a device *(21)*. Furthermore, respirators should never be worn by infants or toddlers because of the risk of choking and suffocation *(68)*. In addition, wearing a poorly fitted respirator or reusing a respirator may be ineffective and provide a false sense of protection, which may lead to decisions or behaviours that increase air pollution exposure *(21)*.

Negative environmental impacts

The environmental impacts of respirators relate to all parts of their life cycle (production, use and disposal). FFP2 and FFP3 respirators are designed for single use. They consist of four layers of material: an outer layer of spun-bond polypropylene, a second layer of cellulose/polyester, a third layer of melt-blown polypropylene filter material and an inner (fourth) layer of spun-bound polypropylene *(69)*. The ear loops of respirators are made from natural and synthetic polyisoprene (i.e. latex-free) rubber. FFP2 respirators are five times heavier than surgical masks (18.14 g for a FFP2 respirator vs 3.5 g for a surgical mask) *(69)*. In 2020 in the United States, 600 metric tonnes of plastic waste from respirators was generated each week *(69)*. In Europe, the European Parliament is estimated to produce 12 000 kg of FFP2 and face mask waste each year *(70)*. A 2020 global survey with more than 1000 participants reported that only 45% of users dispose of their respirators and face masks in a solid or hazardous waste bin. The other 55% reported throwing them away in the street, flushing them down the toilet or burning them *(69)*. Furthermore, the production of each FFP2 respirator (excluding transportation) releases 50 g of carbon dioxide equivalent (CO_2-eq) *(71)*.

Personal costs

In recent years, the price of respirators has varied. For example, in Spain in 2020 prices ranged from €0.50 to €2.00 *(72)*. Although the retail cost of an individual FFP2 respirator may be considered low in most developed countries, respirators are designed for single use only. Therefore, their cost must be multiplied by the number of respirators needed to maintain protection over time. Furthermore, filters are designed to remove particles only: the effective removal of gaseous pollutants requires the addition of adsorbent material such as activated charcoal (which is inconsistently effective) at a cost of around €8 per device (in 2021) *(38,73)*.

Social factors

Owing to the relatively low cost per device and relative ease of use, respirator use may be considered an acceptable action to reduce personal-level exposure to air pollution. Respirator use to reduce pollutant inhalation during high air pollution episodes has become more commonplace and socially acceptable worldwide, particularly in Asia *(38)*. A recent study reported an increased acceptance of respirators and face masks in Europe during the COVID-19 pandemic *(74)*: however, a review found that face coverings were not universally accepted during this period *(75)*. In the United States, COVID-19 face covering mandates led to an increase in mask-wearing to 90% on average *(76)*.

However, the pandemic also showed that wearing face masks may confer an exaggerated or false sense of security, resulting in risk compensation behaviour (e.g. reduced physical distancing or hygiene) *(75)*. Although risk compensation behaviour has not been reported for respirator use in the context of air pollution, it should be considered a potential outcome that may result in greater exposure to air pollution. Illness stigma is another social factor that may discourage sick people from wearing a respirator *(75)*. Minority groups may also experience stigma and assumptions of criminality. For example, a review found that black people in the United States were reluctant to wear face masks in public during the COVID-19 pandemic for fear of being mistaken for criminals *(75)*. Empirical evidence also shows that political preference and mistrust of science are factors that influence the wearing of face masks in public *(77)*.

Furthermore, vulnerable groups (e.g. people with low incomes) may be less aware of the availability and efficacy of respirators. However, even among vulnerable people who are aware of the benefits of respirator use in reducing air pollution exposure, a lack of knowledge and training on the proper use could reduce the efficacy of these devices. Moreover, people may decide to reuse respirators to reduce costs even though this reduces the protection against air pollution. Inclusive communication and information strategies to increase awareness and knowledge about the effectiveness, types and costs of respirators, together with instructions for their proper use, should be considered to reduce inequities and increase the benefits of respirators.

Barriers and facilitators to implementation

The effectiveness of respirators can be limited by facial hair, which can interfere with the face seal and cause leaks. Furthermore, some people cannot obtain a good seal because the dimensions of the respirator are incompatible with the size and shape of their face, and most types of respirators have not been certified for use by children *(21)*. The respirator training and fit-testing offered for respiratory protection in the workplace are not generally available to the public *(21)*. Respirator use may also have adverse respiratory and cardiovascular effects due to the reduction of airflow and consequent difficulty in breathing, especially for people with underlying respiratory or cardiovascular diseases *(21)*. For this reason, the United States Occupational Safety and Health Administration requires medical clearance for occupational respirator use *(78)*. However, even among relatively healthy workers, the evidence basis for medical clearance for respirator use is limited, and currently no guidelines are available to assess the ability of members of the general public to use respirators to prevent exposure to outdoor air pollution *(21,78)*. Furthermore, respirators can cause discomfort by increasing the effort needed for breathing and creating a dead space under the face piece *(21,79)*. However, a few studies found that respirator use is well tolerated by healthy people, including pregnant women *(21)*.

Respirator classifications such as FFP2, KN95 and N95, which refer to the particle removal efficiency, have not been patented or copyrighted and can be used by any face mask manufacturer, even without proper testing *(3)*. Therefore, packaging should be examined for certification or approval by a national or international authority.

Six factors ensure that a respirator is effective: (i) putting it on correctly, (ii) ensuring that it fits appropriately, (iii) its continuous use during exposure, (iv) replacing the respirator or filter when it becomes saturated, (v) confirming that it is approved to remove ≥ 95% of particles (e.g. FFP2, KN95, N95) and (vi) certification by a relevant agency (e.g. European Agency for Safety and Health at Work). Consider removing facial hair if this breaks the face seal and ensure that the respirator is not used by children. Consider taking appropriate respirator training, such as the training modules created by the International Society for Respiratory Protection *(3)*. Although respirator use can be perceived as a simple, low-cost method of protection against air pollution, it is only recommended under certain conditions. This is because of limited evidence of effectiveness, evidence that a respirator with very high theoretical efficacy often has limited or no effectiveness in real-life conditions of use by the general population, and their social and environmental impacts. Lastly, the lack of distinction between respirators and face masks among the general public may be a barrier to the selection of respirators over face masks.

Practical advice for general and vulnerable populations

Only consider using a respirator when air pollution exposure is unavoidable, such as occupational exposure and for protection against air pollutants during wildfires, volcanic eruptions, desert dust episodes or clean-up after disasters.

- Choose respirators over face masks.
- Only consider using close-fitting respirators that have been approved to remove at least 95% of particles (e.g. FFP2, N95, KN95).
- Respirators are only validated for use by adults.
- Facial hair can reduce the efficacy of respirators.
- People with respiratory, cardiac or other health conditions that make breathing difficult should check with their health care provider before using a respirator for protection against air pollution.
- Follow the respirator's instructions and consider its limitations.
- Change the respirator according to the manufacturer's recommendations.
- Consider other measures to reduce personal-level exposure to air pollution.

Face masks

Definition

Face masks include cloth masks and synthetic masks *(61)*. Synthetic masks include surgical anti-projection masks, which are medical devices *(59)*. Under current European regulations, face masks are not considered personal protective equipment. Their function is not to protect the wearer's respiratory tract but rather to prevent them from contaminating the environment *(59)*.

Effectiveness in reducing exposure to air pollution

The effectiveness of face masks relates to the filter quality and coverage, the number of different filter layers, and how well the mask fits the face. Cloth masks are inexpensive and are commonly used in developing regions. However, they remove only 15% of particles of the size typically found in diesel engine emissions and are far less protective against fine particles compared with respirators (e.g. FFP2) *(38)*. Surgical masks appear to be more effective than cloth or bandana-style masks. However, the design of surgical masks confers poor facial fit, often leading to high inward leakage during use *(38)*.

Effectiveness in improving health

A modelling study on the use of face masks during wildfires suggested that the use of cloth masks leads to minor reductions in respiratory hospitalizations from smoke inhalation (2–11%). Use of surgical and synthetic-fibre masks may lead to slightly higher reductions in smoke-attributable hospitalizations (9–24% and 7–18%, respectively) *(60,61)*.

Health risk or harms

Face masks can trap warm, moist air, leading to rashes and potentially to pathogen retention *(80)*. Perioral dermatitis or flare-up of inflammatory facial skin diseases have also been reported among workers who are required to constantly wear face masks *(65,66)*. The use of face masks (cloth or synthetic) may even confer a false sense of security that reduces efforts to avoid air pollution.

Negative environmental impacts

The environmental cost of face masks relates to all parts their life cycle (production, use and disposal). Mask production is associated with 59 g CO_2-eq emissions per surgical mask and about 60 g CO_2-eq emissions per cloth mask *(69)*. Furthermore, as with respirators, face masks are not often disposed of appropriately in solid or hazardous waste bins. During the COVID-19 pandemic, face masks were discarded in streets and water bodies or even incinerated, thereby contributing to air pollution *(69)*.

Personal costs

In recent years, the retail cost of a surgical mask has varied. For example, in Spain in 2020 prices ranged from €0.10 to €2.00 *(72)*. Although the retail cost of surgical masks may be considered low in most developed countries, they are designed for single use. Therefore, their cost should be multiplied by the number of face masks needed to maintain the protection over time.

Social factors

The social factors related to face masks are similar to those described for respirators. They include a lack of universal use, use-related stigma and discrimination, risk compensation behaviours, and a lack of knowledge about the various types of face masks, their efficacy and how they should be used.

Barriers and facilitators to implementation

The efficacy of face masks is limited by their filtration efficiency and leakage rate and by the compliance rate (i.e. the length of wear time and proportion of population wearing the device). Since their function is not to protect the wearer's respiratory tract but rather to prevent them from contaminating the environment, there is no specific advice on their effective use in reducing air pollution exposure. Therefore, although face masks are simple to use and have a low initial cost, they should not be recommended as a method to protect people against air pollution exposure based on their low effectiveness, impact on the environment and social factors.

Practical advice for general and vulnerable populations

- The evidence does not support a recommendation to use face masks (cloth or surgical) to reduce exposure to air pollution.
- Consider other measures to reduce personal-level exposure to air pollution.

Transport, active transportation, routes, driving style and vehicle settings

Carefully deciding on active transportation and routes

Definition

Active transportation (also known as active travel or active transport) is transport that is powered by human energy, primarily walking and bicycling. Transport routes are the designated paths that people, vehicles or other modes of transportation follow to reach their destinations.

Effectiveness in reducing exposure to air pollution

TRAP exposure inside a vehicle can be caused by exhaust emissions from the vehicle itself or nearby vehicles *(81)*. Walking or cycling along roads with motorized traffic can also result in TRAP exposure *(82–85)*. A comparison of air pollutant concentrations between active and motorized travel modes showed that car drivers who kept the vehicle window open experienced the highest exposures of air pollutants ($PM_{2.5}$, black carbon and ultrafine particles (UFPs)) and cyclists and pedestrians the lowest exposures *(36,38,81,86,87)*. When inhalation rates related to physical activity (walking or cycling) were taken into account, the total inhaled dose of air pollutants was slightly higher for those using active transportation modes compared with motorized vehicles *(81,83,88,89)*. Overall, cyclists had the highest inhalation dose of air pollutants (because of their proximity to traffic, increased respiration rates and longer journeys), followed by pedestrians; train and light rail users had the lowest *(38,90)*.

Proximity to motorized traffic is associated with greater exposure to air pollution for cyclists and pedestrians *(12,38)*. TRAP levels decline rapidly with increasing distance from motorized vehicles; for example, concentrations of black carbon decline by up to 10 times at a distance of 10 m from roads with heavy traffic *(91)*. Studies also found that crossing to the lower-emission side of a road[5] can reduce $PM_{2.5}$ exposure by around 18% *(92,93)*. Furthermore, the use of pavements and off-road bicycle lanes (7 m and 19 m from the roadside, respectively) may significantly lower air pollution exposure *(38)*. Traffic intersections have the highest concentrations of particles, at 29-fold higher than in free-flowing traffic *(94)*. In contrast, roads in urban areas with open and green space or heterogeneous building morphology have around twofold to threefold lower TRAP concentrations than roads in urban areas without open or green spaces *(95)*.

Effectiveness in improving health

Whereas active transportation such as cycling and walking has been linked to a higher inhaled dose of air pollutants, the substantial health benefits of physical activity generally outweigh the risks associated with exposure. Studies suggest that engaging in active transportation, even in high air pollution environments, can reduce the risk of mortality *(36,41,83,85)*. However, for older people and those with a pre-existing health condition that increases their susceptibility to air pollution, the risks of exposure may outweigh the benefits of physical activity *(38)*.

Therefore, the effectiveness of active transportation in improving health depends on individual factors and air-quality conditions. For healthy adults, the benefits of physical activity typically outweigh the risks of air pollution exposure. However, people with an underlying health condition or who belong to a susceptible group are suggested to consult their health-care providers to determine the appropriate physical activity levels and strategies to minimize the air pollution risks.

Health risk or harms

Children are particularly vulnerable to air pollution because of their faster respiratory rate and shorter stature, which places them closer to the source of TRAP, and may confer greater health risks *(38)*. Older people and those with underlying health conditions may also be more susceptible to TRAP, resulting in reduced health benefits from active transportation such as walking and cycling *(83)*. In addition, active transportation carries the inherent risk of traffic-related injuries and fatalities *(81)*.

[5] That is, with less traffic or with downhill (rather than uphill) traffic.

However, people of all ages can reduce their exposure to TRAP by avoiding busy roads and major intersections. Choosing to walk or cycle on the side of the road with the least traffic can significantly minimize exposure to harmful air pollution.

Negative environmental impacts
No known direct negative environmental impacts are linked to active transportation. However, as discussed in previous sections, all parts of the life cycle (production, use and disposal) of bicycles, especially electric bikes, can impact the environment. However, this impact is expected to be lower than for a motorized vehicle.

Personal costs
Walking and choosing a cleaner route are cost-free alternatives to motorized transport. Bicycling costs relate to the purchase and maintenance costs, which may be significant for electric bikes (average cost of €2000 in 2019) and bikes for disabled people (average cost of €2500 in 2021) *(96,97)*.

Social factors
Besides the perception of risk related to active transportation, social factors such as stigma and cultures that perceive car transportation as the norm or associate active transportation with low income levels can reduce rates of walking and cycling. Similarly, perceptions of a longer travel time for walking and cycling and fear of road traffic injuries in areas lacking a safe infrastructure can deter people from using active transportation *(98)*. In contrast, the availability of alternative, pleasant and safe routes may increase the likelihood of cycling and acceptance of longer travel times rather than using a more direct but more polluted mode of transport.

Barriers and facilitators to implementation
Active transportation modes are not accessible to everyone. People with disabilities or those living in areas lacking the relevant infrastructure may have limited access to walking or cycling. Although bicycles designed for people with physical disabilities (e.g. tricycles, wheelchair bikes) are available, they are not suitable for people with all types of disability (e.g. blindness) *(99)*. Furthermore, bikes for disabled people are not commonly available in shops or public bicycle systems, and can be more expensive to buy. Moreover, the cycling infrastructure is not always designed to support alternative types of bicycles *(100)*. Use of an active transportation infrastructure also depends on the climate and weather conditions *(101)*, as well as on geographical conditions (e.g. hilly or mountainous terrain). Lack of availability or access to cleaner cycling routes can be another limitation in specific locations *(102)*. Other important limitations for active transportation include a lack of walking and cycling infrastructure (e.g. pavements, bicycle lanes, bicycle parking), cycling network connectivity and/or approachable destinations, and multimodal services (e.g. trains or buses that allow travel with bicycles, bike-and-ride facilities to safely park bicycles near to public transport nodes). Lastly, safety perceptions related to active travel may vary among different groups (e.g. women, children). Excessive speed of motorized vehicles, a lack of segregated infrastructure, pavements and bicycle lanes, and intersections that are dangerous or perceived as such can limit the adoption of active transportation and increase the risk of injuries to cyclists and pedestrians *(103)*. In contrast, access to a safe, clean active transportation infrastructure may increase walking and cycling rates and, thereby, reduce air pollution exposure. Special attention should be paid to increasing the distance between pedestrians/cyclists and traffic in order to lower their exposure to vehicle emissions. Choosing to walk or cycle on the downhill side of the road (relative to traffic flow) instead of uphill may also help to reduce air pollution exposure since driving uphill increases the engine load and, therefore, vehicle emissions *(38)*. Active transportation

and use of cleaner routes are feasible actions as long as the infrastructure is available and personal factors allow.

Practical advice for general and vulnerable populations

- Change from motorized transport to active transportation (cycling or walking).
- Avoid major intersections, queuing traffic, heavily trafficked roads and the higher-emission side of roads.
- Choose routes with open, green spaces and greater heterogeneity in building morphology to facilitate the dispersal of air pollutants.
- Choose designated off-road cycle tracks rather than on-road bicycle lanes.
- Use up-to-date, real-time information on local air quality provided by mobile phone apps, news feeds and websites to guide the route and timing of travel.

Using appropriate driving styles and vehicle settings

Definition

Driving styles encompass a range of driving patterns – those that avoid frequent acceleration and engine idling can minimize air pollutant emissions. Vehicle settings that are relevant to air pollutant exposure include features that control air filtration and ventilation.

Effectiveness in reducing exposure to air pollution

Closing windows and using air conditioning and cabin air filters can reduce air pollution exposure for people travelling in motorized vehicles *(23)*. Car microenvironments have similar air pollutant concentrations to outdoor PM and carbon monoxide (CO) levels when the windows are open *(104)*. Compared with driving in traffic with the windows closed, driving with open windows is suggested to increase black carbon and UFP concentrations inside cars by twofold to fourfold and inside buses by threefold *(38,88,105)*. Driving vehicles with the windows closed reduced traffic-related $PM_{2.5}$ exposure by threefold compared with driving with the windows open *(38,86)*. In cars, air conditioning and filters can help to extract and filter PM from the internal microenvironment. Driving with the windows closed and the air conditioning set to recirculate air reduced in-vehicle PM concentrations by up to 75% and $PM_{2.5}$ exposure levels by 40% compared with driving with windows open *(23,38)*. While driving in traffic, setting the air conditioning to recirculate air rather than the external circulation mode reduces TRAP exposure *(86)*. One study showed that air recirculation through a HEPA filter reduced UFP exposure by up to 20% *(106)*. The use of driving styles that include frequent acceleration and engine idling increases vehicle emissions *(104)*. Frequent idling is associated with high air pollutant exposure for motorized vehicle travellers in congested routes (as well as increasing the external levels of air pollutants). Engine idling increased the in-vehicle concentrations of air pollutants such as UFPs and black carbon and in-car volatile organic compound concentrations by 1.3–5.0-fold compared with switching the engine off *(21)*. Idling prohibition or anti-idling campaigns near schools have significantly reduced levels of PM and harmful pollutants around schools *(107)*. Older vehicles tend to have higher emissions owing to deterioration of vehicle control systems, incomplete combustion of fuel and oil, abrasion and wear of tyres and metallic components, and more permissive emission standards compared with newer vehicles *(38)*.

Effectiveness in improving health

Closing windows combined with the use of cabin air filters lowered the in-car $PM_{2.5}$ levels by 37%, which correlated with a reduction in oxidative stress markers *(23)*.

Health risk or harms

One review emphasized the trade-offs between (i) closing windows and recirculating cabin air to reduce PM concentrations and (ii) opening windows or using the external circulation mode to prevent high levels of carbon dioxide from the occupant's breath accumulating inside the cabin. This trade-off should be considered because high levels of carbon dioxide can cause drowsiness and impair cognitive function *(12)*.

Negative environmental impacts

In general, the use of motorized vehicles has direct negative impacts on air quality and the environment through pollutants and greenhouse gas emissions, environmental noise pollution and the need to transform land for the use of motorized vehicles (streets and parking), all of which reduce local biodiversity and soil and water quality. Worldwide, most motorized vehicles still have fossil fuel combustion engines. Furthermore, electric vehicles also produce non-exhaust emissions from tyre, brake and road surface wear, along with road dust resuspension *(108)*. Additionally, environmental impacts of all parts of the life cycle (production, use and disposal) should be considered for both fossil fuel and electric vehicles. Moreover, activating the air conditioning and ventilation systems can increase the vehicle's fuel consumption.

Personal costs

In 2021 the average cost of a medium-sized electric car was €33 300, compared with €18 600 for a petrol/gasoline car *(109)*. Besides the purchase cost of a motorized vehicle, activating the air conditioning and ventilation systems can increase the fuel consumption and maintenance costs.

Social factors

Social consideration should be taken into account for people with low incomes, who may only have access to old cars or vehicles in poor condition that lack the features needed to reduce air pollution exposure. Approaches to reducing $PM_{2.5}$ and UFP exposure during travel may be especially important for people who spend large amounts of time travelling in motorized vehicles *(23)*.

Barriers and facilitators to implementation

Air conditioning and cabin air filters are common features in new vehicles, but may be lacking or nonfunctional in older vehicles. Furthermore, old vehicles and some new convertible vehicles may have limited cabin isolation, which increases the penetration of outdoor air pollution even when the windows are closed *(110)*. Additionally, most vehicles currently have fossil fuel combustion engines and, therefore, high exhaust emissions, and their brakes and tyres contribute to non-exhaust emissions. The evidence suggests that closing windows combined with using air conditioning and cabin air filters can reduce air pollution exposure inside the vehicle *(110)*. For people who drive a motorized vehicle, changing driving style and using air conditioning and appropriate filter settings while driving are feasible actions to adopt, as long as these features are available and the costs are manageable.

Practical advice for general and vulnerable populations

- Optimize and maintain vehicle filtration/ventilation systems and, when external air pollution levels are high, drive with the windows closed and the air conditioning set to recirculate air.
- Avoid rapid acceleration and deceleration, restrict engine idling and ensure that vehicles are maintained correctly.
- Whenever possible, shift from motorized to active transportation (cycling or walking).

Conclusions

This report summarizes the most widely recognized or feasible approaches for people to reduce their air pollution exposure. It describes personal-level actions that can reduce air pollution exposure during daily activities and/or high air pollution episodes (summarized in Table 1). Use of face masks was the only personal-level action for which there was insufficient evidence for a reduction in air pollution exposure. Although most of the actions described in this report reduce air pollution exposure, all have several limitations and, most importantly, are associated with inequities related to their use, affordability or availability. Therefore, these inequities and limitations should be especially considered when recommending personal-level actions to communities. However, to effectively reduce air pollution exposure, air pollution emissions must be reduced at source. Until this can be achieved, personal-level actions should be considered as temporary, supplementary solutions.

Table 1. Key personal-level actions and suggested prioritization based on the narrative review and expert consultation

Personal-level action	Effectiveness	Limitations	Risks/harms	Environmental impacts	Personal costs	Social factors and inequities	Reference population
Reducing time spent in polluted outdoor environments	++++	+	+	+	+	+	Everyone
Physical activity: location and timing	++++	+	+	+	+	+	Everyone
PACs	++++	++	+++	+++	+++	+++	Everyone
Central air cleaners/HVACs	+++	++	+	++++	++++	++++	Everyone
Respirators	+++	++	++	+++	++	+++	Adults
Face masks	+		++	+++	++	+++	No one
Active transportation and cleaner routes	+++	+	++	+	++	++	Everyone
Driving style and vehicle settings	+++	++	++	+++	++	++	Everyone

Four-point scale: +, low; ++++, high.

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