enHEALTH

Health impacts of indoor air quality

ISSUES PAPER

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1 Executive summary

Indoor air pollution kills and science needs to step up.

Researchers and policymakers are only now waking up to the effects of dirty indoor air ...

Nature editorial, 8 February 2023 [1]

Clean air is as important as clean water and food. We consume a large volume of air every day.[2] We breathe most of this air inside – in our homes, offices, shopping centres, schools, public transport, hospitals, residential aged care and elsewhere.

There are well-established ways to help keep our water and food healthy. We also have opportunities to improve and maintain the quality of our indoor air. There are simple things we can do, as individuals and as a society, to make Australia's indoor air healthier.

This report proposes a way forward, towards healthier indoor air for all Australians. It proposes the Australian Centre for Disease Control lead collaborative work across the Australian Government and with endorsement from the Environmental Health Standing Committee (enHealth) to address the health impacts of indoor air quality. This work would have three initial areas of focus:

1. exploring health-based national indoor air quality performance goals
2. developing specific policy options for sensitive use settings, including schools, early childhood education and aged care, that are aligned with the performance goals
3. providing public guidance materials on ways to improve indoor air quality.

Through the support and stewardship of enHealth, action in all three areas will improve indoor air quality and raise awareness of the importance of indoor air health in Australia.

This report outlines approaches to improve the health impacts of indoor air quality. It sets out the negative health impacts of various pollutants in indoor air in Australia, noting that every organ in the body can be affected by pollutants in indoor air. Some pollutants can pass from the lungs into the bloodstream and travel around the body, with the potential to cause inflammation, cardiovascular and respiratory disease, cancer and many other diseases.[3]

The report identifies a range of positive impacts on human health from good indoor air quality, including improved cognition and less disease transmission in indoor environments. This can lead to better educational and work performance outcomes, with associated economic productivity benefits. Leading private sector companies are already taking steps to ensure good indoor air quality, investing in human capital to reduce health costs and increase productivity. There is an opportunity for more Australian organisations to reap the same rewards.

Australians typically spend significant amounts of their day indoors. During severe bushfire seasons, Australians are frequently advised to stay indoors to avoid hazardous outdoor air conditions. During heat waves, Australians are advised to stay indoors to avoid extreme heat. This reliance on staying indoors highlights the critical importance of good indoor air quality for Australians.

Good indoor air quality is increasingly important in the context of climate change. A drier climate brings potentially poorer air quality from outdoor sources, with impacts from dust, bushfire smoke and other plant-related pollutants (such as volatile organic compounds). Improving indoor air quality can also help Australia on the path to climate resilience, balancing energy efficiency and healthy indoor air quality settings.

This report discusses the national and international policy and regulatory landscape on the health aspects of indoor air quality. It recognises the application of work health and safety laws, and associated risk management obligations, to all workplaces. It sets out policy options, including public guidance, to reduce indoor air pollution at its source, reduce pollution levels in indoor air, and reduce its negative impacts on the health and wellbeing of the people of Australia.

The examination of policy options in this report is informed by the outcomes of a project commissioned through the National Science and Technology Council to synthesise the evidence on the impact of indoor air quality on the transmission of airborne viral diseases in indoor public environments, and strategies to reduce the transmission of airborne viral diseases in indoor public settings.[4] That project found significant direct and indirect socioeconomic impacts occur as a result of airborne disease transmission and outbreaks.

The potential benefits to Australia's health system and economy are substantial. A recent report from the Centre for Safe Air, a National Health and Medical Research Council Centre of Research Excellence, looked at both outdoor and indoor air quality, and found coordinated action to make air safer is one of the best investments in Australian health.[5]

It is likely to be more costly not to act to improve indoor air quality. Key international studies demonstrate the substantial cost of poor indoor air quality. A key 2014 French study estimated the socioeconomic cost of indoor air pollution in France by six pollutants at around 20 billion euros each year.[6] A recent Chinese study found the financial costs of disability-adjusted life years in China attributable to the ten indoor air pollutants studied was equivalent to around 3.45% of China's gross domestic product.[7] A 2008 US study estimated the total cost of indoor air pollution on health and productivity in California as at least USD60 billion each year (2007 USD).[8] It should be noted these studies were in countries with potentially different outdoor and indoor air quality issues to Australia. It would be helpful to have an up-to-date estimate of the economic impacts in Australia.

Added to these international estimates, airborne pandemic diseases – which are largely transmitted indoors when air quality is poor - can add extraordinary pressure to the national economy. For example, COVID-19 caused significant disruption to historic patterns of growth in the Australian economy, resulting in an estimated cumulative loss of $158 billion (to June 2022) in Gross Domestic Product level compared to its pre-pandemic trajectory.[9] While not all of this loss is attributable to poor indoor air quality, improved indoor air quality is likely to have led to less disease transmission and less economic loss, though the precise proportion is difficult to quantify.

The report provides the basis for improving the quality of indoor air. It outlines potential policy approaches to enhance Australia's indoor air quality to reduce risks to human health. The report proposes a coordinated approach to improving indoor air quality to enable Australian jurisdictions to work together to deliver health and economic benefits for Australia.

The report offers the opportunity to create significant and lasting change in the public health arena in addressing the health impacts of indoor air quality.

The report looks at the impact of indoor air quality on human health, addressing the influence of the built environment and natural ecosystems, as well as the contributions of animal matter to indoor air quality. The report recognises the interrelationship between the health of people, animals and ecosystems, and indoor air quality. Integrated, collaborative and coordinated solutions to optimising indoor air quality for health are needed.

This report is intended to be used as a basis for policy development at both national and state and territory level, with non-government stakeholder engagement, to reduce the health impacts of poor indoor air quality on Australians. The report is intended to inform discussion by public health practitioners. The only materials intended for immediate adoption are the public guidance materials outlined in **Appendix C**.

Public guidance

As a first step, the report includes public guidance on the health impacts of indoor air quality, developed during the preparation of this report and outlined in **Appendix C** on an Australian Centre for Disease Control 'Indoor air quality' webpage. The report also suggests working to ensure consistency of messaging across Commonwealth, state and territory governments on the health impacts of indoor air quality.

Possible focus areas

The report sets out three focus areas for further consideration. This includes collaborative work across the Australian Government and through enHealth to address the health impacts of indoor air quality. This work would have as its initial focus the following three focus areas:

Focus area 1. Explore health-based national indoor air quality performance goals

The Australian Centre for Disease Control should lead work to review existing Australian indoor air quality guidance, with a view to informing development of health-based national indoor air quality performance goals, including maximum concentration levels for specified pollutants, and equivalent clean air delivery or ventilation rates or proxy measures, taking into account airborne virus infection control.

As a starting point for development, expert input should be sought on the following possible pollutants and levels, drawn largely from a 2024 *Science* paper by Morawska et al[10]:

- $PM_{2.5}$ – 15 micrograms of fine particulate matter per metre cubed of air ($\mu g/m^3$) (averaged over an hour), 7 $\mu g/m^3$ (averaged over a year)
- carbon monoxide – 25 parts per million (ppm) (averaged over an hour), 9 ppm (averaged over 8 hours), and 3 ppm (averaged over 24 hours, with 3 to 4 exceedances allowed each year)
- carbon dioxide – 800 ppm (absolute value)
- clean air supply rate – at least 14 litres of clean air supplied per second per person.

Focus area 2. Develop specific policy options for sensitive use settings, including schools, early childhood education, and aged care, that are aligned with the performance goals

The work should consider establishing model indoor air quality guidance for schools, early childhood education centres, residential aged care and other sensitive use settings to promote greater alignment in guidance across jurisdictions, building on existing guidance materials.

The work should also consider options for monitoring, display, and certification or ratings schemes against indoor air quality performance goals, initially for sensitive use settings.

Focus area 3. Provide public guidance materials on ways to improve poor indoor air quality

See the public guidance materials developed during the preparation of this report and outlined in Appendix C on the health impacts of poor indoor air quality and how to improve indoor air quality.

Section 8 discusses the policy options related to these focus areas in detail.

2 Introduction

Australian adults spend over 80% of their lives indoors.[11] The quality of the air we breathe indoors matters. Poor indoor air quality is a significant contributor to poor health outcomes. It can affect every part of the human body, trigger allergies and asthma, and potentially lead to respiratory diseases, inflammation, heart disease, cancer and premature death.[12] Poor indoor air quality has also been associated in some studies with lowering cognition, affecting education, employment and productivity.[13]

Indoor air pollution comes from multiple sources. There is not a 'typical' indoor environment, and sources and concentrations of indoor air pollutants can vary within and between indoor spaces.[14] Some indoor air pollutants are the same as found in outdoor air but many are different, are present in different concentrations, or interact with other substances in the indoor environment to form secondary pollutants.[15] Air pollution from outdoor sources, such as industry, bushfire smoke, and emissions from vehicles and other equipment with combustion engines (such as power generators) can come into buildings, impacting indoor air quality. There are also many indoor sources of air pollution, which vary depending on the type of indoor space. These include pollutants from gas heating and cooking, wood heaters, photocopiers and printers, smoking, vaping, cleaning products, fragrances, and pests. Building-related sources of indoor air pollutants include gases coming from building structures, materials and equipment, as well as interior furniture and furnishings.[16]

Chemical pollutants affecting indoor air quality include gases such as carbon monoxide, carbon dioxide and nitrogen oxides, as well as volatile organic compounds like formaldehyde and benzene. Biological sources – bioaerosols - include viruses, mould, other fungi and bacteria, household dust mite allergens, dander from pets, and skin cells. Physical sources include radon.

A 1993 US Environmental Protection Agency (EPA) publication discussed EPA studies of human exposure to air pollutants that found indoor levels of many pollutants may be two to five times, and occasionally more than 100 times, higher than outdoor levels.[17] A 2002 study of homes in Melbourne found volatile organic compound levels were four times higher inside established homes than outside, and much higher again in new or renovated buildings.[18] A 2012 study of 40 homes in Melbourne found concentrations of some pollutants, including formaldehyde, and total volatile organic compounds, were between 8 and 12 times higher than outdoor levels. Other pollutants, including $PM_{2.5}$, carbon dioxide, carbon monoxide, benzene and toluene, were between 1.1 to 3 times higher compared to outdoor concentrations. Ozone, nitrogen dioxide and PM_{10} were significantly lower than outdoors.[19] A 2018 study of indoor volatile organic compounds at an Australian university found indoor concentrations were higher than outdoor concentrations for 97% of all volatile organic compound measurements.[20]

Over recent decades, as part of sustainability practice, buildings have often been built with a focus on energy efficiency and are well air-sealed, but this can lead to inadequate ventilation in some circumstances. Inadequate ventilation can exacerbate dampness and mould problems, as well as increasing indoor air pollutant levels and negative health impacts.[21] Many older buildings lack the

airtightness of newer constructions, mitigating ventilation issues when outdoor air is cleaner than indoor air. However, this also means when outdoor air quality is poor, such as during bushfires or other pollution events, poor sealing may allow more harmful outdoor pollution to come indoors.

Modern building materials are often synthetic, potentially off-gassing (releasing) a range of indoor air pollutants. Building and furnishing materials that contribute to poor indoor air quality include some paints, varnishes and solvents. Older buildings may also contain lead-based paints, which when deteriorated or disturbed, can release harmful lead particles or dust into the air. Despite asbestos being banned in Australia since 2003, it remains an issue, particularly when older asbestos-containing buildings, products or equipment are renovated or deteriorate.[22]

There is an increasing understanding of the significant contribution made by biological sources to indoor air pollution. Mould generally thrives in moist or humid, poorly ventilated environments, and affects many Australian indoor spaces, including homes, increasing the risk of associated health effects. Some viruses can be transmitted through the air, and concentration levels can build up in poorly ventilated or unfiltered indoor air, increasing the risk of transmission to other people indoors. Some bacteria can also be transmitted through the air, also increasing the risk of transmission indoors, where conditions are often more favourable than outdoors for bacteria to remain intact and multiply.[23] Proper design and maintenance of heating, ventilation and air conditioning systems is important to prevent growth of bacteria such as Legionella species.

Exposure to poor indoor air quality can vary among individuals depending on where they spend their time and the amount of time spent there, as well as their activities and breathing rates in the spaces. Some people are more sensitive than others to particular pollutants. This increased susceptibility could be due to factors such as youth or old age, pregnancy, asthma, diabetes, genetic predispositions, and existing lung or heart issues. UNICEF notes that children are particularly vulnerable to the impacts of air pollution because their brains, lungs and other organs, as well as their immune systems, are still developing.[24]

Poor indoor air quality also affects workers. Depending on the occupation, those working in industrial settings or crowded indoor environments are likely to be more exposed to some forms of indoor air pollution.[25]

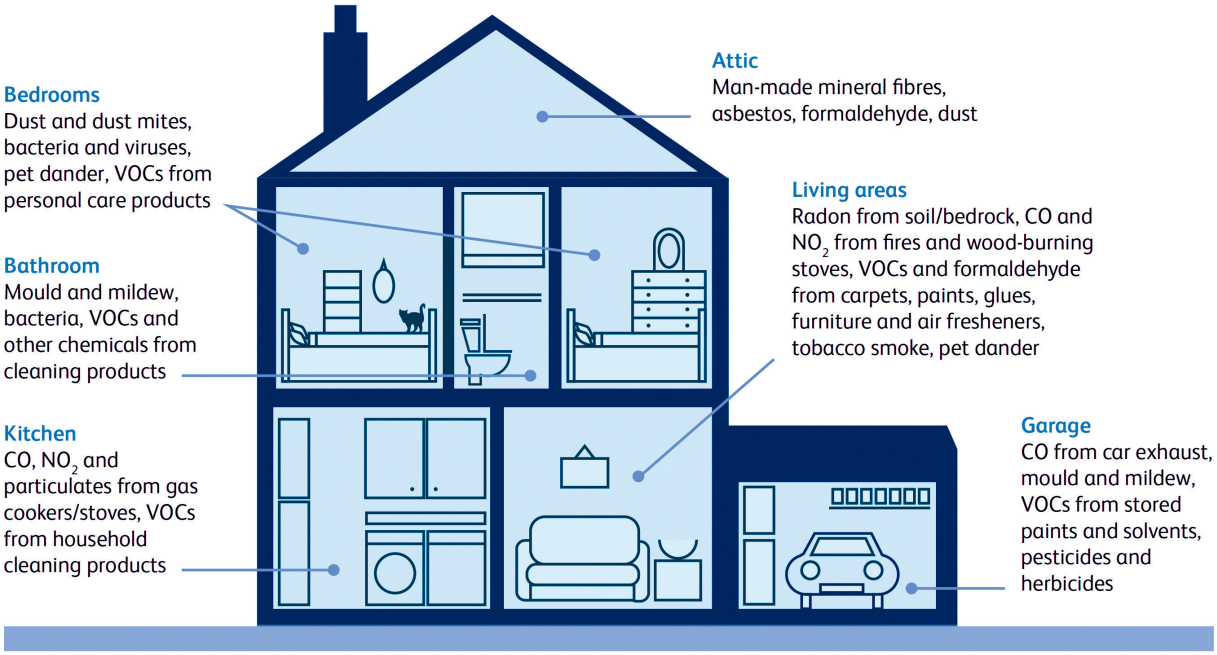
Housing quality is also a significant influence on indoor air quality, with uneven impacts across different socioeconomic and cultural groups in Australia.[26]

Existing ventilation arrangements are very important. Some indoor spaces are naturally ventilated, and others have mechanical ventilation systems. As the National Science and Technology Council has advised, a multifaceted approach will be needed to improve indoor air quality, tailored to specific building types and scenarios of use.[27]

Whilst action to improve indoor air quality is essential, it is impacted by the quality of the outdoor air. Outdoor air can be polluted in a range of ways, including from vehicle pollution near busy roads, industrial emissions, smoke events (such as controlled burns, and building- and bushfires), and from wood heater emissions. Climate change is adding further layers of risk, with the impact of increasing temperatures and drought on natural and chemical emissions potentially increasing air pollution.[28] Climate change could exacerbate the intensity of events such as bushfires (with associated smoke pollution), floods (which can increase mould), and thunderstorms (some of which can increase asthma). A holistic, integrated approach is needed to improve indoor air quality and minimise any associated health impacts.

Figure 1 below shows some of the common sources of indoor air pollution that may be present in homes.

Figure 1. Indoor air pollutant sources (source: UK Royal College of Physicians, 2016)[29]



Sources and types of indoor pollution encountered in homes. VOCs = volatile organic compounds. Please note that these lists are not exhaustive and that the actual pollutants present, and their amounts, will vary from household to household.

3 Indoor air pollutants and their health impacts

In 2019, the World Health Organization identified air pollution as the greatest environmental risk to health.[30] Australia is thought to have generally good air quality, but there is increasing evidence that, for some pollutants – in particular, $PM_{2.5}$, there is no safe level of exposure, and health effects are observed even at low exposure levels.[31]

There are many potential pollutants of indoor air in Australia. Two key Australian scientific reviews, from 1997 and 2001,[32] identified the following pollutants as being among those of particular importance: particulate matter, formaldehyde, volatile organic compounds, nitrogen dioxide, carbon dioxide, carbon monoxide and ozone.[33] More recently, the COVID-19 pandemic and flood events have further highlighted the significance of biological indoor air pollutants. Indoor air pollutants are included in this report following a targeted scan of Australian and international indoor air quality literature.

The concentration of indoor air pollutants can be affected by a number of factors. These include the rate at which outdoor air is coming into an indoor space, the rate at which indoor air pollutants are generated, the level of local outdoor air pollution, the extent of air recirculation within the space, the level of air treatment, and whether contamination is generated within the space's ventilation system.[34] There are many interactive effects in indoor spaces. For example, indoor air pollutants can react with chemicals in dust, flooring, furniture and paint, and with other pollutants in the air, forming secondary pollutants. A lower ventilation rate can also result in higher concentrations of secondary pollutants, which can be reactive and irritating.[35]

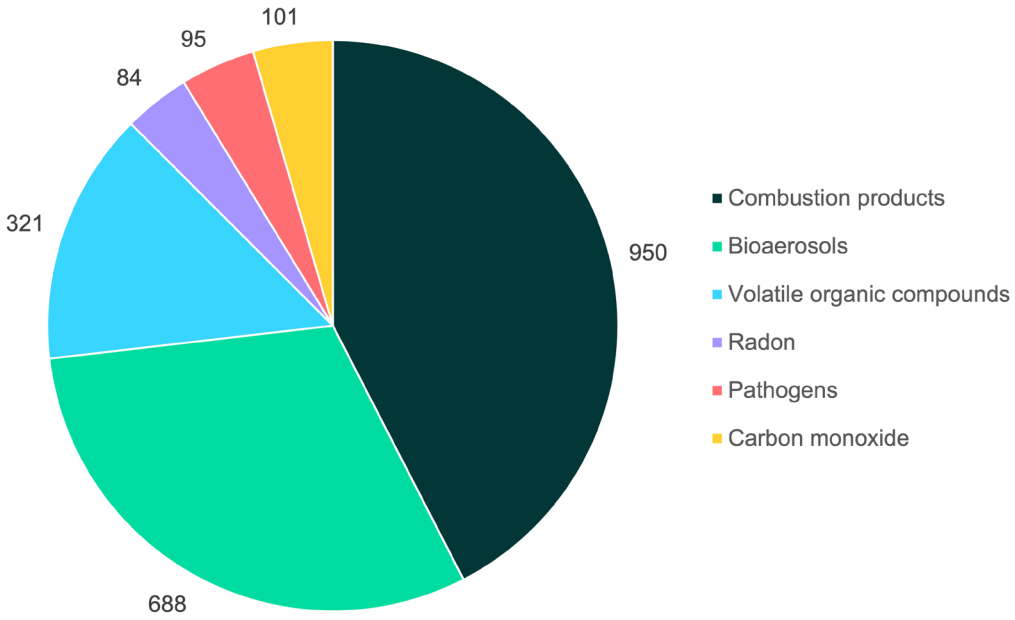
Defining which pollutants have the greatest impact on health can be complex. While measuring concentration levels of particular indoor air pollutants is a way of estimating the level of pollution, it does not necessarily reflect the health impact of those pollutants. The exposure to the pollutant is important in determining the level of risk to health. Exposure to a low concentration of one pollutant (with a higher toxicity) may have a greater health impact than exposure to a higher concentration of another pollutant with lower toxicity.[36] Long term exposure at low levels can also have health impacts, depending on the pollutant. For example, exposure to lower levels of $PM_{2.5}$ over a longer period can have similar and possibly greater impacts than exposure to higher levels over a shorter period.[37] Additionally, individuals may have different susceptibilities to the same level of exposure.

An effective way to reflect health impacts may be to estimate the population-averaged annual cost in terms of disability-adjusted life years (DALYs) from chronic (long-term) exposure to air contaminants in indoor spaces.[38] Disability-adjusted life years are a measure of healthy life lost in a population, and include years of life lost through premature death or living with disability due to illness or injury.[39] In a recent study of indoor air quality in dwellings globally, researchers from the United Kingdom's University of Nottingham, the United States' Lawrence Berkeley National Laboratory and the Catholic University of Chile found that, among the contaminants investigated, particulate matter (particularly fine particulate matter - $PM_{2.5}$) had the highest median DALY loss estimate. This was followed by nitrogen dioxide and formaldehyde, then radon and ozone. An earlier

study by the same research group suggested mould-related bioaerosols could also pose health concerns.[40] Viral pollutants were not included in the analysis.

A European study estimated the disability-adjusted life years lost each year in Europe due to poor indoor air quality.[41] Figure 2 below provides a breakdown of the contribution of indoor air exposures to symptom and disease burden in Europe.[42]

Figure 2. Contribution of indoor air exposures to symptom and disease burden in Europe, DALYs per year (thousands) (source: EnVIE Co-ordination Action on Indoor Air Quality and Health Effects report, 2009)[43]



Environmental tobacco smoke (ETS) is not included. Note, the study categorised 'pathogens' as indoor air exposures that cause respiratory infections, and 'bioaerosols' as indoor air exposures that, amongst other exposures, cause sick building syndrome, sensory irritation, asthma and allergy.

A November 2023 study of ten indoor air pollutants ranked them in order of their contribution to DALYs in China in 2017 as follows: $PM_{2.5}$, carbon monoxide, radon, benzene, nitrogen dioxide, ozone, sulphur dioxide, formaldehyde, toluene and p-dichlorobenzene.[44] There are likely to be differences in both outdoor and indoor environments in China and Australia, preventing a direct extrapolation of these results to the Australian context.

The Australian Building Codes Board publishes the *Indoor Air Quality Verification Methods Handbook* (last updated in May 2023), which includes tables summarising some common air contaminants, their sources and potential health effects.[45] Some contaminants (such as particulate matter and airborne microplastics) are not included in the current version of the tables. A compilation of the current tables is included in **Appendix A** of this report.

Box 1. Health impacts of outdoor air pollutants

The Australian Institute of Health and Welfare (AIHW) estimated that, in 2018, 1.3% of the total disease burden in Australia was attributed to outdoor fine particulate matter ($PM_{2.5}$) air pollution. This estimate is the amount of burden that could have been avoided if everyone in Australia was not exposed to $PM_{2.5}$, with the $PM_{2.5}$ levels as measured in certain outdoor locations around Australia. The AIHW study causally linked outdoor $PM_{2.5}$ air pollution to the following diseases—coronary heart disease, chronic obstructive pulmonary disease (COPD), stroke, lung cancer, type 2 diabetes and lower respiratory tract infections.[46]

The AIHW estimated that outdoor $PM_{2.5}$ air pollution was responsible for 8.6% of the total burden of coronary heart disease, 8.3% of the total burden of stroke, 6.7% of the total burden of both COPD and type 2 diabetes burden, 5.7% of the total burden of lower respiratory tract infections and 3.4% of the total burden of lung cancer (in terms of disability-adjusted life years).[47]

Total disease burden attributable to outside $PM_{2.5}$ air pollution was 2.2 times greater in the lowest (most disadvantaged) socioeconomic group compared with the highest (least disadvantaged) group.[48]

3.1 Particulate matter

Fine particulate matter (measured in outdoor air) has recently been found to be the greatest external threat to global public health, with a bigger impact on global life expectancy than smoking or alcohol use. It causes the average person globally to lose 1.9 years of life expectancy (comparable to smoking and 4.4 times that of high alcohol use), according to the University of Chicago's 2024 Air Quality Life Index (which converts air pollution concentrations into their impact on life expectancy).[49]

Particulate matter is a mixture of solid and liquid particles in the air, categorised by size, expressed as $PM_{x.y}$ (x.y refers to the particle size in micrometres). PM_{10} is particles with a diameter of 10 micrometres or less, $PM_{2.5}$ – fine particulate matter – is particles with a diameter of 2.5 micrometres or less, and $PM_{0.1}$ – ultrafine particulate matter – is particles with a diameter of 0.1 micrometres (100 nanometres) or less.

Particulate matter can be naturally occurring, such as dirt/dust, sea salt, pollen and bushfire smoke, or anthropogenic, such as from industry, wood heaters, gas stoves, cooking, vehicle emissions, tobacco smoking, vaping, and candles, and can come from outdoor or indoor sources.[50] Black carbon, or soot, is a type of particulate matter formed from incomplete combustion of organic matter. Secondary particulate matter can be formed by chemical reactions between air pollutants. A substantial part of $PM_{2.5}$ in indoor air may be bioaerosols, depending on the environment.[51]

The AIHW attributed more than 3,200 deaths in Australia in 2018 (2% of all deaths that year), and 1.3% of the total burden of disease in 2018, to $PM_{2.5}$ air pollution (measured in outdoor air).[52] Including indoor air sources of $PM_{2.5}$ may increase this attribution rate. Recent epidemiological research suggests there is no $PM_{2.5}$ concentration threshold below which health effects do not occur.[53]

A January 2024 report published by the US National Academies of Science, Engineering and Medicine Committee, *Health Risks of Indoor Exposures to Fine Particulate Matter and Practical Mitigation*

Solutions, stated there is strong evidence that exposure to indoor $PM_{2.5}$ has adverse effects on the respiratory and cardiovascular systems and likely other organ systems, with evidence less well developed but emerging of a role of indoor $PM_{2.5}$ in neurologic, metabolic, and reproductive outcomes. The committee stated that it can be concluded that reducing $PM_{2.5}$ exposure would have a significant public health benefit.[54]

Particulate matter enters the lungs when a person breathes in. It can also be deposited in the mouth, nose and throat, and be ingested. Some very small particles once inhaled can move into the bloodstream from the lungs, and some can enter the brain.[55] $PM_{2.5}$ can have both short- and long-term health impacts. It can affect almost every organ in the human body.[56] It is a serious risk factor for non-communicable disease.[57] It is associated with cardiovascular disease (see Box 5), lung disease, stroke and cancer.[58] Long-term exposure causes disease and/or increases the rate of progression of a disease (such as cardiovascular and respiratory diseases and reduced life expectancy).[59]

$PM_{2.5}$ is also associated with increased inflammation in the lungs,[60] with long term exposure to $PM_{2.5}$ potentially heightening the risk of infection by communicable diseases such as COVID-19.[61] $PM_{2.5}$ may also be a carrier of viruses, able to transport them through the air.[62] The World Health Organization's International Agency for Research on Cancer has classified particulate matter contained in polluted outdoor air as carcinogenic to humans.[63] The agency noted exposure to outdoor air pollution occurs virtually continuously, across microenvironments, including indoors, with the composition of the mixture and the absolute levels of air pollutants changing, with many different air pollutants present.[64] Indoor air sources of particulate matter may change the exposure profile and health impact.

Particulate matter has been reported to affect cognitive function in office workers, as well as student performance in classrooms (see Box 2). This is potentially linked to recently identified associations between exposure to $PM_{2.5}$ and various effects on the central nervous system and neurodegeneration. A hypothesised mechanistic pathway is that inhalation of $PM_{2.5}$ may lead to chronic, systemic inflammation that impacts the central nervous system.[65]

Particulate matter has also been associated with Alzheimer's disease and dementia.[66] A July 2022 report by the UK Government Committee on the Medical Effects of Air Pollutants reviewed almost 70 epidemiological studies looking at possible links between air pollution and a decline in mental ability and dementia in older people, as well as studies which investigated how air pollution might affect the brain. The committee concluded it is likely that air pollution does contribute to these effects, most likely through effects on circulation.[67] A 2018 Swedish longitudinal study looked at the association between air pollution from residential wood burning and dementia. It found emission of $PM_{2.5}$ from local residential wood burning was associated with dementia. The authors concluded if the associations observed were causal, then air pollution from residential wood burning may be an independent important risk factor for dementia.[68] A June 2024 Irish study found long term exposure to higher levels of $PM_{2.5}$ is associated with higher levels of depression and anxiety in older adults.[69]

A 2020 paper found, in high income countries, households with higher household occupant density, lower income, lower education levels and higher unemployment have been found to have higher levels of particulate matter. The same study noted higher household occupant density led to higher levels of indoor particulate matter because increased movement leads to resuspension of these particles. Indoor smoking, indoor solid fuel use in open fire places, cooking practices without efficient ventilation, and poorer quality housing may be factors linked to these socioeconomic differences in indoor air pollution exposure.[70]

Aboriginal people in remote areas may be more exposed than other people to factors such as dust and biomass smoke exposure. They are also disproportionately exposed to overcrowding in

housing.[71] A 2022 Asthma Australia survey found Aboriginal and Torres Strait Islander people were more than twice as likely to have a wood heater than non-Aboriginal and Torres Strait Islander people. They were also 1.5 times more likely to report unflued gas heating.[72]

There is growing concern about the health impacts of ultrafine particles ($PM_{0.1}$) in indoor air. These particles are the greatest proportion, by number, of the inhaled particles breathed indoors. While buildings provide some protection against outdoor ultrafine particle exposure, indoor emission sources like cooking and hair drying contribute ultrafine particles.[73]

There is substantial evidence of the negative health impacts of ultrafine particles. The systemic health effects of PM_{10} and $PM_{2.5}$ are often attributable to the ultrafine particle component of those particles.[74] After they enter the human body through the lungs, ultrafine particles can travel to essentially all organs in the body. Ultrafine particles cause more lung inflammation and are retained longer in the lungs than $PM_{2.5}$ as a whole. They also have a relatively larger surface area and can absorb other material. They trigger coughing and asthma, and cause systemic inflammation, endothelial dysfunction and coagulation changes, predisposing people to cardiovascular disease and hypertension. They can cause cerebral and autonomic dysfunction, travelling up the olfactory nerves to the brain. The risk of low birthweight is increased by *in utero* exposure.[75]

3.2 Volatile organic compounds

Many volatile organic compounds are found in higher concentrations indoors than outdoors. Health effects of volatile organic compounds, or 'VOCs', may include eye, nose and throat irritation, headaches, loss of coordination and nausea, and damage to the liver, kidney and central nervous system. Some volatile organic compounds are suspected or known to cause cancer in humans.[76] There is little known about the health hazards when volatile organic compounds mix with each other and with other pollutants.[77]

A 2018 study of 41 different volatile organic compounds across 20 locations at a large Australian university found indoor concentrations higher than outdoor concentrations for 97% of all volatile organic compounds. Some air pollutants (formaldehyde, benzene, toluene and xylenes) were up to an order of magnitude higher indoors than outdoors. Others (including d-limonene) were up to two orders of magnitude higher.[78] A systematic evaluation of investigations of volatile organic compounds within indoor environments in Australia found that new homes had the highest volatile organic compound levels among all studies of domestic housing.[79]

Formaldehyde is one of the most common volatile organic compounds. It is found in building materials - pressed wood products like particleboard, medium density fibreboard and hardwood plywood are common and long-lived sources of formaldehyde indoors.[80] It is also released from carpets, carpet backing, vinyl floors, wall coverings and some insulation products.[81] Emissions from wood heaters are another significant source of formaldehyde.[82] Formaldehyde is also found in many household consumer products, including cosmetics, shampoos, conditioners, shower gels, liquid hand soap and toothpaste. High levels of exposure can cause a range of health impacts including sensory irritation, breathing difficulties and asthma, and, where there is chronic high exposure, cancer.[83]

The Western Australian Department of Energy, Mines, Industry Regulation and Safety states that one insulation product, urea formaldehyde foam insulation, was used in 50,000 to 70,000 Australian homes, with the extent of use in commercial buildings unknown. The insulation product may break down and release dust into occupied areas.[84] It has also been found to release formaldehyde.[85]

Benzene is another volatile organic compound found in indoor air.[86] The World Health Organization has concluded that benzene is a human carcinogen and that no safe level of exposure can be recommended.[87] Long term benzene exposure is linked with bone marrow depression and leukaemia, specifically acute myeloid leukaemia.[88] In Australian homes, building materials such as engineered wood products, carpets and paints can be significant sources of benzene, particularly in recently renovated, tightly sealed or energy efficient buildings.[89] A 2022 US study of homes with gas and propane stoves found that benzene emissions from a gas burner on high or a gas oven at 350 degrees Fahrenheit (approx. 180 degrees Celsius) could create higher concentrations of benzene than indoor benzene levels attributable to second-hand tobacco smoke.[90] Several Canadian studies have found that houses with attached garages have significantly more benzene in indoor air than houses without such a garage.[91]

Toluene (methylbenzene), another volatile organic compound, is in some paints, lacquers, inks, adhesives, rubber, cleaning agents and tobacco smoke. Human exposure occurs mainly by being breathed in. Short term exposure at significant levels can lead to dizziness, sleepiness, unconsciousness and sometimes death. Low level long term exposure can affect kidneys. Toluene has also been linked to neurological effects, including poor performance in tests of short-term memory, attention and concentration.[92]

Benzene and toluene are often grouped with other common volatile organic compounds, namely ethylbenzene and xylenes, which are known together as BTEX. A 2007 Australian study investigated ambient and indoor air BTEX exposure of over 200 non-smoking, non-occupationally exposed people from four Australian cities. It found increased exposure from vehicle repair and machinery use, vehicle refuelling, being in an enclosed car park and doing arts and crafts. The study found a highly significant difference between the mean exposures in each city.[93]

Acrolein (2-propenal), another volatile organic compound, is a highly flammable liquid. Vapours can come from environmental tobacco smoke, vehicle exhaust, burning wood, and overheated cooking oil or grease. Inhalation can cause irritation to the respiratory system, decreased lung function, lung oedema, chronic respiratory disease, and systemic effects to the respiratory, reproductive, neurological and haematological systems.[94]

1,3-butadiene (vinyl ethylene) is a volatile organic compound found in tobacco smoke, some consumer products, and also in vehicle emissions. It can irritate the eyes, nose and throat, and in high levels can have a range of health impacts including damage to the central nervous system, nausea and unconsciousness. Long term exposure is shown to have increased damage to the heart and lungs. It has been classified as a probable human carcinogen.[95]

1,4-dichlorobenzene, another volatile organic compound, is used to control moths, mould and mildew and as a bathroom deodoriser and car freshener.[96] It can affect multiple organ systems including the liver, kidneys, skin, lung and the central nervous system.[97]

Limonene, a terpene, is the most common compound found in air fresheners. Health impacts from exposure to air fresheners at significant levels include respiratory difficulties, mucosal symptoms, migraines, skin problems and asthma episodes.[98]

Trichloroethylene and tetrachloroethylene (perchloroethylene) are examples of other volatile organic compounds found in indoor air with negative health impacts.[99] Tetrachloroethylene and other volatile organic compounds can contaminate soil or groundwater. Vapours can then move through building foundations into indoor spaces and contaminate indoor air, in a process called vapour intrusion.[100]

3.3 Per- and poly-fluoroalkyl substances

Per- and poly-fluoroalkyl substances (PFAS) are a class of manufactured chemicals that have been used to make products that resist heat, stains, grease, and water. Products that may contain PFAS include furniture and carpets treated for stain resistance, packaged food containers, makeup, personal care products, cleaning products, and some firefighting foams. Because of their widespread use, most people are likely to have had some exposure to PFAS. The range of PFAS used in these products is complex.[101]

Carpets and dust have been observed to be major sources of certain volatile PFAS in air.[102] The February 2024 enHealth guidance statement on PFAS states inhalation of dust contaminated with PFAS is a minor exposure pathway for humans.[103] A Norwegian study found variation in PFAS exposure pathways, with a combination of house dust ingestion and indoor air inhalation as the main contributor of PFAS intake for a small proportion of participants in the study.[104]

PFAS take a long time to break down in the environment, including indoors. PFAS can remain in the human body for years, so as a precaution limiting exposure is recommended.[105]

3.4 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons are produced by incomplete combustion, including from tobacco smoke, smoke from home heating (when burning wood or oil), and when meat is cooked at high temperature, including pan frying and grilling.[106] Residential wood burning is a major source of these hydrocarbons in winter urban air.[107] Individual polycyclic aromatic hydrocarbons, including benzo(*a*)pyrene, have been classified by the International Agency for Research on Cancer as carcinogenic to humans.[108]

Naphthalene, a polycyclic aromatic hydrocarbon is associated with the risk of severe toxicity from relatively small oral or inhaled exposures, including in children. Naphthalene is commonly used indoors in toilet deodorisers and moth (repellent) balls. Acute exposure to naphthalene is associated with haemolytic anaemia, liver damage, neurological damage in infants, and possibly death.[109] The US EPA has classified naphthalene as a possible human carcinogen.[110]

3.5 Carbon monoxide

Carbon monoxide is a gas emitted from inefficient combustion of most organic materials. Indoor sources include combustion-based heating or cooking, smoking, or from vehicles via attached garages.[111] When carbon monoxide is breathed in and enters the bloodstream, it reduces the blood's ability to carry oxygen. This reduces the amount of oxygen going to the brain, heart and other parts of the body. Low concentrations of carbon monoxide can lead to cognitive impairment, while high concentrations can result in death, though there is wide variation in individual responses to similar levels of carbon monoxide exposure.[112]

3.6 Nitrogen oxides

Although nitrogen dioxide levels vary between homes, the average level in homes without combustion appliances is about half of the outdoor levels. In homes with gas stoves or unvented gas space heaters, indoor levels can often exceed outdoor levels.[113] A 1998 study found that the presence of gas stoves in homes is the main activity influencing personal exposure to nitrogen dioxide.[114] An October 2024 analysis by researchers at Spain's Jaume I University found the presence of gas cookers at home and exposure to nitrogen dioxide from gas cooking appliances produces far more health impacts in the European population than previously thought, including premature deaths and asthma.[115] A paper from the Harvard School of Public Health found low income individuals are often at highest risk, as they are more likely to live in smaller volume dwellings, have multiple sources of nitrogen dioxide, use gas stoves for supplemental heating, and have poor ventilation.[116] Proximity to vehicle emissions is another potential factor in greater nitrogen dioxide exposure in socioeconomically deprived areas.[117] In Australia, several states allow unvented gas space heaters as primary heaters and these are significant sources of nitrogen dioxide and other pollutants.[118]

Nitrogen dioxide emissions due to air pollution can irritate airways. Short term exposure can aggravate respiratory diseases such as asthma, and is linked to asthma hospitalisations.[119] As an example, during 2006 in Melbourne 193 (3.1%) of the 6,200 asthma hospitalisations are estimated to have been related to exposure to nitrogen dioxide.[120] Longer term exposure to elevated concentrations of nitrogen oxides may contribute to the development of asthma and potentially increase the susceptibility to respiratory infections. Asthmatics, children and the elderly are generally at higher risk.[121]

Nitrogen dioxide can react with indoor surface materials, leading to the formation of nitrous acid. Nitrous acid is itself an indoor air pollutant with known short and long term health impacts. A 2016 paper found nitrous acid photolysis is the main source of indoor hydroxyl radicals[122]

3.7 Carbon dioxide

Unless fresh air comes into an indoor space, carbon dioxide concentration levels will generally rise because of occupant respiration, and any combustion process happening in the space or in outside air that comes into the space.[123] Carbon dioxide is a simple asphyxiant, with elevated levels depriving the human body of oxygen. A 1964 study of six volunteers suggested inhaling moderately elevated concentrations of carbon dioxide caused marked changes in respiration, circulation and cerebral electrical activity.[124]

A 2012 study suggested there are direct effects of low to moderate carbon dioxide concentrations on human decision making.[125] However, the mechanism for carbon dioxide's effect on cognitive function at relatively low concentrations (<3000 ppm) is still not fully understood. Elevated levels of carbon dioxide in the bloodstream from ambient exposure may result in sympathetic activation of the autonomic nervous system. Another 2012 study found activation of the sympathetic nervous system influences cognitive performance, including strategy and working memory.[126]

Carbon dioxide concentration is increasingly being used as a proxy measure of the level of ventilation occurring in an indoor space.[127] If carbon dioxide levels increase above an accepted threshold relative to outdoor concentration, it generally means that ventilation is inadequate relative to that threshold.[128]However, other indoor air quality interventions- such as air filtration – may reduce the concentration of some other pollutants, such as viruses, dust and other particulate matter. National Science and Technology Council advice to the Australian Government is that measuring carbon dioxide is the most promising proxy measure for ventilation effectiveness in indoor air quality studies.

However, the Council advises that limitations around how these measurements are interpreted, in the presence of other indoor air quality interventions, must be taken into consideration.[129] Clear guidance would be needed to support interpretation of carbon dioxide monitoring.

Historically, mechanical ventilation standard thresholds were set at outdoor airflow rates or air exchange rates that were perceived as 'acceptable' from occupant odour perspectives.[130] Ventilation thresholds are increasingly being set for levels of carbon dioxide related to the infection risk from airborne viruses in indoor spaces.[131] However, there are several ways in which this relationship can break down. As an example, if other indoor air quality mitigations – such as air filtration or cleaning – are in use, the levels of infectious bioaerosols may be lower than indicated by the carbon dioxide concentration. In the opposite direction, a 2009 paper by Morawska *et al* found vocalisation – for example, speaking - in an indoor space can increase the emission rate of exhaled aerosols.[132] This increases their concentration and thus any infection risk, above that predicted by the carbon dioxide concentration.[133] In this latter circumstance, measuring carbon dioxide concentrations may still be broadly useful, but only as an indicator of the baseline level of risk. Carbon dioxide sensors are now widely available, and could be considered for use in indoor spaces in a similar way to smoke alarms, with guidance provided around their use.[134]

Moderate increases in carbon dioxide levels have recently been shown to significantly increase the stability of airborne viruses, prolonging their infectivity in the air.[135]

High levels of carbon dioxide in indoor spaces are associated with reduced cognitive performance, including lower educational performance in school classrooms and lower productivity in office environments (see Box 2).[136]

The increase in atmospheric carbon dioxide due to climate change poses significant challenges in maintaining low carbon dioxide levels in indoor environments. As climate change continues, outdoor carbon dioxide levels are expected to rise further, influencing indoor air quality through various mechanisms.[137]

Box 2. Indoor air quality and cognition

Both carbon dioxide and particulate matter indoor air concentration are independently associated with cognition and decision-making abilities.[138]

A February 2025 paper in Nature Communications found even brief exposure to high levels of particulate matter affected people's executive cognitive functioning, including their ability to focus on tasks.[139]

A 2025 paper from Harvard University found lower carbon dioxide levels are associated with higher creativity. A relatively small (100 ppm) increase in carbon dioxide was associated with up to 11% differences in various measures of creativity.[140]

A 2023 paper from MIT found that a modest (10 ug/m^3) increase in indoor air concentration of fine particulate matter ($PM_{2.5}$) increased a competitive chess player's probability of making an error by 26%.[141]

A 2014 study of over 1,000 students at 51 schools in Coimbra, Portugal, found a statistically significant association between a lack of concentration in the children and exposure to high levels of carbon dioxide.[142] A 2007 UK study found high carbon dioxide levels in a classroom are likely to lead to students being less attentive and less able to concentrate. The study estimated that the size of this effect is of a similar magnitude to what is observed over a morning when students have not eaten breakfast.[143]

A 2018 paper from Harvard found the performance of aeroplane pilots is affected by cockpit carbon dioxide levels.[144]

A 2016 US study of 24 office workers found that cognitive scores were 61% higher in a 'green' indoor environment with low carbon dioxide concentration, compared with a conventional building more representative of a 'typical' US office. The same study found a 400 ppm increase in carbon dioxide level was associated with a 21% decrease in a typical participant's cognitive test scores, and a 500 ug/m^3 increase in total volatile organic compounds concentration was associated with a 13% decrease in these test scores.[145]

In an era of widespread COVID-19 infection, cognitive deficits may be compounded, with emerging evidence suggesting COVID-19 infections may have an impact on cognition.[146] A 2022 study from the University of Oxford and the University of Cambridge of over one million COVID-19 patients found that the risk of cognitive deficit was higher than that in matched controls at six months, and that the risk remained higher at the end of the two-year follow-up period.[147]

Climate change may increase the impact on cognition further. Rising atmospheric carbon dioxide levels as a result of climate change are expected to increase urban and indoor carbon dioxide levels, which may reduce decision-making ability and strategic thinking.[148]

3.8 Ozone

Ozone is a secondary pollutant that forms due to chemical reactions between volatile organic compounds and sources of oxygen such as nitrogen oxides or carbon monoxide.[149] On hot and sunny days, ozone concentrations in ambient air generally increase, especially in cities.[150] Most ozone indoors is thought to come from outdoor sources, but indoor sources can significantly increase ozone concentration indoors.[151] Indoor sources include some devices sold as air cleaners (see section 8.3.7.5), and laser printers and copiers.[152] Ozone is a known lung irritant. It can aggravate lung diseases such as asthma, emphysema and chronic bronchitis.[153] Ozone can contribute to death and illness during heat and heatwaves.[154]

Ozone is a highly reactive gas and has been found to react with organic materials and surfaces indoors, producing secondary pollutants. These secondary pollutants, including formaldehyde and ultrafine particles formed by condensation/nucleation processes, may have further health impacts.[155]

A 2023 paper found some human skin oil compounds react with ozone, potentially reducing ozone from outdoor air that comes into residences by 15%. It found more is removed as occupant density indoors increases. In classrooms, the proportion of ozone removal attributable to skin oil may be between 35 and 55%.[156]

3.9 Sulphur dioxide

Sulphur dioxide is an air pollutant that can impair respiratory function.[157] It is generated from a range of sources including industry, vehicle exhausts and natural emissions.[158] It can also be generated from indoor sources such as wood heaters and other forms of combustion.[159] While indoor levels tend to be lower than outdoor levels, the infiltration of outdoor air into buildings is often a significant source of indoor levels.[160]

3.10 Environmental tobacco smoke and vape aerosols

Even though smoking in public indoor places has declined in recent years, smoking remains a source of indoor air pollution in Australia, including in homes. For Aboriginal and Torres Strait Islanders, in 2018–19, 10% (83,900) lived in households with a daily smoker who smoked indoors. Of Aboriginal and Torres Strait Islander children aged 0–14, 9% (23,900) lived with someone who smoked indoors.[161]

The World Health Organization states there is no safe level of exposure to tobacco.[162] Breathing even small amounts of tobacco smoke can be harmful to smokers and non-smokers.[163] Environmental tobacco smoke (second-hand smoke) can cause or worsen conditions and diseases including cancer, heart attacks, heart disease, asthma and diabetes, as well as respiratory infections such as pneumonia.[164]

Environmental tobacco smoke can move between the rooms of a building, including between apartment units. The US EPA advises several studies have shown that while ventilation, filtration and air cleaning techniques can reduce environmental tobacco smoke they do not eliminate it.[165] Environmental tobacco smoke can adhere to indoor dust, as well as to surfaces like walls, floors, furniture, curtains and clothes. It can then go back into the air as thirdhand smoke, creating chronic exposure.[166]

Aerosols from vapes are an increasing concern as an indoor air pollutant for users and non-users. There is a high certainty of evidence that e-cigarette use increases airborne particulate matter in

indoor environments, meaning that people may passively inhale e-cigarette emissions.[167] E-cigarette users are exposed to chemicals and toxins that have the potential to cause adverse health effects.[168] Hazardous substances can be found in e-cigarette liquids and in the aerosols produced by e-cigarettes, including known cancer-causing agents such as formaldehyde, acetaldehyde and acrolein.[169]

Shisha and hookah smoking also have health-related impacts on indoor air quality.[170]

3.11 Viruses

Some viruses that cause disease in humans can be airborne. These viruses can spread through the air in small particles, called respiratory aerosols or infectious respiratory particles, in a range of sizes (from sub-micrometres to millimetres in diameter).[171] These particles can float and travel in air flows, infecting people who inhale them at both short and long distances from the infected person.[172] Particle distribution, spread and impacts on other people depend on many factors, including environmental conditions and particle size.[173] Viruses can also adhere to particulate matter.

The concentration of virus-containing respiratory aerosols can build up in an indoor space from infected people.[174] In a recent study (in preprint), COVID-19 patients exhaled an average 80 copies of the virus each minute during the first eight days of infection, with considerable variation and spikes of over 800 copies a minute in some patients.[175] A December 2023 study found the infectivity of exhaled COVID-19 viral aerosols was sufficient to transmit disease through the air within minutes.[176] Some viruses can remain viable in the air for several hours, even after the infectious person has left the indoor space.[177]

There is strong evidence supporting the airborne transmission of many viruses, including those that cause measles, influenza, respiratory syncytial virus infection (RSV), the common cold, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS) and COVID-19.[178] Airborne transmission is considered the dominant mode of transmission for numerous respiratory infections.[179]

Research suggests that airborne disease transmission of some viruses may come from people with asymptomatic, presymptomatic or sub-clinical infections.[180] Disease transmission mitigation measures that address symptomatic infections only may therefore not be sufficient to contain transmission.

The health impacts of some airborne viral infections, such as with SARS and SARS-CoV-2, go beyond the acute phase of an initial infection, and the long-term health impacts can be worse than the initial health impacts.[181] The chances of long-term health impacts may increase with repeated infections.[182] Emerging evidence suggests that infection with some airborne viruses is associated with a significantly increased risk of subsequent infection with other pathogens, potentially due to the long-term adverse health effects of the first virus.[183]

Other air pollutants can exacerbate the direct health impacts of airborne viruses.[184] Air pollution from particulate matter, nitrogen dioxide and black carbon (soot) have been found to influence COVID-19 severity.[185] Exposure to air pollution near roads is also a risk factor for COVID-19 severity, independent of regional $PM_{2.5}$ and NO_2 exposure.[186] Increased carbon dioxide levels were recently found to increase COVID-19 infection risk.[187] Other pollutants, including benzene and wood smoke, have also been linked to respiratory diseases.[188] The Centre for Safe Air, an NHMRC Centre of Research Excellence, states that improving indoor and outdoor air quality would reduce the burden of respiratory infections.[189]

3.12 Bacteria

Some bacteria can be airborne, either on their own, via their spores, or attached to other particles such as dust.[190] For example, group A streptococcus, which causes acute rheumatic fever, strep throat and other illnesses, can be transported on small airborne particles such as dust.[191]

Bacteria and fungi can form biofilms on surfaces, including on the cooling coils of commercial air conditioning units, potentially leading to the aerosolisation of microbes into indoor spaces in a building.[192]

Legionella bacteria species cause Legionnaires' disease. The bacteria is most commonly transmitted via a person inhaling contaminated aerosols produced in conjunction with water sprays, jets or mists of contaminated water sources such as air conditioning cooling towers.[193] Legionnaires' disease is more often contracted in places such as hotels, hospitals and offices, due to bacteria in the water supply.[194] It can also be contracted at home, where the bacteria can be in damp or wet environments like damp gardening soils, air conditioners and spa baths.[195] With increasing heat events linked to climate change, there is likely to be an increased reliance on air conditioning, with associated increased risk of bacterial infection.

Mycobacterium tuberculosis bacteria causes tuberculosis. The bacteria is transmitted via a person inhaling contaminated airborne particles, which can be spread through air currents in a room or building.[196]

Bacterial infections, such as those caused by *Clostridioides difficile*, may occur in a hospital setting through airborne transmission.[197]

Not all inhaled bacteria are necessarily bad for health. The lungs are thought to have a microbiome, thought to be in a state of flux, with microbial immigration and clearance. Some diseases may disrupt the microbial-host interface.[198]

3.13 Mould and fungi

Mould spores and fragments can become airborne and can be inhaled by humans. This can trigger nasal congestion, sneezing, coughing or wheezing, and respiratory infection. Mould can also worsen asthma and allergic conditions. Contact with mould can also irritate eyes and skin. People who are more likely to experience these symptoms include those with weakened immune systems, allergies, severe asthma or lung diseases.[199] Children in home environments with visible mould and mould spore exposure may have increased risk of allergic respiratory health outcomes.[200] The World Health Organization states there is no level of exposure to mould that can be considered safe for health.[201]

In November 2023, the Australian Government Department of Health and Aged Care published *Biotoxins (indoor damp and mould) Clinical Pathway* to support clinical decision making for patients who report debilitating symptoms with a history of exposure to indoor damp or mould, and that cannot be attributed to another condition.[202] The Australian Building Codes Board provides information about moulds and fungi relating to condensation and inadequate ventilation.[203] Work health and safety regulators also provide guidance on mould in occupational settings.[204]

Mould generally thrives in moist or humid, poorly ventilated environments. The World Health Organization estimates that indoor dampness affects 10 to 50% of indoor environments.[205]

The World Health Organization states that the most important way to avoid adverse health effects of mould is the prevention (or minimisation) of persistent dampness and microbial growth on

interior surfaces and in building structures.[206] Dampness and mould may be more prevalent in poorly maintained housing for socioeconomically disadvantaged people. In Australia, rental properties are more likely to be mouldy than other homes.[207] The World Health Organization states that addressing the conditions leading to adverse exposure should be a priority to prevent further ill health in these populations who already have an increased burden of disease.[208]

A number of fungal species can infect people via the air. In 2022, the World Health Organization published *WHO fungal priority pathogens list to guide research, development and public health action*.[209] Of the four fungi WHO ranked as of critical importance, two - *Cryptococcus neoformans* and *Aspergillus fumigatus* - are widely accepted as being primarily transmitted through the inhalation of spores in the air.[210] Of the remaining two, while *Candida auris* is not thought to be primarily transmitted through the air, a 2019 UK study highlighted the potential for *Candida auris* to become airborne during aerosol-generating high turbulence activities such as bed making.[211] The fourth fungi ranked by the WHO as of critical importance is *Candida albicans*. Although *Candida albicans* is not considered a usual indoor air contaminant, a 2022 Ethiopian study of indoor air samples in different wards of an Ethiopian hospital found *Candida albicans* was a frequently obtained yeast isolate.[212] A 2024 Italian study of laboratory and insect experiments suggests the presence of microplastics could exacerbate the ability of *Candida albicans* to infect people.[213]

Another fungal species on the WHO list is *Pneumocystis jirovecii*, which is airborne and a common cause of pneumonia in patients with cancer-related immunosuppression.[214]

To contain the expanding burden of disease from the fungal priority pathogens, the WHO called for work on the role of air quality, the built environment, coinfections and other drivers at the population level.[215]

Exposure to some airborne fungi is associated with asthma prevalence. Household airborne *Penicillium* is associated with airway hyperreactivity in asthmatic children.[216]

3.14 Human skin cells, bioeffluents, dust mites, and animal dander, hair and excreta

As well as viruses, bacteria, mould and fungi, a wide range of other biological material can be found in indoor air. This includes: human skin cells; animal dander (dried skin cells and saliva); particles from feathers; and animal and insect excreta and body parts.[217]

Negative health impacts from this biological material can include allergic responses, including hay fever, eczema, some types of asthma, psittacosis, and hypersensitivity pneumonitis.[218]

Human skin cells in household dust become colonised by moulds, yeasts and bacteria, and provide food for house dust mites.[219] As discussed in section 3.8, certain compounds in human skin cells may reduce ozone concentration in indoor air.[220] However, these compounds may also contribute to ammonia and volatile fatty acid production in bacteria-colonised air conditioning units, causing odour issues.[221]

Bioeffluents are also indoor air pollutants, produced during the metabolic processes that take place within human bodies.[222]

3.15 Pollen

While pollen is largely generated outdoors, it can enter indoor spaces through open windows, doors and vents, via cracks around closed windows and doors, and through heating, ventilation and air conditioning systems.

Pollen can trigger an allergic response like hay fever (allergic rhinitis), with symptoms such as a runny nose, sneezing and watery, itchy eyes.[223]

Thunderstorm asthma is thought to be triggered by a unique combination of high amounts of grass pollen in the air and a type of thunderstorm. It happens more often in spring and early summer than other times of the year. Grass pollen grains get swept up in the wind and carried for long distances; some can burst open and release tiny particles that are concentrated in the wind gusts that come just before a thunderstorm. The grains release pollen allergens which move down to ground level where people can breathe the allergens into their lungs and experience asthma. For people who have asthma or hay fever this can trigger severe asthma symptoms. It can affect people who have never had asthma before. Symptoms may include shortness of breath, chest tightness, wheezing when breathing, and/or persistent coughing.[224]

Box 3. Asthma and indoor air quality

Asthma is a chronic lung disease affecting people of all ages. Around 2.8 million Australians (11%) have asthma. Aboriginal and Torres Strait Islander people have asthma at a higher rate (16%) than other Australians.[225] People with asthma experience episodes of wheezing, shortness of breath, coughing, chest tightness and fatigue due to widespread narrowing of the airways.[226]

While the fundamental causes of asthma are not completely understood, environmental exposure to inhaled substances and particles – asthma triggers – may lead to allergic reactions or irritated airways. Many of these triggers can be present in indoor environments, including house dust mites, mould, pollens, animal dander, tobacco smoke, and strong odours like perfume.[227] A 2018 study found 12.3% and 7.9% of the total asthma burden in children in Australia is associated with exposure to gas cooktop stoves and damp housing, respectively. The study also found if all homes with gas stoves were fitted with high efficiency range hoods venting outside, the gas stove-associated burden reduced to 3.4%.[228] A 2023 study estimates that 12.7% of current childhood asthma disease risk in the USA is attributable to gas stoves, similar to the childhood asthma burden attributed to secondhand smoke exposure.[229] For every asthma hospitalisation due to air pollution, it is likely many more people have asthma episodes of less severity.[230]

Recent Asthma Australia research found nearly one-third of people with asthma or allergies report experiencing worse symptoms after spending time in their homes. It found people living in private rental and social housing, and homeowners on low incomes, were more likely to report barriers to making changes to their homes to support good health, including indoor air quality.[231]

Occupational exposure to pollutants in indoor air in workplaces can also trigger asthma.

The National Asthma Strategy outlines Australia's national response to asthma, and identifies actions to reduce the impact of asthma in the community.[232] The Australian Asthma Handbook provides practical advice for primary healthcare professionals.[233] In November 2023, the Australian Government Department of Health and Aged Care published the Biotoxins (indoor damp and mould) Clinical Pathway, which included asthma (development, current, exacerbation) as a health effect for which there is sufficient evidence of association with exposure to indoor damp and mould.[234]

3.16 Airborne microplastics

Microplastics – tiny pieces of plastic - are increasingly present throughout the environment, including in the air, and may form part of $PM_{2.5}$ pollution, depending on their size.[235] Studies have found higher concentrations of airborne microplastics in indoor air compared to outdoors.[236]

Clothing is a potentially large source of indoor airborne microplastics, including polyester microfibres, often from dryers and washing machines.[237] A recent Australian study looked at levels of airborne microplastics in air samples from seven different types of indoor locations. It found the highest indoor microplastic concentration was at a childcare site, followed by an office and a school. Polyethylene terephthalate[238] was the prominent polymer type found at most sites in the Australian study.[239]

While research is ongoing to understand the detailed health impacts of airborne microplastics, recent research suggests that repeated inhalation of airborne microplastics can result in an inflammatory response in the lungs.[240] Another study suggests that exposure to polystyrene airborne microplastics increases the risk for chronic obstructive pulmonary disease.[241]

As well as the potential health impacts of the airborne microplastics themselves, airborne microplastics may also carry other pollutants through the air, like viruses, mould, bacteria and chemicals.[242] As an example, a 2024 Italian study suggests the presence of microplastics can exacerbate the ability of *Candida albicans* to infect people.[243]

3.17 Silica dust

When engineered stone is cut or ground, it releases fine silica dust. This hazard can cause silicosis and other silica-related diseases when inhaled into the lungs.[244] Silica dust can also be generated from other activities, such as demolition work.[245]

A ban on the manufacture, supply, processing and installation of engineered stone benchtops, panels and slabs has been in effect since 1 July 2024.[246] On 18 September 2024, the Australian Government announced a ban on the importation of engineered stone benchtops, slabs and panels from 1 January 2025.[247]

Results from a study published in December 2023 suggested that silica is not the only component of concern in engineered stone products. The study highlighted that caution is required when alternative materials are produced in an effort to reduce disease risk.[248]

3.18 Asbestos

Approximately one third of all homes in Australia are estimated to contain asbestos products in one form or another.[249] Asbestos can be friable or non-friable (bonded). Non-friable asbestos is asbestos mixed with cement or resin to keep fibres in place. Non-friable asbestos poses a risk of releasing airborne fibres if it gets damaged. Friable asbestos - asbestos that is easily crushed into a powder - has a higher risk of airborne fibres being released when it is handled and is of particular concern.[250] In addition, vehicles made before 2003 may have asbestos-containing components like brake pads/shoes, clutch plates and gaskets.[251]

Asbestos fibres can become airborne if there is damage to asbestos building products, such as during renovations or demolition, to industrial plant or mechanical equipment (e.g., machinery, or air conditioning) or during vehicle maintenance and repair. Inhaling asbestos fibres can cause lung

disease, including asbestosis, lung cancer and mesothelioma.[252] A 2011 Australian study found malignant mesothelioma after exposure to asbestos during home renovation was an increasing problem in Western Australia. The authors noted such cases would probably continue to increase due to the many homes still containing asbestos.[253]

3.19 Radon

Breathing in radon gas can lead to lung cancer.[254] The risk of developing lung cancer from radon depends on how much radon humans breathe in and for how long.[255]

In outdoor air, radon levels are low. Indoors, radon concentration can be higher, as buildings can trap radon that can originate from certain soil types. Radon levels indoors are highly variable, depending on the type of house and the flow of air through the home. A nationwide survey of over 3300 homes found the average concentration of radon in Australian homes is low, and about one quarter of the worldwide average. The survey found approximately one in a thousand homes may have high levels of radon (exceeding an annual average radon concentration of 200 Bq m^{-3}).[256]

Generally, homes that are well ventilated, made of timber or built on stumps have lower radon levels compared to homes on concrete slabs with brick walls. However, the only way to be certain of radon levels in a home is by testing.[257]

In relation to workplaces, the Australian Radiation Protection and Nuclear Safety Agency notes that there are only a limited set of scenarios that might give rise to elevated radon levels, including highly energy efficient buildings in areas of high radon potential, underground workplaces, and enclosed workspaces with limited ventilation.[258]

The Australian Government has published the Australian Radon Action Plan, a long-range strategy for reducing radon-induced lung cancer in Australia.[259] Actions include raising awareness, residential meters and occupational monitors.[260]

3.20 Lead and other heavy metals

The main sources of exposure to lead are from work involving lead (processes and products), old paint flaking, sanded or disturbed during home and building renovations, lead-contaminated dust (including remnants from leaded petrol car exhaust, and from contaminated soil), recreational shooting, hobbies involving lead, and some alternative medicines. People can bring lead residues into their homes and other indoor spaces on clothes, skin, hair and equipment.[261] Environmental contamination from airborne lead-contaminated dust from smelting operations is an ongoing source of lead exposure for some Australian communities.[262] The World Health Organization notes there are multiple exposure pathways, with the most important routes of exposure being ingestion (particularly for young children) and inhalation.[263]

Lead can be harmful to health. Unborn babies, infants and children are especially vulnerable, and lead exposure even at low levels can affect their physical and mental development.[264] Lead can be absorbed into their bloodstream and impair brain and nervous system development.[265]

A 2019 Macquarie University study looked at residential indoor vacuum dust from 224 Sydney homes. It found that residential soil levels explained part of the presence of some metals in indoor dust, with higher levels of lead in indoor dust in older parts of Sydney. The levels of chromium and lead measured in indoor dust posed potentially significant health risks, including a carcinogenic risk for children from chromium, though the inhalation pathway risk was lower than for ingestion and dermal pathways.[266]

3.21 Cosmetics, fragrances, aerosol deodorants and cleaning products

Cosmetics, fragrances and cleaning products, including some detergents, contain substances that can irritate the respiratory system. Air fresheners can emit chemicals into the air, including volatile organic compounds like formaldehyde, benzene and toluene.[267] These emissions can react with other indoor air pollutants like ozone to generate secondary pollutants, like acetaldehyde and ultrafine particles.[268]

Ammonia can be emitted from cleaning products, as well as from other sources such as tobacco smoke, building materials, and humans. A 2019 US study of indoor chemistry in a test house found that ammonia levels increased during cooking, cleaning and occupancy activities, with the greatest concentrations found during cleaning activities. The study also found that ammonia levels were strongly influenced by indoor temperatures and the operation of heating, ventilation and air conditioning systems.[269]

4 Other factors influencing the health impacts of indoor air quality

A 2020 analysis of 141 indoor air quality studies across 29 countries (including Australia) concluded that household characteristics and occupant activities play a large role in indoor exposures. Particularly influential factors identified were cigarette smoking for $PM_{2.5}$, gas appliances for nitrogen dioxide, and household products for volatile organic compounds and polycyclic aromatic hydrocarbons. The analysis also found that location near busy roads, small house size, and redecorating also contributed to indoor air pollution, while ventilation reduced indoor air pollution.[270]

From 2008 to 2009, CSIRO studied indoor air quality in 40 Australian temperate zone dwellings in Melbourne. The study found that ventilation and activities associated with combustion and cooking were the major influences on indoor air quality.[271] The researchers stated in a further analysis that differences from region to region and country to country are likely due to a broad range of influencing factors such as outdoor concentrations, ventilation rates, domestic appliances, occupant activities, differing lifestyles and habits of occupants, and the occupant density in the homes.[272]

Other factors that influence the health impacts of indoor air quality include:

- **insufficient ventilation**, often in well-sealed modern buildings designed for energy efficiency[273]
- ventilation with and/or infiltration of **polluted outside air**, including from nearby industry and combustion, into inside spaces, often in older 'leaky' buildings or via ventilation systems[274]
- **air movement** within an indoor space, with varying concentrations of some pollutants in different parts of the space, and poor internal layout or layout changes affecting air flow (tracer gas can be used to determine airflow and pollutant migration in an indoor space). Air circulation and air change rates are important for the control of moisture issues, including mould in still environments
- **time** spent in the indoor space, affecting the risk of exposure[275]
- **individual sensitivities**, with a significant proportion of the population having greater sensitivity to some pollutants. These groups include newborns, young children, the elderly, heart patients, people with bronchitis, asthma, hay fever, emphysema or diabetes, pregnant people, and smokers.[276] Some air pollutants can cross the placental barrier, disrupting its function and contributing to adverse pregnancy outcomes, including lower birth weight, reduced foetal growth, and an increased frequency of preterm births.[277] Additionally, pregnant women in general are vulnerable to respiratory infection, and maternal COVID-19 infection has been linked to increased risks of complications, further affecting foetal health.[278]
- formation of **secondary pollutants**, where pollutants in indoor air can interact with other pollutants in the air, or with interior surfaces, objects or living things in the indoor space[279]
- **humidity and condensation**, where high relative humidity levels indoors can contribute to condensation and mould, as well as house dust mite allergy,[280] and low relative humidity indoors can cause dry eye problems.[281] Relative humidity also may affect the survival of different types of airborne viruses differently[282]

- **temperature**, which has an impact on the quality of indoor air and can increase the concentration of some pollutants[283]
- **climate zones**,[284] with different types of climate having an impact on indoor air quality, though microclimate variation can be significant within zones
- **climate change**, with potential climate-related drivers of poor indoor air quality including increased bushfire smoke, ozone, volatile organic compounds, and thunderstorm asthma.[285] More flooding is likely to lead to indoor mould proliferation, with adverse effects on indoor air quality and human health.[286] A recent *Nature Climate Change* systemic review estimated climate change is anticipated to aggravate 60 airborne pathogenic diseases.[287] Targeting climate mitigation policies to also achieve air quality outcomes can achieve significant and rapid health benefits[288]
- **socioeconomic status**, noting that while there are many complexities to the relationship, generally the lower a person's socioeconomic status the higher their indoor pollutant exposures.[289] People with lower incomes are more likely to live in poorly insulated housing with limited shade and air conditioning.[290] They may also be exposed to increased sources of air pollution, such as living close to busy roads or industrial emissions[291]
- **human activity** in an indoor space, for example a choir singing loudly, or a group of people riding exercise bikes in a small room, are more likely to create more bioaerosols than one person sleeping in the same space.[292] Activities and hobbies involving indoor air pollutants (for example, from paints and varnishes) also affect exposure.[293] Housekeeping practices, including frequency of dust removal, can also affect indoor air quality. Work practices and occupant behaviour can have an impact on indoor air quality in occupational settings
- **population density** - household crowding can affect indoor air quality and is linked with disease transmission.[294] In 2021, Aboriginal and Torres Strait Islander people were 2.9 times as likely to live in an overcrowded dwelling as non-Indigenous Australians, with the rate across jurisdictions ranging between 1.5 times higher (in New South Wales), to 6.1 times higher (in the Northern Territory)[295]
- **housing quality and type** - the World Health Organization's *WHO Housing and health guidelines* notes that improved housing conditions can save lives, prevent disease, increase quality of life, reduce poverty, and help mitigate climate change.[296] US EPA researchers have found a link between renovating housing and decreased childhood asthma rates.[297]
- **commercial activities** – the World Health Organization recognises that commercial determinants of health – private sector activities that affect people's health, directly or indirectly, positively or negatively – have an impact on air pollution as a risk factor for health.[298]

4.1 Issues specific to particular types of indoor spaces

4.1.1 Residential settings

A 2024 paper found, in general, the most harmful indoor air contaminants in dwellings globally are $PM_{2.5}$, $PM_{10\text{-}2.5}$, nitrogen dioxide, formaldehyde, radon and ozone. Airborne viruses were not examined in the study.[299]

A 2012 Australian study of 40 homes in Melbourne found concentrations of some pollutants, including formaldehyde, and total volatile organic compounds, were between 8 and 12 times higher than outdoor levels. Other pollutants, including $PM_{2.5}$, carbon dioxide, carbon monoxide, benzene and toluene, were between 1.1 to 3 times higher compared to outdoor concentrations. Ozone, nitrogen dioxide and PM_{10} were significantly lower than outdoors.[300] The study did not look at airborne viruses.

4.1.2 Schools and early childhood education

Indoor air quality problems in schools and early childhood education facilities can cause increased absences due to respiratory infections, allergic reactions, and adverse reactions to the chemicals used.[301] Mould, proximity to busy roads, nearby construction activities, bushfire smoke and contaminated playgrounds can have health impacts.[302]

The Australian Health Protection Committee states that three specific principles apply to minimise disease in schools:

- reducing opportunities for introduction of viruses to schools
- reducing transmission of the virus if introduced
- early use of containment measures if spread occurs.[303]

A 2023 Chinese study used wearable devices to track close contact interactions between students in school classrooms. The study found that airborne transmission of COVID-19 over longer distances was generally the dominant form of transmission in the classroom (more than close contact and full or partial face-to-face interactions within 1.5 metres), both during classes and in breaks. Short-range airborne transmission was dominant only during breaks when no (surgical) masks were worn.[304] However, a 2022 paper suggested airborne transmission of the SARS-CoV-2 Delta variant was more likely to occur within conversational distance due to the concentration of inhalable particles near their source.[305] A 2023 Swiss paper also suggested mask mandates were associated with greater reductions in aerosol concentrations than air cleaners.[306]

Various studies have investigated the effectiveness of ventilation and/or air purifiers in educational settings. A 2021 German study found High Efficiency Particulate Air (HEPA) filters reduced aerosol concentration by more than 90% within 30 minutes when running the purifiers in a high school classroom with the windows and door closed.[307] Preliminary results of an ongoing study in Iceland in November 2023 found that air purifiers in daycare centres reduced children's illness by almost a third.[308] An Italian study found that COVID transmission can be reduced by 80% with improved indoor ventilation and air filtration.[309]

In Australia, a recent University of New South Wales study concluded that natural ventilation supplemented with the use of HEPA filter units in schools was the most effective way to reliably improve indoor air quality year-round. The authors highlighted the need for real-time outdoor air pollution sensing to guide decisions about how often, and for how long, windows could safely remain open to provide outdoor air when outdoor air quality was poor.[310]

There is also established literature supporting the impact of indoor air quality and ventilation on student performance and attendance.[311] A recent Victorian study found a low to moderate correlation between ventilation rates and student performance across four terms, particularly for speed and accuracy, with the students measured for total number of items processed, omission and commission errors, and concentration performance. The authors stated that this demonstrated that indoor air quality does impact student concentration performance.[312]

A Queensland study measured indoor air quality in classrooms in Brisbane and explored how to engage classroom occupants with awareness of indoor air quality and how to develop healthier ventilation habits.[313] The research identified significant and prolonged air pollution exceedances in many classrooms. It also identified several human factors that affected classroom ventilation levels. These included disabling window operation to minimise potential student interference, keeping windows closed in naturally ventilated buildings to improve energy efficiency, and difficult to reach exhaust fan switches.[314] School classroom design could help address some of these issues in new schools, rather than having to address them administratively during operation.[315]

4.1.3 Hospitals

Indoor air quality in hospitals can have significant health impacts, as patients may be particularly susceptible to infection, respiratory issues or other health issues linked with indoor air pollution. This may be due to their having pre-existing conditions or compromised immune systems.[316] There is also often high occupant density, including with other people with contagious illnesses. Hospital ventilation systems may sometimes not be operating effectively.[317]

Box 4. Hospital-acquired airborne disease and infection control measures

Between 2020 and April 2023, 5614 people were suspected to have caught COVID-19 while in Victorian public hospitals. Over 10% of these patients were confirmed or suspected to have died as a result of their hospital-acquired infection. This led to calls for greater consistency around infection control measures.[318]

An earlier Victorian report stated that '[h]ealth services identified a need for increased consideration of infection prevention and control in health infrastructure design, increased access to rapid testing, and support for effective and consistent personal protective equipment (PPE) for staff.'[319]

As a comparison of scale to another source of infections in hospitals, in Victoria's public hospitals, there are around 300 or 400 cases annually of health care-associated *Staphylococcus aureus* ('golden staph') bloodstream infections.[320] There are widely used infection control measures for these types of infections.[321] Even though the mortality rate is likely higher for golden staph than COVID-19 hospital-acquired infections (up to 30%,[322] compared with over 10%, respectively), the number of golden staph-related deaths may be lower than for hospital-acquired COVID-19 infections given the generally higher number of COVID-19 infections.

Airborne methicillin-resistant *Staphylococcus aureus* may also be of concern.[323]

4.1.4 Residential aged care homes

Many elderly people spend much of their time indoors, including those with limited mobility or neurological issues. The importance of indoor air quality increases in such circumstances, including for residents with pre-existing conditions or who are immunocompromised.

A 2024 report commissioned for the National Science and Technology Council found a higher infection risk in Australian aged care homes compared with the general population, and a higher cost of managing COVID-19 infection risk in aged care homes.[324] There is significant variability in the impact of COVID-19 outbreaks in different aged care residences. Mitigations introduced by each aged care home are important influences on the number of infections that occur.[325]

The Australian Government has developed and released National Aged Care Design Principles and Guidelines for residential aged care. These Design Principles and Guidelines were introduced in July 2024. They recognise the importance of clinical support and safety features, including infection prevention and control measures and good air quality and ventilation.[326]

The Design Principles and Guidelines have been introduced on a voluntary basis and the level of uptake within the aged care sector will inform recommendations about long-term arrangements and future regulatory considerations.

4.1.5 Disability services

Disability support providers often provide in-home support to people with disability, many of whom are at higher risk of severe outcomes from COVID-19 infection. In a June 2023 paper, researchers from the Australian National University, the Australian Government Department of Health and Aged Care and ACT Health emphasised the importance of planning and strong partnerships in emergency response, and ongoing collaboration between government and industry, to properly target response measures towards a complex sector.[327] *Ventilation and COVID-19: Information for disability providers* provides information on ventilation to lower the risk of disease transmission, including information on methods to optimise air flow to reduce viral load within a room.[328]

4.1.6 Vehicles and public transport

Many people spend significant amounts of time in cars.[329] Vehicle exhaust can enter a car from outside, exposing occupants to air pollutants including carbon monoxide, nitrogen dioxide, particulate matter (including ultrafine particles from exhaust fumes, brake and tyre wear, and road dust) and volatile organic compounds including benzene. Materials within the car can generate pollutants via off-gassing into the indoor air, including volatile organic compounds and semi-volatile organic compounds.[330]

Health effects from air pollution exposure inside vehicles include respiratory and cardiovascular disease, as well as increased risk of cancer.[331] Recent research from the University of Washington found that traffic air pollution levels inside cars can cause a significant rise in blood pressure within an hour of being in traffic and can last up to 24 hours. This spike is reportedly comparable to the effect of a high-sodium diet and can contribute to cardiovascular problems.[332] In the University of Washington study, in-vent and portable HEPA with active carbon filtration in a vehicle reduced the particle count by 86% from outside air coming into the vehicle.[333]

Particulate matter can be an issue in public transport hubs and tunnels.[334] A recent UK study found that pollutant concentration and passenger exposure on trains varied depending on the train type, the location of the exhaust, the track gradient and whether the train was in a tunnel. High levels of all the pollutants measured were found during time spent in stations and tunnels.[335] Children can be exposed to high levels of air pollution from buses, including when they are travelling in them.[336]

4.1.7 Industrial and agricultural settings

Industrial settings often deal with a wide range of potential indoor air pollutants that differ from those in residential, public or office settings. This report looks largely at indoor air quality in non-industrial settings. Workplace exposure standards/limits cover exposure to a wide range of indoor air pollutants in workplace settings.

Some agricultural settings, such as poultry farms and dairies, have risks of zoonotic disease transfer to humans, including through airborne transmission of viruses in indoor settings.

Pesticide spray from agricultural operations can drift into neighbouring homes, affecting human health.

5 Cost effectiveness of better indoor air

Improving IAQ is one of the most profitable activities society can undertake in the building sector. Even small improvements in IAQ will reduce labour costs. Since these are estimated to be 10–100 times greater per square meter of office space than energy and other operational costs of a building, the economic gain can be tremendous.

World Health Organization, Strategic approaches to indoor air policy-making, 1999[337]

Reducing the negative health impacts of indoor air quality has economic benefits as well as health benefits. As well as reducing cost pressures on the health system, better indoor air quality reduces absences due to sickness (from both communicable and non-communicable diseases), and has a direct impact on cognition, affecting educational outcomes and employee performance, and reducing unit labour costs, with a potential impact on inflation. Improving indoor air quality is an investment in human capital that could make a significant contribution to economic productivity.[338]

5.1 Economic costs of poor indoor air quality

The Centre for Safe Air's September 2023 report, *Safer Air, Healthier Communities: Ten reasons for investment in Australia*, states that the economic impacts of air pollution are high and underestimated, and return on investment is high. It stated that air pollution is an important risk factor for non-communicable diseases, which account for two-thirds of the disease burden in Australia. The report looked at both ambient and indoor air pollution, and noted that costs are likely to be underestimated as they typically account for particulate matter to the exclusion of other important air pollutants, and do not include non-health related costs such as labour, productivity, and educational impacts.[339]

The report commissioned for the National Science and Technology Council found significant direct and indirect socioeconomic impacts occur as a result of airborne viral transmission. It found health and wellbeing impacts include increased morbidity and mortality, increased medical care costs for both acute and long-term impacts, and public health costs of outbreak management. It found economic productivity and workforce participation impacts include reduced productivity, absenteeism, presenteeism, declining employee engagement, increased sick leave costs, and greater working errors. The report found educational impacts include learning loss or slower learning gain for primary school students. It found aged care impacts, including a higher infection risk in Australian aged care homes compared with the general population, and a higher cost of managing COVID-19 infection risk in aged care homes.[340]

The NHMRC Centre for Research Excellence in Healthy Housing estimates the health costs (measured in disability-adjusted life years) of respiratory and cardiovascular disease from mouldy or damp housing are about three times the health costs of sugary drinks in Australia.[341] Recent work estimates that approximately one third of Australian homes have some levels of mould. The work estimates that eradication of indoor mould exposure in Australia would see 109,000 health adjusted life years gained over 20 years.[342] People living in vulnerable circumstances may be more prone to encountering indoor dampness, with damp housing more prevalent in low-income communities.[343]

Communicable disease outbreaks, many of which are exacerbated by poor indoor air quality, cause significant direct and indirect socioeconomic impacts. A January 2024 systematic review found the COVID-19 pandemic, and influenza, influenza A (H1N1), Severe Acute Respiratory Syndrome, tuberculosis and norovirus outbreaks caused increased morbidity, mortality, and health costs. The review found indirect social impacts included employment crises and reduced workforce size. Indirect economic impacts included demand shock, supply chain disruptions, increased supply and production cost, service and business disruptions, and financial loss.[344]

Allergies, some of which are triggered by poor indoor air quality, are also estimated to have significant socioeconomic impacts. A 2007 Access Economics study found the financial cost of allergies in Australia was $5.6 billion (2007 AUD) in lost productivity. It found a further cost of $21.6 billion (2007 AUD) in lost wellbeing (disability and premature death).[345]

In relation to international estimates of the costs of poor indoor air quality specifically, a 2017 French study estimated the socioeconomic cost of indoor air pollution in France by six pollutants - benzene, trichlorethylene, radon, carbon monoxide, particulate matter and environmental tobacco smoke – at around 20 billion euros in 2004.[346] A recent estimate of the financial costs of disability-adjusted life years in China attributable to the ten indoor air pollutants studied (which did not include airborne viral transmission) found it was equivalent to around 3.45% of China's gross domestic product.[347] A 2008 US study estimated the total cost of indoor air pollution on health and productivity in California as at least USD60 billion each year (2007 USD). This estimate included an estimated 2% reduction in worker productivity in office and school settings, due to indoor air pollution and poor ventilation.[348]

The health costs of conditions and diseases exacerbated by poor indoor air quality are high. In 2020-21, an estimated $4.0 billion spent in the Australian health system was for respiratory conditions, representing 3.0% of total health expenditure.[349] Not all of this expenditure was due to poor indoor air quality, but it is likely that poor indoor air quality contributed to the spread of respiratory conditions and thus to the expenditure burden. Likewise, respiratory syncytial virus (RSV), which can be transmitted through the air, represents a significant cost burden to Australia's healthcare system.[350] Chronic lower respiratory diseases are a major cause of morbidity and mortality in Australia.[351] A recent Australian modelling study estimated Long COVID from COVID infections in 2022 caused a GDP loss of $9.6 billion due to a reduction in the labour supply and other factors.[352]

In terms of overall mortality, deaths caused by diseases that can be exacerbated by poor indoor air quality are among the leading causes of death in Australia.[353] In 2020-2022, COVID-19 contributed to a decline in life expectancy in Australia.[354]

In Australia, over the period 2019–20 to 2021–22, the estimated health spending on the response to COVID–19 in Australia was $47.9 billion, representing 7.2% of total health spending over that period.[355] In addition to health spending, there was significant spending on other responses to the pandemic, including pandemic leave disaster payments, and employment and unemployment-related payments such as Job Keeper and increases to Job Seeker. The *Sydney Morning Herald* reported in July 2024 that hundreds of programs were put in place by all levels of government to support the economy during the COVID-19 pandemic. It reported an estimated $150 billion to $200 billion in total

government spending, in addition to over $300 billion in Reserve Bank of Australia quantitative easing and very low interest rates.[356] Not all of this expenditure was due to poor indoor air quality, but it is likely that poor indoor air quality contributed to the spread of COVID-19, and thus to the expenditure burden.

In 2021, the global monthly economic harm from COVID-19 was estimated as at least USD1 trillion (approx. AUD1.49 trillion).[357] The precise contribution of poor indoor air quality to these costs is currently unquantified but potentially significant.

A recent Spanish study assessed the health impacts and costs associated with indoor nitrogen dioxide exposure from gas cooking in the European Union and the United Kingdom. It found gas cooking is associated with a significant burden of mortality and asthma, particularly in countries with high gas cooking prevalence. It estimated the economic cost of premature deaths related to gas cooking in the EU and UK combined is 160 billion euros, with Italy having the highest per country cost (54 billion euros). It estimated the costs of paediatric asthma associated with gas cooking at 2.6 billion euros in the EU, and 4 billion euros for the EU and UK combined.[358]

Box 5. Air pollution is an important modifiable risk factor for cardiovascular disease

Air pollution is estimated to be responsible for over three million deaths each year globally due to ischaemic heart disease or stroke.[359]

Numerous studies have confirmed that $PM_{2.5}$ exposure increases the risk of cardiovascular mortality and non-fatal cardiovascular events.[360] It has both short- and long-term health impacts.[361] Any decrease in $PM_{2.5}$ levels can lead to a reduction in cardiovascular events.[362]

$PM_{2.5}$ levels are, therefore, an important modifiable risk factor for cardiovascular disease.

5.2 Air pollution impacts productivity directly

The National Science and Technology Council advises that improved indoor air quality is associated with enhanced worker productivity and reduced sick leave, but the magnitude of the effect is variable and not well defined in terms of scale of impact.[363]

Several research studies have found poor indoor air quality negatively affects productivity at the microeconomic level, although some of these studies are in relation to ambient air, rather than indoor air. While studies have shown high levels of carbon dioxide and particulate matter negatively affect cognition (see Box 2), economic studies have also investigated whether there are direct links between air quality and productivity.

A 2004 review article summarised the size of the effect of poor indoor air quality on most aspects of office work performance as being as high as 6-9%, with the higher value obtained in field validation studies.[364] More recent work for the UK Royal Academy of Engineering found improving ventilation and ensuring good air quality is expected to improve productivity by around 1-4%, though there is uncertainty in these estimates at a wider scale.[365]

A 2023 Columbia University study showed pollution can reduce the productivity of individual workers,

indicating pollution has subtle effects on workers by reducing output while on the job.[366]

A 2016 study of indoor box packers found a 10 ug/m^3 increase in $PM_{2.5}$ concentration reduced the productivity of the packers by 6% of average hourly earnings.[367]

Studies have also looked at the impact of pollution on productivity in less physically and more cognitively demanding roles. A 2019 study of workers at a Shanghai call centre found that a 10-unit increase in an air pollution index was associated with a 0.35% decrease in the number of calls that workers completed.[368] A 2015 US study of 24 'knowledge workers' (managers, architects and designers) varied the air quality conditions of their workspace, from conventional conditions that met minimum standards to optimised conditions. Changes included an increased ventilation rate bringing in more outside air, reducing sources of volatile organic compounds, and controlling for different levels of carbon dioxide. The study found that cognitive function scores were significantly better under the optimised conditions across all domains tested. Reduced volatile organic compound and carbon dioxide levels were independently associated with better cognitive scores.[369]

5.3 Cost savings and return on investment from improvements in indoor air quality

The scientific and economic literature suggests there is potential for significant returns on investment in initiatives that improve indoor air quality.

Although it did not address indoor air quality specifically, a 2019 OECD Working Paper found large economic benefits from reducing air pollution compared with relatively small abatement costs. The authors stated this meant more stringent air quality regulations could be warranted based solely on economic grounds, aside from the large avoided mortality benefits.[370]

5.3.1 Building performance, productivity and workplace absences

US estimates from 1997 indicated the potential financial benefits of improving indoor environments exceeded costs by a factor of 18 to 47.[371] More recently, international evidence shows that the return on investment is high, where a dollar spent on action on air pollution could return between $2 to $90.[372] A 2015 study of the financial implications of modifications to building filtration systems found the benefits of improving filtration outweighed the additional costs by 10 to 1.[373] A 2022 study from the University of Maryland, University of Cambridge and Columbia University, concluded that it was cost-effective to improve filtered air supply to 12 air changes per hour using standalone HEPA units in small businesses in older buildings that lack HVAC systems during the pandemic.[374]

A 2004 review article looked at the effects of indoor air quality on performance and productivity. It found it was usually more energy efficient to eliminate sources of pollution than to increase outdoor air supply rates. It also found that in cost-benefit analyses for either solution, the high cost of labour per unit floor area in buildings means payback time is usually as low as two years.[375]

A paper released in September 2024 by the Facilities Management Association of New Zealand found improving indoor air quality in offices and schools would reduce sickness and improve concentration levels. It estimated that while these improvements would cost up to NZD253 million, they could benefit New Zealand up to NZD1 billion over ten years.[376]

In the UK, a social cost benefit analysis prepared for the Royal Academy of Engineering estimated that infection control measures could save up to GBP23 billion (approx. AUD41 billion) a year if there is another pandemic. The academy called for operational performance of buildings, including ventilation and infection resilience, to be regulated.[377]

If building ventilation was improved, resulting in less COVID-19 transmission indoors, some of the costs of responding to the COVID-19 pandemic may have been reduced.[378]

The National Science and Technology Council-commissioned report found the economic productivity and workforce participation impacts of airborne infectious disease transmission included reduced productivity, absenteeism, presenteeism, impaired employee engagement, work loss and work errors.[379] Reducing the negative health impacts of poor indoor air quality could reduce the amount of illness transmitted in workplaces. In addition, lower levels of CO2 and $PM_{2.5}$ are associated with improved cognition. Combining these benefits could lead to a healthier, more productive workforce.

Estimates of the investment in modern indoor air quality management systems required to address airborne infections suggest it would be likely to be less than a 1% increase in the construction cost of a typical office building.[380]

In relation to existing buildings and ventilation systems, a 2015 study found that doubling the ventilation rate from the American Society of Heating, Refrigerating and Air-Conditioning Engineers standard's minimum rate, cost less than USD40 per person per year in all climate zones investigated. The study also found that using an energy recovery ventilation system significantly reduced energy costs, and in some scenarios led to net savings. The ventilation change improved the performance of workers by 8%, equivalent to a USD6,500 increase in employee productivity each year. Reduced absence and improved health were also observed with enhanced ventilation.[381]

In October 2023, the Johns Hopkins Center for Health Security estimated increasing clean air levels to meet ASHRAE241's Infection Risk Management Mode for 16 weeks annually, during peak respiratory virus transmission, would reduce COVID costs by around USD40 billion. This was about 10 times the cost of the intervention. Additional benefits, including productivity and reduction in infections with other viruses, could add an additional USD20 billion to USD40 billion, though the cost-benefit ratio would likely differ in different buildings.[382]

The National Science and Technology Council advised that the impact of indoor air quality strategies on the energy efficiency of buildings is dependent on factors such as the type of intervention, climate, and the building size, characteristics and hours of operation. It found that while relatively few studies have analysed the energy efficiency impact of interventions in the Australian context, international studies suggest that while interventions impact building efficiency, there is significant variation in the size of the impact as these factors change.[383]

The National Science and Technology Council advised that improved indoor air quality is associated with enhanced worker productivity and reduced sick leave, but the magnitude of effect is variable and not well defined in terms of scale of impact. It advised that, nevertheless, the Australian Government can build on the findings in the commissioned report by focusing action where the best return on investment is found.[384]

US studies in the late 1990s and early 2000s looked at the cost to US businesses of respiratory illnesses and concluded that enhancing indoor air quality could reduce a significant portion of illness and absences in the office workforce due to respiratory illnesses or allergies.[385] A Harvard study of over 3,700 employees of a large US manufacturing company found that sick leave increased for employees in poorly ventilated areas, and that the cost of providing additional ventilation may be more than offset by the savings that result from reduced sick leave.[386]

In Australia, employee absences, including due to sickness (sickness type unspecified), were estimated to cost Australian businesses over $24 billion in 2022.[387] An earlier report suggested employee absences cost the Australian economy an estimated $44 billion a year.[388]

According to the World Green Building Council in 2014, staff costs, including salaries and benefits, typically account for around 90% of a commercial office-based business's operating costs, with a further 9% in rental costs, and 1% in energy costs.[389] Given that staff costs are such a high proportion of a business's operating costs, the productivity of its staff, or anything that impacts their ability to be productive, has potentially significant economic implications for the business.[390] The University of Oxford's Saïd Business School argues that even a small improvement in staff health, productivity or satisfaction is likely to represent a significant financial gain for employers.[391] A 2004 study stated the high cost of labour per unit floor area ensures that payback times for eliminating pollution sources or increasing outdoor supply rates would usually be as low as two years.[392]

A 2023 Australian absence management and wellbeing survey report found an average employee absence rate in 2022 of 6% across the organisations surveyed.[393] In businesses where staff costs are a significant proportion of the business cost base, a reduction in employee absence rates is a potentially significant cost saving. An increase in employee productivity due to better indoor air quality could also be significant.[394]

Box 6. Examples of indoor air quality initiatives in the private sector

A November 2023 article in the Harvard Business Review stated that the movement toward real-time air quality monitoring is growing, and that organisations that are not yet thinking about how to implement real-time 'health' monitoring in their buildings should do so soon. A January 2024 market analysis report predicted that the particulate matter monitoring market would see rapid growth in the next few years, due to several factors including public health initiatives, a focus on indoor air quality, and preparedness for global health crises.[395]

In 2015, US company Aclima announced that it had been working with Google for several years on a global indoor environmental sensor network of 500 sensors across 21 Google offices around the world to process 500,000,000 data points each day on indoor environmental quality, including temperature, humidity, noise, and light, and pollutants such as carbon dioxide and particulate matter. Aclima stated that the information allows Google to evaluate environmental factors in their offices and make future decisions on workplace design to support employee wellbeing, productivity and creativity.[396]

It was reported in 2022 that when Google moved into a new headquarters in Mountain View, California, it was offered air filtration that cut pollutants to extremely low levels. It reportedly instead opted for zero parts per billion, paying more to obtain it.[397]

The company Amazon has reportedly rolled out a real-time air quality monitoring network across its entire global commercial office portfolio.[398] In an October 2023 US 60 Minutes report, Amazon's director of health and safety said Amazon had been updating many of its heating, ventilation and air conditioning systems, including in its warehouses. She said 'COVID shifted everybody's mindset in terms of air quality in terms of communicable or infectious diseases.'[399]

The 60 Minutes segment also reported that a 2022 survey of facility managers in the US and Canada found that since March 2020, roughly two-thirds of respondents had upgraded their MERV (Minimum Efficiency Reporting Value) air filters and increased their air exchange rates.[400]

The Honeywell 2022 Healthy Buildings Survey report, *Workplace Air Quality: A Global Concern Emerges*, found that healthy indoor conditions are increasingly becoming a 'make-or-break' factor in workers' decisions to remain at their jobs. More than six in ten respondents said they would leave their job if their employer did not take measures to create a healthier work environment, though survey results varied by region.[401]

The Honeywell survey also found that more than half of the senior executive respondents were very or extremely worried about their building's indoor air quality.[402]

Recent Australian work for The Safer Air Project on the benefits of improved indoor air quality estimates the benefits of reduced sickness from reducing COVID-19 infections by 60% could range between $24 billion and $50 billion over the 2022-2024 period. It estimates the costs of this reduction of up to approximately $16 billion, through installing and maintaining air filtration units.[403]

A 2022 social cost benefit analysis performed by NERA for the Royal Academy of Engineering found that improving ventilation was expected to reduce long range aerosol transmission by about 50%. The analysis found improving ventilation and ensuring good air quality was also expected to improve productivity by around 1 to 4%.[404]

More detailed economic analysis in the Australian context would be helpful to better understand the comparative costs and consequences of maintaining the status quo versus adopting additional action to improve indoor air quality. In a June 2024 publication, the Australian Institute of Health and Welfare identified data gaps around the health burden attributable to low indoor air quality. It identified the potential for including indoor air quality in its Australian Burden of Disease Study, incorporating a range of exposures and health outcomes, including from types of air pollution and airborne viruses.[405]

It would also be helpful to develop case studies of effective funding of indoor air quality improvement initiatives. This would build confidence, test frameworks and methodologies, and identify opportunities for further investment.

5.3.2 Healthcare settings indoor air quality cost benefits

Reducing respiratory disease transmission indoors could mean fewer hospital admissions, with associated health cost savings.[406] A recent Victorian study found admission screening and staff wearing N95 masks was cost-effective in reducing COVID-19 hospital-acquired infections, with reduced patient bed days and staff replacement needs.[407]

5.3.3 School indoor air quality cost benefits

It may be that some of the mitigations needed to address poor indoor air quality are very cost effective. For example, the UK Government funded nearly 400,000 carbon dioxide monitors for state schools from September 2021. A UK Government survey in December 2022 of monitor recipients found recipients were able to use the monitors to identify when ventilation in a room needed to increase in 95% of the survey respondents' settings. Of the respondents, while 12% of settings using the monitors reported sustained high carbon dioxide readings of at least 1,500 ppm, the majority of these settings were able to remedy this through quick fixes such as opening windows. Only 3% of settings using the monitors reported sustained high carbon dioxide readings of at least 1,500 ppm that could not be remedied through quick fixes or remedial building works.[408] Outside temperature and air quality would need to be considered in relation to such quick fix mitigations, as well as energy use in maintaining comfortable indoor temperatures.

Offsetting the costs of monitors and mitigations for schools are the potential benefits, including less illness among students and teachers, fewer absences (and absences from working parents caring for their sick children), as well as improved educational performance from increased attendance and better cognition. The December 2023 Australian report, *Improving Outcomes for All: The Report of the Independent Expert Panel's Review to Inform a Better and Fairer Education System*, states any absence from school can be a loss of educational opportunity. It cites a finding from The Smith Family that students with higher attendance were more likely to do better in English and maths.[409]

An Australian estimate in October 2024 suggested the annual costs of not air conditioning Australian schools exceed $1 billion and may exceed $2 billion. This is set against an estimated $2 billion cost per year over five years to provide air conditioning for every Australian school.[410]

A 2023 Johns Hopkins Center for Health Security cost-benefit analysis found an over tenfold return on investment in a range of indoor air quality initiatives in schools in terms of increased learning, and reduced asthma and absences.[411]

5.3.4 Particulate matter cost benefits

There are also likely to be economic benefits from reducing the negative health impacts from other indoor air pollution sources. For example, the health costs attributable to wood heater emissions are estimated at more than $4,000 per wood heater per year, applicable across several Australian states.[412] One-off subsidies to encourage the replacement of wood heaters with less polluting heating sources, and subsidies for solar panels and batteries or ongoing energy costs for low-income households, may cost less than that annualised health cost.

The Centre for Safe Air estimated that replacing 50% of Australia's existing stock of wood heaters with non-combustion heating such as electricity would have large benefits for health and the environment. The centre estimated that the replacement could reduce Australia's annual average $PM_{2.5}$ pollution burden by $1.61 to $1.93 billion per year through reduced mortality, saving 303 to 364 lives a year.[413]

A July 2024 Deloitte Access Economics report for the Australian Council of Social Service found a $10 to $17 billion opportunity (net present value) for Australia's economy from delivering thermal efficiency and electrification upgrades to 1.2 million low-income households.[414]

A January 2024 report on the health risks of indoor exposure to fine particulate matter published by the US National Academies of Science, Engineering and Medicine recommended studies evaluate the full impact of policies on indoor $PM_{2.5}$ exposure and health, including cost–benefit analyses estimating the economic and public health costs of *not* implementing interventions. The committee stated that governments must balance competing priorities when determining policy, and understanding the costs associated with inaction would allow for better informed decisions on the need for action to reduce indoor $PM_{2.5}$ exposure.[415]

A United States study looked at the mortality-related benefits and costs of improvements in particle filtration in United States homes and commercial buildings. It found that the largest reductions in mortality were from interventions with continuously operating portable air cleaners with HEPA filters. For some interventions, predicted annual mortality-related economic benefits exceed $1,000 per person. The study found that the economic benefits always exceeded the costs with benefit-to-cost ratios ranging from approximately 3.9 to 133.[416]

As discussed in the National Health and Climate Strategy, studies from the United States have quantified the air quality co-benefits of replacing fossil-fuel-generated electricity with renewable energy. The studies found the air quality co-benefits due to improved health outcomes exceeded the cost of such deployment.[417]

5.3.5 Industry-specific opportunities

AIRAH, the industry association for the Australian heating, ventilation, air conditioning and refrigeration industry, states that the industry is worth over $38 billion, uses more than 24% of the country's electricity, and accounts for around 11.5% of Australia's carbon dioxide emissions.[418] Interventions to improve indoor air quality present opportunities for industry growth, including in advanced manufacturing. Retrofitting activities to improve indoor air quality would be likely to boost employment opportunities.

Insurance companies are likely to take account of the health impacts of indoor air pollution, including the long-term health impacts from infection from airborne diseases.[419] Air pollution has been recognised as an emerging risk factor for the insurance sector, and may become an important part of

pricing strategies. It may also lead to insurance companies seeking to encourage behavioural change from customers.[420]

The *Superannuation Industry (Supervision) Act 1993* (Cth) requires superannuation funds to perform their duties and exercise their powers in the best financial interests of their members.[421] Some superannuation funds are increasingly interested in the environmental, social and governance settings of companies in which they are considering investing, and are recognising the need to balance short-term investments with sustainable long-term returns.[422] Funds are also interested in the potential legal exposures of investment targets. A growing awareness of the importance of indoor air quality in public buildings, and legal liability for property owners and managers who do not provide healthy indoor air environments, may influence investment decisions of superannuation funds investing in commercial real estate portfolios.

6 Existing air quality policy and regulation in Australia

6.1 Outdoor air quality

Policies and regulations in Australia for outdoor air pollution include a National Clean Air Agreement, as well as the National Environment Protection (Ambient Air Quality) Measure. The Australian Government Department of Climate Change, Energy, Environment and Water (DCCEEW) leads this work at the national level.

The National Clean Air Agreement provides a mechanism for Commonwealth, state and territory governments to identify, prioritise and develop solutions for air quality issues. Work plans under the agreement outline projects that respond to air quality priorities.[423]

The key legislation at the national level is the *National Environment Protection Council Act 1994* (Cth) with mirror legislation in state and territory jurisdictions.[424] The National Environment Protection Council makes, assesses and reports on the implementation and effectiveness of national environment protection measures. These measures are incorporated, sometimes with stricter requirements, in state and territory regulations.

The National Environment Protection (Ambient Air Quality) Measure sets out regulatory standards for outdoor concentrations of six key outdoor air pollutants, as well as the time periods over which these concentrations are averaged. The standards are set using a weight-of-evidence approach that considers health protection and alignment with the prevailing health evidence, the ability of jurisdictions to achieve the standards, and the availability and efficiency of abatement measures to lower concentrations. Environment Ministers have recognised for many of the pollutants there are no identified threshold below which adverse health effects are not observed. They stated this means there will be health benefits in continuing to pursue concentrations below the standards.[425]

There is also a National Environment Protection (Air Toxics) Measure, for benzene, formaldehyde, polycyclic aromatic hydrocarbons, toluene and xylene.[426]

Additionally, some specific air pollution sources have separate regulatory regimes at the Commonwealth level. These include road vehicle emission standards and fuel quality standards. Other air pollution sources are regulated at both national and state/territory level. Wood heater appliances, for example, have Australian Standards for emissions, efficiency and installation, which are then incorporated into regulations at state and territory level.

In some jurisdictions local government plays a regulatory role in relation to local air quality issues, for example, in responding to complaints about outdoor odour.

6.2 Indoor air quality

In contrast to outdoor air pollution, there is no national environment protection measure for indoor air. There is no specific national framework for the ongoing assessment, monitoring, control or management of indoor air quality, outside occupational settings.[427] Instead, there are some regulations for particular pollutants, some for particular indoor settings and some for reducing exposure.[428]

The National Construction Code is Australia's national set of building design and construction provisions. It sets minimum required levels for building safety, health, amenity, accessibility and sustainability.[429] The code is produced and maintained by the Australian Building Codes Board for the Australian Government and state and territory governments.[430]

The code contains Performance Requirements, which are the minimum standards that buildings, building elements, and plumbing and draining systems must meet. Building, plumbing and drainage solutions comply with the code if they satisfy these mandatory Performance Requirements. Performance Requirements can be met by using either a Performance Solution (Alternative Solution) or a Deemed-to-Satisfy Solution.[431]

The code also contains assessment methods, any combination of which can be used to determine whether a building or plumbing and drainage solution complies with the Performance Requirements. One assessment method is verification methods. These are tests, inspections, calculations or other methods that determine whether a proposed building or plumbing and drainage solution complies with the relevant performance requirements.[432]

For ventilation and indoor air quality in particular, the code has specific performance requirements, verification methods and deemed-to-satisfy provisions. The performance requirements are mandatory. Verification methods and deemed-to-satisfy provisions are not mandatory but can be used as the compliance pathway for a specific building solution.[433]

The indoor air quality verification methods in the code set out maximum indoor exposure levels for the following air pollutants, as well as the time periods over which the concentrations are averaged: carbon dioxide; carbon monoxide; nitrogen dioxide; ozone; total volatile organic compounds; formaldehyde; and particulate matter (PM_{10} and $PM_{2.5}$) (see **Appendix B** for details).[434] The current version of the verification methods excludes biological contaminants, industrial contaminants, and contaminants associated with environmental tobacco smoke.[435]

In terms of current requirements for pollutant concentration levels, there is also guidance for workplace exposures. Safe Work Australia publishes *Workplace exposure standards for airborne contaminants*. This contains a list of standards for various airborne contaminants and guidance to meet Work Health and Safety Act and Regulations duties (see **Appendix B** for details).[436] A new *Workplace exposure limits – airborne contaminants* will be introduced from December 2026, to replace the workplace exposure standards.[437] These standards/limits are specific for 'workplace' exposures to air contaminants, though persons conducting a business or undertaking have duties to protect visitors to workplaces, as well as to protect employees.

The workplace exposure standards apply to any workplace and wherever work is undertaken. They are not specific to indoor settings. The exposure is measured in the breathing zone of the worker.[438] Exposed employees are assumed to be adult, healthy and working for eight hours a day for a five-day week, without taking into account more vulnerable populations, such as the very young or elderly.[439]

The current ventilation standards for new buildings and major refurbishments in Australia are *AS 1668.2:2024 The use of ventilation and airconditioning in buildings, Part 2: Mechanical ventilation in buildings* and *AS 1668.4:2024 The use of ventilation and airconditioning in buildings, Part 4: Natural ventilation of buildings*.[440] AS 1668.2, relevant to mechanically ventilated buildings, sets a 10 litre per second per person minimum effective outdoor airflow rate (ventilation) requirement for most types of occupancies. AS 1668.2 is referenced in the National Construction Code, and is mandatory when following a Deemed-to-Satisfy compliance pathway for new buildings and refurbishment of existing buildings. For natural ventilation, the National Construction Code requires direct ventilation openings such as operable external windows and doors to be present in a building, with an area of not less than 5% of the floor area of the room required to be ventilated, with further provision for borrowed ventilation requirements.[441]

There is no general ongoing ventilation compliance requirement for buildings after construction, outside of specific settings such as occupational settings.[442] However, there are air handling system maintenance requirements across both new and existing buildings for specific pollutants, including microbial control,[443] and for fire protection systems and equipment.[444]

Other standards, codes and guidelines in Australia relevant to indoor air include standards for gas appliances and wood heaters, UV lamps, various building materials, and the management of particular pollutants. These are generally nationally agreed standards, sometimes incorporated into state and territory regulations.[445]

There are also regulatory and policy settings focused on particular airborne pollutants including mould and condensation, some chemicals and fragrances, cosmetic ingredients, radon, asbestos, tobacco smoke, and infectious aerosols (e.g., tuberculosis).[446]

States and territories regulate a number of aspects of indoor air quality. They have general public health and environment protection frameworks and publish a range of guidance. States and territories also have building regulations that give legal effect to the National Construction Code.[447]

Some local governments have also adopted indoor air quality-related measures in their planning regulations. For example, Waverley Council in Sydney, NSW, sets out a number of measures in its development control plan. The measures are aimed at promoting human health by reducing polluting fuels and increasing ventilation.[448]

6.2.1 Healthcare settings

The Australasian Health Facility Guidelines are an initiative of the Australasian Health Infrastructure Alliance, with representatives from all jurisdictions in Australia and New Zealand. They aim to enable public health facilities to be planned and designed effectively. They include guidance on infection prevention and control, including air handling.[449]

Standards include the National Safety and Quality Health Service Standards. These require Australian health service organisations to have systems in place to prevent, manage and control infections and reduce harm for patients, consumers and the workforce, as well as to achieve good health outcomes for patients.[450] Organisations are also required to use evidence-based systems to reduce infection risk using the hierarchy of controls and infection prevention and control systems. The hierarchy of controls ranks hazard controls from most to least reliable. If it is not reasonably practicable to eliminate a risk, the risk must be minimised as far as is reasonably practicable. This is done using one or more substitution, isolation or engineering controls, followed by administrative controls and the use of personal protective equipment (PPE).[451] Standard 3.08(e) requires consideration of environmental controls, including ventilation.

The Australian Commission on Safety and Quality in Health Care is the national agency for health safety and quality in Australia. It sets standards, resources and guidance for health services and patients, including guidance on infection prevention and control.

The National Construction Code also applies to health-care buildings (hospitals) and other health care facilities.

6.2.2 Residential aged care

The Aged Care Quality and Safety Commission regulates Australian aged care services. Indoor air quality policy issues of specific relevance to residential aged care include the development and introduction of the National Aged Care Design Principles and Guidelines, which include a guideline focused on clean air. Guideline 1.9 recognises that a range of factors contribute to poor air quality in aged care homes, and that these can affect health, usability and accessibility.[452] The Design Principles and Guidelines recommend a range of measures to improve air quality.

6.2.3 Workplaces

Most public places in Australia are also workplaces, and covered by work health and safety legislation.

Work health and safety legislation applies to the health and safety risks that arise from indoor air quality.

Under the model Work Health and Safety (WHS) laws, a person conducting a business or undertaking must ensure, so far as reasonably practicable, the health and safety of workers (including volunteers). They must also ensure, so far as is reasonably practicable, that the health and safety of other persons (e.g., visitors, customers) is not put at risk from work carried out as part of the conduct of the business or undertaking.

To ensure health and safety so far as reasonably practicable, a person conducting a business or undertaking must eliminate health and safety risks at work, or if that is not reasonably practicable, minimise these risks so far as is reasonably practicable. This includes the risks that arise from poor air quality.

The model WHS laws have been adopted by all jurisdictions, except Victoria which has retained its *Occupational Health and Safety Act* 2004. WHS laws are regulated by the WHS regulator in each jurisdiction.

Safe Work Australia develops national policy relating to work health and safety and workers' compensation, including developing and evaluating the model WHS legislative framework. This includes the workplace exposure standards for airborne contaminants and how to meet duties under the Work Health and Safety Act and Regulations.[453] A person conducting a business or undertaking is required to ensure that no person in the workplace is exposed to an airborne contaminant at a concentration exceeding the standards.[454]

Air monitoring must be carried out if the person conducting the business or undertaking is not certain on reasonable grounds if the standard has been exceeded or to determine if there is a risk to health. Workers' exposure is measured by air monitoring in their breathing zone.[455] Protection provided by respiratory protective equipment (like masks) worn by a worker can generally be taken into account when measuring exposure levels.[456]

Safe Work Australia states the standards are generally set at the lowest airborne concentration unlikely to cause an adverse effect. However, some people may still experience adverse health effects from exposure at levels below the standards, so exposure to airborne contaminants should be kept as low as reasonably practicable to protect people (including visitors) in the workplace.[457]

Safe Work Australia publishes guidance on the interpretation of the workplace exposure standards for airborne contaminants.[458]

Under the model WHS Regulations, a person conducting a business or undertaking has a duty to ensure that workplace ventilation allows workers to carry out work without risk to health and safety.[459] Safe Work Australia provides guidance on improving ventilation in indoor workplaces.[460] States and territories also provide various work health and safety related guidance. For example, Western Australia's *WorkSafe: the way forward 2023-24 to 2025-26* strategic plan includes repeat hazard exposure and dust-related respiratory hazards as priorities.[461] SafeWork NSW provides guidance on managing respiratory conditions in the workplace.[462] WorkSafe Victoria has published guidance on the use of respiratory protective equipment to reduce the risk of exposing healthcare and social care workers to COVID-19.[463]

Inclusion and access issues are also relevant, reflecting that some people are more vulnerable than others to some indoor air quality issues.[464]

6.2.4 Fiscal measures

Some policy responses relate to fiscal assistance, such as grant programs and direct investment in carbon dioxide monitoring, as well as improved ventilation for schools and other indoor settings. Examples of such programs include:

- free carbon dioxide monitors for schools (ACT)[465]
- a schools upgrade fund (Commonwealth)[466]
- an audit of windows, fans and ventilation systems in public schools (NSW)[467]
- an audit of air-conditioning units at government schools (NT)[468]
- the provision of portable air purifiers to schools without central air-conditioning systems (NT)[469]
- a school ventilation program (SA)[470]
- free air purifiers in all public schools and an audit of school windows (TAS)[471]
- a small business ventilation grant program (VIC)[472]
- an air purification and shade sails for schools program (VIC)[473]
- an audit of ventilation of all classrooms in public schools, and air purifiers and carbon dioxide monitors (WA).[474]

In addition, the Australian Government is providing funding for the Australian Research Council Training Centre for Advanced Building Systems Against Airborne Infection Transmission (THRIVE). This includes $5 million through the Australian Research Council Industrial Transformation Training Centres Scheme. The aim of the centre is to design and engineer building systems whose elements work together to reduce airborne infection transmission by improving indoor air quality while maintaining comfort and efficiency.[475]

The International Laboratory for Air Quality and Health conducts research, postgraduate training and consulting on air quality and human health, focused particularly on ultrafine and nanoparticles. It is the World Health Organization Collaborating Centre for Air Quality and Health.[476] Academics from

different disciplines and faculties of Queensland University of Technology (QUT) are involved.[477]

The Australian Government is also providing funding for the Centre for Safe Air, a National Health and Medical Research Council Centre of Research Excellence. The centre aims to bring together researchers from around Australia with a focus on air quality and health. Its vision is for a healthier community through cleaner air, underpinned by evidence-informed policy and practice.[478]

The Australian Government is also providing funding for the Healthy Environments And Lives (HEAL) National Research Network. The network aims to translate knowledge into action addressing environmental and climate change and its impacts on health across every Australian state and territory.[479]

On 31 July 2024, the Victorian Government announced the Pathway to Clean Indoor Air in Victoria project. The $9.87 million project aims to generate evidence, develop policy and funding options, and inform the statewide roll-out of indoor air quality initiatives. The two-year project is a collaboration between the Victorian Government, the Burnet Institute and other research partners.[480]

On 31 July 2024, the New South Wales Government announced it was providing funding for a Fresh AIR Innovators program as part of the $800,000 Natural Hazards STEM Support Program. The Fresh AIR Innovators program enhances STEM education for upper primary students in NSW, focusing on bushfire management and indoor air quality.[481]

The Queensland Government, through the Office of the Queensland Chief Scientist, has provided funding support for the Study Fresh program. The program engages school children with indoor air quality by running workshops where students learn about, build and use indoor air quality sensors to monitor and improve air quality in their classrooms.[482]

The Victorian Government also provided grant funding for a 2018-2020 project investigating indoor air quality for vulnerable populations. The study documented indoor air quality in school classrooms and in residential aged care home common rooms, including the impact of design, operation and geographic location. It analysed the effect of indoor air quality on students' learning performance.[483]

Homes Victoria is implementing energy efficiency upgrades to social housing in Victoria. These include replacing older gas heaters with reverse-cycle air conditioning.[484]

6.2.5 Voluntary industry rating schemes and standards

There are a number of voluntary industry rating schemes and standards that assess indoor air quality. In Australia, these include Green Star and National Australian Built Environment Rating System (NABERS).[485] NABERS is a national government program that measures the environmental performance of Australian buildings and tenancies, including indoor environment quality.[486] Nationwide House Energy Rating Scheme (NatHERS), also a government program, provides energy ratings for new dwellings. In October 2022, NatHERS announced that new options, aiming to improve air quality, were being considered for possible introduction.[487]

Other rating schemes and standards include:

- Green Star, which includes a Green Star – Interiors certification, with an indoor environment category that includes credits addressing air quality and thermal comfort[488]
- WELL Building Standard™ version 2, which includes the WELL Air concept that aims to achieve high levels of indoor air quality across a building's lifetime, including by eliminating or reducing pollutants at source, building design and operation strategies, and human behaviour[489]

- Fitwel, which includes an Indoor Air Quality Policy and an Indoor Air Quality Assessment Protocol[490]
- Indoor Air Hygiene Institute's Inside Advantage™ Certification Program, which enables indoor facilities to continually manage their indoor air hygiene[491]
- TAIL (performance rating of the thermal (T) environment, acoustic (A) environment, indoor air (I), and luminous (L) environment), developed to rate indoor environment quality in offices and hotels undergoing major energy renovation during their normal use[492]
- IEQ-Compass, which evaluates indoor air quality, and thermal, visual and acoustic indoor environmental quality, without considering user influence[493]
- Deutsche Gesellschaft fur Nachhaltiges Bauen, a certification system assessing environmental, economic and sociocultural and functional quality of buildings over their lifecycle[494]
- Global Real Estate Sustainability Benchmark, measuring the environmental, social and governance performance of buildings, including parameters associated with indoor environmental quality[495]
- Building Research Establishment Environmental Assessment Method, which is used to specify and measure the sustainability performance of buildings across their lifecycle[496]
- Leadership in Energy and Environmental Design, a certification system with a range of prerequisites and credits, including in relation to indoor environmental quality[497]
- Living Building Challenge, which includes a certification program for sustainability in the built environment, including in relation to indoor air quality and a healthy indoor environment.[498]

AIRAH, the industry association for professionals and practitioners in the heating, ventilation, air conditioning, and refrigeration and building services industries, publishes *DA26 Indoor Air Quality*, looking at measures to remediate indoor air quality issues generally without major redesign or system modification.[499]

7 International initiatives

Many countries are focusing on efforts to improve indoor air quality, recognising the health and economic benefits available from such improvement.

International initiatives in place or under development include carbon dioxide monitoring and the display of monitored carbon dioxide concentrations in public indoor spaces, product labelling for their pollutant emissions, indoor air quality standards, use of masks, public guidance, and ventilation minimum standards.

Initiatives have been adopted or are under development in many jurisdictions and by some multilateral bodies, including from Belgium, Canada, China, Denmark, Europe, France, Germany, India, Japan, the Netherlands, New Zealand, South Korea, Taiwan, the UK, the USA, and the World Health Organization.

There are a number of indoor air quality standards or guidelines developed internationally, with different pollutants that could be considered for adoption in Australia to improve the health impacts of indoor air quality.[500] The World Health Organization has published the *Roadmap to improve and ensure good indoor ventilation in the context of COVID-19*.[501] The World Health Organization also released new Air Quality Guidelines in September 2021 that could be used to set national indoor air quality standards to protect human health.[502] The European Parliament is reportedly considering aligning requirements for several pollutants with the new World Health Organization guidelines.[503] While these guidelines are based on health impacts, they do not as yet include airborne viruses.

Other standards that could inform Australia's approach include Japan's standards for air environment and the healthy management of buildings (see Box 9).[504] The US CDC recommended in May 2023 to, when possible, aim for ventilation rates of five or more air changes per hour of clean air in occupied spaces, and recommended air filtration at a Minimum Efficiency Reporting Value 13 or better.[505] The American Society of Heating, Refrigerating and Air-Conditioning Engineers new *Standard 241 Control of Infectious Aerosols* aims to reduce the risk of infectious disease transmission in new and existing buildings.[506] It applies to periods of elevated risk, such as the emergence of a new pathogen or a period of high risk with existing pathogens. It establishes minimum 'equivalent clean air delivery' requirements for different indoor spaces, and allows it to be achieved by ways other than ventilation.[507] It focuses primarily on addressing the risk of long-range transmission of infectious aerosols rather than near field transmission.[508] There is also guidance available from the Federation of European Heating, Ventilation and Air Conditioning Associations, the Canadian Centre for Occupational Health and Safety, and the Lancet COVID-19 Commission Task Force on Safe Work, Safe School, and Safe Travel.[509] New Zealand has published ventilation guidance for the general public.[510]

8 Possible policy options

The current indoor air quality policy and regulatory landscape in Australia is discussed in Section 6. Areas of focus for policy options to address gaps in this landscape include:

- reducing pollutants at their source
- reducing pollutant concentrations in indoor air
- protecting people – including vulnerable people – at points of pollutant exposure
- issues relevant to specific settings
- education and awareness raising.

Box 7. Some related reports and studies

In a 2022 article in *The Medical Journal of Australia*, Distinguished Professor Lidia Morawska and co-authors made a range of indoor air quality-related recommendations including establishing indoor air quality standards, and strengthening building design and engineering standards, including a greater focus on airborne infection control.[511]

In August 2024, the National Science and Technology Council advised government that a broad base of experimental literature supports the use of various indoor air quality interventions to address airborne viral disease transmission in public spaces. It found a limited number of studies linking indoor air quality interventions with health outcomes, such as reduced infection transmission risk, morbidity and mortality, though it noted that stronger evidence may emerge over the next 12 to 18 months as current studies conclude.[512]

Several stakeholders have released reports on indoor air quality policy options. These include The Burnet Institute, the Australian Academy of Science and the University of Melbourne, which jointly released *Clean Indoor Air: 2024 Collaboration and Global Action*, and The Safer Air Project advocacy organisation, which released its report, *Safer shared air – a critical accessibility and inclusion issue*, on 20 November 2024.[513]

This report proposes the following focus areas, discussed in detail later in this section:

Focus area 1. Explore health-based national indoor air quality performance goals

The Australian Centre for Disease Control should lead work to review existing Australian indoor air quality guidance, with a view to informing development of health-based national indoor air quality
performance goals, including maximum concentration levels for specified pollutants, and equivalent clean air delivery or ventilation rates or proxy measurements, taking into account airborne virus infection control.

A starting point for development could be the following pollutants and levels, drawn largely from a 2024 *Science* paper by Morawska et al[514]:

- $PM_{2.5}$ – 15 micrograms of fine particulate matter per metre cubed of air (µg/m^3) (averaged over an hour), 7 µg/m^3 (averaged over a year)
- carbon monoxide – 25 parts per million (ppm) (averaged over an hour), 9 ppm (averaged over 8 hours), and 3 ppm (averaged over 24 hours, with 3 to 4 exceedances allowed each year)
- carbon dioxide – 800 ppm (absolute value)
- clean air supply rate – at least 14 litres of clean air supplied per second per person.

Focus area 2. Develop specific policy options for sensitive use settings, including schools, early childhood education, and aged care, that are aligned with the performance goals

The work should consider establishing model indoor air quality guidance for schools, early childhood education centres, residential aged care and other sensitive use settings to promote greater alignment in guidance across jurisdictions, building on existing guidance materials.

The work should also consider options for monitoring, display, and certification or ratings schemes against indoor air quality performance goals initially for sensitive use settings.

Focus area 3. Provide public guidance materials on ways to improve indoor air quality

See the public guidance materials developed during the preparation of this report and outlined in **Appendix C** on the health impacts of poor indoor air quality and how to improve indoor air quality.

8.1 Indoor air quality policy co-ordination and governance

> *'Regulatory actions related to indoor air quality are limited, especially in comparison to regulation of outdoor air quality and industrial workplace air—a feature also common overseas. While some guidance has been provided by authorities …, there is a need for a more structured approach for evaluation and control of indoor air quality. A severe limitation is the absence of a single government authority with responsibility for indoor air quality.'*
>
> *National State of the Environment Report - Indoor Air Quality (1997)*[515]

In 1999, the World Health Organization European Centre for Environment and Health recommended that countries establish an interministerial indoor air quality task force, and develop and implement a national indoor air quality strategy.[516]

Various countries have established cross-departmental indoor air quality groups. The UK established the Cross Government Working Level Group on Indoor Air Quality in September 2021, aiming to ensure a coordinated approach across government departments and other government bodies on indoor air quality.[517] The USA has a Federal Interagency Committee on Indoor Air Quality, established by the US Congress in 1983.[518] The USA also has an Office of Radiation and Indoor Air, within the Office of Air and Radiation.[519] Hong Kong has an inter-department Indoor Air Quality Management Group, with representatives from five government bureaux and fourteen departments, to coordinate control of indoor air quality in Hong Kong.[520] Belgium has created an Indoor Air Quality Platform, a consultation space for all stakeholders directly involved in improving indoor air quality in publicly accessible enclosed spaces.[521] The UK has an Air Quality Expert Group.[522] The New Zealand Ministry of Education formed a Ventilation Technical Advisory Group.[523]

In 2001, a parliamentary committee recommended an inter-agency standing committee be established to commence action on indoor air quality in NSW, recognising indoor air quality is a complex issue requiring action across a number of portfolios and jurisdictions.[524] At a state level in Australia, the Victorian Government formed a Ventilation Technical Advisory Panel.[525]

In a 2022 paper in *The Medical Journal of* Australia, Distinguished Professor Lidia Morawska, Professor Guy Marks and Professor Jason Monty recommended the establishment of a consistent national regulatory infrastructure for clean indoor air for Australians.[526]

The current regulatory infrastructure for ambient air national environment protection measures is set out under the National Environment Protection Council Act 1994 (Cth).[527] Additionally, the existing National Clean Air Agreement has an Air Project Management Group from Commonwealth, state and territory governments supporting the National Clean Air Agreement work plan process, with secretariat support from the Department of Climate Change, Energy, the Environment and Water. The National Air Technical Advisory Group (NATAG) supports the Air Project Management Group, as well as providing technical advice to the Meeting of Environment Ministers and the Senior Officials Group that supports that meeting.

The National Science and Technology Council has advised that work done at the state and territory level, including evidence-based advice on ventilation strategies, could be drawn on, where suitable, for application nationally.[528]

Box 8. Pace of public health structural change

Some significant public health policy changes have taken decades to implement fully, despite increased mortality, morbidity and economic costs in the interim.

An understanding of the need for good hand hygiene stemmed from the work of Dr Ignaz Semmelweis in 1847, but it took many decades for good hand hygiene to be accepted widely in hospitals and beyond.[529]

Water hygiene and sewage treatment also took many decades to implement in both the UK and Australia. In London in the early 1800s, cholera was rife over decades. Despite Dr John Snow developing the theory that cholera was waterborne, it was not until 1865 that a new sewerage system for London was opened.[530] It took many decades more for water filtration and chlorination to be used widely.[531]

In Australia, Melbourne was nicknamed 'Smellbourne' in the 1800s, with diseases like typhoid widespread, until a Royal Commission in the late 1880s led to the establishment of the Melbourne and Metropolitan Board of Works and a sewerage system.[532]

Australia has the opportunity to learn from this history and work to implement effective indoor air quality interventions quicker. We have the impetus of COVID-19, recent bushfires and climate change, as well as an increased knowledge of the health and economic benefits of action and the costs of inaction.

8.2 Reducing negative health impacts of pollutants at their source

8.2.1 Reducing emissions of outdoor air pollutants at their source

DCCEEW coordinates most of the regulation of outdoor air pollution at the national level, with state and territory environmental protection bodies leading the work at state and territory level. This work includes developing and implementing policy settings to reduce emissions of vehicle, industry and wood heater pollution. Much of the work is done in projects that are part of work plans under the National Clean Air Agreement.

8.2.2 Reducing emissions of indoor air pollutants at their source[533]

8.2.2.1 Low emission building and interior products, and product and installation standards

Pollutants are often emitted from building materials, finishes and furnishings.[534] Installing low-emission materials would reduce such emissions and indoor air pollutant levels irrespective of building ventilation. The Australian Building Codes Board's *Indoor Air Quality Verification Methods Handbook* provides advice on information about selecting low-emission materials. However, the handbook notes that it is difficult to identify low-emission materials when there is inadequate information available on the air contaminants that may be emitted by a product, though more data sources are becoming available.[535]

Care also needs to be taken that unintended consequences do not emerge from products intended to improve air quality. As an example, the Royal Society of Chemistry notes that photocatalytic paints, intended to reduce air pollution, released other pollutants as a by-product of the reaction.[536]

8.2.2.2 Product phase outs or bans

Product phase outs or bans are a way of responding to a product's health impacts. In December 2023, the Australian, state and territory governments made the decision to ban the use of engineered stone in response to the rise of silicosis. The Australian Government also introduced a ban on the importation of engineered benchtops, slabs and panels from 1 January 2025. Various state governments have also announced phase outs in relation to residential gas and/or wood heaters or other heating products.[537]

8.2.2.3 Reducing indoor air pollution from energy sources (e.g. gas and wood heating and cooking)

Wood heaters are the predominant source of human-linked $PM_{2.5}$ emissions in many cities and towns in Australia.[538] The ACT Government has endorsed a position to phase out wood heaters in the ACT by 2045.[539] There are a number of potential policy options that could be considered at the national and/or state and territory level to reduce the health impacts of wood heater emissions.[540]

Under project 2.3 of the National Clean Air Agreement 2021-2023 work plan ('share information to reduce pollution from wood heaters'), jurisdictions collaborate on the management of wood heaters, education and community outreach, and measures to encourage compliance with wood heater standards.[541]

Gas cooking and heating is a source of indoor air pollution.[542] In Victoria, gas connections have been banned in all new homes and government buildings since 1 January 2024, whilst South Australia is diluting natural gas with hydrogen.[543] The ACT will transition away from fossil fuel gas to renewable electricity by 2045.[544] In addition, Victoria and Western Australia have banned some types of open-flued gas heaters.[545]

As buildings are increasingly designed with greater attention to draught-proofing (air tightness), the fumes from any combustion process can cause more harm if not actively managed. As Victorian Coroner Jacqui Hawkins noted in a 2018 inquest, '[n]ew and renovated housing, commonly characterised by a reduction in ventilation, together with the use of internal exhaust fans, can be a deadly combination when an [open-flued gas] heater is installed and operating.' She stated open-flued gas heaters pose an 'important public health and safety issue'.[546]

The national Climate Change Authority recommended that the Australian Government work with states and territories on a coordination plan to phase out new and existing gas connections. The Minister for Climate Change and Energy noted that there is considerable variability in household reliance on gas between states, with Tasmania at around 5% and Victoria at over 70%. The Australian Government is providing funding for household and social housing electrification.[547]

Indoor air pollution generated from frying, grilling, baking and toasting food can also have negative health effects.[548] Using a rangehood can assist to reduce pollutant levels in some cases, and microwave cooking has been found to produce much lower levels of particle pollution than conventional stoves.[549]

The National Construction Code does not require rangehoods to be installed in home kitchens, but any rangehoods that are installed in new homes must be vented to outdoor air.[550]

8.2.2.4 Face masks (respirators)

Mask wearing to reduce exposure is discussed in section 8.4.1. Mask wearing to reduce infectious respiratory airborne emissions at their source can also be effective when an appropriate well-fitted respirator mask is worn continuously, as part of a system-based approach to risk management using the hierarchy of control to apply mitigations.[551]

An *eBioMedicine* paper published in May 2024 compared efficacy of cloth and surgical masks and respirators (KN95 and N95) as source control for viral load in exhaled breath of volunteers with COVID-19. The authors reported that all masks and respirators significantly reduced exhaled viral load, without fit tests or training. A duckbill N95 reduced exhaled viral load by 98%, significantly outperforming a KN95, and cloth and surgical masks. The authors stated the results suggest N95 respirators could be the standard of care in nursing homes and healthcare settings when respiratory viral infections are prevalent in the community and healthcare-associated transmission risk is raised.[552]

Social acceptance of mask wearing has been challenging in Australia since mandates were removed.[553] A 2021 World Economic Forum article examined various strategies used by countries to increase mask wearing. These include incentives and penalties, from free masks to fines, as well as behavioural interventions such as political and community leaders setting an example by wearing masks in public, media campaigns on TV, radio and social media, and viral social media content.[554]

8.3 Reducing negative health impacts of pollutants in the air

8.3.1 Considering the establishment of national indoor air quality goals

The Australian Government could consider establishing national indoor air quality goals, including health-based maximum concentration levels for specified pollutants, and equivalent clean air delivery or ventilation rates or proxy measurements.[555]

Potential mechanisms through which the goals could be enforced, by incorporating into existing or new enforceable standards, might include:

- **National Construction Code (including the Indoor Air Quality Verification Methods)** – the code and supporting documents are a possible mechanism, but its ventilation levels and pollutant limits currently only apply to new building (and major refurbishment) design and are not required to be verified during ongoing performance (other than air handling for fire safety).
- **Introduce indoor air quality building operation requirements** – just as essential safety measures for fire safety are enforceable under state and territory building regulations, regulations could be introduced to enable National Construction Code indoor air quality design phase requirements to be enforced in the operation phase of buildings.[556] This would require the agreement of states and territories.
- **Safe Work Australia's Workplace Exposure Standards/Limits** - while duties are generally limited to occupational settings, they extend to ensure the health and safety of others who may be affected by the carrying out of work, such as visitors. Some of the current exposure standard levels are significantly higher than in other Australian and international guidance and standards, and do not include all relevant pollutants. Measurements under these standards/limits are done in the breathing zone of a worker, in contrast to general air or environmental monitoring, and are set at levels for healthy workers rather than for entire populations with old, young and otherwise vulnerable people.

- **Safe Work Australia's Model Code of Practice: Managing the work environment and facilities** – the code already includes guidance around ventilation and discusses the workplace exposure standards. It could be adapted to incorporate any new health-based indoor air quality goals, but consideration would need to be given to its alignment with the Workplace Exposure Standards/ Limits in occupational settings.
- **Ventilation Code of Practice** – this could be a mechanism, and would support the ventilation duty in the model Work Health and Safety Regulations 2011, though would be limited to occupational settings.[557]
- **Biological Hazards Code of Practice** – this could be a mechanism to cover work-related exposures to biological hazards. The International Labour Organization is working on a standard covering biological hazards.[558]
- **Expansion of Legionella risk management arrangements** – the regulatory system under public health regulations designed to control Legionella growth in cooling towers could be expanded to cover other pollutants and HVAC systems generally.
- **A Standards Australia-developed Australian Standard** – Standards Australia, a non-government national standards body could coordinate the development of an Australian Standard, through a consensus process with participating stakeholders.
- **Commercial Building Disclosure Program** – this program could be used to require indoor environment information to be disclosed when some types of commercial office space are offered for sale or lease, with the possibility of Minimum Indoor Air Quality Performance Standards for low-performing buildings that do not respond to mandatory disclosure.[559]
- **Premises Standards** – The Safer Air Project recommended these standards, intended to ensure people have dignified, equitable, cost effective and reasonably achievable access to buildings, and facilities and services within buildings, could be amended to include standards on indoor air quality. These standards are due for review in 2026.[560]
- **NABERS** - The Burnet Institute, supported by other stakeholders, has called for the development of an indoor air quality performance indicator and rating system under the National Australian Built Environment Rating System (NABERS).[561]

Note that while levels for certain outdoor air pollutants are set in a National Environment Protection Measure, the enabling legislation for such measures expressly limits them to 'ambient' air measures.[562] Environment ministers agreed to a review of the measure, to commence in 2025.[563]

Note also that the National Health and Medical Research Council (NHMRC) had previously determined a series of air quality goals for some key air pollutants based on their human health effects. Some were for ambient air, and others for indoor air. The ambient air goals were replaced by the National Environment Protection (Ambient Air Quality) Measure. No similar replacement arrangement was put in place for the NHMRC's indoor air quality goals, and these were rescinded.[564]

As well as setting performance goals, and aligning existing and possible future standards, consideration could be given to an accompanying requirement or guidance to minimise concentration levels of pollutants as far as is reasonably practicable. This multiple duty model already exists in work health and safety regulation of air quality in occupational settings.

Existing legislation, guidance, standards and other documents have served different purposes over time. The roles of various regulators and alignment with existing regulatory requirements and guidance should be considered carefully. This includes work health and safety airborne contaminant regulations and exposure standards/limits. For example, the carbon dioxide workplace exposure standard/limit is 5,000 ppm (and 12,500 ppm in underground coal mines).[565]

8.3.1.1 Maximum concentration levels for specified pollutants

As with the World Health Organization's *Air quality guidelines*, any national indoor air quality goals should be a target to work towards improving people's health by reducing the health impacts of air pollution.[566] Consideration could be given for maximum concentration guidance levels to be set at a concentration level unlikely to cause an adverse effect. As with work health and safety requirements, any guidance associated with the levels could also suggest exposure is kept as low as reasonably practicable to protect anyone in the indoor space, including more vulnerable individuals.

An Australian Government 'red tape reduction principle' is to utilise international standards and risk assessments from trusted international sources where appropriate.[567] The maximum concentration levels for specified pollutants outlined below have been developed drawing on relevant standards and assessments from both domestic and international sources. These could then be further developed using a health risk assessment approach. Such an approach could seek to estimate a health risk-concentration relationship for the specified pollutant to assist in determining maximum concentration levels in Australia.[568]

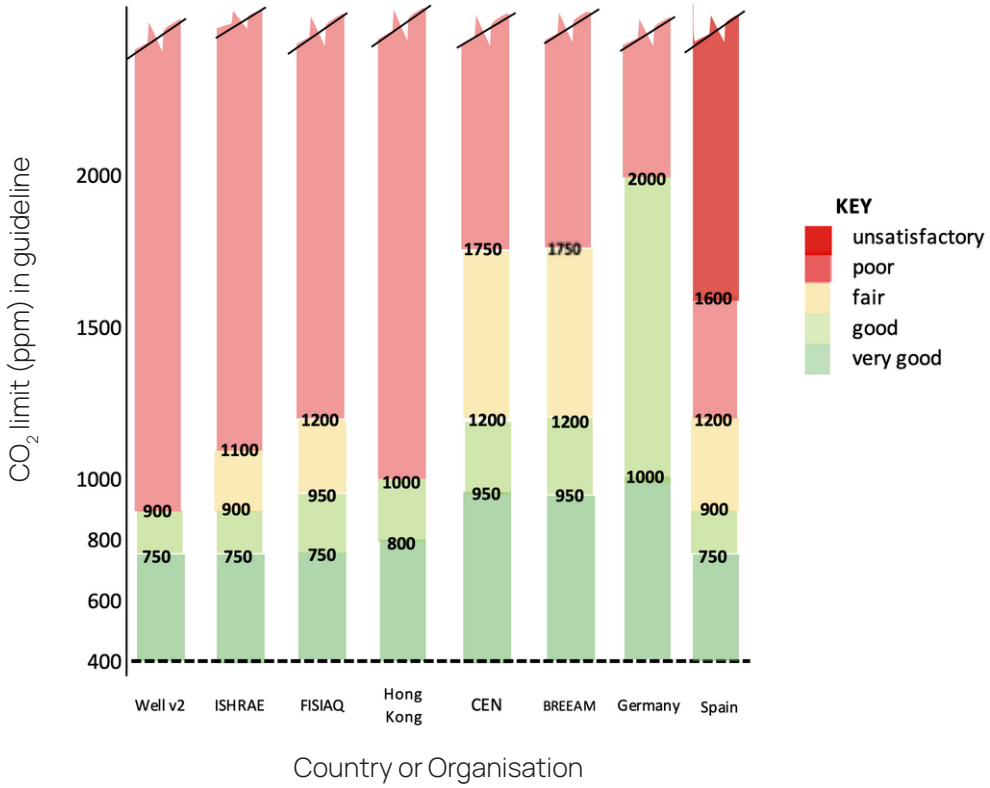
A recent paper in *Science* by Distinguished Professor Lidia Morawska and other international experts proposed including $PM_{2.5}$, carbon dioxide and carbon monoxide in performance standards for public spaces, with a focus on addressing airborne infection transmission.[569] The paper proposed maximum concentration levels, set out in Table 2 in **Appendix B**. These levels are compared in Table 2 with examples of existing Australian and international guidance.

As a starting point for development of nationally uniform indoor air quality pollutant levels, and with reference to the guidance levels set out in Table 2, this report proposes the following pollutant levels for further consideration:

- $PM_{2.5}$ – 15 µg/m^3 (1-hour averaging time), 7 µg/m^3 (1-year averaging time)
  - Note that µg/m^3 is a measurement of concentration in the air in terms of mass per unit of volume. A concentration of 15 µg/m^3 means that there are 15 micrograms ($15x10^{-6}$ grams) of pollutant in every cubic metre of air.
  - Note also that averaging time is the period over which air pollution data are averaged and used to check against a standard level.
  - The 2021 World Health Organization Air Quality Guidelines, which apply to both ambient and indoor air, recommend 15 µg/m^3 (24-hour averaging time).[570] There is currently no 1-hour averaging time level in either the WHO guidelines or the National Environment Protection (Ambient Air Quality) Measure. The measure states the 1-year averaging goal for $PM_{2.5}$ from 2025 is 7 µg/m^3, while the WHO guidelines level is 5 µg/m^3.
  - Recent epidemiological research suggests there is no $PM_{2.5}$ concentration threshold below which health effects do not occur.[571]
- carbon monoxide – 25 ppm (1-hour averaging time), 9 ppm (8-hour averaging time), and 3 ppm (24-hour averaging time, 99th percentile)
  - Note that 24-hour averaging time, 99th percentile provides for 3 to 4 exceedance days each year.
  - 25 ppm (1-hour averaging time) aligns with the Australian Building Codes Board's *Indoor air quality Verification Methods Handbook*, and the Canadian *Residential indoor air quality guidelines*. It is lower than the existing World Health Organization 2010 *WHO Guidelines for indoor air quality: selected pollutants* 1-hour level of approximately 31 ppm. The lower level has been selected as a conservative preliminary level, noting the World Health Organization 2010 guidelines assume light exercise and that such exposure levels do not occur more often than once a day (see Table 2 in **Appendix B**).

  - 9 ppm (8-hour averaging time) is the ambient air concentration specified in the National Environment Protection (Ambient Air Quality) Measure, and in several international guidance documents (see Table 2 in **Appendix B**).[572]
  - 3 ppm (24-hour averaging time, 99th percentile) is approximately the same as the 24-hour level in the World Health Organization 2021 Air Quality Guidelines (see Table 2 in **Appendix B**).
  - Consideration could be given to requiring carbon monoxide alarms in indoor spaces with combustion appliances, to detect faulty appliances emitting high levels of carbon monoxide. While there is no Australian standard for carbon monoxide alarms, the European Standard (EN50291) requires alarm activation at different time intervals for different concentrations of carbon monoxide.[573]
- carbon dioxide – 800 ppm (absolute value)
  - The *Science* paper recommends an absolute value of 800 ppm for carbon dioxide where the outside air carbon dioxide concentration is 450 ppm (or a value of 350 ppm above the concentration in the supply air).[574]
  - Several jurisdictions have proposed guidelines to maintain indoor carbon dioxide concentrations below values ranging from 800 to 1,000 ppm.[575] In Australia, the National Aged Care Design Principles and Guidelines checklist for Guideline 1.9 on Clean Air recommends keeping levels to less than 1,000ppm.[576] Belgium had proposed two reference levels - 800 and 1,000 ppm.[577] In 2023 in the UK, the British Council for Offices updated its Guide to Specification, changing the recommended carbon dioxide levels from <1,000 ppmv to <800 ppmv (parts per million by volume).[578] In the US, the Indoor Air Hygiene Institute sets <600ppm as part of its indoor air excellence levels.[579] New Zealand Standard 4303:1990 states that comfort (odour) criteria are likely to be satisfied if the ventilation rate is set so that 1,000 ppm is not exceeded.[580] Ireland's *Code of Practice for Indoor Air Quality* states that in most occupied spaces, a carbon dioxide concentration consistently below 1,000 ppm is likely to indicate that an indoor space is adequately ventilated.[581]
  - Under the classroom scenario in the *Science* paper described above, 1,000 ppm would be likely to result in infection occurring.
  - Further illustrating the variety of thresholds adopted in other jurisdictions, Figure 3 is taken from a recent review, published in the *Journal of Exposure Science & Environmental Epidemiology*, of current indoor carbon dioxide guidelines worldwide and the supportive evidence provided.[582] It shows eight identified carbon dioxide guidelines set with multi-tier limits, by country or organisation.

Figure 3. Eight identified CO_2 guidelines set with multi-tier limits, by country or organisation (source: Mendell et al, 'Carbon dioxide guidelines for indoor air quality: a review', *J Expo Sci Environ Epidemiol,* 2024, 34:555–569, doi:10.1038/s41370-024-00694-7)



International developments should continue to be monitored when considering indoor air quality goals for Australia. A collaborative group, Global Open Air Quality Standards, is working on a set of air quality standards, beginning with indoor air quality. The group has published a White Paper, outlining indoor air quality thresholds at two levels.[583] In January 2025, the Federation of European Heating, Ventilation and Air Conditioning Associations published model indoor environmental regulations.[584] The World Health Organization has released an updated WHO Air Quality Standards database, compiling national standards on the criteria pollutants in the 2021 WHO Air Quality Standards into a single database.[585]

Consideration could also be given to measuring other key indoor environment parameters, such as relative humidity and temperature, as these can have substantial effects on the health impacts of indoor air quality. Different climate zones across Australia may influence any levels set.

Direct detection of selected biological contaminants, such as viruses, may be feasible in the future as technology develops. An April 2024 report from the European Commission's Joint Research Centre, and the Health Emergency Preparedness and Response Authority, assesses technologies for managing indoor pathogen transmission, including pathogen detection, as well as air and surface

decontamination.[586] The US is offering significant research funding in this space. Its Advanced Research Projects Agency BREATHE program is looking for opportunities to develop indoor air biosensors to detect airborne biothreats, develop respiratory risk assessment software to determine whether health impacts are likely, and optimise building controls for enhanced health and energy efficiency.[587]

Several standards or guidelines also set out the methods for measuring pollutant levels. The Australian Building Codes Board's Indoor Air Quality Verification Methods Handbook is a source of guidance on measurement methods. Schedule 3 of the National Environment Protection (Ambient Air) Measure sets out Australian Standards Methods for Pollutant Monitoring, in relation to ambient air monitoring of the pollutants targeted. The NABERS Indoor Environment for Offices Rules sets out assessment requirements for measuring various pollutants and ventilation effectiveness.[588]

8.3.1.2 Equivalent clean air delivery or ventilation rates

There are several ways to measure ventilation, including by volume of outdoor air delivered (air changes per hour), by person (e.g., litres per second per person), or by floor area (e.g., litres per second per metre squared). In addition, ventilation effectiveness can be estimated using carbon dioxide levels, or (generally for investigative purposes rather than ongoing monitoring) using a tracer gas.

The US CDC recommended in May 2023 to aim for five or more air changes per hour of clean air in occupied spaces.[589] The new ASHRAE *Standard 241 Control of Infectious Aerosols* establishes minimum 'equivalent clean air delivery' requirements for different indoor spaces, and allows the standard to be achieved by ways other than ventilation.[590] There is also guidance available from the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) and the Canadian Committee on Indoor Air Quality and Buildings.[591]

The recent paper in *Science* discussed in section 8.3.1.1 proposed a ventilation level of 14 litres/second/person when a space is occupied, with a focus on addressing airborne infection transmission. The paper's proposed level is based on a risk assessment model, in which the ventilation level keeps carbon dioxide levels at a level where transmission is unlikely to occur even for respiratory pathogens with high transmissibility.[592] This level is above the current Australian ventilation standard (AS 1668), which sets a 10 litres/second/person minimum effective outdoor airflow requirement for many types of occupancies. It is also above the World Health Organization-recommended minimum rate for most settings, also 10 litres/second/person.[593] The proposed level is the base of the 'best' category established by the Lancet COVID-19 Commission Task Force on Safe School, Safe Work, and Safe Travel.[594]

The *Science* paper authors note the higher level is in line with a recommended rate based on an experimental exposure study of a cohort of school children in Italy. This study looked at the link between ventilation and reported SARS-CoV-2 transmission in school children in more than 10,000 classrooms. It found that in classrooms with mechanical ventilation systems, the relative risk of infection of students decreased at least by 74% compared with a classroom with only natural ventilation. The study found the relative risk decreased by at least 80% for ventilation rates greater than 10 litres/second/student, with a relative risk reduction in the range of 12% to 15% for each additional unit of ventilation rate per person.[595]

The *Science* paper authors recommended a supply of *clean* air in the breathing zone, not necessarily outdoor air. They noted that additional measures such as air cleaning and disinfection can reduce the need to increase outdoor air supply. However, the authors also recommended concurrent measurement of carbon dioxide levels to assess ventilation adequacy. They noted that if the carbon

dioxide concentration rises above an accepted threshold relative to the outside concentration or the concentration in the recirculated air brought into a space, the ventilation in that space is inadequate.

The proposed ventilation level of 14 litres/second/person could be used as the basis to develop Australian ventilation levels for most indoor spaces, in the building performance phase, in addition to the requirements for the specification and design phases. Consideration should be given to how allowing clean air rather than necessarily outdoor air as part of effective outdoor airflow, would interact with the proposed 800 ppm carbon dioxide level. Consideration should also be given to the details of how the ventilation level would be measured.

The National Science and Technology Council advised that review studies investigating the role of cleaner air supply for diluting indoor contaminants remain inconclusive on the optimum amount of cleaner air for infection control purposes. The council stated it is likely to depend on the geometry of the space, the occupancy level, the heating, ventilation and air conditioning characteristics and the installation of any other air cleaning technology (for example, filtration).[596]

The newly revised AS 1668 should be considered when developing performance-based Australian ventilation levels. As provided in AS 1668, different ventilation requirements would be needed for particular indoor spaces, for example, operating rooms and delivery rooms. Also as provided in AS 1668, minimum exhaust ventilation flow rates should also be considered for different indoor spaces.

8.3.2 Voluntary industry rating schemes and standards

As discussed in section 6.2.5, there are a number of voluntary industry rating schemes and standards that assess indoor air quality in Australia, including NABERS, WELL and Green Star. These are used to create awareness and market competition to achieve better indoor air quality.

As an example, NABERS assesses indoor air quality in office buildings by assessing levels of carbon dioxide, carbon monoxide, particulate matter (PM_{10}), Total Volatile Organic Compounds and formaldehyde.[597]

Internationally, private sector programs are available. For example, the Indoor Air Hygiene Institute's The Inside Advantage™ Certification Program measures carbon dioxide, particulate matter ($PM_{2.5}$), Total Volatile Organic Compounds, absolute humidity and temperature. It adds sensors on site to actively monitor $PM_{2.5}$, carbon dioxide, temperature, relative humidity and volatile organic compounds.[598]

8.3.3 Applying standards to new buildings and major renovations, and retrofitting existing building stock

Consideration could be given to requiring new buildings and major renovations in Australia to comply with new indoor air quality standards. While building asset lives vary depending on the type of building, the Australian Bureau of Statistics estimates asset lives of private brick dwellings are 70 years, and alterations and additions are 25 years. The bureau estimates non-dwelling constructions have an estimated average age at demolition of 62 years.[599] This means it would take some time before these standards apply to the majority of buildings in Australia.

Encouraging compliance with new indoor air quality standards for *existing* buildings in Australia would shorten the time required to upgrade Australia's building stock to improve indoor air quality. Different solutions may be needed for different existing building types, with consideration needed of a range of issues, including occupancy rates and activities in the indoor spaces.

8.3.4 Monitoring indoor air pollutants

Indoor air sensors can be used to detect indoor air pollutants.[600] If a direct sensor detects the presence of a pathogen, or a proxy sensor detects high levels of carbon dioxide, the signal could be used to trigger action – either setting off an alarm to prompt people to either leave the space or for someone to open a window to increase ventilation, or, in the case of a mechanically ventilated space, for the ventilation and filtration system to increase its ventilation and filtration levels. Clear guidance as to recommended actions would be needed if alarms were used. In spaces such as schools, real-time monitoring should be applied where possible.

A third option is to use a risk assessment model that assesses factors beyond direct or proxy pollutant levels to assess the risk of airborne transmission of pollutants. The World Health Organization and CERN have recently published a model that aims to quantify the risk of SARS-CoV-2 airborne transmission, with an accompanying online tool to assess transmission risk in residential, public and healthcare settings.[601]

The National Science and Technology Council advises that monitoring indoor air quality can help reduce airborne disease transmission by identifying high-risk areas and informing appropriate mitigating actions. It notes that monitoring technologies are affected by feasibility constraints, use costs, and variability depending on the time-point, location and activities in the space.[602]

The council found that carbon dioxide measurement (discussed in section 8.3.4.2 below) is the most promising proxy measure for ventilation effectiveness in indoor air quality studies. It noted that limitations around how carbon dioxide measurements are interpreted in the presence of other indoor air quality interventions must be taken into consideration.[603]

Box 6 earlier in this report discusses examples of indoor air quality monitoring in the private sector. As well as monitoring, however, there is a need to ensure that a system-based approach to risk management is adopted to ensure appropriate responses to the measurements obtained through monitoring.

8.3.4.1 Direct

There are established ways to directly detect or monitor the levels of various pollutants in the air, including $PM_{2.5}$, carbon monoxide, carbon dioxide and radon, as well as smoke alarms and detectors. Researchers are developing new technologies for direct, real-time measurement of other airborne pollutants such as viruses.[604] There are also potential artificial intelligence applications.[605] Companies are developing technology to enable mobile phones to measure air quality, smoke levels, temperature and ultraviolet light exposure. Data could be used by the phone owners themselves, or combined to provide anonymous point sources of data of air pollution over a wide area,[606] such as during the 2019-20 bushfire season.

The reliability of low-cost sensors for low concentrations of pollutants such as $PM_{2.5}$ and carbon monoxide should be considered. A February 2025 paper in *Aerosol Science and Technology* by Morawska et al sets out a framework for using $PM_{2.5}$ low cost sensors for compliance monitoring of indoor air.[607]

8.3.4.2 Proxy

Proxy measures, particularly carbon dioxide, are sometimes used to measure the amount of ventilation (air changes) occurring in an indoor space. However, as discussed in the previous section, feasible direct monitoring technologies are emerging. Until then, and likely beyond, work should continue on understanding what effective proxy measures – such as carbon dioxide - would be, including what pollutants and concentration levels should be used. New direct monitoring technologies may not be able to measure all pollutants of concern. Using both direct and proxy measures adds layers of protection.

Carbon dioxide levels depend on occupancy density and do not measure the effectiveness of all infection prevention and control measures put in place. In addition, where there is continuous talking or singing, or high levels of physical activity, a higher level of ventilation may be required to manage carbon dioxide levels. Carbon dioxide monitors may be less useful in some situations, such as in areas that rely on air cleaning units, or large, open spaces with high ceilings, or areas with very limited occupation density.[608]

The use of carbon dioxide as a proxy measure has the potential to create confusion, if it is perceived as a measure of 'pollution'. It is instead more a marker of 'ventilation' than pollution, that is, how well carbon dioxide produced in an indoor space (from human respiration, for example) is ventilated to the outdoors. When indoor pollutants such as particulate matter are high, low carbon dioxide should not be interpreted as meaning pollution is low. Further, in the context of poor ventilation but adequate (HEPA) filtration, carbon dioxide can be elevated while particulate pollutant and pathogen concentrations are low – another source of potential confusion. Good education is needed for users of carbon dioxide sensors.[609]

Box 9. Examples of monitoring and display requirements in other jurisdictions

In Thailand, 'Notification of the Department of Health regarding Indoor Air Quality Monitoring Standards in Public Building B.E. 2565 (2022)' is a guideline for indoor air quality monitoring in public buildings. Parameter values and acceptability criteria reportedly include thermal comfort and air pollutants such as carbon dioxide, $PM_{2.5}$, PM_{10}, total volatile organic compounds, carbon monoxide, formaldehyde, ozone, total bacterial count and total fungal count.[610]

In Japan, in 1970 'the Law for Maintenance of Sanitation in Buildings' was enacted, requiring building owners to maintain a good level of environmental health within the building, including indoor air quality.[611] Indoor air quality in Japanese buildings is measured and displayed through technological devices, and must be monitored by health centres of local governments through regular inspections.[612] In addition to regular buildings, anecdotally, some areas of Japan measure the indoor air quality of taxis, restaurants and cinemas, and display it to customers on visible devices.[613]

In Belgium, the Law of 6 November 2022 on the improvement of indoor air quality in closed spaces accessible to the public focuses on using monitoring, certification and labelling to make indoor air quality and its management visible. The law sets air quality reference levels, and in the future may encourage people responsible for an indoor space to measure the indoor air quality, carry out a risk analysis of the premises and the activities within them, and implement an action plan to meet the reference levels. The levels are indicative targets, not mandatory.[614]

In the USA, the Johns Hopkins Centre for Health Security proposes a state-level legal framework for indoor air quality in public spaces - the *Model State Indoor Air Quality Act*.[615] It requires owners of some building types to regularly test indoor air for specific contaminants or for proxies. Test results

must be displayed on-site and online. The model act authorises building occupants to assess indoor air quality (using tools such as carbon dioxide meters), to take remedial measures, and to seek limited civil remedies.[616] Compliance is encouraged via incentives, with penalties for persistent non-compliance. The model act outlines how to monitor implementation, inform the public about indoor air quality, adjust standards based on research, and seek compliance by building owners.[617]

Figure 4. IAQ certification mark in Taiwan (source: CP Hu and JH Cheng, 'Indoor Air Quality Certification and Consumers' Willingness: Taiwan's Experience and Survey', ***Atmosphere***, 2021, 12(10):1320, doi:10.3390/atmos12101320)



In Taiwan, the Indoor Air Quality Management Act requires certain types of public buildings to comply with various requirements, including establishing a plan of indoor air quality maintenance management, regularly implemented indoor air quality inspections and measurements. These obligations have been gradually extended to more types of public locations over time, and more indoor air contaminants have been included to be managed at certain types of locations.[618] A self-managed IAQ certification mark scheme is available (see Figure 4).[619]

Under South Korea's *Indoor Air Quality Control in Public-use Facilities, etc. Act*, South Korea mandates managers of public facilities to conduct annual monitoring on pollutants subjected to mandatory air quality standards and to conduct semi-annual monitoring of other pollution sources. Managers are required to report the monitored outcomes before January each year. The installation of air cleaners and ventilation equipment is also mandatory.[620] A regularly updated 'Five Year Basic Plan for Indoor Air Quality Management' proposes detailed measures on indoor pollutant and management facilities.[621]

France has a regulatory system for monitoring indoor air, which is being extended to different building types over time. The first buildings required to implement the monitoring were facilities hosting children under six years old, nursery schools and primary schools. From 1 January 2020, this was extended to recreational facilities and secondary education or vocational training places. The regulatory system was amended in December 2022. It now requires: mandatory yearly assessment of ventilation systems, including measuring carbon dioxide; self-diagnosis every four years of indoor air quality in the premises; measuring regulatory pollutants at each key stage of the building's life; and establishing a detailed action plan in the event of air quality issues. Starting from the end of 2024, these requirements will be extended to other building types.[622]

Hong Kong has a voluntary IAQ Certification Scheme for Offices and Public Places, which encourages property owners and management to adopt good indoor air quality management practices in their premises. Certification includes engaging a certifier who inspects the premises. Any indoor air quality issues identified must be rectified. The assessment includes measuring indoor air quality and assessing mould. There are also registration and display provisions.[623]

8.3.4.3 Encouraging or mandating the use or installation of air quality monitors

One aspect of indoor air quality – smoke – already has monitors in place in indoor spaces across Australia. Smoke alarms are compulsory in Australian homes, though detailed requirements vary between jurisdictions. Fire safety systems are also required for commercial buildings in Australia.[624]

Public guidance about indoor air quality monitors has been developed, supported with funding from the Australian Government's National Environmental Science Program.[625] The purchase and use of monitors in indoor spaces could be encouraged. The monitors could monitor carbon dioxide (ventilation) and $PM_{2.5}$, and possibly others, such as carbon monoxide, nitrogen dioxide, formaldehyde (or volatile organic compounds more generally), and relative humidity.

In their recent *Science* paper, Morawska *et al* state compliance monitors are too costly and complex for use in all indoor spaces to monitor all six pollutants in the World Health Organization Air Quality Guidelines. In the context of targeting airborne infection transmission, they recommend $PM_{2.5}$ and carbon monoxide as the two most relevant candidates from the World Health Organization guidelines for routine regulatory indoor air quality monitoring. They state the feasibility of monitoring indoor air quality parameters depends on various aspects of the monitor or sensor, including calibration, ease of data interpretation, size, cost, robustness and operating noise level.[626]

8.3.4.4 Installing carbon dioxide monitors in public buildings

Consideration could be given to installing air quality monitors in indoor environments, particularly those buildings where airborne disease transmission risk may be higher, including schools, kindergartens and childcare, residential aged care homes, disability services, correctional facilities, and healthcare settings.

The New Zealand Ministry of Education is installing Internal Environment Monitoring devices to help assess indoor air quality and other indicators.[627] In 2022, the ministry provided over 12,500 portable carbon dioxide monitors to schools at no cost to the schools. Schools, early childhood services and other education providers were then able to purchase additional carbon dioxide monitors at a discount from the ministry's supplier.[628]

In the UK, the UK Government provided nearly 400,000 carbon dioxide monitors free to all state-funded educational establishments from September 2021. A UK Government survey in December 2022 of recipients of the free monitors found that, of the survey respondents, 95% were able to use them to identify when ventilation in a room needed to increase.[629]

In Australia, the CleanAir Schools pilot program is being rolled out across 100 schools in New South Wales to monitor indoor and outdoor air pollution levels. Participating schools will have two air quality sensors installed, to operate for two years, measuring $PM_{2.5}$, nitrogen dioxide, carbon dioxide, temperature and relative humidity.[630]

8.3.5 Display and reporting

Some voluntary rating schemes provide some information publicly about indoor air quality ratings. However, detailed information about the assessment of the indoor environment is often available only to building owners.[631] In a 2021 paper in *Science*, Professor Lidia Morawska and her co-authors stated the wide use of monitors displaying the state of indoor air quality should be mandated, as visible displays would advance public awareness.[632]

8.3.6 Indoor air quality rating or certification scheme

While monitoring and display make aspects of indoor air quality visible, certification or rating would make indoor air quality management visible.

A national indoor air quality certification scheme could require building owners to display a label that informs the public that the indoor air quality is being measured and controlled in that space to minimise possible negative health impacts.[633] Instead of a compulsory scheme, a voluntary certification scheme could alternatively be considered, such as Hong Kong's voluntary IAQ Certification Scheme for Offices and Public Places.[634]

If a ratings scheme was considered, decisions would be needed to determine the appropriate pollutants and rating levels, sensor calibration and positioning requirements, and how to express the information on the certificate.

Building owners could be required to conduct risk assessments and to develop and maintain risk management plans. Such plans are already required for Legionnaires disease in some Australian states and territories.[635]

8.3.7 Ventilation, filtration and other cleaning methods

There are different ways to 'clean' indoor air. Methods include ventilation, filtration, ultraviolet radiation, thermal inactivation,[636] electrostatic capture, plasma inactivation,[637] chemical aerosolisation,[638] microwave radiation, lysozyme-based filters,[639] photocatalytic oxidation,[640] sorbent trapping of volatile organic compounds,[641] and pressure differentials. This report does not look in detail at all of these methods. They all have limitations, and vary in efficacy, safety and reliability. Some generate harmful pollutants as by-products of their operation.

In a 2022 US White House statement, representatives of the US Office of Science and Technology Policy stated that transmission of COVID-19 can be reduced by 80% with improved indoor ventilation and air filtration.[642] Ventilation brings outdoor air into a space, and takes the old polluted air with viruses and other pollutants out.[643] However, a November 2022 paper suggests that where there is a high density of occupants and highly infectious pathogens, ventilation alone cannot adequately reduce the risk of infection.[644] This is also the case for many other pollutants generated indoors. There are additional technologies available. Appropriate filtration can remove viruses and some other pollutants. Various disinfection methods aim to remove or inactivate some biological pollutants, but do not exchange the air or, other than sorbent traps, remove other pollutants. Negative pressure rooms and air extraction systems can also be used.[645] Combinations of these techniques are also possible.[646] The Australian Building Codes Board's *Indoor Air Quality Verification Methods Handbook* discusses various options.[647]

The National Science and Technology Council identifies two indoor air quality strategies as having the greatest potential to improve air quality, reduce indoor bioaerosol concentrations and affect airborne infection transmission risk. The first is using ventilation to dilute contaminated air with cleaner air. The second is air cleaning technologies such as HEPA cleaners, and air disinfection technologies such as ultraviolet-C light (UVC) disinfection.[648] Cleaning technologies can reduce the concentrations of some, though not all, pollutants from indoor air.

When using ventilation, care needs to be taken to ensure that pushing air into a space does not result in localised turbulence, or air movement, that concentrates toxic or harmful pollutants in one place. Extraction ventilation can be more effective.

Ireland's *Code of Practice for Indoor Air Quality* advises that local air cleaning is not a substitute for good ventilation. It states local air cleaning may be beneficial in reducing risks in some spaces, particularly where it is not possible to increase ventilation using natural or mechanical means. However, it suggests priority be given to making improvements in other ways to poorly ventilated spaces before using an air cleaning device.[649]

8.3.7.1 Ventilation assessments and upgrades of public buildings

Consideration could be given to requiring ventilation assessments of public indoor spaces such as schools, residential aged care homes, correctional facilities and healthcare institutions. Such assessment should be not only at construction, but at regular intervals over the life of a building as a key maintenance factor. This could be expressly required to comply with the ventilation duty under work health and safety legislation.[650]

In the US, legislation has been proposed to allow a tax credit for non-residential building owners to conduct indoor air quality assessments and upgrade ventilation and filtration systems.[651]

8.3.7.2 Ventilation

> *'Understanding and controlling building ventilation can improve the quality of the air we breathe and reduce the risk of indoor health concerns...'*
>
> *World Health Organization*[652]

Ventilation is the use of outdoor air to replace indoor air for the health and comfort of building occupants. The amount of ventilation – the outdoor air delivery rate – has been influenced since the 1940s by research evaluating the outdoor air dilution ventilation rates needed for an occupied room such that 80% of visitors to the room did not find body odours in the room objectionable.[653] That is, ventilation requirements have traditionally been set for decades by reference to subjective control of odours, rather than by reference to the many other indoor air pollutants from buildings and their contents.

The World Health Organization has published the *Roadmap to improve and ensure good indoor ventilation in the context of COVID-19*, for both natural and mechanical ventilation.[654] The report states that mechanical ventilation is an active process of supplying air to or removing air from an indoor space by powered air movement components, while natural ventilation occurs as a result of only natural forces, such as wind pressure or differences in air density through openings in a building envelope such as windows and doors.[655]

The Australian Health Protection Committee recognises the importance of ventilation, noting the spread of certain respiratory diseases such as COVID-19 in indoor environments may be reduced by improved ventilation. Its statement added that ventilation controls may be relevant in high-risk indoor environments, such as schools and aged care residential facilities. It notes that the appropriateness of a particular strategy will depend upon several factors, such as building design and operation, occupancy level, and environmental, seasonal and climate factors.[656]

The National Science and Technology Council advised government there is satisfactory evidence mechanical ventilation can reduce the risk of SARS-CoV-2 transmission in a school classroom

environment. It also advised that multiple review studies have shown mechanical ventilation can reduce the total bioaerosol concentration in indoor spaces.[657]

There are different types of ventilation relevant to indoor air quality, beyond the natural-mechanical distinction, including hybrid or mixed, spot, cross or wind-driven, exhaust only, supply only, and task conditioning.

In displacement ventilation (or buoyancy driven or stack ventilation) the airflow pattern in a room – the way the air moves around - is mainly guided by the convection flows from the heat sources present in the room.[658] Displacement ventilation uses temperature differentials between where outdoor air is introduced and where stale air is extracted. A City of Melbourne research project in 2022 found that displacement ventilation was the most effective and energy efficient system of the three tested, and reduced COVID-19 transmission by 83%, while also reducing energy consumption by 20%. The other two systems included in-ceiling air filters and natural airflow through open windows.[659]

Upwards displacement ventilation relies on lifting pollutants above the breathing zone.[660] However, particles on surfaces and floors can be reintroduced into air through re-suspension, creating potential health risks.[661] And there is a risk that not all bioaerosols will be lifted sufficiently out of the breathing zone.[662]

Outside air may need to be filtered in some circumstances, e.g. traffic, bushfire smoke, suggesting that a hybrid ventilation system may be appropriate – using windows naturally but switching to mechanical ventilation and filtration when needed.

Air flow direction is important, to avoid polluted air moving towards susceptible occupants. Consideration is needed for air inflow and outflow positioning for both natural and mechanical ventilation. Occupant activities and location, and fittings and furniture placement, can also affect air flow direction.

When considering what cleaning method to adopt, energy efficiency is also important. Adding high efficiency filters to mechanical ventilation systems may result in more energy consumption. This is because the system's fans may need to run faster or against higher back-pressures - using more energy to maintain the same supply air flow rate while compensating for the pressure drop caused by the filters.[663] In relation to in-duct filtration, for use in mechanical ventilation systems, filter choice can affect filtration effectiveness, as well as energy efficiency and costs.[664] Australia is moving to replace Australian Standard 1324 with ISO/AS 16890, to more accurately define what particulate matter is stopped by each filter.[665]

Technologies such as heat recovery ventilation enable savings in energy and energy costs in relation to conditioning outside air to the desired indoor temperature. Policy responses to climate change represent an opportunity to improve building ventilation while making changes to mitigate and adapt to climate change.[666] Work on the *Trajectory for Low Energy Buildings and its Addendum* national plan should include considering the health impacts of indoor air quality, including improving heating, ventilation and air conditioning systems.[667]

Building design and orientation are important factors in reducing the need for mechanical ventilation and in contributing to energy efficiency. Additionally, 'leaky' homes create high air change rates, while more airtight homes create health risks associated with inadequate ventilation.

A 2015 CSIRO study found the average air-tight level of newly constructed Australian houses was leaky by international standards, though there was considerable variation between houses.[668] A 2024 update to that study found, based on the sample homes tested, that the new homes were 50% more

airtight than those built nine years ago. The report recommended requiring controlled ventilation in new buildings to reduce indoor pollutants and moisture. It also recommended making air barriers mandatory in all homes.[669]

8.3.7.3 Inspect ventilation systems in operation/performance and maintenance requirements

The report commissioned for the National Science and Technology Council found that poor maintenance can significantly impact ventilation system effectiveness.[670]

A 2013 heating, ventilation and air conditioning (HVAC) industry article stated more than 50 percent of all indoor air quality issues are directly related to HVAC systems. These issues include a lack of ventilation, but also include contamination spread by the HVAC system itself, such as from rusting metal surfaces and deteriorated internal insulation. The article noted conducting regular internal inspections of HVAC systems to verify their cleanliness could help address this issue.[671]

The Australian Building Codes Board *Indoor Air Quality Verification Methods Handbook* notes regular maintenance of the HVAC system and appropriate management of HVAC hygiene are essential aspects of indoor air quality, with filters and outdoor air intakes particularly critical.[672] The Department of Climate Change, Energy, the Environment and Water also has produced a guide to best practice maintenance and operation of HVAC systems for energy efficiency.[673]

There are specific ongoing ventilation maintenance requirements around microbial control, and around essential fire safety systems.[674]

In addition, Safe Work Australia's states that air-conditioning and other ventilation systems should be regularly serviced and maintained in accordance with manufacturers' instructions. It also notes that further information regarding air quality is available in AS 1668.2–2002.[675]

In Sweden, there has been a legislative requirement since 1991 for recurring ventilation inspections. The building owner is responsible for ensuring that the inspections are carried out.[676]

In the USA, *ANSI/ASHRAE Standard 62.1-2022: Ventilation and Acceptable Indoor Air Quality* includes a section on operations and maintenance, including minimum maintenance activity and frequency for ventilation system equipment and associated components.[677]

8.3.7.4 Filtration

The COVID-19 pandemic has increased awareness of the use of air purifiers in homes, schools and workplaces to reduce the concentration of indoor air pollutants such as bioaerosols and particulate matter. Air filtration devices such as High Efficiency Particulate Air (HEPA) filters and Minimum Efficiency Reporting Value (MERV) filters are available commercially, for both portable units or in-duct use. Do-it-yourself filters, such as Corsi-Rosenthal boxes, can reduce the concentration of infectious aerosols in the air.[678] Carbon filters can assist with reducing the amounts of some gaseous pollutants.[679] Heating ventilation and air conditioning (HVAC) systems within buildings can provide in-built air filtration/cleaning with ventilation.

In indoor environments, indoor pollutant levels are dynamic, often being both continually increased from indoor and outdoor sources and continually reduced through ventilation and other means.[680] It is important to select the appropriately sized HEPA filter or filters for indoor spaces, and to position them effectively in the space. There can be noise, heat, maintenance and energy consumption considerations with HEPA filter use.[681]

An Australian study found that HEPA cleaners have the potential to substantially improve indoor air quality during episodic smoke episodes.[682] A 2016 Canadian paper called for portable air cleaners to be at the forefront of the public health response to landscape fire smoke.[683]

In relation to airborne viral disease, a May 2024 report commissioned for the National Science and Technology Council found laboratory studies show HEPA air cleaners are effective at reducing concentrations of infectious particles in the air.[684]

The council advised that in educational institutions, HEPA air cleaners (and UVC lights, discussed in the next section), are effective, especially when properly sized and positioned relative to infected and susceptible persons. It also found HEPA air cleaners could reduce aerosol particle load by 85-95% within less than 20 minutes of operation.[685]

A randomised trial of HEPA air filters in UK schools reportedly found using HEPA filters reduced the number of COVID-19-related sick days by more than 20% (note the study was not yet published in a peer-reviewed journal at the time of writing this report).[686] A September 2024 report of a study of four daycare centres in Helsinki found an 18% reduction in children's infections from use of air purifiers in two of the centres without other interventions.[687]

A US CDC study of COVID-19 in 123 schools found infection rates were 41% lower for schools using HEPA air purifiers in their classrooms than those without them. Classrooms with improved ventilation also had a lower virus infection rate compared to schools without, but combining ventilation and filtration worked better than either strategy alone. Combining strategies reduced virus transmission by 47% compared to schools that did nothing.[688]

A German study found no effect of portable HEPA filters on COVID-19 period prevalence in German kindergartens between November 2021 and May 2022 during the Omicron wave. The researchers stated that air circulation, person density, mask wearing and activity type conducted in the room were very likely to affect the risk of infection.[689] Notably, there was significantly more frequent ventilation in the control group than in the group with HEPA filtration, which is likely to have influenced the results.[690]

The National Science and Technology Council advised that HEPA air cleaners in healthcare settings reduce clearance times significantly, compared with HVAC systems alone. The council also reported that using two domestic HEPA air cleaners on a ward reduced 99% of all aerosols substantially faster than on wards with no air cleaners.[691]

In Australia, a number of governments established HEPA filter grant programs in response to the COVID-19 pandemic.[692] Several Australian states provided standalone HEPA filters directly to schools.

8.3.7.5 Other air cleaning technologies

As well as filtration, there are other technologies that aim to clean indoor air, including ultraviolet light of various wavelengths, plasmas, ionisers, photocatalysis and chemical aerosolisation. Carbon dioxide capture in buildings has also been explored.[693]

Ultraviolet light has been used for the disinfection of drinking water for over a century. In relation to air, there are several types of ultraviolet light technologies – germicidal, light emitting diode (LED) and far-UV.

Germicidal UV irradiation lamps shine ultraviolet light at a wavelength of around 254 nm, inactivating viruses and bacteria in the air. As such light can damage human eyes and skin, lamps are placed high in a room away from people, with rising air currents bringing the pathogens up for inactivation. The air then circulates back down into the occupied part of the indoor space.[694]

Another type of ultraviolet light technology, LED irradiation lamps, uses 277 nm ultraviolet light. As with 254 nm germicidal UV, 277 nm LED light kills human eye and skin cells in vitro.[695]

Far-UV light is UV light with a wavelength of 222 nm and is being explored as a potentially safer option for pathogen inactivation in indoor spaces.[696] However, 222 nm far-UV exposure has been shown to result in DNA damage and transcriptional changes to mammalian cells in vitro.[697] Additionally, recent Massachusetts Institute of Technology (MIT) laboratory experiments found 222 nm far-UV generates ozone and hydroxyl radicals, which can react with volatile organic compounds to form secondary organic pollutants.[698] The report commissioned for the National Science and Technology Council also found some UVC lights have been reported to cause secondary chemistry effects by increasing particulate concentrations.[699]

The National Science and Technology Council found that UVC light systems have been shown in experimental and laboratory settings to effectively reduce and neutralise infectious bioaerosols by up to 99%. It found limited evidence from in-situ studies to show UVC lights alone are effective at reducing bioaerosol concentrations in office spaces and hospital wards. It also found limited evidence that UVC lights alone can reduce airborne disease infection transmission risk in kindergartens.[700]

The council advised optimal sizing, positioning and design are very important for effective UVC operation. It noted direct exposure of people to UVC light is dangerous. Some types of louvres installed in UVC systems for safety reasons were found to render them much less effective than otherwise.[701]

The report commissioned for the National Science and Technology Council found the effectiveness of UVC systems for in-duct air-conditioning installations depends on the design and size of the system, with very large systems effective in disinfecting air in ventilation ducts. It noted further research was required to determine if transmission risk of airborne diseases is lowered.[702]

There is ongoing research in Australia on the effectiveness of ultraviolet light in situ. In a study in South Australia germicidal UV lights were installed in five residential aged care homes to investigate their effectiveness in reducing the number of respiratory illnesses in residents.[703] In May 2024, the Victorian Government announced funding of $16.8 million for a trial led by the Burnet Institute assessing the efficacy of germicidal ultraviolet light technology in a real-world setting to help reduce the level of COVID-19 and other airborne viruses in aged care residences.[704]

Ionisers aim to remove particles from the air, but they may emit ozone and potentially aldehydes as a by-product of their operation.[705]

Both the Western Australian Department of Health and the University of Melbourne have suggested avoiding units that include ionisers, plasma/ozone/photocatalytic oxidation/precipitators and UV purification.[706] Ozone or other chemicals produced from units with these add-on technologies may act as a respiratory irritant.[707] For ozone generators that are sold as air cleaners, the US EPA advises that available scientific evidence shows that at concentrations that do not exceed public health standards, ozone is generally ineffective in controlling indoor air pollution. The US EPA also states that in the process of reacting with chemicals indoors, ozone can produce other chemicals that themselves can be irritating and corrosive.[708]

The UK's SAGE Environmental Modelling Group investigated the potential for different methods of air cleaning to reduce the potential for transmission of Covid-19 indoors. The group found that technologies based on ionisers, plasma, chemical oxidation, photocatalytic oxidation and electrostatic precipitation had limited evidence to demonstrate effectiveness against COVID-19, and that their use could lead to the production of harmful secondary air pollutants, including ozone and nitrogen oxides.[709]

A 2021 MIT article reported that some air cleaners that claim to remove volatile organic compounds from the air may only remove minimal amounts and may add additional volatile organic compounds and/or harmful oxidation by-products.[710]

8.3.7.6 Minimum rental standards for heating, ventilation and mould

Australian laws about minimum rental standards for private properties vary from jurisdiction to jurisdiction. Some states and territories have set minimum rental standards for heating. Victoria, for example, requires rental properties to have an energy efficient fixed heater in the main living area.[711] Others have set minimum rental standards for ventilation, with the requirements differing between jurisdictions.[712] Queensland is introducing minimum housing standards that include a requirement that the property is free from damp and mould.[713]

Overseas, New Zealand has minimum rental standards requiring rental homes to have openable windows in the living room, dining room, kitchen and bedrooms. Kitchens and bathrooms must have extractor fans or an acceptable continuous mechanical ventilation system.[714]

Work to establish consistent national minimum rental standards could consider ways to reduce the impact of gas and wood heating on indoor air quality and review the list of heaters that satisfy minimum rental standards for heating. This work could align with the Australian Government's work with state and territory governments to improve home energy efficiency, in order to reduce rental home energy consumption and costs.[715]

8.3.7.7 Vehicle filtering, monitoring and display

Australians spend considerable time commuting in cars, taxis, school buses and public transport. Vehicle occupants can be exposed to outside air pollution coming into the vehicle as well as air pollution from within the vehicle, with potentially significant health effects including respiratory and cardiovascular disease.[716] Given that HEPA filtration can significantly reduce particle count in vehicles,[717] air filtration should be encouraged as an effective mitigation against some of the health impacts of poor indoor air quality in vehicles.[718]

Smoky vehicle reporting schemes operate in several Australian jurisdictions. These schemes may reduce outside air pollution that would otherwise come into vehicles and other indoor spaces.[719]

Additionally, the build-up of carbon dioxide in vehicles without adequate ventilation could contribute to poor cognition, and is a possible risk factor for vehicle accidents.[720] Carbon monoxide is also a major pollutant emitted from vehicles and can build up in vehicles.[721]

8.3.8 Building safety measures

In Australia, the building regulations in each state and territory require minimum performance standards in buildings for fire safety, requiring 'essential safety measures' to be installed and maintained.[722]

New Essential Air Quality Safety Measures could be included in the essential safety measures arrangements.[723] These could include air quality monitoring for pollutants such as carbon dioxide, $PM_{2.5}$ and carbon monoxide, and regular inspection and maintenance of all heating, ventilation and air conditioning systems.[724] Buildings such as schools, kindergartens, and health and aged care settings could be the first to adopt these essential air quality safety measures.

A NSW parliamentary committee recommended in 2001 that a compliance schedule for mechanical ventilation and air-conditioning systems be included in the then Building Code of Australia to ensure the systems were fit for health, noting that such an approach was included in the New Zealand 1992 building regulations. The committee also recommended that HVAC systems in buildings be monitored on an annual basis to ensure compliance with the schedule.[725]

8.4 Reducing negative health impacts of pollutants at point of exposure and in sensitive use settings

8.4.1 Face masks (respirators)

Wearing masks to reduce infectious respiratory airborne emissions at their source is discussed in section 8.2.2.5 above. Masking with a well-fitting high-quality respirator such as an N95 mask is also effective in reducing the risk of becoming infected by an airborne virus,[726] as well as in mitigating the impact of poor indoor air quality caused by particulate matter.[727,i]

In December 2023, the World Health Organization advised people to take measures to prevent COVID-19 infections and severe disease using all available tools, including wearing a mask when in crowded, enclosed, or poorly ventilated areas.[728]

In the USA, the federal government provided free N95 respirators through pharmacies, local health clinics, community support agencies, and other organisations.[729]

8.4.2 High risk and sensitive use settings

Some types of indoor spaces have higher risks of transmission of airborne viruses such as COVID-19. These include spaces where people are in groups, such as aged care homes, healthcare services, correctional facilities, schools and early childhood education centres.[730]

The COVID-19 National Guideline for Public Health Units (or COVID-19 SoNG) was recently updated to provide advice to manage transmission in high risk settings (such as health care and residential care) and other special settings (including correctional facilities, child care centres, and cruise ships), including improving indoor air quality. The SoNG states that high-risk settings are settings where both a high proportion of people are at increased risk of severe disease, and there is an increased risk of COVID-19 transmission.[731]

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i N95 is an American standard broadly equivalent to the Australia standard of P2.

8.4.3 Hospital airborne infection control

There is considerable variation in airborne virus infection control in Australia, with some hospitals requiring masks to be worn in some areas, and some not.

An August 2020 rapid systematic review looked at the efficacy of face masks and respirators against respiratory transmissible viruses. It found trials in healthcare workers support the use of respirators continuously during a shift, and that this may prevent healthcare worker infections and deaths from COVID-19.[732]

A September 2023 paper from the University of Texas Southwestern Medical Center found that universal masking (by healthcare personnel, patients and visitors) in all clinical buildings in its children's hospital was effective in reducing respiratory virus transmission and that masking only for patient encounters (by healthcare personnel, with patients and families encouraged to do so) was not as effective. The authors recommended that universal masking should be considered as part of the infection prevention toolbox in certain scenarios.[733]

Measures to prevent infection by one airborne virus can also protect against other airborne viruses. A December 2023 research paper found that measures to prevent SARS-CoV-2 transmission also prevented non-SARS-CoV-2 respiratory viral infections (influenza and respiratory syncytial virus).[734]

A National Air Hygiene Initiative could be considered, as a parallel to the National Hand Hygiene Initiative, to educate participants on the importance of clean indoor air and airborne infection prevention and control.

8.4.4 Schools and early childhood education centres

A 2019 paper looking at the indoor air quality conditions of 10 Victorian schools found, in an early preliminary analysis, carbon dioxide concentration levels exceeding 1,000 ppm during school hours. The study's authors were concerned by the low air change rates in the classrooms studied.[735] The study found that average carbon dioxide levels ranged from 912 to 2,235 ppm, with maximum concentration levels of up to 5,000 ppm during some occupied times.[736] A study in New South Wales found carbon dioxide levels exceeded 2,900 ppm during the occupied period.[737] A study of naturally ventilated schools in Brisbane, while finding that carbon dioxide levels were generally low, found that average concentrations for some classrooms ranged from 1,043 to 1,370 ppm.[738]

Consideration could be given to establishing a model indoor air quality program for schools to adopt. Such a program should be pragmatic and consider potential work health and safety risks that may arise. A US CDC study found that schools with a formal indoor air quality program are more likely to support policies and engage in practices that promote superior indoor air quality.[739] A University of Surrey study published in 2023 found that air purifiers, HVAC systems with MERV 11-16 filters, clean fuel policy interventions within school buses and from bus exhausts, and green barriers – such as hedges and trees - were all effective interventions. The study found that a combination of interventions may work effectively against particulate matter and gaseous pollutants.[740]

There are many other indoor air quality initiatives underway in schools internationally. For example, the City of London is reportedly installing air filters in 200 schools, at a cost of £2.7m ($5.2m), including the cost of the filters, maintenance, school engagement, educational materials and monitoring the impact of the program.[741] In addition, the Schools' Air quality Monitoring for Health and Education program is establishing a network of air quality monitors in over 1,000 schools across the UK to help researchers better understand indoor air quality in schools. The monitors measure carbon dioxide, volatile organic compounds, particulate matter, temperature and relative humidity.[742]

In the USA, the Efficient and Healthy Schools Program, Center for Green Schools and the US EPA co-developed the Clean Air in Buildings Challenge for Schools online training course. The free, 6-module course covers ventilation, filtration, air cleaning and monitoring school indoor air quality.[743]

Also in the USA, Boston Public Schools has installed indoor air quality sensors in all classrooms, nurses' offices and main offices in schools across the district, with roof-top units installed to measure outdoor air as a baseline. The sensors measure carbon dioxide, carbon monoxide, airborne particulates (PM_{10} and $PM_{2.5}$), temperature and relative humidity. The sensors report in real-time, with the data used to identify, review, and respond to indoor air quality and temperature issues.[744]

In Latvia, indoor air quality is monitored in public schools, and social care and rehabilitation centres, with real-time levels of carbon dioxide, air temperature and relative humidity displayed on a publicly available website. Government funding is available for constructing ventilation systems.[745]

In Australia, there are various existing airborne infection in school-related national resources, including an October 2021 Australian Health Protection Principal Committee (AHPPC) statement on COVID-19, schools and reopening Australia, a January 2022 National Framework for Managing COVID-19 in Schools and Early Childhood, and national 'Help stop the spread' resources from May 2020.[746] The National Health and Medical Research Council recently released *Staying healthy: Preventing infectious diseases in early childhood education and care services - 6th edition*, providing ways for education and care services to help limit the spread of infectious diseases among children.[747]

The Victorian Government requires Victorian schools to continue to implement various practices to reduce the risk of COVID-19 transmission,[748] and provides ventilation and air purification guidance.[749] The ACT Government reportedly purchased over 1,000 carbon dioxide monitors for public schools to help schools improve ventilation.[750]

AIRAH, the Australian heating, ventilation, air conditioning and refrigeration industry association, has published guidance to improve school ventilation, *Guidance Document for Primary and Secondary Schools – COVID-19 Ventilation Optimisation*.[751] In February 2024, a non-government group launched the COVID Safety for Schools Course, a video-based course for principals and teachers at Australian primary and secondary schools about minimising the risk of COVID spreading at schools.[752] OzSAGE, another non-government group, published guidance on making schools and childcare safer.[753]

8.4.5 Residential aged care homes

Indoor air quality is important in residential aged care homes, as older people generally spend more time indoors than other people, and can be more susceptible to the health impacts of poor indoor air quality.[754]

A 2020 report from RMIT University for the Victorian Department of Environment, Land, Water and Planning and Virtual Centre for Climate Change Innovation reported on an investigation of indoor air quality in aged care homes (and schools) using one-year long monitoring and measurements. The study found the occupancy rates of aged care home common rooms varied significantly during the day. The study found carbon dioxide levels in the common rooms of up to 2,000ppm. The researchers also looked at the effect of adding a fresh filtered air ventilation system to the common rooms, and found that the system reduced the indoor carbon dioxide levels by up to 1,000ppm.[755]

The Australian Government introduced the National Aged Care Design Principles and Guidelines in July 2024. The Design Principles and Guidelines consider clinical supports and safety features, including infection prevention and control measures and good air quality and ventilation.[756]

The Principles and Guidelines are being introduced on a voluntary basis and the level of uptake within the aged care sector will inform recommendations about long-term arrangements and future regulatory considerations.[757]

The Australian Commission on Safety and Quality in Health Care published *The Aged Care Infection Prevention and Control Guide*.[758] This aims to support the prevention and control of infections in all settings where aged care is provided. The guide supplements *The Australian Guide for the Prevention and Control of Infection in Healthcare*, which sets out a national approach to infection prevention and control, focusing on core principles and how healthcare organisations can reduce the impact of infection-related risks.[759]

8.4.6 Planning, design and green screens

Outdoor pollution from, for example, vehicles and industry, can be worse near these pollution sources. A study in Wollongong and Liverpool, NSW, found particulate pollution at busy intersections at levels ten times worse than background levels measured at official air monitoring stations nearby.[760]

Land use planning, buffers, siting and design guidance can assist in reducing this outdoor air pollution from coming into nearby indoor spaces. This can have a particular impact where outdoor pollution sources are proposed to be near sensitive use sites like childcare centres, schools, residential aged care and hospitals.[761] It can also have a particular impact when high-density housing is zoned around pollution sources, such as busy roads, railway stations or rail freight routes. Green walls/spaces may also assist in reducing outdoor air pollution before it enters nearby buildings. However, this is likely to depend on species selection and location.[762] In particular, care should be taken not to compound air pollution issues by increasing the pollen load in the air.

Planning and design can also be used to reduce indoor sources of air pollution, and to address energy efficiency. The National Science and Technology Council identified an opportunity at the building planning stage for indoor air quality to be improved, avoiding the need for added interventions post-construction. It advised that the building industry should explicitly consider how the built environment could support natural ventilation as a lower cost intervention. It advises that government could support this planning step with updated building policy settings, considering current codes.[763]

Care is also needed to ensure that air-tightness energy efficiency upgrades do not reduce ventilation, with potentially significant airborne disease transmission risks and other health impacts. Recognising this, Asthma Australia recently called for sealing gaps to minimise infiltration of outdoor air pollution, support thermal comfort, and reduce energy costs, but without compromising indoor air quality.[764]

8.4.7 Clean air shelters

When outside air is heavily polluted, such as during bushfires or industrial incidents, people are sometimes advised to shelter in public buildings with central air conditioning systems. These buildings may include local libraries and shopping centres. There is some research and guidance examining the effectiveness of these shelters, including in Australian settings.[765]

8.5 Guidance, education and awareness

Safe Work Australia provides guidance around indoor air quality in occupational settings.[766] The Australian Building Codes Board provides guidance to assist in understanding the National Construction Code's indoor air quality requirements.[767] Several organisations provide health-related indoor air quality advice in healthcare settings, including the Australian Commission on Safety and Quality in Health Care and the Infection Control Expert Group. Australian, state and territory governments currently provide varying levels of public guidance on their webpages on the health impacts of indoor air quality.[768] The National Clean Air Agreement 2021-2023 work plan has better knowledge, education and awareness as one of its four key strategic approaches and includes a project aiming to ensure national consistency of public air quality information and health advice.[769]

While COVID-19 and bushfire smoke have raised awareness in some parts of the community of the importance of indoor air quality, there remains significant scope for additional guidance. This guidance would aim to motivate individuals to take steps to reduce the impacts of poor indoor air quality on their health. There is also scope to increase awareness among key professional stakeholders, including in the building, healthcare, aged care and education sectors.[770]

There is scope for provision of this guidance to be coordinated, with sharing of guidance materials and research within and between jurisdictions.

8.5.1 Professional guidance and education

Noting that many actions to improve indoor air quality depend on the people designing, using and maintaining buildings, the World Health Organization recommends that training should be provided to professionals, especially in the building sector (design, construction, operation and maintenance) and other decision-makers, including health professionals working in public health as well as clinical care.[771]

In the UK, a 2020 coroner's report found the adverse effects of air pollution on health were not being communicated sufficiently to patients and their families by medical and nursing professionals. The coroner called on this to be addressed at undergraduate and postgraduate levels and in professional guidance.[772] A 2020 joint publication of the UK Royal College of Physicians and the Royal College of Paediatrics and Child Health recommended that guidance should be provided to health professionals to understand the health risks of poor indoor air and how to support their patients with indoor air-related illnesses.[773]

Consideration could be given to including the health impacts of air pollution in curricula for medical and health professionals in Australia.

Additional guidance on indoor air quality issues in workplaces could also be considered.

8.5.2 Public guidance and education

The World Health Organization also recommends the dissemination of information to the public to raise public awareness and assist people to take reasonable measures to reduce the risks to their health from indoor air pollution.[774]

Systemic changes are likely to be more effective and proportionate than actions by individuals themselves in reducing some of the negative health effects of poor indoor air quality. However, while systemic changes are considered and implemented, a first step is to raise public awareness of the health impacts of indoor air quality.

Public guidance has been developed during this project and is available on the Australian Centre for Disease Control website at https://www.cdc.gov.au/topics/environmental-health/indoor-air-quality

An existing relevant short course is the University of Tasmania's free online short course on bushfire smoke, covering the physical and mental health impacts of bushfires and bushfire smoke, and what people can do to reduce their risk.[775]

Figure 5. Example of existing UK campaign





Source: https://m.facebook.com/northlincscouncil/videos/6628212050582386/?refsrc=deprecated&locale2=ms_MY&_rdr
[video animation – screenshots above]

8.5.3 Teaching air quality safety at school

Air quality safety could be taught in schools. Water, sun, road and food safety are referred to in the Australian Curriculum and may be covered under one of the eight learning areas or through a Curriculum Connection.[776] '[M]aintenance of clean air' is already referenced in the sustainability cross curriculum priority currently included in Version 9 of the Australian Curriculum.[777] Teaching activities could cover issues such as indoor air quality, and bushfire smoke.

8.5.4 Product information, labelling and rating schemes

The World Health Organization states that product information has a vital role in awareness raising and stimulating behaviour change.[778]

In Australia, the Australian Building Codes Board's *Indoor Air Quality Verification Methods Handbook* lists a number of data sources for low-emission materials.[779] In November 2024, the Green Building Council of Australia published Responsible Products Guidelines, including a focus area on healthy products, considering issues like occupational health and safety and chemicals of concern.[780]

Jurisdictions including Japan, France, Denmark, Finland and the United States have various product emission labelling schemes. Japan, for example, has a formaldehyde emission grade label that is placed on building materials (wooden materials, paints, adhesives, etc) that may emit formaldehyde.[781] The Finnish M-1 Label (Finnish Classification of Indoor Climate) is an emission classification of building materials that aims to promote the development and use of low-emitting building materials, fixed furniture and office furniture.[782] Denmark has Danish Indoor Climate Labelling, a labelling scheme for building materials, furniture and fixtures documenting the influence on indoor air quality.[783] The European Union has a harmonisation framework for health based evaluation of indoor emissions from construction products.[784] The US EPA developed the Safer Choice label, which includes a restriction on volatile organic compound content to minimise indoor air pollution and associated respiratory concerns.[785]

There are many indoor air quality devices coming onto the market in Australia, with different purposes, effectiveness, safety profiles, maintenance requirements, benefits and risks. For indoor air cleaning devices, the University of Melbourne publishes the *Guide to air cleaners.*[786] Several other jurisdictions have developed government-provided public guidance in relation to portable air purifiers. For example, in California, USA, the California Air Resources Board provides guidance on how to select a safe and effective air cleaner.[787]

In terms of rating air cleaning devices by their impact on indoor air quality, consideration could be given to adopting a system like the energy efficiency star rating schemes, but for pollutant removal efficacy instead of energy usage. In Belgium, air purification devices and carbon dioxide meters are covered by product health and environmental quality requirements defined as part of the legislation on product standards.[788]

Appendix A – Summary of air contaminants, sources and potential health effects

Table 1 is adapted from tables in the Australian Building Codes Board's *Indoor Air Quality Verification Methods Handbook* (2023).[789] Contaminants not included in the handbook tables include airborne microplastics, as well as particulate matter as a whole, PM_{10}, $PM_{2.5}$ or ultrafine particles.

Table 1. Summary of common air contaminants, their sources and potential health effects (source - Tables 2.1 to 2.6 of the ABCB's Indoor Air Quality Verification Methods Handbook[790])

Contaminant	Source	Health effects
Animal products		
Danders	Protein materials from skins of domestic animals.	Allergic responses in susceptible individuals, including asthma, hay fever, eczema and hives.
Particles from feathers, bird, bat and rodent excreta.	Birds & bats roosting in buildings, rodent infestation.	Shortness of breath, hay fever, wheezing and asthma.
Scales, hairs and faecal matter from dust mites, cockroaches and other insects and arthropods.	Microscopic mites (which feed on shed human and domestic animal skin scales). Other insects and arthropods.	House dust mite faecal matter and shed hairs can initiate asthmatic responses and various allergic conditions.
Microorganisms		
Bacteria such as *Legionella pneumophilia*	Waters and soils containing the organisms; e.g. aerosols from airconditioning system cooling towers & shower roses, dust from potting mix & building site debris.	Potential infectious agents. Infections may range from fever & cough to severe pneumonia and death. Potential sensitising agents, particularly airborne pyrogens.
Mycobacterium tuberculosis	Infected individuals.	Tuberculosis.

Contaminant	Source	Health effects
Moulds and mould metabolites	Fungi actively growing (Mycotoxins including Trichothecines, aflatoxins). Non actively growing fungi (Spores, hyphae fragments, organic metabolites).	Potential infectious agents. Allergic reactions. Allergic reactions.
Viruses	Viruses ... from infected people can remain viable in air for at least 2 hours.	Various viral diseases, from minor to life threatening including rhinovirus (common cold), influenza, measles, severe acute respiratory syndrome (SARS), middle east respiratory syndrome (MERS), COVID-19.
Combustion products		
Carbon monoxide	Incomplete combustion of carbon in fuels in gas fires and stoves, kerosene heaters, wood burning stoves and open fires, especially if with inefficient flues and poor ventilation; smoke; car exhaust in buildings, carparks and near busy roads.	Haemoglobin in the blood is converted to the more stable carboxyhaemoglobin, so that oxygen carrying capacity is reduced. This can lead to headache and nausea, dizziness, impaired vision, loss of brain function, unconsciousness and death. Particularly harmful to angina sufferers, pregnant women and their foetuses.
Carbon dioxide	Unvented heaters and stoves. People in overcrowded rooms.	Giddiness and headache. Loss of mental acuity.
Nitric oxide	Fuel burning, including unflued gas burners, smoke.	Respiratory disorders.
Nitrogen dioxide	Fuel burning especially gas and kerosene; smoke.	Respiratory disorders especially in young children and people with other respiratory illnesses, shortness of breath and wheezing. Since nitrogen dioxide is less soluble than, say, sulphur dioxide it penetrates much more deeply into the lungs, where it can cause acute lung damage. Eye irritation.
Sulphur dioxide	Wood burning fires and stoves.	Since sulphur dioxide dissolves to form sulphurous acid it has an irritant effect on moist surfaces of the nasal passages. The adverse effects are increased with increased body activity. Sulphur dioxide deposited on mucous membranes is transported by the bloodstream and damages liver tissue. Effects are more severe in the elderly and people with respiratory disorders.

Contaminant	Source	Health effects
Organic compounds		
Formaldehyde (…[methanal])	Urea-formaldehyde insulating foam, particle board, carpet backing, permanent-press clothing, cigarette smoke.	Eye irritation, dermatitis, headaches, nausea and respiratory complaints. Carcinogenic.
Insecticides		
Organochlorides, including aldrin and dieldrin.	Soil treatment for termite control.	Highly toxic, especially to nerve and liver tissue. Carcinogenic.
Chlordane/ heptachlor	Termite, ant, cockroach and spider control.	Nausea, headaches, convulsions. Damages membranes. Suspected carcinogen.
Dichlorvos	Some pest strips and flea collars. Some surface spray insecticides.	Flu-like symptoms, breathing difficulties, asthma.
Lindane	Flea control and some head lice treatments.	Affects liver function.
Others		
Organic solvents	Adhesives, cosmetics, solvents, polyurethane insulation materials, paints, cleaning liquids, duplicating machines, various plastics, correction fluids, and smoke.	Effects vary with the solvent concerned. Many cause irritation of eyes and respiratory tract; some cause nausea; some are carcinogenic.
Ozone	Photocopiers, ultraviolet light sources, electrostatic air cleaners, car exhausts, photochemical smog.	Respiratory disorders, especially in asthmatics, the elderly and people with pre-existing respiratory diseases, eye irritation. Reduced exercise capability.
Radon and radon daughters	Radioactive decay of uranium-238 in soil, masonry, depending on the geographic region. Particularly high in granite regions.	Carcinogenic, especially with respect to lung cancer. The effect with smoke is greater than additive.

Appendix B – Examples of air quality standards and guidance levels relevant to indoor air quality

This appendix looks at the following examples of air quality standards and guidance levels relevant to indoor air quality:

- **Morawska et al** (2024)[791]
- **Safe Work Australia** *Workplace exposure standards for airborne contaminants*[792] (to transition to workplace exposure limits from December 2026)[793, i]
- **Australian Building Codes Board** *Indoor air quality Verification Methods Handbook*[794]
- **NHMRC** previously recommended indoor air quality goals[795]
- **AS 1668:** The use of ventilation and airconditioning in buildings[796]
- **National Aged Care** Design Principles and Guidelines[797]
- **France** – Regulatory system for monitoring indoor air quality
- **Japan** – Standards for air environment and health management of buildings (as at 2020)[798]
- **Thailand** – Notification of the Department of Health regarding Indoor Air Quality Monitoring Standards in Public Building B.E. 2565 (2022)[799]
- **Hong Kong** – *A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places*[800]
- **Canadian** *Residential indoor air quality guidelines*[801 ii]
- **World Health Organization 2010** *WHO Guidelines for indoor air quality: selected pollutants*[802]
- **World Health Organization 2021** *Air Quality Guidelines*[803]
- National Environment Protection (Ambient Air Quality) Measure **(NEPM (AAQ))** [804]

i The Safe Work Australia Workplace exposure standards for airborne contaminants are measured in the breathing zone of the worker by an appropriately trained person. Inclusion in the table is for information, noting measurements under other standards in the table are determined using other types of air or environmental monitoring.

ii Also has recommended exposure limits for acetaldehyde, acrolein, toluene and xylenes (not included in this table).

Table 2. Examples of air quality standards and guidance levels relevant to indoor air quality

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
$PM_{2.5}$	Morawska et al	15 µg/m³	1 hour
	Australian Building Codes Board	25 µg/m³	24 hour (99th percentile)
		10 µg/m³	1 year
	Thailand	No more than 25 µg/m³	24 hour average
	World Health Organization 2021	15 µg/m³	24-hour (99th percentile) (i.e. 3-4 exceedance days per year)
		5 µg/m³	Annual
	NEPM (AAQ)	25 µg/m³	1 day
		8 µg/m³ [i]	1 year
PM_{10}	Australian Building Codes Board	50 µg/m³	24 hour (99th percentile)
		20 µg/m³	1 year
	NHMRC	90 µg/m³ [ii]	1 year
	Japan	0.15 mg/m³ [iii]	Measured at least every 2 months or more frequently
	Thailand	50 µg/m³	24 hour average
	Hong Kong	20/100 µg/m³	8-hour
	World Health Organization 2021	45 µg/m³	24-hour (99th percentile) (i.e. 3-4 exceedance days per year)
		15 µg/m³	Annual (99th percentile) (i.e. 3-4 exceedance days per year)
	NEPM (AAQ)	50 µg/m³	1 day
		25 µg/m³	Annual (99th percentile) (i.e. 3-4 exceedance days per year)

i Table 2 of the National Environment Protection (Ambient Air Quality) Measure states the goal for $PM_{2.5}$ from 2025 is 20 µg/m³ (1 day) and 7 µg/m³ (1 year).
ii 'Total suspended particulates' rather than PM_{10} specifically.
iii 'Suspended particles' rather than PM_{10} specifically.

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Carbon dioxide	Morawska et al	800 ppm (absolute value, scenario-based)	Threshold
		350 ppm (delta)	Threshold
	Safe Work Australia	5,000 ppm	eight hour time weighted average (TWA)[i]
		30,000 ppm [805]	short term exposure limit (STEL)[ii]
	Australian Building Codes Board	850 ppm[iii]	8 hours
	National Aged Care	1,000 ppm	
	France	800 ppm indicates satisfactory air exchange[806]	Direct-reading measurement (at least two hours)
	Japan	1,000 ppm	Measured at least every 2 months or more frequently
	Thailand	No more than 1,000 ppm	
	Hong Kong	1,440/1,800 mg/m^3	8 hour
		800/1,000 ppmv	8 hour
	Canada	1,800 mg/m^3	24 hours
		(1,000 ppm)	

i TWA - the maximum average airborne concentration of a substance when calculated over an eight hour working day, for a five day working week.
ii STEL - a 15 minute time weighted average exposure limit which must not be exceeded at any time during an eight hour working day, even if the exposure during the full day is less than the TWA exposure standard. Exposures at the STEL must not be longer than 15 minutes and must not be repeated more than four times per day. There must be at least 60 minutes between successive exposures at the STEL.
iii Based on body odour metric (i.e. 450 ppm above ambient CO2 level of 400 ppm).

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Carbon monoxide	Morawska et al	100 mg/m^3	15 mins
		35 mg/m^3	1 hour
		10 mg/m^3	8 hours
	Safe Work Australia	34 mg/m^3 (30 ppm)[807]	eight hour time weighted average (TWA)
	Australian Building Codes Board	90 ppm	15 mins
		50 ppm	30 mins
		25 ppm	1 hour
		10 ppm	8 hours
	NHMRC	9 ppm	8 hour
	Japan	10 ppm	Measured at least every 2 months or more frequently
	Thailand	No more than 9 ppm	
	Hong Kong	2,000/7,000 µg/m^3	8 hour
		1.7/6.1 ppmv	8 hour
	Canada	28.6 mg/m^3 (25 ppm)	1 hour
		11.5 mg/m^3 (10 ppm)	24 hours
	World Health Organization 2010	100 mg/m^3	15 mins
		35 mg/m^3 [i]	1 hour
		10 mg/m^3	8 hours
		7 mg/m^3	24 hours
	World Health Organization 2021	4 mg/m^3	24-hour (99th percentile) (i.e. 3-4 exceedance days per year)
	NEPM (AAQ)	9.0 ppm	8 hours

i Assuming the 15 minutes and 1 hour exposure levels do not occur more often than once per day.

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Nitrogen dioxide	Safe Work Australia	3 ppm (5.6 mg/m^3)	eight hour time weighted average (TWA)
		5 ppm (9.4 mg/m^3)	short term exposure limit (STEL)
	Australian Building Codes Board	200 µg/m^3 (0.0987 ppm)	1 hour
		40 µg/m^3 (0.0197 ppm)[i]	1 year
	NHMRC	Under review at time of publication (2002)	Under review at time of publication
	Hong Kong	40/150 µg/m^3	8 hour
		21/80 ppbv	8 hour
		100/200 µg/m^3	1 hour
		53/106 ppbv	1 hour
	Canada	20 µg/m^3 (11 ppb)	24 hours
		170 µg/m^3 (90 ppb)	1 hour
	World Health Organization 2010	200 µg/m^3	1 hour average
		40 µg/m^3	annual average
	World Health Organization 2021	25 µg/m^3	24-hour (99th percentile) (i.e. 3-4 exceedance days per year)
		10 µg/m^3	Annual
	NEPM (AAQ)	0.080 ppm	1 hour
		0.015 ppm	1 year

i Based on pressure of 101.325 kPa and temperature of 25°C (i.e. the conversion is mg/m^3 = ppm (molecular weight/24.4)).

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Ozone	Safe Work Australia	0.1 ppm (0.2 mg/m^3) peak limitation	eight hour time weighted average (TWA)
	Australian Building Codes Board	100 µg/m^3 (0.0473 ppm)	8 hour, daily maximum limit
	NHMRC	120 ppb	1 hour
	Thailand	No more than 0.05 ppm	
	Hong Kong	50/120 µg/m^3	8 hour
		25/61 ppbv	8 hour
	Canada	40 µg/m^3 (20 ppb)	8 hours
	WHO 2021	60 µg/m^3	Peak season[i]
		100 µg/m^3	8 hour
	NEPM (AAQ)	0.065 ppm[ii]	8 hours
Formaldehyde	Safe Work Australia	1 ppm (1.2 mg/m^3)	eight hour time weighted average (TWA)
		2 ppm (2.5 mg/m^3)	short term exposure limit (STEL)
	Australian Building Codes Board	0.1 mg/m^3	30 mins
	NHMRC	130 µg/m^3	
	France	100 µg/m^3 [808]	Short-term exposure
	Japan	0.1 mg/m^3 (0.08 ppm)	Conditionally measured; when newly-built, repaired, reformed
	Thailand	No more than 0.08 ppm, no more than 100 ug/m^3	
	Hong Kong	30/100 µg/m^3	8 hour
		24/81 ppbv	8 hour
		70/100 µg/m^3	30 mins
		57/81 ppbv	30 mins
	Canada	50 µg/m^3 (40 ppb)	8 hours
		123 µg/m^3 (100 ppb)	1 hour
	World Health Organization 2010	0.1 mg/m^3	30-minute average

i Average of daily maximum 8-hour mean ozone concentration in the six consecutive months with the highest six-month running average ozone concentration. Note: Annual and peak season is long-term exposure, while 24 hour and 8 hour is short-term exposure.
ii 'Photochemical oxidants (as ozone)'.

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Total volatile organic compounds	Australian Building Codes Board	500 µg/m^3	1 hour
	NHMRC	500 µg/m^3 [i]	
	Thailand	No more than 1,000 ppm	
	Hong Kong	200/600 µg/m^3	8 hour
		87/261 ppbv	8 hour
Sulphur dioxide	Safe Work Australia	2 ppm (5.2 mg/m^3)	eight hour time weighted average (TWA)
		5 ppm (13 mg/m^3)	short term exposure limit (STEL)
	NHMRC	500 ppb	10 min
		220 ppb	1 hour
		20 ppb	1 year
	World Health Organization 2021	40 µg/m^3	24-hour (99th percentile) (i.e. 3-4 exceedance days per year)
	NEPM (AAQ)	0.10 ppm	1 hour
		0.02 ppm	1 day
Benzene	Safe Work Australia	1 ppm (3.2 mg/m^3)	eight hour time weighted average (TWA)
	France	2 µg/m^3	Long-term exposure
	Hong Kong	5.3 ppbv (17 ug/m^3)	8 hour
	World Health Organization 2010	No safe level of exposure can be recommended	
Tetrachloroeth-ylene	Safe Work Australia	50 ppm (340 mg/m^3)	eight hour time weighted average (TWA)
		150 ppm (1020 mg/m^3)	short term exposure limit (STEL)
	Hong Kong	37 ppbv (250 µg/m^3)	8 hour
	World Health Organization 2010	0.25 mg/m^3	annual average

i With single volatile organic compounds at 50% total volatile organic compounds concentration.

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Trichloroeth-ylene	Safe Work Australia	10 ppm (54 mg/m^3) 40 ppm (216 mg/m^3)	eight hour time weighted average (TWA) short term exposure limit (STEL)
	Hong Kong	43 ppbv (230 µg/m^3)	8 hour
	World Health Organization 2010	Risks and concentrations discussed but no threshold provided	
Naphthalene	Safe Work Australia	10 ppm (52 mg/m^3) 15 ppm (79 mg/m^3)	eight hour time weighted average (TWA) short term exposure limit (STEL)
	Hong Kong	1.9 ppbv (10 ug/m^3)	8-hour
	Canada	10 µg/m^3 (1.9 ppb)	24 hours
	World Health Organization 2010	0.01 mg/m^3	annual average
Polycyclic Aromatic Hydrocarbons (as benzo(a) pyrene)	Hong Kong	1.2 x 10^{-4} ppbv (1.2 ng/m^3)	8 hour
	World Health Organization 2010	No threshold can be determined and all indoor exposure is considered relevant to health	
Radon	NHMRC	200 Bq/m^3	1 year
	France	300 Bq/m^{-3}	
	Hong Kong	150/167 Bq/m^{-3}	8-hour
	Canada	200 Bq/m^3	Exposure limit
	World Health Organization 2010	Risks and concentrations discussed but no threshold provided	
Lead	Safe Work Australia	0.05 mg/m^3	eight hour time weighted average (TWA)
	NHMRC	1.5 µg/m^3	3 month
	NEPM (AAQ)	0.50 µg/m^3	1 year

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Total bacterial count	Thailand	No more than 500 CFU/m^3	1 year
	Hong Kong	500/1,000 cfu/m^3	8 hour
Mould	Hong Kong	Assessment in form of prescriptive checklist	
Total fungal count	Thailand	No more than 500 CFU/m^3	
Ventilation (other than carbon dioxide proxy – set out in carbon dioxide row above)	Morawska et al	14 litres/s per person clean air supply rate in the breathing zone	When the space is occupied
	Australian Building Codes Board	Provides guidance on how to comply with National Construction Code ventilation provisions	
	AS 1668	10 litres/s per person minimum effective outdoor airflow (mechanical ventilation) Direct ventilation openings like operable external windows and doors, with an area of not less than 5% of the floor area of the enclosed space (natural ventilation)	
	National Aged Care	Guideline 1.9 makes a number of recommendations, including spot checking indoor air quality, creating cross-ventilation, and maximising use of outdoor areas.	
	France	Annual ventilation assessments required. [809]	

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Ventilation cont.	Hong Kong	Ventilation rate: For office – 8.5 L/s/person For mall – 4.6 L/s/person Occupancy density: For office – layout plan (7-10 occupants/100m^2 For mall – occupancy permit (40 transient occupants/100m^2)	
Indoor spaces	Morawska et al	Public spaces	
	Safe Work Australia	Workplaces	
	Australian Building Codes Board	Most buildings[i]	
	NHMRC	For formaldehyde – residences, schools	
	AS 1668	Most new building types	
	National Aged Care	Residential aged care homes	
	France	Facilities hosting children under six years old, nursery schools and primary schools, recreational facilities and secondary education or vocational training places	
	Japan	Gross floor space > 3,000 m^2 (exclusively, school > 8,000 m^2)	

i Higher maximum exposure levels for carbon monoxide in carparks.

Pollutant	Standard/source	Level	Averaging time or set point (AT or SP)
Indoor spaces cont.	Thailand	Buildings used for public gatherings for public activities such as politics, education, religion and society recreational or commercial facilities where air conditioning systems are used[810, i]	
	Hong Kong	Offices and public places	
	Canada	Residential	
	World Health Organization 2010	Indoor exposure to air pollutants	
	World Health Organization 2021	Outdoor and indoor environments globally, other than occupational settings (due to specific characteristics of the relevant exposure and risk reduction policies and potential differences in population susceptibility of the adult workforce in comparison with general population)	
	NEPM (AAQ)	Monitored in ambient air	

i Public buildings include: office buildings; shopping malls, shopping centres, supermarkets; convention centre buildings, auditoriums, meeting rooms, exhibition centres; services facilities; food and beverage facilities; fitness facilities, indoor sports; schools; hotels; theatres; public transit buildings; library, art gallery, museums; religious buildings; aged care; early childhood; other public buildings can apply indoor air quality monitoring values as appropriate.

Appendix C – Public guidance

Australian Centre for Disease Control 'Indoor air quality' webpage

- https://www.cdc.gov.au/topics/environmental-health/indoor-air-quality
- linked from Australian Centre for Disease Control 'Air quality' website (https://www.cdc.gov.au/topics/environmental-health/air-quality)

Indoor air quality

Australians spend most of our time indoors. The air quality within these spaces affects our health. Learn about how you can improve indoor air quality.

Indoor air quality

Indoor air quality is affected by many things, including:

- outside air pollution coming inside, such as emissions from vehicles and industry and smoke from bushfires and wood heaters
- particulate matter from sources in the home, such as wood heaters
- volatile organic compounds, such as formaldehyde, emitted from building materials and furnishings
- microorganisms like viruses, bacteria and fungi (including moulds) which can be transmitted through the air
- gases like carbon dioxide, carbon monoxide and nitrogen dioxide from sources such as gas heaters, cooktops and stoves
- tobacco smoke and vape aerosols
- dust, dust mites and pollen
- asbestos
- lead
- pollutants from domestic pets, such as pet dander.

Indoor air can have much higher concentrations of some pollutants and different health risks than outdoor air.

Learn more about specific indoor air pollutants.

Health impacts of poor indoor air quality

Health impacts from air pollution in indoor environments include:

- carbon monoxide poisoning from using wood or gas heaters without enough ventilation
- transmission of infectious diseases like influenza, RSV and COVID-19 by airborne viruses
- respiratory and cardiovascular impacts from particulate matter
- asthma from dust mite allergens.

High levels of carbon dioxide and particulate matter pollution can affect educational results in school classrooms and reduce workplace productivity.

Ways to improve indoor air quality

There are simple ways to improve indoor air quality and reduce health problems. You can:

- not smoke or vape
- increase outside air flow by opening windows (if the outside air is clean)
- wear a P2 or N95 respirator mask to reduce the spread of airborne viruses
- use high efficiency particulate air (HEPA) filters suitable for the size of the indoor space
- when cooking, use a high-efficiency exhaust fan vented outside to remove emissions and cooking odours
- use an exhaust fan to remove steam and moist air
- keep exhaust fans clean from dirt and grease
- avoid generating moisture indoors (for example, using a clothes dryer without sufficient ventilation) or having damp surfaces that encourage microbiological growth
- manage moisture in buildings, in both the internal environment and in the fabric of the building itself
- use a door mat to help keep outdoor dust out
- remove indoor dust regularly, and clean air conditioner filters regularly
- ensure any mechanical ventilation systems are well-maintained, and have a high-grade filter, to bring clean outside air indoors
- where possible, choose an alternative method than a wood heater to heat your home
- avoid cleaning products, air fresheners, scents and sprays, cosmetics, glues, paint, varnishes, carpet and fibreboard with high volatile organic compound content
- avoid running a vehicle engine in a garage attached to a dwelling
- avoid using charcoal bead cookers, barbecues, camping stoves or outdoor heaters indoors
- keep your pets and their bedding clean.

Make sure you have sufficient ventilation, even when sealing draughts to save money on heating and cooling costs.

What to do if the outside air is polluted

Keep inside air as clean as possible from outdoor air pollutants such as smoke, vehicle fumes and industrial pollution. You can:

- close windows and doors during short episodes of outside air pollution and open them when air quality improves
- use a reverse cycle air conditioner or set other types of air conditioners to recirculate indoor air during short episodes of outside air pollution
- avoid using evaporative coolers during short episodes of outside air pollution, as they bring outside air inside
- during lengthy periods of outside air pollution, air out indoor spaces when the outside air quality improves even temporarily
- use a suitable HEPA filter to reduce airborne viruses and some other indoor air pollutants
- wear a P2 or N95 respirator mask.

If you or anyone in your care has trouble breathing, chest pain or discomfort call 000 for an ambulance.

People who are sensitive to smoke should actively monitor symptoms and follow their health management plan recommended by their doctor.

More information

Find more information about:

- indoor air quality in homes
- ventilation and reducing the risk of COVID-19 transmission
- choosing an air purifier (including HEPA filters)
- face masks
- wood heaters and their alternatives
- the Australian Government's Energy Savings Package, which will support upgrades to household energy efficiency
- the links between indoor air quality and climate change in the National Health and Climate Strategy
- managing air quality risk in workplaces
- guidance on good air quality and ventilation in residential aged care home in the National Aged Care Design Principles and Guidelines.

Appendix D – Descriptions of some indoor air pollutants

Asbestos is a group of six types of naturally occurring, rock forming silicate minerals made up of thin, microscopic fibres or a mixture that contains one or more of these minerals. Before being banned, asbestos was used in a range of industries including in the construction and transport industries, and can be found in older buildings and products, such as fibrous cement sheeting, flue pipes, drains, roofs, gutters, brakes, clutches and gaskets.[811]

Carbon dioxide is produced by human and animal respiration, and also through the combustion of carbon-based materials such as fuels, gas and wood.

Carbon monoxide is a colourless, tasteless, odourless, non-irritating, but very toxic, gas. It is produced from the incomplete combustion of fuels such as kerosene, gas, wood or charcoal, as well as in cigarette smoke, and can build up in poorly ventilated garages.[812]

Microplastics – tiny pieces of plastic - are increasingly present throughout the environment. Airborne microplastics are increasingly being recognised as an emerging contaminant and potential risk to human health. These tiny fragments of plastic can be inhaled, and have been found in the lungs and bloodstream, and in organs and tissues throughout the body.[813]

Mould is a type of fungus that grows in moist or humid places. Mould spores and fragments in the air can be inhaled or swallowed.[814]

Nitric oxide (NO) and **nitrogen dioxide (NO_2)** are two of the most toxicologically significant oxides of nitrogen.[815] Traffic is the main outdoor source of nitrogen dioxide, and outdoor sources can influence indoor concentrations. Indoor sources include tobacco smoke, as well as gas and wood burning appliances such as cooktops, ovens, space and water heaters and fireplaces, particularly unflued or poorly maintained appliances. Underground parking garages can have high levels of nitrogen dioxide.[816]

Particulate matter - PM or particle pollution - is a mixture of solid and liquid particles in the air categorised by size (but not by constituents, so can consist of many substances). PM_{10} is particulate matter with a diameter of 10 µm or less; $PM_{2.5}$ is fine particulate matter, with a diameter of 2.5 µm or less; and PM0.1 is ultrafine particulate matter, with a diameter of 0.1 µm or less.[i] To give a sense of scale, a human hair strand has an average diameter of 50 to 70 µm.[817]

Per- and poly-fluoroalkyl substances (PFAS), are a class of manufactured chemicals that have been used to make products that resist heat, stains, grease, and water. There are many different types of PFAS, including perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA).[818]

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i µm = micrometre. 1 µm is the same length as one millionth of a metre.

Polycyclic aromatic hydrocarbons are formed by the incomplete combustion of coal, oil, petrol, wood, tobacco and other organic materials.[819] Naphthalene is traditionally used as the main ingredient in mothballs for home use. It also has industrial and veterinary uses.

Radon is a naturally occurring radioactive gas that comes from rocks and soil. It releases radioactive particles when it decays.

Sulphur dioxide is a non-flammable, colourless gas with a strong odour.[820]

Viruses are tiny infectious agents that multiply inside the cells of a host organism. There is robust evidence supporting the airborne transmission of many respiratory viruses.[821]

Volatile Organic Compounds (VOCs), are organic chemicals that are generally liquids at room temperatures but being volatile, they are capable of forming vapours in air. They often arise in indoor air from organic solvents used in a diverse range of building and consumer products as these dry over days to months. Tobacco smoke and e-cigarette aerosols both contain VOCs.[822] Several hundred VOCs may exist in indoor air environments. The World Health Organization has defined organic compounds based on boiling points as: VOCs, very volatile organic compounds (VVOCs) and slightly volatile organic compounds (SVOCs). This report uses the term VOCs for these for simplicity. A measure known as total VOC (TVOC) is an aggregated concentration of all VOCs in the boiling point range of ~60-80°C to 240-260°C.

Other indoor air pollutants discussed in this report include:

- **bacteria**
- **cosmetics, fragrances, aerosol deodorants and cleaning products**
- **environmental tobacco smoke and vape aerosols**
- **human skin cells, bioeffluents, dust mites, and animal dander, hair and excreta**
- **lead and other heavy metals**
- **ozone**
- **pollen**
- **silica dust.**

References

1 Editorial, 'Indoor air pollution kills and science needs to step up', *Nature*, 2023, 614:196, doi:10.1038/d41586.023.00338.0.

2 JD Pleil, MAG Wallace, MD Davis and CM Matty, 'The physics of human breathing: flow, timing, volume, and pressure parameters for normal, on-demand, and ventilator respiration', *Journal of Breath Research*, 2021, 15(4), p.7, doi:10.1088/1752-7163/ac2589; and United States Environmental Protection Agency (US EPA), *Exposure Factors Handbook* (2011 Edition) Chapter 6, US EPA website, 2011.

3 DE Schraufnagel, JR Balmes, CT Cowl, S De Matteis, S Jung, K Mortimer, R Perez-Padilla, MB Rice, H Riojas-Rodriguez and 5 more authors, 'Air Pollution and Noncommunicable Diseases A Review by the Forum of International Respiratory Societies' Environmental Committee, Part 1: The Damaging Effects of Air Pollution', CHEST, 2019, 155(2):409-416, doi:10.1016/j.chest.2018.10.041.

4 University of Wollongong, *The Impact of Indoor Air Quality on the Transmission of Airborne Diseases in Public Buildings. A report to the National Science and Technology Council, Australian Government, Canberra* [PDF], Chief Scientist's website, 2024, accessed 9 April 2025.

5 DG Pillay, B Dodd, A Cartwright, N Borchers Arriagada, P Jones, C Cowie, R Norman and FH Johnston, *Safer Air, Healthier Communities: Ten reasons for investment in Australia* [PDF], Centre for Safe Air website, 2023, p.iii, accessed 9 April 2025.

6 G Boulanger, T Bayeux, C Mandin, S Kirchner, B Vergriette, V Pernelet-Joly and P Kopp, 'Socio-economic costs of indoor air pollution: A tentative estimation for some pollutants of health interest in France', *Environment International*, 2017, 104:14-24, doi:10.1016/j.envint.2017.03.025. See also ANSES, CSTB and Observatoire de la qualite de l'air interieur (OQAI), *Socio-economic cost of indoor air pollution* [PDF in French], OQIA website, 2014, accessed 9 April 2025.

7 N Liu, W Liu, F Deng, Y Liu, X Gao, L Fang, Z Chen, H Tang, S Hong, M Pan and 25 more authors, 'The burden of disease attributable to indoor air pollutants in China from 2000 to 2017', *Lancet Planetary Health*, 2023, 7(11):E900-E911, doi:10.1016/S2542-5196(23)00215-2.

8 TJ Phillips, 'The Cost of Health and Productivity Impacts of Indoor Air Pollution in California', *Epidemiology*, November 2008, 19(6):S324, doi:10.1097/01.ede.0000340509.02236.07.

9 Australian Bureau of Statistics (ABS), 'Economic gains and losses over the COVID-19 pandemic', ABS website, 7 August 2022, accessed 9 April 2025.

10 L Morawska, J Allen, W Bahnfleth, B Bennett, P M Bluyssen, A Boerstra, G Buonanno, J Cao, S J Dancer, A Floto and 33 more authors, 'Mandating indoor air quality for public buildings', *Science*, 2024, 383, 1418-1420, doi:10.1126/science.adl0677.

11 Environmental Health Standing Committee (enHealth), *Environmental Health Risk Assessment—Guidelines for assessing human health risks from environmental hazards* [PDF], Department of Health and Aged Care (DoHAC) website, 21 March 2024, Table 7, accessed 29 April 2025.

12 World Health Organization (WHO), 'WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide', WHO website, 21 September 2021, accessed 29 April 2025.

13 JG Allen, P MacNaughton, U Satish, S Santanam, J Vallarino and JD Spengler, 'Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: a controlled exposure study of green and conventional office environments', *Environmental Health Perspectives*, 2015, 124(6):805-812, doi:10.1289/ehp.1510037; and M Pulimeno, P Piscitelli, S Colazzo, A Colao and A Miani, 'Indoor air quality at school and students' performance: Recommendations of the UNESCO Chair on Health Education and Sustainable Development & the Italian Society of Environmental Medicine (SIMA)', *Health Promotion Perspectives*, 2020, 10(3):169-174, doi:10.34172/hpp.2020.29. See also, though noting variability in outdoor air $PM_{2.5}$ concentrations and lack of assessment of other potential influences on performance, JGC Laurent, P MacNaughton, E Jones, AS Young, M Bliss, S Flanigan, J Vallarino, LJ Chen, X Cao and JG Allen, 'Associations between acute exposures to $PM_{2.5}$ and carbon dioxide indoors and cognitive function in office workers: a multicountry longitudinal prospective observational study' , *Environmental Research Letters*, 2021, 16(9):094047, doi:10.1088/1748-9326/ac1bd8; and C Sweeney, *Office air quality may affect employees' cognition, productivity* [media release], Harvard T.H Chan School of Public Health website, 9 September 2021, accessed 29 April 2025.

14 European Commission Scientific Committee on Health and Environmental Risks (SCHER), M Fernandez and GreenFacts, 'Indoor Air Quality', European Commission website, 2008, accessed 29 April 2025.

15 Department of Environment and Heritage (DEH), 'State of Knowledge Report: Air Toxics and Indoor Air Quality in Australia', DEH website, 2001, accessed 27 April 2025; and JE Yocom, 'Indoor-Air Quality Relationships: A Critical Review', *Journal of the Air Pollution Control Association*, 1982, 32(5):500-520, doi:10.1080/00022470.1982.10465427.

16 The Australian Building Codes Board (ABCB), *Indoor Air Quality Verification Methods Handbook* [PDF], ABCB website, 2023, p.82, accessed 9 April 2025.

17 United States Environmental Protection Authority (US EPA), *Targeting Indoor Air Pollution EPA's Approach and Progress* [PDF], US EPA website, 1993.

18 SK Brown, 'Volatile organic pollutants in new and established buildings in Melbourne, Australia', *Indoor Air*, 2002, 12:55–63, doi:10.1034/j.1600-0668.2002.120107.x.

19 SB Molloy, M Cheng, IE Galbally, MD Keywood, SJ Lawson, JC Powell, R Gillett, E Dunne and PW Selleck, 'Indoor air quality in typical temperate zone Australian dwellings', *Atmospheric Environment*, 2012, 54:400-407, doi:10.1016/j.atmosenv.2012.02.031.

20 NB Goodman, AJ Wheeler, PJ Paevere, PW Selleck, M Cheng and A Steinemann, 'Indoor volatile organic compounds at an Australian university', *Building and Environment*, 2018, 135:344-351, doi:10.1016/j.buildenv.2018.02.035.

21 S Nath, M Dewsbury and J Douwes, 'Has a singular focus of building regulations created unhealthy homes?', *Architectural Science Review*, 2020, 63(5):387-401, doi:10.1080/00038628.2019.1703636. See also Victorian Government, *Victorian Government response to the Coroners Court inquest into the death of Sonia Sofianopoulos* [PDF], Department of Energy, Environment and Climate Action website, n.d., accessed 9 April 2025.

22 Safe Work Australia (SWA), 'Topic/Asbestos – Overview', SWA website, n.d., accessed 9 April 2025.

23 See University of Wollongong, op. cit. n.4; and CR Du, SC Wang, MC Yu, TF Chiu, JY Wang, PC Chuang, R Jou, PC Chan and CT Fang, 'Effect of ventilation improvement during a tuberculosis outbreak in underventilated university buildings', *Indoor Air*, 2020 May, 30(3):422-432, doi:10.1111/ina.12639.

24 United Nations International Childrens Emergency Fund (UNICEF), *Childhood Air Pollution Exposure Key Messages* [PDF 1,204KB], UNICEF website, 2022, accessed 9 April 2025.

25 See, for example, D Dam, M Chen, EE Rees et al, 'Risk factors associated with the intensity of COVID-19 outbreaks in Canadian community settings: a retrospective analysis of outbreak-level surveillance data', *BMC Public Health*, 2024, 24:2409, doi:10.1186/s12889-024-19853-4.

26 See, for example, S Haddad, A Synnefa, R Paolini and M Santamouris, 'Indoor air and environmental quality in social housing dwellings in Australia', 40th AIVC - 8th TightVent - 6th venticool Conference - Ghent, Belgium - 15-16 October 2019, AIVC website, 2019, accessed 9 April 2025.

27 National Science and Technology Council, *The impact of indoor air quality on the transmission of airborne diseases in public buildings – NSTC advice to government* [PDF], August 2024, accessed 9 April 2025.

28 K Emmerson, 'How will a changing climate (and emissions reduction measures) impact sources of air pollution and secondary pollutant formation?', National Environmental Science Program Sustainable Communities and Waste Hub - Air Quality Stream mid-point follow-up workshop, 14 August 2024, accessed 9 April 2025.

29 UK Royal College of Physicians, Every breath we take: The lifelong impact of air pollution. Report of a working party. London: RCP, 2016, p.21.

30 R Akbar, *Ten threats to global health in 2019* [media release], World Health Organization (WHO) website, 2019, accessed 9 April 2025.

31 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Australia State of the Environment Report: Air Quality Key Findings', DCCEEW website, 2021, accessed 9 April 2025.

32 S Brown, 'National State of the Environment Report – Indoor Air Quality', Department of Environment, Sports and Territories, Canberra, 1997; and Department of Environment and Heritage (DEH), op. cit. n.15.

33 See also P Dingle and P Franklin, 'Formaldehyde levels and the factors affecting these levels in homes in Perth, Western Australia', *Indoor and Built Environment*, 2002, 11(2), doi:10.1177/1420326X0201100206; and L Morawska, C He, J Hitchins, K Mengersen and D Gilbert, 'Characteristics of particle number and mass concentrations in residential houses in Brisbane, Australia', *Atmospheric Environment*, 2003, 37(30): 4195-4203, doi:10.1016/S1352-2310(03)00566-1; and Molloy et al, op. cit. n.19.

34 The Australian Building Codes Board, op. cit. n.16, p 11.

35 CJ Weschler and HC Shields, 'The influence of ventilation on reactions among indoor pollutants: *modeling* and experimental observations', *Indoor Air*, 2000, 10(2):92-100, doi:10.1034/j.1600-0668.2000.010002092.x.

36 R Oommen, J Hauser, D Dayton, J Swift, M Jones, A Pope and J Hemby, *Identifying Priority Hazardous Air Pollutants of Potential Concern: A Comparison* [PDF 150KB], Eastern Research Group, Inc. (ERG, Inc.) and United States Environmental Protection Agency (US EPA), n.d., accessed 9 April 2025.

37 Environmental Health Standing Committee, *enHealth guidance – Guidance for public health agencies – Managing prolonged smoke events from landscape fires* [PDF], Department of Health and Aged Care website, 19 August 2024, accessed 9 April 2025.

38 G Morantes, B Jones, C Molina and MH Sherman, 'Harm from Residential Indoor Air Contaminants', *Environ Sci Technol.*, 2024 Jan 9, 58(1):242-257, doi:10.1021/acs.est.3c07374. See also G Morantes, B Jones, M Sherman and C Molina, 'A preliminary assessment of the health impacts of indoor air contaminants determined using the DALY metric', *International Journal of Ventilation*, 2023, 22(4):307-316, doi:10.1080/14733315.2023.2198800; and M Wilson, 'Moving Toward a Health-Based Ventilation Standard: A Conversation with Max Sherman', Energy Technologies Area Berkeley Lab, April 3 2013, accessed 9 April 2025; and WJ Fisk, D Black and G Brunner, 'Benefits and costs of improved IEQ in U.S. offices', *Indoor Air*, 2011, 21(5):357-67, doi:10.1111/j.1600-0668.2011.00719.x.

39 Australian Institute of Health and Welfare, 'Burden of disease', AIHW website, 20 November 2024, accessed 9 April 2025.

40 Morantes et al (2024) op. cit. n.38. See also Morantes et al (2023), op. cit. n.38.

41 E de Oliveira Fernandes, M Jantunen, P Carrer, O Seppänen, P Harrison and S Kephalopoulos, *EnVIE: coordination action on indoor air quality and health effects – Publishable Final Activity Report* [PDF], Indoor Air website, 2009, p 76, accessed 9 April 2025.

42 Ibid, p.80.

43 Ibid.

44 Liu et al, op. cit. n.7. See also L Morawska, 'The burden of disease due to indoor air pollution and why we need to know about it', *Science Bulletin*, 2024, 69(9):1161-1164, doi:10.1016/j.scib.2024.02.031.

45 The Australian Building Codes Board (ABCB), op. cit. n. 16, p 10.

46 Australian Institute of Health and Welfare (AIHW), 'Australian Burden of Disease Study 2018: Interactive data on risk factor burden', AIHW website, 24 November 2021, accessed 9 April 2025.

47 Ibid.

48 Ibid.

49 M Greenstone, T Ganguly, C Hasenkopf, N Sharma and H Gautam, Annual Update [PDF], Air Quality Life Index website, 2024, accessed 9 April 2025.

50 KM Emmerson and MD Keywood MD, *Australia State of the Environment 2021: Air Quality* [PDF], Department of Climate Change, Energy, the Environment and Water (DCCEEW) website, 2021, accessed 9 April 2025; and MA Torkmahalleh, S Gorjinezhad, HE Unluevcek and PK Hopke, 'Review of factors impacting emission/concentration of cooking generated particulate matter', *Science of The Total Environment*, 2017, 586:1046-1056, doi:10.1016/j.scitotenv.2017.02.088; and United States Environment Protection Agency (US EPA), 'Sources of Indoor Particulate Matter (PM)', US EPA website, 25 September 2023, accessed 9 April 2025 . See also AM Coggins, N Wemken, AK Mishra, M Sharkey, L Horgan, H Cowie, E Bourdin and B McIntyre, 'Indoor air quality, thermal comfort and ventilation in deep energy retrofitted Irish dwellings', Building and Environment, 2022, 219:109236, doi:10.1016/j.buildenv.2022.109236.

51 OM Morakinyo, MI Mokgobu, MS Mukhola, RP Hunter, 'Health outcomes of exposure to Biological and Chemical components of inhalable and respirable particulate matter', *International Journal of Environmental Research and Public Health*, 2016,13(6):592, doi:10.3390/ijerph13060592; and SM Mack, AK Madl, KE Pinkerton, 'Respiratory Health Effects of Exposure to Ambient Particulate Matter and Bioaerosols', Comprehensive Physiology, 2019, 10(1):1–20, doi:10.1002/cphy.c180040.

52 Australian Institute of Health and Welfare, op. cit. n.46.

53 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Particulate matter (PM10 and PM2.5)', DCCEEW website, 30 June 2022, accessed 9 April 2025; and O Milman, ''Safe' air-quality levels in US, UK and EU still harmful for health, study says', *The Guardian*, 22 February 2024, accessed 9 April 2025; and J Chen and G Hoek, 'Long-term exposure to PM and all-cause and cause-specific mortality: a systematic review and meta-analysis', *Environment International*, 2020, 143, doi:10.1016/j.envint.2020.105974; and P Orellano, J Reynoso, N Quaranta, A Bardach and A Ciapponi, 'Short-term exposure to particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O3) and all-cause and cause-specific mortality: Systematic review and meta-analysis', *Environment International*, 2020, 142, doi:10.1016/j.envint.2020.105876.

54 National Academies of Sciences, Engineering, and Medicine, *Health Risks of Indoor Exposure to Fine Particulate Matter and Practical Mitigation Solutions,* Washington, DC: The National Academies Press, 2024, p. 160, doi:10.17226/27341.

55 Y Qi, S Wei, T Xin, C Huang, Y Pu, J Ma, C Zhang, Y Liu, I Lynch and S Liu, 'Passage of exogeneous fine particles from the lung into the brain in humans and animals', *Proceedings of the National Academy of Sciences*, 2022, 119(26), doi:10.1073/pnas.2117083119.

56 DE Schraufnagel, JR Balmes, CT Cowl, S De Matteis, SH Jung, K Mortimer, R Perez-Padilla, MB Rice, H Riojas-Rodriguez, A Sood, GD Thurston, T To, A Vanker and DJ Wuebbles, 'Air pollution and noncommunicable diseases: A review by the Forum of International Respiratory Societies' Environmental Committee, Part 2: Air pollution and organ systems', *Chest*, 155(2):409-416, doi:10.1016/j.chest.2018.10.

57 LN Schwartz, JD Shaffer and G Bukhman, 'The origins of the 4 × 4 framework for noncommunicable disease at the World Health Organization', *SSM Population Health*, 2021, 13, 100731, doi:10.1016/j.ssmph.2021.100731.

58 E Sanidas E, DP Papadopoulos, H Grassos, M Velliou, K Tsioufis, J Barbetseas and V Papademetriou, 'Air pollution and arterial hypertension. A new risk factor is in the air', *Journal of the American Society of Hypertension*, 2017, 11(11):709–715, doi:10.1016/j.jash.2017.09.008.

59 NSW Health, 'Particulate matter (PM10 and PM2.5)', NSW Government website, 25 November 2020, accessed 9 April 2025.

60 W Li, KS Dorans, EH Wilker, MB Rice, PL Ljungman , JD Schwartz, BA Coull, P Koutrakis, DR Gold, JF Keaney Jr, RS Vasan, EJ Benjamin and MA Mittleman, 'Short-Term Exposure to Ambient Air Pollution and Biomarkers of Systemic Inflammation: The Framingham Heart Study', *Arteriosclerosis, Thrombosis, and Vascular Biology*, 2017, 37(9):1793–1800, doi:10.1161/ATVBAHA.117.309799.

61 G Veronesi, S De Matteis, G Calori, N Pepe and MM Ferrario, 'Long-term exposure to air pollution and COVID-19 incidence: a prospective study of residents in the city of Varese, Northern Italy', *Occupational and Environmental Medicine,* 2022, 79(3):192–199, doi:10.1136/oemed-2021-107833; and M Brauer, B Casadei, RA Harrington, R Kovacs and K Sliwa, The WHF Air Pollution Expert Group, 'Taking a stand against air pollution – the impact on cardiovascular disease: A Joint Opinion from the World Heart Federation, American College of Cardiology, American Heart Association, and the European Society of Cardiology', European Heart Journal, 2021, 42(15):1460–1463, doi:10.1093/eurheartj/ehaa1025.

62 NSM Nor, CW Yip, N Ibrahim, MH Jaafar, ZZ Rashid, N Mustafa, HHA Hamid, K Chandru, MT Latif, PE Saw, CY Lin, KM Alhasa, JH Hashim and MSM Nadzir, 'Particulate matter ($PM_{2.5}$) as a potential SARS-CoV-2 carrier', *ScientificReports*, 2021, 11, 2508, doi:10.1038/s41598-021-81935-9.

63 International Agency for Research on Cancer (IARC), *Outdoor air pollution. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 109* [PDF], World Health Organization (WHO) website, 17 December 2013, accessed 27 April 2025; and International Agency for Research on Cancer (IARC), *IARC: Outdoor air pollution a leading environmental cause of cancer deaths [media release]*, World Health Organization (WHO) website, 17 October 2013, accessed 10 April 2025.

64 International Agency for Research on Cancer (IARC) (17 December 2013), ibid, p.35.

65 Laurent et al, op. cit. n.13; Pulimeno et al, op. cit. n.13.

66 See, for example, E Casey, Z Li, D Liang, S Ebelt, AI Levey, JJ Lah, TS Wingo and A Hüls, 'Association between Fine Particulate Matter Exposure and Cerebrospinal Fluid Biomarkers of Alzheimer's Disease among a Cognitively Healthy Population-Based Cohort', *Environmental Health Perspectives*, 132(4):047001, doi:10.1289/EHP13503; and C Gunawan, C Fleming, PJ Irga, RJ Wong, R Amal, FR Torpy, S Mojtaba Golzan, and KC McGrath, 'Neurodegenerative effects of air pollutant particles: Biological mechanisms implicated for Early-Onset Alzheimer's disease', *Environment International*, 2024, 185:108512, doi:10.1016/j.envint.2024.108512; and J Wang et al, 'Ambient air pollution and the dynamic transitions of stroke and dementia: a population-based cohort study' *eClinicalMedicine*, January 2024, 67, 102368.

67 Committee on the Medical Effects of Air Pollutants, 'Air pollution: cognitive decline and dementia', UK Government website, 25 July 2022, accessed 10 April 2025.

68 A Oudin, D Segersson, R Adolfsson and B Forsberg, 'Association between air pollution from residential wood burning and dementia incidence in a longitudinal study in Northern Sweden', *PLoS One*, 2018 Jun 13, 13(6):e0198283, doi:10.1371/journal.pone.0198283.

69 S Lyons, A Nolan, P Carthy et al, 'Long-term exposure to $PM_{2.5}$ air pollution and mental health: a retrospective cohort study in Ireland', *Environ Health*, 2024, 23(54), doi:10.1186/s12940-024-01093-z.

70 L Ferguson, J Taylor, M Davies, C Shrubsole, P Symonds and S Dimitroulopoulou, 'Exposure to indoor air pollution across socio-economic groups in high-income countries: A scoping review of the literature and a modelling methodology', *Environment International*, 2020, 143:105748, doi:10.1016/j.envint.2020.105748.

71 HD Clifford, G Pearson, P Franklin, R Walker and GR Zosky, 'Environmental health challenges in remote Aboriginal Australian communities: clean air, clean water and safe housing', *Australian Indigenous Health Bulletin*, 25 May 2015, 15(2), retrieved 17 December 2024 from https://healthbulletin.org.au/articles/environmental-health-challenges-in-remote-aboriginal-australian-communities-clean-air-clean-water-and-safe-housing.

72 Asthma Australia, *Homes, Health and Asthma in Australia* [PDF], Asthma Australia website, 2022, accessed 10 April 2025, pp.4, 14.

73 WW Nazaroff, 'Ten questions concerning indoor ultrafine particles', *Building and Environment*, 2023, 243:110641, doi:10.1016/j.buildenv.2023.110641; and S Audignon-Durand, O Ramalho, C Mandin, A Roudil, O Le Bihan, F Delva and A Lacourt, 'Indoor exposure to ultrafine particles related to domestic activities: A systematic review and meta-analysis', *Science of The Total Environment*, 2023, 904:166947, doi:10.1016/j.scitotenv.2023.166947.

74 HS Kwon, MH Ryu and C Carlsten, 'Ultrafine particles: unique physicochemical properties relevant to health and disease', *Exp Mol Med*, 2020, 52:318–328, doi:10.1038/s12276-020-0405-1.

75 DE Schraufnagel, 'The health effects of ultrafine particles', *Exp Mol Med*, 2020, 52:311–317, doi:10.1038/s12276-020-0403-3.

76 United States Environmental Protection Agency (US EPA), 'Volatile Organic Compounds' Impact on Indoor Air Quality', US EPA website, 15 August 2023, accessed 10 April 2025.

77 Australian Government, 'Indoor air quality', Your Home website, 2020, accessed 10 April 2025; and United States Environmental Protection Agency, ibid; and A Heeley-Hill, SK Grange, AC Lewis, N Owen, C Jordan, G Hodgson and G Adamson, 'Frequency of use of household products containing VOCs and indoor atmospheric concentrations in homes', *Environmental Science: Processes and Impacts*, 2021, 23(5):699-713, doi:10.1039/D0EM00504E.

78 Goodman et al, op. cit. n.20.

79 NB Goodman, A Steinemann, AJ Wheeler, PJ Paevere, M Cheng and SK Brown, 'Volatile organic compounds within indoor environments in Australia', *Building and Environment*, 2017, 122:116-125, doi:10.1016/j.buildenv.2017.05.033. See also CH Halios, C Landeg-Cox, SD Lowther, A Middleton, T Marczylo and S Dimitroulopoulou, 'Chemicals in European residences - Part I: A review of emissions, concentrations and health effects of volatile organic compounds (VOCs)', *Sci Total Environ.*, 2022 Sep, 15:839:156201, doi:10.1016/j.scitotenv.2022.156201.

80 SK Brown, 'Chamber Assessment of Formaldehyde and VOC Emissions from Wood-Based Panels', *Indoor Air*, 1999, 9:209-215, doi:10.1111/j.1600-0668.1999.t01-1-00008.x.

81 Government of South Australia (SA), 'Formaldehyde', Government of SA website, 2022, accessed 10 April 2025; and T Salthammer, S Mentese and R Marutzky, 'Formaldehyde in the indoor environment', *Chemical Reviews*, 2010, 110(4):2536-72, doi:10.1021/cr800399g.

82 New South Wales EPA, 'Reducing wood smoke emissions', New South Wales EPA website, 2021, accessed 10 April 2025.

83 Australian Competition and Consumer Commission (ACCC), 'Formaldehyde in cosmetic products', ACCC website, n.d., accessed 23 July 2024; and Australian Building Codes Board (ABCB), *Indoor air quality* [PDF], Australian Building Codes Board, 2021, accessed 10 April 2025; and Australian Competition Consumer Commission (ACCC), *ACCC analytical survey of formaldehyde in false eyelash glues supplied in Australia* [PDF 872KB], ACCC, 2015, accessed 10 April 2025.

84 Western Australia Department of Energy, Mines, Industry Regulation and Safety, 'Urea Formaldehyde Foam Insulation (UFFI)', Western Australia Department of Energy, Mines, Industry Regulation and Safety website, 2015, accessed 23 July 2024; see also SK Brown, 'Hydrolysis and durability of urea formaldehyde foam insulation', *Polymer Degradation and Stability*, 1990, 27(2):121-143, doi:10.1016/0141-3910(90)90104-F.

85 CB Crawford and CJ Shirtliffe, 'Problems with urea-formaldehyde foam insulation,' National Research Council Canada Publications Archive website, 1984, accessed 10 April 2025.

86 World Health Organization (WHO), 'WHO guidelines for indoor air quality: selected pollutants', WHO website, 1 January 2010, accessed 10 April 2025.

87 *Air Toxics NEPM - Benzene Health Review* [PDF 186KB], National Environment Protection Council website, 2003, accessed 9 April 2025, pp.3-4.

88 Ibid.

89 Goodman et al, op. cit. n.79.

90 YS Kashtan, M Nicholson, C Finnegan, Z Ouyang, E Lebel, DR Michanowicz, SBC Shonkoff and RB Jackson, 'Gas and Propane Combustion from Stoves Emits Benzene and Increases Indoor Air Pollution', *Environmental Science and Technology*, 2023, 57(26):9653-9663, doi:10.1021/acs.est.2c09289.

91 See, for example, AJ Wheeler, SL Wong, C Khouri and J Zhu, 'Predictors of indoor BTEX concentrations in Canadian residences', *Health Rep.*, 2013 May, 24(5):11-7, PMID: 24258095. See also Health Canada, *Guidance for Benzene in Residential Indoor Air* [PDF], Government of Canada website, 2013, accessed 10 April 2025.

92 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Toluene (methylbenzene)', DCCEEW website, 15 August 2022, accessed 10 April 2025; and Health Canada, *Residential Indoor Air Quality Guidelines – Toluene* [PDF], Government of Canada website, 2011, accessed 10 April 2025.

93 AL Hinwood, C Rodriguez, T Runnion, D Farrar, F Murray, A Horton, D Glass, V Sheppeard, JW Edwards, L Denison and 8 more authors, 'Risk factors for increased BTEX exposure in four Australian cities', *Chemosphere*, 2007, 66(3):533-541, doi:10.1016/j.chemosphere.2006.05.040.

94 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Acrolein (2-propenal)', DCCEEW website, 30 June 2022, accessed 10 April 2025; and DP Ghilarducci and RS Tjeerdema, 'Fate and effects of acrolein', *Rev Environ Contam Toxicol*, 1995, 144:95-146, doi:10.1007/978-1-4612-2550-8_2.

95 Department of Climate Change, Energy, the Environment and Water (DCCEEW), '1, 3-Butadiene (vinyl ethylene)', DCCEEW website, 30 June 2022, accessed 10 April 2025.

96 D Eastmond and S Balakrishnan, '1,4 Dichlorobenzene', in R Krieger (eds), *Hayes Handbook of Pesticide Toxicology*, Academic Press, California, 2010.

97 D Dubey, VD Sharma, SE Pass, A Sawhney and O Stüve, 'Para-dichlorobenzene toxicity - a review of potential neurotoxic manifestation', *Therapeutic Advances in Neurological Disorders*, 2014, 7(3):177-87, doi:10.177/1756285614521889.

98 N Goodman, N Nematollahi, G Agosti and A Steinemann, 'Evaluating air quality with and without air fresheners', *Air Qual Atmos Health*, 2020, 13:1–4, doi:10.1007/s11869-019-00759-9.

99 United States Environmental Protection Agency (US EPA), 'Sources, emission, and exposure for trichloroethylene (TCE) and related compounds', US EPA website, 2001, accessed 10 April 2025; and N Bonvallot, P Harrison, and M Loh, *'Trichloroethylene'* in 'WHO Guidelines for Indoor Air Quality: Selected Pollutants', National Library of Medicine website, 2010, accessed 10 April 2025; and Centers for Disease Control and Prevention, 'Trichloroethylene', Centers for Disease Control and Prevention Archive website, 2019, accessed 10 April 2025; and Centers for Disease Control and Prevention, 'Tetrachlorothylene (Perchloroethylene)', Centers for Disease Control and Prevention Archive website, 2019, accessed 10 April 2025.

100 EPA Victoria, *1953: Tetrachloroethene (PCE) from vapour intrusion and your health* [PDF], EPA Victoria website, 31 August 2023, accessed 10 April 2025. See also Environmental Health Standing Committee (enHealth), *Guidance for the human health risk assessment of volatile chlorinated hydrocarbon vapour intrusion* [PDF], Department of Health and Aged Care website, 20 December 2023, accessed 10 April 2025; and United States Environmental Protection Agency (US EPA), 'What is vapour intrusion?', US EPA website, 26 September 2024, accessed 10 April 2025.

101 Environmental Health Standing Committee (enHealth), 'enHealth guidance statement – Per- and polyfluoroalkyl Substances (PFAS)', Department of Health and Aged Care website, 16 February 2024, accessed 9 April 2025.

102 ME Morales-McDevitt, J Becanova, A Blum, TA Bruton, S Vojta, M Woodward and R Lohmann, 'The Air That We Breathe: Neutral and Volatile PFAS in Indoor Air', *Environmental Science Technology Letters*, 2021, 8(10):897-902, doi:10.1021/acs.estlett.1c00481; and G Zheng, SM Eick and A Salamova, 'Elevated Levels of Ultrashort- and Short-Chain Perfluoroalkyl Acids in US Homes and People', *Environmental Science Technology Letters*, 2023 57(42):15782-15793, doi:10.1021/acs.est.2c06715.

103 Environmental Health Standing Committee (enHealth), op. cit. n.101.

104 S Poothong, E Papadopoulou, JA Padilla-Sanchez, C Thomesn and LS Haug, 'Multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFAS): From external exposure to human blood', *Environment International*, 2020, 134(105244), doi:10.1016/j.envint.2019.105244.

105 Department of Health and Aged Care (DoHAC), 'Environmental toxins and contaminants', DoHAC website, 7 June 2024, accessed 10 April 2025.

106 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Polycyclic aromatic hydrocarbons', DCCEEW website, 29 July 2022, accessed 10 April 2025; and National Cancer Institute (NCI), 'Chemicals in Meat Cooked at High Temperatures and Cancer Risk', NCI website, 11 July 2017, accessed 10 April 2025.

107 LY Zou, W Zhang and S Atkiston, 'The characterisation of polycyclic aromatic hydrocarbons emissions from burning of different firewood species in Australia', Environmental Pollution, 2003, 124(2):283-289, doi:10.1016/S0269-7491(02)00460-8.

108 TR Driscoll, *The Australian Work Exposures Study (AWES): Polycyclic Aromatic Hydrocarbons* [PDF], Safe Work Australia, 2014, accessed 10 April 2025.

109 Therapeutic Goods Administration (TGA), '2.2 Napthalene', TGA website, 2019, accessed 23 April 2025.

110 DL Sudakin, DL Stone and L Power, 'Naphthalene Mothballs: Emerging and Recurring Issues and their Relevance to Environmental Health', *Current Topics in Toxicology*, 2011, 7:13-19.

111 D Penney, V Benignus, S Kephalopoulos, D Kotzias, M Kleinman and A Verrier. 'Carbon monoxide' in World Health Organization (WHO), 'WHO guidelines for indoor air quality: selected pollutants', WHO website, 1 October 2010, accessed 10 April 2025.

112 LD Prockop and RI Chichkova, 'Carbon monoxide intoxication: An updated review', *Journal of the Neurological Sciences*, 2007, 262(1-2):122-130, doi:10.1016/j.jns.2007.06.037.

113 United States Environmental Protection Agency (US EPA), 'Nitrogen Dioxide's Impact on Indoor Air Quality', US EPA website, 2024, accessed 10 April 2025; and JD Spengler, BG Ferris Jr, DW Dockery and FE Speizer, 'Sulfur dioxide and nitrogen dioxide levels inside and outside homes and the implications on health effects research', *Environmental Science Technology,* 1979, 13(10):1276-1280, doi:10.1021/es60158a013; and JM Logue, NE Klepeis, AB Lobscheid and BC Singer, 'Pollutant exposures from natural gas cooking burners: A simulation-based assessment for Southern California', *Environmental Health Perspectives*, 122(1):43-50, doi:10.1289/ehp.1306673.

114 JI Levy, 'Impact of Residential Nitrogen Dioxide Exposure on Personal Exposure: An International Study', *Journal of the Air & Waste Management Association*, 1998, 48(6): 553-560, doi:10.1080/10473289.1998.10463704. See also K Lee, W Yang and ND Bofinger, 'Impact of Microenvironmental Nitrogen Dioxide Concentrations on Personal Exposures in Australia', *Journal of Air and Waste Management Association*, 2000, 50:1739-1744, doi:10.1080/10473289.2000.10464212.

115 JM Delgado-Saborit, A Cartanyà Hueso, AR Hole, P Carrasco, A Esplugues, M Estarlich and F Ballester, *Assessment of the health impacts and costs associated with indoor nitrogen dioxide exposure related to gas cooking in the European Union and the United Kingdom* [PDF], 2024. Universitat Jaume I, Castellon de la Plana, Spain.

116 A Zota, G Adamkiewicz, JI Levy and JD Spengler, 'Ventilation in public housing: implications for indoor nitrogen dioxide concentrations', *Indoor Air*, 2005 Dec; 15(6):393-401, doi:10.1111/j.1600-0668.2005.00375.x.

117 L Wickham, J Metcalfe and K Mason, *Air Quality and Social Inquiry in Aotearoa: A Preliminary Assessment* [PDF], 14 November 2023, accessed 9 April 2025.

118 SK Brown, KJ Mahoney and M Cheng, 'Room chamber assessment of the pollutant emission properties of (nominally) low-emission unflued gas heaters', *Indoor Air*, 2004, 14 Suppl 8:84-91, doi:10.1111/j.1600-0668.2004.00296.x. See also M Ward, ''Banned' school heaters still in use across thousands of classrooms', *Sydney Morning Herald*, 11 May 2024, Sydney Morning Herald website, accessed 10 April 2025.

119 United States Environmental Protection Agency (US EPA), 'Basic Information about NO2', US EPA website, 25 July 2023, accessed 10 April 2025.

120 Australian Institute of Health and Welfare (AIHW), 'Monitoring the impact of air pollution on asthma in Australia: a methods paper', AIHW website, 22 March 2010, accessed 10 April 2025.

121 United States Environmental Protection Agency, op. cit. n.119.

122 Ferguson et al, op. cit. n.70; and S Gligorovski, 'Nitrous acid (HONO): An emerging indoor pollutant', *Journal of Photochemistry and Photobiology A: Chemistry*, 2016, 314:1-5, doi:10.1016/j.jphotochem.2015.06.008.

123 L Morawska, GB Marks and J Monty, 'Healthy Indoor Air is Our Fundamental Need: The Time to Act is Now', *The Medical Journal of Australia*, 2022, 217(11):578-581, doi:10.5694/mja$_{2.5}$1768; and The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 'ASHRAE Position Document on Indoor Carbon Dioxide', ASHRAE website, 2 February 2022, accessed 10 April 2025.

124 OV Eliseeva, *Gig. i. Sanit.*, 1964, No. 8, 10, in MS Goromosov, *The physiological basis of health standards for dwellings* [PDF], World Health Organization (WHO), WHO website, 1968, accessed 10 April 2025, pp.41-42.

125 U Satish, MJ Mendell, K Shekhar, T Hotchi, D Sullivan, S Streufert and WJ Fisk, 'Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance', *Environmental Health Perspectives*, 2012, 120(12):1671-1677, doi:10.1289/ehp.1104789.

126 Starcke and Brand 2012 in Laurent et al, op. cit. n.13.

127 AK Persily, 'Field measurement of ventilation rates', *Indoor Air*, 2016, 26(1):97-111, doi:10.1111/ina.12193; and The American Society of Heating, Refrigerating and Air-Conditioning Engineers, op. cit. n.123.

128 Morawska et al, op. cit. n.123.

129 National Science and Technology Council, op. cit. n.27, p.4.

130 Brown, op. cit. n.32.

131 MJ Mendell, W Chen, DR Ranasinghe et al, 'Carbon dioxide guidelines for indoor air quality: a review', *Journal of Exposure Science & Environmental Epidemiology*, 2024, doi:10.1038/s41370-024-00694-7.

132 L Morawska, G Johnson, Z Ristovski, M Hargreaves, K Mengersen, S Corbett, C Chao, Y Li and D Katoshevski, 'Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities', *Journal of Aerosol Science*, 2009, 40(3):256-269, doi:10.1016/j.jaerosci.2008.11.002.

133 B Moseley, J Archer, CM Orton, HE Symons, NA Watson, B Saccente-Kennedy, KEJ Philip, JH Hull, D Costello, JD Calder, PL Shah, BR Bzdek and JP Reid, 'Relationship between Exhaled Aerosol and Carbon Dioxide Emission Across Respiratory Activities', *Environmental Science & Technology*, 2024, 58 (34):15120-15126, doi:10.1021/acs.est.4c01717.

134 Morawska et al, op. cit. n.123.

135 A Haddrell, H Oswin, M Otero-Fernandez, JR Robinson, T Cogan, R Alexander, JFS Mann, D Hill, A Finn, AD Davidson and 1 more author, 'Ambient carbon dioxide concentration correlates with SARS-CoV-2 aerostability and infection risk', *Nature Communications*, 2024, 15:3487, doi:10.1038/s41467-024-47777-5. See also BP Luo et al, 'Expiratory aerosol pH: the overlooked driver of airborne virus inactivation', *Environmental Science & Technology*, Dec 2022, doi:i10.1021/acs.est.2c05777; and A Haddrell et al, 'Differences in airborne stability of SARS-CoV-2 variants of concern is impacted by alkalinity of surrogates of respiratory aerosol', *Journal of The Royal Society Interface*, 21 June 2023, 20(203), doi:10.1098/rsif.2023.0062.

136 Laurent et al, op. cit. n.13; and Pulimeno et al, op. cit. n.13; and KB Karnauskas, SL Miller and AC Schapiro, 'Fossil Fuel Combustion Is Driving Indoor CO2 Toward Levels Harmful to Human Cognition', GeoHealth, 2020, 4(5), doi:10.1029/2019GH000237.

137 Allen et al, op. cit. n.13; CM Calama-González, AL León-Rodríguez and R Suárez, 'Indoor Air Quality Assessment: Comparison of Ventilation Scenarios for Retrofitting Classrooms in a Hot Climate' *Energies*, 2019, 12(24):4607, https://doi.org/10.3390/en12244607; and Satish et al, op. cit. n.125.

138 Laurent et al, op. cit. n.13; and Pulimeno et al, op. cit. n.13.

139 T Faherty, JE Raymond, G McFiggans and FD Pope, 'Acute particulate matter exposure diminishes executive cognitive functioning after four hours regardless of inhalation pathway', *Nature Communications*, 2025, 16:1339, doi:10.1038/s41467-025-56508-3.

140 S Dedesko, J Pendleton, J Petrov, BA Coull, JD Spengler and JG Allen, 'Associations between indoor environmental conditions and divergent creative thinking scores in the CogFx global buildings study', *Building and Environment*, 2025, 270:112531, doi:10.1016/j.buildenv.2025.112531.

141 S Künn, J Palacios and N Pestel, 'Indoor Air Quality and Strategic Decision Making', Management *Science,* 2023, 69(9):5354-5377, doi:10.1287/mnsc.2022.4643; and P Martin, 'An investment in clean indoor air would do more than help us fight COVID – it would help us concentrate, with lasting benefits', ABC News, 9 February 2022, accessed 10 April 2025.

142 AM Ferreira and M Cardoso, 'Indoor air quality and health in schools', *J Bras Pneumol.*, 2014 May-Jun, 40(3):259-68, doi:10.1590/s1806-37132014000300009.

143 DA Coley, R Greeves and BK Saxby, 'The effect of low ventilation rates on the cognitive function of a primary school class', *International Journal of Ventilation*, 2007, 6(2):107-112, doi:10.1080/14733315.2007.11683770.

144 JG Allen, P MacNaughton, JG Cedeno-Laurent, X Cao, S Flanigan, J Vallarino, F Rueda, D Donnelly-McLay and JD Spengler, 'Airplane pilot flight performance on 21 maneuvers in a flight simulator under varying carbon dioxide concentrations', *J Expo Sci Environ Epidemiol,* 2019, 29:457–468, doi:10.1038/s41370-018-0055-8. See also K Gander, 'A Pilot's Performance Is Affected by Cockpit CO2 Levels, Study Suggests', *Newsweek*, 8 August 2018, accessed 10 April 2025.

145 Allen et al, op. cit. n.13.

146 M Quan, X Wang, M Gong, Q Wang, Y Li and J Jia, 'Post-COVID cognitive dysfunction: current status and research recommendations for high risk population', The Lancet Regional Health – Western Pacific, 2023, 38:100836, doi:10.1016/j.lanwpc.2023.100836.

147 M Taquet, R Sillett, L Zhu, J Mendel, I Camplisson, Q Dercon and PJ Harrison, 'Neurological and psychiatric risk trajectories after SARS-CoV-2 infection: an analysis of 2-year retrospective cohort studies including 1 284 437 patients, The Lancet Psychiatry, 2022, 9(10):815-827, doi:10.1016/S2215-0366(22)00260-7; and Quan et al, ibid.

148 Karnauskas et al, op. cit. n.136.

149 US EPA, 'Technical Overview of Volatile Organic Compounds', US EPA website, 24 February 2025, accessed 10 April 2025.

150 SR Utembe, PJ Rayner, JD Silver, E Guerette, JA Fisher, KM Emmerson, M Cope, C Paton-Walsh, AD Griffiths, H Duc, K Monk and Y Scorgie, 'Hot summers: Effect of extreme temperatures on ozone in Sydney, Australia', *Atmosphere*, 2018, 9(12):466, doi:10.3390/atmos9120466.

151 WW Nazaroff and CJ Weschler, 'Indoor ozone: Concentrations and influencing factors', *Indoor Air*, 2022 Jan, 32(1):e12942, doi:10.1111/ina.12942.

152 A Nandan, NA Siddiqui and P Kumar, 'Assessment of environmental and ergonomic hazard associated to printing and photocopying: a review', *Environ Geochem Health*, 2019 Jun, 41(3):1187-1211, doi:10.1007/s10653-018-0205-x.

153 United States Environmental Protection Agency (US EPA), 'Health Effects of Ozone Pollution', US EPA website, 13 March 2025, accessed 10 April 2025.

154 A Alari, C Chen, L Schwarz, K Hdansen, B Chaix and T Benmarhnia, 'The Role of Ozone as a Mediator of the Relationship Between Heat Waves and Mortality in 15 French Urban Areas', *American Journal of Epidemiology*, 2023, 192(6):949–962, doi:10.1093/aje/kwad032.

155 P Wolkoff, 'Indoor air chemistry: Terpene reaction products and airway effects', *International Journal of Hygiene and Environmental Health*, 2020, 225, doi:10.1016/j.ijheh.2019.113439.

156 CJ Weschler and WW Nazaroff, 'Human skin oil: a major ozone reactant indoors', *Environmental Science: Atmospheres*, 2023, 3:640-661, doi:10.1039/d3ea00008g; and D Biello, 'Indoor Air Alert: Ozone Reacts with Human Skin to Produce Potential Irritants', *The Scientific American,* 24 August 2009, accessed 10 April 2025.

157 VV Tran, D Park and YC Lee, 'Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality', *Int J Environ Res Public Health*, 2020 Apr 23, 17(8):2927, doi:10.3390/ijerph17082927.

158 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Sulfur dioxide', DCCCEEW website, 15 August 2022, accessed 10 April 2025.

159 VS Li, Environment Canada, *Conventional Woodstove Emission Factor Study* [PDF], US Environment Protection Agency website, n.d., accessed 10 April 2025.

160 See M Rodney, V Kuku and S Joyce, 'Indoor and outdoor NO_2 and SO2 levels in 13 randomly selected preschools from 7 districts in Mpumalanga Province, South Africa', *Public Health Challenges*, 2024, 3:e175, doi:10.1002/puh2.175.

161 National Indigenous Australians Agency, '2.03 Environmental tobacco smoke' in 'Aboriginal and Torres Strait Islander Health Performance Framework', Department of Health and Aged Care website, 21 May 2024, accessed 10 April 2025.

162 World Health Organization (WHO), *Tobacco [media release]*, WHO, 31 July 2023, accessed 10 April 2025.

163 Department of Health and Aged Care (DoHAC), 'Smoking and tobacco', DoHAC website, 1 February 2024, accessed 10 April 2025.

164 Department of Health and Aged Care (DoHAC), 'Passive smoking', DoHAC website, 21 December 2023, accessed 10 April 2025.

165 United States Environmental Protection Agency (US EPA), 'Secondhand Smoke and Electronic-Cigarette Aerosols', US EPA website, 13 December 2024, accessed 10 April 2025.

166 TF Northrup, P Jacob III, NL Benowitz, E Hoh, PJE Quintana, MF Hovell, GE Matt and AL Stotts, 'Thirdhand Smoke: State of the Science and a Call for Policy Expansion', *Public health reports (Washington, D.C.:1974)*, 2016, 131(2):233-238, doi:10.1177/003335491613100206. See also 'Thirdhand smoke' in 'Tobacco in Australia. Facts & Issues. A comprehensive online resource', Tobacco in Australia website, January 2017, accessed 10 April 2025.

167 E Banks, Yazidjoglou A, S Brown, M Nguyen, M Martin, K Beckwith, A Daluwatta, S Campbell and G Joshy, 'Electronic cigarettes and health outcomes: systematic review of global evidence', report to the Australian Department of Health, Australian National University (ANU) National Centre for Epidemiology and Population Health, 2022, doi:10.25911/XV0F-6C42; and National Health and Medical Research Council (NHMRC), '2022 CEO Statement on Electronic Cigarettes', NHMRC website, 2022, accessed 10 April 2025.

168 National Health and Medical Research Council, ibid.

169 Department of Health and Aged Care (DoHAC), 'About vaping and e-cigarettes', DoHAC website, 1 July 2024, accessed 10 April 2025.

170 See M Weitzman, AH Yusufali, F Bali, MJR Vilcassim, S Gandhi, R Peltier, A Nadas, S Sherman, L Lee, Z Hong and 3 more authors, 'Effects of hookah smoking on indoor air quality in homes', *Tobacco Control*, 2016, 26(5):586-591, doi:10.1136/tobaccocontrol-2016-053165; G Gurung, J Bradley and JM Delgado-Saborit, 'Effects of shisha smoking on carbon monoxide and $PM_{2.5}$ concentrations in the indoor and outdoor microenvironment of shisha premises', *Science of The Total Environment*, 2016, 548–549:340-346, doi:10.1016/j.scitotenv.2015.12.093; and H Qasim, AB Alarabi, KH Alzoubi, ZA Karim, FZ Alshbool and FT Khasawneh, 'The effects of hookah/waterpipe smoking on general health and the cardiovascular system', *Environ Health Prev Med.*, 2019, 24(1):58, doi:10.1186/s12199-019-0811-y.

171 World Health Organization, 'Global technical consultation report on proposed terminology for pathogens that transmit through the air', Geneva: World Health Organization, 2024. p.xii. See also Australasian College for Infection Prevention and Control (ACIPC), *ACIPC Position Statement – Terminology for pathogens that transmit through the air* [PDF], ACIPC website, February 2025, accessed 10 April 2025.

172 Y Drossinos, TP Weber and NI Stilianakis, 'Droplets and aerosols: An artificial dichotomy in respiratory virus transmission', *Health Science Reports*, 2021, 4(2), doi:10.1002/hsr2.275. See also World Health Organization and CERN, 'Indoor airborne risk assessment in the context of SARS-CoV-2: description of airborne transmission mechanism and method to develop a new standardized model for risk assessment', Geneva: World Health Organization, 2024; and World Health Organization, ibid; and D Duval, JC Palmer, I Tudge, N Pearce-Smith, E O'Connell, A Bennett and R Clark, 'Long distance airborne transmission of SARS-CoV-2: rapid systematic review', *British Medical Journal*, 2022 Jun 29;377:e068743, doi:10.1136/bmj-2021-068743; and A Henriques, W Jia, L Aleixo, N Mounet, L Fontana, A Simniceanu, J Devine, P Elson, G Azzopardi, M Rognlien and 5 more authors, 'An integrated airborne transmission risk assessment model for respiratory viruses: short- and long-range contributions', *Journal of the Royal Society Interface*, 2025, 22:20240740, doi:10.1098/rsif.2024.0740. See also University of Wollongong, op. cit. n.4.

173 World Health Organization, op. cit. n.171. p.9.

174 World Health Organization, op. cit. n.171. p.9; and CC Wang, KA Prather, J Sznitman, JL Jimenez, SS Lakdawala, Z Tufekci and LC Marr, 'Airborne transmission of respiratory viruses', *Science*, 2021, 373(6558), doi:10.1126/science.abd9149. See also MMA Mahmoud, P Bahl, AFV de A Aquino, CR MacIntyre, D Green, C Doolan and C de Silva, 'An infection risk model for estimating infection probability and occupancy time: A CFD approach with aerosol measurements', *Building and Environment*, 2025, 279:113035, doi:10.1016/j.buildenv.2025.113035.

175 Note - RNA collected via quantitative reverse transcription polymerase chain reaction from exhaled breath specimens. G Lane, G Zhou, JF Hultquist, LM Simons, R Lorenzo-Redondo, EA Ozer, DM McCarthy, MG Ison, CJ Achenbach, X Wang and 11 more authors, 'Quantity of SARS-CoV-2 RNA copies exhaled per minute during natural breathing over the course of COVID-19 infection (preprint)', doi:10.1101/2023.09.06.23295138; and M Paul, 'COVID patients breathe large amounts of virus early on', *Northwestern University*, 8 September 2023, accessed 10 April 2025.

176 M Alsved, K Nyström, S Thuresson, D Nygren, M Patzi-Churqui, T Hussein, CJ Fraenkel, P Medstrand and J Löndahl, 'Infectivity of exhaled SARS-CoV-2 aerosols is sufficient to transmit covid-19 within minutes', *Scientific Reports*, 2023, 13(21245), doi:10.1038/s41598-023-47829-8.

177 United States Environment Protection Agency (US EPA), 'Indoor Air and Coronavirus (COVID-19)', US EPA website, 31 March 2025, accessed 10 April 2025.

178 Wang et al, op. cit. n.174; and BJ Cowling, DKM Ip, VJ Fang, P Suntarattiwong, SJ Olsen, J Levy, TM Uyeki, GM Leung, JS Malik Peiris, T Chotpitayasunondh, H Nishiura and J Mark Simmerman, 'Aerosol transmission is an important mode of influenza A virus spread', Nature Communications, 2013, 4(1935), doi:10.1038/ncomms2922; and FC Fang, CA Benson, C del Rio, KM Edwards, VG Fowler Jr, DN Fredricks, AP Limaye, BE Murray, S Naggie, PG Pappas, R Patel, DL Paterson, DA Pegues, WA Petri Jr and RT Schooley, 'COVID-19-Lessons Learned and Questions Remaining', Clinical Infectious Diseases, 2020, 1654, doi:10.1093/cid/ciaa1654; and K Nissen; and J Krambrich, D Akaberi, T Hoffman, J Ling, Å Lundkvist, L Svensson and E Salaneck, 'Long-distance airborne dispersal of SARS-CoV-2 in COVID-19 wards', Scientific Reports, 2020, 10(19589), doi:10.1038/s41598-020-76442-2; and JS Kutter, D de Meulder, TM Bestebroer, P Lexmond, A Mulders, M Richard, RAM Fouchier and S Herfst, 'SARS-CoV and SARS-CoV-2 are transmitted through the air between ferrets over more than one meter distance', Nature Communications, 2021, 12(1653), doi:10.1038/s41467-021-21918-6; and JA Lednicky, M Lauzard, ZH Fan, A Jutla, TB Tilly, M Gangwar, M Usmani, SN Shankar, K Mohamed, A Eiguren-Fernandez, CJ Stephenson, MM Alam, MA Elbadry, JC Loeb, K Subramaniam, TB Waltzek, K Cherabuddi, JG Morris Jr and CY Wu, 'Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients', International Journal of Infectious Diseases, 2020, 100:476-482, doi:10.1016/j.ijid.2020.09.025; and CR MacIntyre and MR Ananda-Rajah, 'Scientific evidence supports aerosol transmission of SARS-COV-2' Antimicrobial Resistance and Infection Control, 2020, 9(202), doi:10.1186/s13756-020-00868-6; and JW Tang, WP Bahnfleth, PM Bluyssen, G Buonanno, JL Jimenez, J Kurnitski, Y Li, S Miller, C Sekhar, L Morawska, LC Marr, AK Melikov, WW Nazaroff, PV Nielsen, R Tellier , P Wargocki and SJ Dancer, 'Dismantling myths on the airborne transmission of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2)', Journal of Hospital Infection, 2021, 110:89-96, doi:10.1016/j.jhin.2020.12.022; and JM Samet, K Prather, G Benjamin, S Lakdawala, J Lowe, A Reingold, J Volckens, and LC Marr, 'Airborne Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2): What We Know', Clinical Infectious Diseases, 2021, 73(10):1924-1926, doi:10.1093/cid/ciab039; and R Monroe, 'It's not just SARS-COV-2: most respiratory viruses spread by aerosols', Scripps Institution of Oceanography University of California San Diego, 2021, accessed 10 April 2025; and C-R Du, S-C Wang, M-C Yu, T-F Chiu, J-Y Wang, P-C Chuang, R Jou, P-C Chan and C-T Fang, 'Effect of ventilation improvement during a tuberculosis outbreak in underventilated university buildings', Indoor Air, 2020, 30(3):422-432, doi:10.1111/ina.12639.

179 L Morawska, J Allen, W Bahnfleth, PM Bluyssen, A Boerstra, G Buonanno, J Cao, SJ Dancer, A Floto, F Franchimon and 29 more authors, 'A paradigm shift to combat indoor respiratory infection', Science, 2021, 372(6543):689–691, doi:10.1126/science.abg2025; and Wang et al, op. cit. n.174; and L Morawska, JW Tang, W Bahnfleth, PM Bluyssen, A Boerstra, G Buonanno, J Cao, S Dancer, A Floto, F Franchimon and 26 more authors, 'How can airborne transmission of COVID-19 indoors be minimised?', Environment International, 2020, 142(105832), doi:10.1016/j.envint.2020.105832; and F Rajab, 'Airborne transmission of viruses 'more prevalent than previously recognized', Medical News Today, 4 September 2021, accessed 10 April 2025; and R Zhang, Y Li, AL Zhang and MJ Molina, 'Identifying airborne transmission as the dominant route for the spread of COVID-19', Proceedings of the National Academy of Sciences of the United States of America, 2020, 117(26):14857–14863, doi:10.1073/pnas.2009637117; and JM Warfel, J Beren and TJ Merkel, 'Airborne transmission of Bordetella pertussis', Journal of Infectious Diseases, 2012, 206(6):902–906, doi:10.1093/infdis/jis443.

180 N Shaikh, P Swali, RMGJ Houben, 'Asymptomatic but infectious - The silent driver of pathogen transmission. A pragmatic review', *Epidemics*, 2023 Sep;44:100704, doi:10.1016/j.epidem.2023.100704; and K Ravindra, VS Malik, BK Padhi, S Goel and M Gupta, 'Asymptomatic infection and transmission of COVID-19 among clusters: systematic review and meta-analysis', Public Health, 2022, 203:100–109, doi:10.1016/j.puhe.2021.

181 Y Xie, T Choi and Z Al-Aly, 'Long-term outcomes following hospital admission for COVID-19 versus seasonal influenza: a cohort study', The Lancet Infectious Diseases, 2024, 24(3):239-255, doi:10.1016/S1473-3099(23)00684-9; and C Barber, 'COVID-19 v. Flu: A 'much more serious threat,' new study into long-term risks concludes', Fortune, 15 December 2023, accessed 10 April 2025.

182 B Bowe, Y Xie, Z Al-Aly , 'Acute and postacute sequelae associated with SARS-CoV-2 reinfection', *Nature Medicine*, 2022, 28(11): 2398–2405, doi:0.1038/s41591-022-02051-3; and S Kuang, S Earl, J Clarke, D Zakaria, A Demers and S Aziz, *Experiences of Canadians with long-term symptoms following COVID-19* [PDF 482KB], *Statistics Canada*, 2023, Chart 2 and Table 1, p 5.

183 L Wang, PB Davis, N Berger, DC Kaelber, N Volkow and R Xu, 'Association of COVID-19 with respiratory syncytial virus (RSV) infections in children aged 0–5 years in the USA in 2022: a multicentre retrospective cohort study', Family Medicine and Community Health, 2023, 11, e002456, doi:10.1136/fmch-2023-002456.

184 HM Tran, FJ Tsai, YL Lee, JH Chang, LT Chang, TY Chang, KF Chung, HP Kuo, KY Lee, KJ Chuang and HC Chuang 'The impact of air pollution on respiratory diseases in an era of climate change: A review of the current evidence', Science of The Total Environment, 2023, 898,66340, doi:10.1016/j.scitotenv.2023.166340.

185 S Vos, E De Waele, P Goeminne, EM Bijnens, E Bongaerts, DS Martens, R Malina, M Ameloot, K Dams, A De Weerdt, G Dewyspelaere, R Jacobs, G Mistiaen, P Jorens and TS Nawrot, 'Pre-admission ambient air pollution and blood soot particles predict hospitalisation outcomes in COVID-19 patients', *European Respiratory Journal*, 2023, 62(1), 2300309, doi:10.1183/13993003.00309-2023.

186 Z Chen, BZ Huang, MA Sidell, T Chow, SP Eckel, N Pavlovic, MP Martinez, F Lurmann, DC Thomas, FD Gilliland and AH Xiang, 'Near-roadway air pollution associated with COVID-19 severity and mortality – Multiethnic cohort study in Southern California', *Environment International*, 2021, 157(106862), doi:10.1016/j.envint.2021.106862.

187 Haddrell et al, op. cit. n.135.

188 MC Loaiza-Ceballo, D Marin-Palma, W Zapata and JC Hernandez, 'Viral respiratory infections and air pollutants', *Air Quality, Atmosphere and Health*, 2022, 15(1):105–14, doi:10.1007/s11869-021-01088-6.

189 Pillay et al, op. cit. n.5, p iii.

190 WS Dols, BJ Polidoro, D Poppendieck and SJ Emmerich, A Tool to Model the Fate and Transport of Indoor Microbiological Aerosols (FaTIMA), Technical Note (NIST TN) [PDF 2512KB], National Institute of Standards and Technology, 2020, doi:10.6028/NIST.TN.2095.

191 DD Barth, J Daw, R Xu, S Enkel, J Pickering, T McRae, ME Engel, J Carapetis, R Wyber and AC Bowen, 'Modes of transmission and attack rates of group A Streptococcal infection: a protocol for a systematic review and meta-analysis', *Systematic Reviews*, 2021, 10(1):90, doi:10.1186/s13643-021-01641-5. See also T Auala, BG Zavale, AC Mbakwem and AO Mocumbi, 'Acute Rheumatic Fever and Rheumatic Heart Disease: Highlighting the Role of Group A Streptococcus in the Global Burden of Cardiovascular Disease', *Pathogens*, 2022, 11(5):496, doi:10.3390/pathogens11050496.

192 A Bakker, JA Siegel, MJ Mendell, AJ Prussin 2nd, LC Marr and J Peccia, 'Bacterial and fungal ecology on air conditioning cooling coils is influenced by climate and building factors', Indoor Air, 2020, 30(2):326–334, doi:10.1111/ina.12632. See also RM Donlan, 'Biofilms: microbial life on surfaces', Emerging Infectious Diseases, 2002, 8(9):881-90, doi:10.3201/eid0809.020063.

193 World Health Organization (WHO), 'Legionellosis', WHO, 6 September 2022, accessed 10 April 2025. See also SM Walser, DG Gerstner, B Brenner, C Höller, B Liebl, CE Herr, 'Assessing the environmental health relevance of cooling towers–a systematic review of legionellosis outbreaks', *Int J Hyg Environ Health*, 2014 Mar, 217(2-3):145-54, doi:10.1016/j.ijheh.2013.08.002; and L Girolamini, E Brattich, F Marino, M Rosaria Pascale, M Mazzotta, S Spiteri, C Derelitto, L Tositti and S Cristino, 'Cooling towers influence in an urban environment: A predictive model to control and prevent Legionella risk and Legionellosis events', *Building and Environment*, 2023, 228:109891, doi:10.1016/j.buildenv.2022.109891.

194 NHS England, 'Legionnaires' disease', NHS England website, 21 July 2023, accessed 10 April 2025.

195 Western Australia (WA) Department of Health, 'Minimising the risk of a Legionella infection at home', WA Department of Health website, n.d., accessed 10 April 2025.

196 G Churchyard, P Kim, NS Shah NS, R Rustomjee, N Gandhi, B Mathema, D Dowdy, A Kasma and V Cardenas, 'What We Know About Tuberculosis Transmission: An Overview', *Journal of Infectious Disease*, 2017, Nov 3;216(suppl_6):S629-S635, doi:10.1093/infdis/jix362; and Department of Health and Aged Care (DoHAC), 'Infection control guidelines for the management of patients with suspected or confirmed pulmonary tuberculosis in healthcare settings', *Communicable Diseases Intelligence*, 2016, vol 40, no 3, DoHAC website, accessed 10 April 2025.

197 EL Best, WN Fawley, P Parnell and MH Wilcox, 'The Potential for Airborne Dispersal of Clostridium difficile from Symptomatic Patients, *Clinical Infectious Diseases*, 2010, 50(11):1450–1457, doi:10.1086/652648.

198 JG Natalini, S Singh S and LN Segal, 'The dynamic lung microbiome in health and disease', Nature Reviews Microbiology, 2023, 21:222-35, doi:10.1038/s41579-022-00821-x.

199 Environmental Health Standing Committee (enHealth), 'enHealth guidance – Potential health effects of mould in the environment', Department of Health and Aged Care (DoHAC) website, 31 December 2021, accessed 10 April 2025.

200 C Tischer, CM Chen and J Heinrich, 'Association between domestic mould and mould components, and asthma and allergy in children: a systematic review', European Respiratory Journal, 2011, 38(4):812-824, doi:10.1183/09031936.00184010.

201 World Health Organization (WHO), 'WHO Housing and health guidelines', WHO website, 23 November 2018, accessed 10 April 2025, p.91.

202 Department of Health and Aged Care (DoHAC), 'Biotoxins (Indoor damp and mould) Clinical Pathway', DoHAC website, 30 November 2023, accessed 10 April 2025.

203 Australian Building Codes Board, 'Condensation in buildings handbook', ABCB website, 23 August 2021, accessed 10 April 2025.

204 See, for example, SafeWork NSW, 'Mould at work', SafeWork NSW website, n.d., accessed 10 April 2025.

205 World Health Organization (WHO) Regional Office for Europe, 'WHO guidelines for indoor air quality: dampness and mould', WHO website, 2009, accessed 10 April 2025.

206 Ibid.

207 L Coulburn and W Miller, 'Prevalence, Risk Factors and Impacts Related to Mould-Affected Housing: An Australian Integrative Review', *International Journal of Environmental Research and Public Health*, 2022, 19(3):1854, doi:10.3390/ijerph19031854. See also R Bentley and E Baker, 'Mould and damp health costs are about 3 times those of sugary drinks. We need a healthy housing agenda', CSIRO website, 26 October 2020, accessed 10 April 2025.

208 World Health Organization (WHO) Regional Office for Europe, op. cit. n.205.

209 World Health Organization (WHO), 'WHO fungal priority pathogens list to guide research, development and public health action', WHO website, 25 October 2022, accessed 10 April 2025.

210 TR Dagenais and NP Keller, 'Pathogenesis of Aspergillus fumigatus in Invasive Aspergillosis', *Clinical Microbiology Reviews*, 2009, 22(3):447-65, doi:10.1128/CMR.00055-08; and Victorian Department of Health, 'Cryptococcosis', Victorian Department of Health website, 8 October 2015, accessed 10 April 2025. Note also emerging antimicrobial resistant *A. fumigatus* is a growing public health concern – see, for example, Centers for Disease Control and Prevention (CDC), 'Antimicrobial-Resistant *Aspergillus*', CDC website, 24 April 2024, accessed 10 April 2025.

211 G Moore, O Akinola, D Stevenson, DS Taori, K Jeffrey and C Brown, 'Recovery and survival of airborne Candida auris' in CS Brown and R Guy, 'National Public Health Response to *Candida auris* in England', *Journal of Fungi*, 2019, 5(4):93, doi:10.3390/jof5040093.

212 G Kayta, A Manilal, D Tadesse and M Siraj, 'Indoor air microbial load, antibiotic susceptibility profiles of bacteria, and associated factors in different wards of Arba Minch General Hospital, southern Ethiopia', PLoS ONE, 2022, 17(7), doi:10.1371/journal.pone.0271022.

213 A Maione, M Norcia, M Sinoca, M Galdiero, V Maselli, A Feola, R Carotenut, P Cuomo, R Capparelli, M Guida and E Galdiero, 'Polystyrene Microplastics Exacerbate *Candida albicans* Infection Ability In Vitro and In Vivo', *International Journal of Molecular Sciences*, 2024, 25(1):12, doi:10.3390/ijms25010012.

214 L Cooley, C Dendle, J Wolf, BW The, SC Chen, C Boutlis and KA Thursky, 'Consensus guidelines for diagnosis, prophylaxis and management of Pneumocystis jirovecii pneumonia in patients with haematological and solid malignancies, 2014', *Internal Medicine Journal,* 44(12b):1350-63, doi:10.1111/imj.12599; and A Alanio, M Gits-Muselli, S Mercier-Delarue, F Dromer and S Bretagne, 'Diversity of Pneumocystis jirovecii during Infection Revealed by Ultra-Deep Pyrosequencing', Frontiers in Microbiology, 2016, 7:733, doi:10.3389/fmicb.2016.00733.

215 World Health Organization, op. cit. n.209; and The National Tribune, 'Hidden threat: rise of deadly fungal pathogens', *The National Tribune*, 23 January 2024, accessed 10 April 2025.

216 KW Bundy, JF Gent, W Beckett, MB Bracken, K Belanger, E Triche and BP Leaderer, 'Household airborne *Penicillium* associated with peak expiratory flow variability in asthmatic children', *Ann Allergy Asthma Immunol.*, 2009, 103(1):26-30, doi:10.1016/S1081-1206(10)60139-1.

217 Australian Building Codes Board (ABCB), op. cit. n.16, Table 2.1 to 2.6; and United States Environmental Protection Agency (US EPA), 'What are biological pollutants, how do they affect indoor air quality?', US EPA website, 19 October 2023, accessed 10 April 2025.

218 Australian Building Codes Board (ABCB), op. cit. n.16, Table 2.1 to 2.6; and United States Environmental Protection Agency, ibid; and Better Health Channel, 'House dust mite', Better Health Channel website, 14 July 2022, accessed 9 April 2025; and NSW Health, 'Psittacosis (Ornithosis) fact sheet', NSW Health website, 31 January 2024, accessed 10 April 2025; and Centre of Research Excellence in Pulmonary Fibrosis and Lung Foundation Australia (LFA), *Living with Pulmonary Fibrosis. Hypersensitivity Pneumonitis* [PDF], LFA website, n.d., accessed 10 April 2025.

219 Better Health Channel, ibid.

220 Weschler and Nazaroff, op. cit. n.156.

221 RR Sahay, RI Iraq and AL Wozniak, *Human Skin Cells: A Potential Source of Building Contaminants* [PDF 972KB], Continental Automated Buildings Association (CABA), 2018, accessed 10 April 2025.

222 X Zhang, P Wargocki P, Z Lian, J Xie and J Liu, 'Responses to human bioeffluents at levels recommended by ventilation standards', 2017, *Procedia Engineering*, 205(609-614) in N Dodd, S Donatello and M Cordella, *Level(s) Indicator 4.1: Indoor Air Quality* [PDF 2.64MB], European Commission, 2020, accessed 10 April 2025.

223 HealthDirect, 'Hay fever (allergic rhinitis)', HealthDirect website, November 2022, accessed 10 April 2025.

224 HealthDirect, 'Thunderstorm asthma', HealthDirect website, May 2022, accessed 10 April 2025.

225 Australian Institute of Health and Welfare (AIHW), 'Chronic Respiratory Conditions: Asthma', AIHW website, 27 November 2024, accessed 10 April 2025.

226 Department of Health, 'National Asthma Strategy 2018', Department of Health, Australian Government, 2018.

227 Ibid; and Australian Institute of Health and Welfare, op. cit. n.225.

228 LD Knibbs, S Woldeyohannes, GB Marks and CT Cowie, 'Damp housing, gas stoves, and the burden of childhood asthma in Australia', *Medical Journal of Australia*, 2018, 208(7):299-302, doi:10.5694/mja17.00469.

229 T Gruenwald, BA Seals, LD Knibbs and HD Hosgood III, 'Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States', *International Journal of Environmental Research and Public Health*, 2023, 20(1):75, doi:10.3390/ijerph20010075.

230 Australian Institute of Health and Welfare, op. cit. n.120.

231 Asthma Australia, *Housing and asthma policy position statement* [PDF], Asthma Australia website, June 2024, accessed 10 April 2025.

232 Department of Health, op. cit. n.226.

233 National Asthma Council (NAC), 'Australian Asthma Handbook', NAC website, 2022, accessed 10 April 2025.

234 Department of Health and Aged Care, op. cit. n.202.

235 G Ghirga, 'Rapid Response: In polluted areas, an unknown amount of microplastic and nanoplastic contamination can contribute to the mass of PM2.5 and the number of its ultrafine components', *British Medical Journal*, 13 March 2024.

236 R Dris, J Gasperi, C Mirande, C Mandin, M Guerrouache, V Langlois and B Tassin, 'A first overview of textile fibers, including microplastics, in indoor and outdoor environments', *Environmental Pollution*, 2017, 221:453-458, doi:10.1016/j.envpol.2016.12.013.

237 KG Carpenter, 'Clothes dryers may be a major source of airborne microplastics', ScienceNewsExplores website, 11 February 2022, accessed 10 April 2025.

238 V Dhaka, S Singh, AG Anil, TTSK Naik, S Garg, J Samuel, M Kumar, PC Ramamurthy and J Singh, 'Occurrence, toxicity and remediation of polyethylene terephthalate plastics. A review', *Environ Chem Lett*. 2022, 20(3):1777-180, doi:10.1007/s10311-021-01384-8.

239 K Perera, S Ziajahromi, SB Nash and FDL Leusch, 'Microplastics in Australian indoor air: Abundance, characteristics, and implications for human exposure', *Science of the Total Environment*, 2023, 889(164292), doi:10.1016/j.scitotenv.2023.164292.

240 MS Jeon, JW Kim, YB Han, MH Jeong, HR Kim, H Sik Kim, YJ Park and KH Chung, 'Polystyrene microplastic particles induce autophagic cell death in BEAS-2B human bronchial epithelial cells', *Environ Toxicol*, 2023, 38(2):359-367, doi:10.1002/tox.23705. Epub 2022 Dec 9.

241 CD Dong, CW Chen, YC Chen, HH Chen, JS Lee and CH Lin, 'Polystyrene microplastic particles: In vitro pulmonary toxicity assessment, Journal of Hazardous Materials', *Journal of Hazardous Materials*, 2020, 385(121575), doi:10.1016/j.jhazmat.2019.121575.

242 IV Kirstein, S Kirmizi, A Wichels, A Garin-Fernandez, R Erler, M Loder and G Gerdts, 'Dangerous hitchhikers? Evidence for potentially pathogenic Vibrio spp. on microplastic particles', *Marine Environmental Research*, 2016, 120:1-8, doi:10.1016/j.marenvres.2016.07.004; and C Beans, 'Are microplastics spreading infectious disease?' *PNAS*, 2023, 120(31):1-5, doi:10.1073/pnas.2311253120.

243 Maione et al, op. cit. n.213.

244 Comcare, 'Crystalline silica', Comcare website, 3 February 2025, accessed 10 April 2025.

245 Safe Work Australia, 'Crystalline silica and silicosis - Questions and answers about the impact analysis and consultation', Safe Work Australia website, n.d., accessed 10 April 2025.

246 Safe Work Australia, 'Engineered stone ban. Protecting workers' health and safety', Safe Work Australia website, n.d., accessed 10 April 2025.

247 The Hon Tony Burke MP and Senator the Hon Murray Watt, *Engineered stone importation ban to start January 1* [media release], Ministers' Media Centre website, 18 September 2024, accessed 10 April 2025.

248 C Ramkissoon, Y Song, S Yen, K Southam, S Page, D Pisaniello, S Gaskin and GR Zosky, 'Understanding the pathogenesis of engineered stone-associated silicosis: The effect of particle chemistry on lung cell response', *Respirology*, 2024, 29(3):189-259, doi:10.1111/resp.14625; and University of Tasmania, 'Silica not the only component to pose serious concern for lung health: new study shows', University of Tasmania, 5 December 2023, accessed 10 April 2025; and R Carey and C Ramkissoon, 'Engineered stone is now banned. But how safe are the alternatives?' *The Conversation*, 1 July 2024, accessed 10 April 2025.

249 Asbestos and Silica Safety and Eradication Agency (ASSEA), 'Find out about asbestos', ASSEA website, n.d., accessed 10 April 2025.

250 Safe Work Australia (SWA), op. cit. n.22.

251 Department of Health and Aged Care, op. cit. n.105.

252 International Agency for Research on Cancer (IARC), 'IARC Monographs on the Evaluation of the Carcinogenic Risks to Humans: Man-Made Mineral Fibres and Radon', IARC website, 1988, accessed 10 April 2025.

253 NJ Olsen, PJ Franklin, A Reid, NH de Klerk, TJ Threlfall, K Shilkin and B Musk, 'Increasing incidence of malignant mesothelioma after exposure to asbestos during home maintenance and renovation', *Medical Journal of Australia*, 2011, 195(5):271-274, doi:10.5694/mja11.10125.

254 International Agency for Research on Cancer, op. cit. n.252.

255 S Darby, D Hill, A Auvinen, J M Barros-Dios, H Baysson, F Bochicchio, H Deo, R Falk, F Forastiere, M Hakama and 16 more authors, 'Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies', *British Medical Journal Publishing* Group, 2005, 330:223, doi:10.1136/bmj.38308.477650.63.

256 Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 'Radon map of Australia', ARPANSA website, n.d., accessed 10 April 2025.

257 Ibid.

258 Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 'Australian Radon Action Plan', ARPANSA website, n.d., accessed 10 April 2025.

259 Ibid.

260 Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 'Hire of radiation meters and Radon Monitor', ARPANSA website, 2024, accessed 10 April 2025.

261 Environmental Health Standing Committee (enHealth), 'enHealth guidance – Lead in drinking water from some plumbing products', Department of Health and Aged Care (DoHAC) website, 1 November 2023, accessed 10 April 2025; and National Health and Medical Research Council (NHMRC), 'Evidence on the effects of lead on human health', NHMRC website, 2015, accessed 10 April 2025. See also NSW Environment Protection Authority and Planning NSW, *Managing Lead Contamination in Home Maintenance, Renovation and Demolition Practices. A Guide for Councils* [PDF], Environment NSW website, February 2003, accessed 10 April 2025.

262 SA Health, 'Lead in Port Pirie', SA Health website, n.d., accessed 10 April 2025.

263 World Health Organization (WHO), *WHO guideline for clinical management of exposure to lead* [PDF], WHO website, 2021, accessed 10 April 2025, p.11.

264 NSW Health, 'Lead exposure in children and adults', NSW Health website, 26 September 2024, accessed 10 April 2025.

265 Environmental Health Standing Committee (enHealth), op. cit. n.261; and National Health and Medical Research Council, op. cit. n.261. See also NSW Environment Protection Authority and Planning NSW, op. cit. n.261.

266 INY Doyi, CF Isley, NS Soltani and MP Taylor, 'Human exposure and risk associated with trace element concentrations in indoor dust from Australian homes', *Environment International,* 2019, 133, doi:10.1016/j.envint.2019.105125.

267 SL Cruz SL, MT Rivera-García and JJ Woodward, 'Review of toluene action: clinical evidence, animal studies and molecular targets', *Journal of Drug and Alcohol Research*, 2014, 3:235840, doi:10.4303/jdar/235840.

268 A Steinemann, 'Ten questions concerning air fresheners and indoor built environments', *Building and Environment,* 2017, 111:279-284, doi:10.1016/j.buildenv.2016.11.009.

269 L Ampollini, EF Katz, S Bourne, Y Tian, A Novoselac, AH Goldstein, G Lucic, MS Waring and PF DeCarlo, 'Observations and Contributions of Real-Time Indoor Ammonia Concentrations during HOMEChem', *Environmental Science & Technology*, 2019, 53(15):8591-8598, doi:10.1021/acs.est.9b02157; and HJ Salonen, AL Pasanen , SK Lappalainen , HM Riuttala , TM Tuomi, PO Pasanen , BC Bäck and KE Reijula, 'Airborne Concentrations of Volatile Organic Compounds, Formaldehyde and Ammonia in Finnish Office Buildings with Suspected Indoor Air Problems', *Journal of Occupational and Environmental Hygiene*, 2009, 6(3): 200-209, doi:10.1080/15459620802707835.

270 S Vardoulakis, E Giagloglou, S Steinle, A Davis, A Sleeuwenhoek, KS Galea, K Dixon K and JO Crawford, 'Indoor exposure to selected air pollutants in the home environment: A Systematic Review', *International Journal of Environmental Research and Public Health*, 2020, 17:8972, doi:10.3390/ijerph17238972.

271 Molloy et al, op. cit. n.19.

272 S Molloy, I Galbally, M Keywood, J Powell, S Lawson, M Cheng, R Gillett and E Dunne, *A Comparison of Indoor Air Quality in Australian Dwellings with Indoor Air Quality Overseas* [conference presentation], 20th International Clean Air and Environment Conference, Auckland, 31 July-2 August 2011, accessed 10 April 2025.

273 See, for example, JF Brundage, RM Scott, WM Lednar, DW Smith and RN Miller, 'Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees', *JAMA*, 1988, 259(14):2108–2112, doi:10.1001/jama.1988.03720140028029.

274 P Rajagopalan and N Goodman, 'Improving the Indoor Air Quality of Residential Buildings during Bushfire Smoke Events', *Climate*, 2021, 9(2):32, doi:10.3390/cli9020032.

275 Mahmoud et al, op. cit. n.174.

276 Department of Environment and Heritage, op. cit. n.15; and The Royal Australian and New Zealand College of Obstetricians and Gynaecologists (RANZCOG), Air pollution and pregnancy [PDF], RANZCOG website, 7 June 2021, accessed 10 April 2025.

277 P Franklin, M Tan, N Hemy and GL Hall, 'Maternal Exposure to Indoor Air Pollution and Birth Outcomes', International *Journal of Environmental Research and Public Health*, 2019, 16(8):1364. doi:10.3390/ijerph16081364; S Singh, I Goel, S Tripathi, A Ahirwar, M Kumar, A Rana, R Dhar and S Karmakar, 'Effect of environmental air pollutants on placental function and pregnancy outcomes: a molecular insight', *Environmental Science and Pollution Research*, 2024, 31(50):59819-59851, doi:10.1007/s11356-024-35016-9; and M J Cahuana-Bartra, E Mazarico-Gallego, A J Cahuana-Bartra, R Pascal, L Alonso-Garcia, J Targa, C Muñoz-Lozano, P Dadvand and M D Gómes-Roig, 'Maternal short-term exposure to NO_2 during pregnancy and its relationship with Doppler markers of placental function', *Environmental Research*, 2022, 214:113813, doi:10.1016/j.envres.2022.113813.

278 H Liu, LL Wang, SJ Zhao, J Kwak-Kim, G Mor and AH Liao, 'Why are pregnant women susceptible to COVID-19? An immunological viewpoint', *J Reprod Immunol*., June 2020, 139:103122, doi:10.1016/j.jri.2020.103122; Australian Institute of Health and Welfare (AIHW), 'Maternal and perinatal outcomes during the 2020 and 2021 COVID-19 pandemic', AIHW website, Australian Government, 2024, accessed 12 August 2025; CL DeSisto, B Wallace, RM Simeone, K Polen, JY Ko, D Meaney-Delman and SR Ellington, 'Risk for Stillbirth Among Women With and Without COVID-19 at Delivery Hospitalization - United States, March 2020-September 2021. MMWR' *Morb Mortal Wkly Rep*., 26 November 2021, 70(47):1640-1645, doi:10.15585/mmwr.mm7047e1; and DA Schwartz, SB Mulkey and DJ Roberts, 'SARS-CoV-2 placentitis, stillbirth, and maternal COVID-19 vaccination: clinical–pathologic correlations', *American Journal of Obstetrics & Gynecology*, March 2023, 228(3):261 – 269, doi:10.1016/j.ajog.2022.10.001.

279 JX Wu, ATY Lau and YM Xu, 'Indoor Secondary Pollutants Cannot Be Ignored: Third-Hand Smoke', *Toxics*, 2022, 10(7):363, doi:10.3390/toxics10070363.

280 LG Arlian, JS Neal, MS Morgan, DL Vyszenski-Moher, CM Rapp and AK Alexander, 'Reducing relative humidity is a practical way to control dust mites and their allergens in homes in temperate climates', *The Journal of Allergy and Clinical Immunology*, 2001, 107(1):99-104, doi:10.1067/mai.2001.112119.

281 K Ito and S Takada, 'Effects of indoor low humidity on eye discomfort and associated physiological responses in soft contact lens and non-lens wearers', *Indoor and Built Environment*, 2023, 32(3):590-602, doi:10.1177/1420326X221126352.

282 A Aganovic, Y Bi, G Cao, J Kurnitski and P Wargocki, 'Modeling the impact of indoor relative humidity on the infection risk of five respiratory airborne viruses', *Scientific Reports*, 2022, 12:11481, doi:10.1038/s41598-022-15703-8; and CA Verheyen and L Bourouiba, 'Associations between indoor relative humidity and global COVID-19 outcomes', Journal of the Royal Society Interface, 2022, 19(196), doi:10.1098/rsif.2021.0865.

283 T Salthammer and GC Morrison, 'Temperature and indoor environments', *Indoor Air*, 2022, 32(5):e13022, doi:10.1111/ina.13022. See also D Chen, Z Ren and B Lan, 'The hot issue in houses we have to deal with', CSIRO website, 7 November 2019, accessed 10 April 2025.

284 Australian Building Codes Board (ABCB), 'Climate zone map', ABCB website, n.d., accessed 10 April 2025.

285 A Kevat, 'Thunderstorm asthma: Looking back and looking forward', *Journal of Asthma and Allergy*, 2020, 13:293-299, doi:10.2147/JAA.S265697; and A Mansouri, W Wei, JM Alessandrini, C Mandin and P Blondeau, 'Impact of Climate Change on Indoor Air Quality: A Review', *International Journal of Environmental Research and Public Health,* 2022, 19(23):15616, doi:10.3390/ijerph192315616; and GL Chew and S Saha, 'Chapter 7: Impacts of Climate Change on Indoor Allergens', in PJ Beggs (eds), *Impacts of Climate Change on Allergens and Allergenic Diseases*, Cambridge University Press, Cambridge, 2016. See also J Zhao, E Uhde, T Salthammer, F Antretter, D Shaw, N Carslaw and A Schieweck, 'Long-term prediction of the effects of climate change on indoor climate and air quality', Environmental Research, 15 February 2024, 243:117804, doi:10.1016/j.envres.2023.117804.

286 Health Canada, 'Guide to addressing moisture and mould indoors', Health Canada website, 2020, accessed 10 April 2025.

287 C Mora, T McKenzie, IM Gaw et al, 'Over half of known human pathogenic diseases can be aggravated by climate change', *Nature Climate Change*, 2022, 12:869–875, doi:10.1038/s41558-022-01426-1.

288 SE Kim, Y Xie, H Dai, S Fujimori, Y Hijioka, Y Honda, M Hashizume, T Masui, T Hasegawa, X Xu, K Yi and H Kim, 'Air quality co-benefits from climate mitigation for human health in South Korea', *Environment International*, 2020, 136:105507, doi:10.1016/j.envint.2020.105507.

289 G Adamkiewicz, AR Zota, MP Fabian, T Chahine, R Julien, JD Spengler and JI Levy, 'Moving environmental justice indoors: understanding structural influences on residential exposure patterns in low-income communities', *American Journal of Public Health*, 2011, 101, doi:10.2105/AJPH.2011.300119; and Ferguson et al, op. cit. n.70.

290 Australian Council of Social Services (ACOSS), *ACOSS 2023 Heat Survey* [PDF 576 KB], ACOSS, 2023, accessed 10 April 2025.

291 See, in relation to nitrogen dioxide, Wickham et al, op. cit. n.117. Note, for $PM_{2.5}$, Wickham et al found 81% of New Zealanders were exposed to annual levels above the World Health Organization guideline, and that this exposure did not vary significantly by socioeconomic deprivation.

292 KJ Heo, CE Lim, HB Kim and BU Lee, 'Effects of human activities on concentrations of culturable bioaerosols in indoor air environments', *Journal of Aerosol Science*, 2017, 104:58-65, doi:10.1016/j.jaerosci.2016.11.008. See also W Huang, CX Gao, D Luo, Y Wang, X Zheng, C Liu, Y Wang, Y Li and H Qian, 'Risk evaluation of venue types and human behaviors of COVID-19 outbreaks in public indoor environments: A systematic review and meta-analysis', Environmental Pollution,2024, 341:122970, doi:10.1016/j.envpol.2023.122970. For choirs, see A Tuhkuri Matvejeff, A Laitinen, M Korhonen, L-M Oksanen, A Geneid, E Sanmark, et al, 'Superspreading of SARS-CoV-2 at a choir rehearsal in Finland—A computational fluid dynamics view on aerosol transmission and patient interviews', *PLoS ONE*, 2024, 19(9):e0302250, doi:10.1371/journal.pone.0302250.

293 Environmental Health Standing Committee (enHealth), 'Australian Exposure Factor Guidance: Guidelines for assessing human health risks from environmental hazards', Department of Health and Aged Care (DoHAC) website, 30 June 2012, accessed 10 April 2025.

294 MG Baker, A McDonald, J Zhang and P Howden-Chapman, 'Infectious Diseases Attributable to Household Crowding in New Zealand: A systematic review and burden of disease estimate', He Kāinga Oranga/Housing & Health Research Programme, University of Otago website, 2013, accessed 10 April 2025.

295 Australian Institute of Health and Welfare, '2.01 Housing, Aboriginal and Torres Strait Islander Health Performance Framework', AIHW website, 2 July 2024, accessed 10 April 2025.

296 World Health Organization, op. cit. n.201.

297 AF Beck, L Wymer, E Pinzer, W Friedman, PJ Ashley and S Vesper, 'Reduced prevalence of childhood asthma after housing renovations in an under resourced community', *Journal of Allergy and Clinical Immunology: Global*, 2023, 2(4), doi:10.1016/j.jacig.2023.100143; and M Payne, 'Renovated Housing Linked to Decrease in Childhood Asthma Rate in Cincinnati Neighbourhood', United States Environmental Protection Agency (US EPA) *Science Matters Newsletter*, 21 November 2023, accessed 10 April 2025.

298 World Health Organization (WHO), 'Commercial determinants of health,' WHO website, 21 March 2023, accessed 29 August 2024. See also Australian Institute of Health and Welfare (AIHW), 'What are determinants of health?', AIHW website, 2 July 2024, accessed 10 April 2025.

299 Morantes et al, op. cit. n.38.

300 Molloy et al, op. cit. n.19.

301 United States Environmental Protection Agency (US EPA), 'Evidence from Scientific Literature about Improved Academic Performance', US EPA website, 20 August 2024, accessed 10 April 2025. See also P Taptiklis and R Phipps, *Indoor Air Quality in New Zealand Homes and Schools* [PDF], January 2017, accessed 10 April 2025.

302 S Brockmeyer and A D'Angiulli, 'How air pollution alters brain development: the role of neuroinflammation', *Translation Neuroscience*, 2016, 7(1):24-30, doi:10.1515/tnsci-2016-0005; and M MacNeill, N Dobbin, N St Jean, L Wallace, L Marro, T Shin, H You, R Kulka, RW Allen and AJ Wheeler, 'Can changing the timing of outdoor air intake reduce indoor concentrations of traffic-related pollutants in schools?' Indoor Air, 2016, 26(5):687–701.

303 Australian Health Protection Principal Committee (AHPPC), 'Australian Health Protection Principal Committee (AHPPC) statement on COVID-19, schools and reopening Australia', Department of Health and Aged Care (DoHAC) website, 1 October 2021, accessed 10 April 2025. See also Department of Education (DoE), 'Coronavirus (COVID19)', DoE website, 2024, accessed 10 April 2025.

304 Y Guo, Z Dou, N Zhang, X Liu, B Su, Y Li and Y Zhang, 'Student close contact behaviour and COVID-19 transmission in China's classrooms', PNAS Nexus, 2023, 2(5), doi:10.1093/pnasnexus/pgad142.

305 A Mikszewski, L Stabile, G Buonanno and L Morawska, 'Increased close proximity airborne transmission of the SARS-CoV-2 Delta variant', *Science of The Total Environment*, 2022, 816:151499, doi:10.1016/j.scitotenv.2021.151499.

306 N Banholzer, K Zurcher, P Jent, P Bittel, L Furrer, M Egger, T Hascher and L Fenner, 'SARS-CoV-2 transmission with and without mask wearing or air cleaners in schools in Switzerland: A modeling study of epidemiological, environmental, and molecular data', *PLoS Med*, 2023, 20(5):e1004226, doi:10.1371/journal.pmed.1004226.

307 J Curtius, M Granzin and J Schrod, 'Testing mobile air purifiers in a school classroom: Reducing the airborne transmission risk for SARS-CoV-2', *Aerosol Science and Technology*, 2021, 55:1-18, doi:10.1080/02786826.2021.1877257.

308 H Sharp, 'Air purifiers brought to daycare centres reduced children's illness by almost a third', Yle News, 27 November 2023, accessed 10 April 2025; and JYS Loh and MM Andaman, *A Review of IAQ Standards and Guidelines for Australian and New Zealand School Classrooms* [PDF 420 KB], Architectural Science Association website, 2017, accessed 10 April 2025.

309 Fondazione David Hume, 'Controlled Mechanical Ventilation (CMV) works', Fondazione David Hume website, 25 March 2022, accessed 10 April 2025.

310 D Green, N Cooper, C Silva, P Bahl, S Bhattacharjee, MMA Mahmoud, C Doolan and CR Macintyre, 'Demonstrating the most effective interventions to improve classroom air quality. What novel in situ tests of real-world conditions show is still missing in our guidance', Environmental Research Health, 2023, doi:10.1088/2752-5309/ace5c9.

311 MJ Mendell, 'Do indoor pollutants and thermal conditions in school influence student performance? A critical review of the literature', *Indoor air: International Journal of Indoor Environment and Health*, 2004, 15(1), doi:10.1111/j.1600-0668.2004.00320.x; and WJ Fisk, 'The ventilation problem in schools: literature review', *Indoor air: International Journal of Indoor Environment and Health*, 2017, 27(6), doi:10.1111/ina.12403; and HW Brink, MGLC Loomans, MP Mobach and HSM Kort, 'Classroom's indoor environmental conditions affecting the academic achievement of students and teachers in higher education: A systematic literature review', Indoor Air: International Journal of Environment and Health, 31(2), doi:10.1111/ina.12745.

312 P Rajagopalan, MM Andaman and J Woo, 'Enhanced Indoor Air Quality for Improving the Well-Being of Vulnerable Population in Victoria', RMIT University website, 2020, accessed 10 April 2025.

313 S Snow, R Danam, P Leardini, M Glencross, B Beeson, LM Ottenhaus and M Boden, 'Human factors affecting ventilation in Australian classrooms during the COVID-19 pandemic: Toward insourcing occupant's proficiency in ventilation management', *Frontiers In Computer Science*, 2022, 4, doi:10.3389/fcomp.2022.888688; and The University of Queensland, 'Research brings a breath of fresh air to Brisbane classrooms', University of Queensland website, 16 September 2022, accessed 10 April 2025.

314 Snow, ibid; and The University of Queensland, ibid.

315 See Safe Work Australia, *Model Code of Practice: How to manage work health and safety risks* [PDF], SWA website, 14 November 2024, accessed 10 April 2025.

316 R Araujo, A Carneiro, S Costa-Oliveira, AG Rodrigues and JE Guimaraes, 'Fungal infections after haematology unit renovation: evidence of clinical, environmental and economical impact', European Journal of Haematology, 2008, 80(5):436-443, doi:10.1111/j.1600-0609.2008.01034.x.

317 KW Ng, *Green healthcare facilities: assessing the impacts of indoor environmental quality on the working environment from the perspective of health care workers* [thesis], The University of New South Wales, December 2011, accessed 10 April 2025.

318 H Cook, 'Victoria COVID: More than 600 people die after catching virus in hospital', The Age, 26 June 2023, accessed 10 April 2025. See also H Cook, 'Hundreds of patients died after catching COVID in Victorian hospitals, new data shows', The Age, 6 May 2024, accessed 10 April 2025, and XJ Lee, AJ Stewardson, LJ Worth, N Graves and TM Wozniak, 'Attributable Length of Stay, Mortality Risk, and Costs of Bacterial Health Care–Associated Infections in Australia: A Retrospective Case-cohort Study', Clinical Infectious Diseases, 2021, 72(10):e506–e514, doi:10.1093/cid/ciaa1228.

319 Better Health Channel, 'Coronavirus (COVID-19) Victoria', Better Health website, 11 April 2023, accessed 10 April 2025.

320 Australian Institute of Health and Welfare (AIHW), 'Admitted patient safety and quality', AIHW website, 11 August 2023, accessed 23 July 2024.

321 Australian Commission on Safety and Quality in Health Care, 'Staphylococcus aureus bloodstream infection (SABSI) prevention resources', Australian Commission on Safety and Quality in Health Care website, 2024, accessed 10 April 2024.

322 A bloodstream infection caused by *S.aureus* can have up to 30% mortality – VICNISS, *Staphylococcus aureus (Golden Staph) bloodstream (SAB) infections* [PDF], VICNISS website, n.d., accessed 10 April 2025.

323 X Li, Y Qiu, A Yu, W Shi, G Chen, Z Zhang and D Liu, 'Characteristics of airborne Staphylococcus aureus (including MRSA) in Chinese public buildings', Aerobiologia, 2015, 31:11-19, doi:10.1007/s10453-014-9342-6.

324 University of Wollongong, op. cit. n.4, p.x.

325 E Hodge, S Oversby and J Chor, 'Why are some outbreaks worse than others? COVID-19 outbreak management strategies from a PHU perspective', BMC Public Health, 2023, 23(1), 597, doi:10.1186/s12889-023-15498-x. See also L Wagg and L Zhong, *Optimizing Ventilation Strategies for Mitigating SARS-CoV-2 Transmission in Long-Term Care Facilities: A Collaborative Study with Practical Implications* [PDF], eSIM 2024, 5 to 7 June 2024; and F McAndrew, R Sacks-Davis, RG Abeysuriya, D Delport, D West, I Parta, S Majumdar, M Hellard and N Scott, 'COVID-19 outbreaks in residential aged care facilities: an agent-based modeling study' *Front. Public Health*, 2024, 12:1344916, doi:10.3389/fpubh.2024.1344916.

326 Department of Health and Aged Care, 'Improving accommodation in residential aged care', Department of Health and Aged Care website, 7 November 2024, accessed 10 April 2025.

327 A Phabmixay, B Polkinghorne, A Marmor, N Pingault, TS Sloan-Gardner and MD Kirk, 'Lessons from a COVID-19 outbreak in the disability support sector, Australian Capital Territory, August 2021', Communicable Diseases Intelligence, 2023, 47, doi:10.33321/cdi.2023.47.34.

328 National Disability Gateway, *Ventilation and COVID-19: Information for disability providers* [PDF 10KB], Australian Government, 2022, accessed 10 April 2025; and NSW Health, 'COVID-19: Advice for disability service providers', NSW Government website, 4 February 2025, accessed 10 April 2025.

329 Commonwealth Scientific and Industrial Research Organisation, *CSIRO Media Release – Beating The $12 Billion Cost Of Polluted Air, S Brown 1998* [media release], Healthy Interiors website via Wayback Machine website, 1998, accessed 10 April 2025.

330 California Air Resources Board (CARB), 'Car and Bus Exposure Studies', CARB website, n.d., accessed 10 April 2025; and S Howie and J O'Brien, 'Rush-hour traffic in Seattle increases blood pressure, but not for the reason you think', KUOW, 28 November 2023, accessed 10 April 2025; and D Carrington, 'Air pollution more harmful to children in cars than outside, warns top scientist,' The Guardian, 12 June 2017, accessed 10 April 2025.

331 California Air Resources Board (CARB), ibid.

332 A Uteuova, 'Like a high-sodium diet: traffic pollution can cause rise in blood pressure – study', The Guardian, 30 November 2023, accessed 10 April 2025.

333 Ibid; and MT Young, K Jansen, KE Cosselman, TR Gould, JA Stewart, T Larson, C Sack, S Vedal, AA Szpiro and JD Kaufman, 'Blood Pressure Effect of Traffic-Related Air Pollution: A Crossover Trial of In-Vehicle Filtration', Annals of Internal Medicine, 2023, 176(12):1586-1594, doi:10.7326/M23-1309; and S Liu, R Wu, Y Zhu, T Wang, J Fang, Y Xie, N Yuan, H Xu, X Song and W Huang, 'The effect of using personal-level indoor air cleaners and respirators on biomarkers of cardiorespiratory health: a systematic review', Environment International, 2022, 158, 10698, doi:10.1016/j.envint.2021.106981.

334 N Molden, C Hemming, F Leach, JG Levine, K Ropkins and W Bloss, 'Exposures to Particles and Volatile Organic Compounds across Multiple Transportation Modes', Sustainability, 2023, 15(5), 4005, doi:10.3390/su15054005; and M Moglia, CA Nygaard. H Ghaderi and H Dia, 'Air quality at many train stations is alarmingly bad. Here's how to improve it', The Conversation, 27 March 2024, accessed 10 April 2025. See also recent media reports, for example, ABC News, 'Why Melbourne's Southern Cross Station may have some of the 'least clean' air in the city', ABC website, 6 March 2024, accessed 10 April 2025; and Sydney Morning Herald, 'Shocking air quality on rail network threatens passengers and staff', Sydney Morning Herald, 20 February 2024, accessed 10 April 2025.

335 Rail Safety and Standards Boards (RSSB), 'CLEAR: Analysis of Air Quality On Board Trains (T1188)', RSSB website, 2021, accessed 10 April 2025; and Department of Transport, 'Air quality onboard trains: a response to the Rail Safety and Standards Board report', UK Government website, 5 June 2023, accessed 10 April 2025.

336 California Air Resources Board (CARB), 'Children's School Bus Exposure and Mitigation Studies', CARB website, n.d., accessed 10 April 2025.

337 World Health Organization (WHO), *Strategic approaches to indoor air policy-making*, WHO, Copenhagen, 1999, p.26.

338 JG Zivin and M Neidell, 'The Impact of Pollution on Worker Productivity', The American Economic Review, 2012, 102(7):3652–3673, doi:10.1257/aer.102.7.3652.

339 Pillay et al, op. cit. n.5, p iii.

340 University of Wollongong, op. cit. n. 4, p.x.

341 Bentley and Baker, op. cit. n.207.

342 R Bentley, 'Indoor mould and population health: estimating the costs', presentation at AIRAH IAQ 2024, Melbourne, 15 July 2024.

343 Department of Health and Aged Care, op. cit. n.202, p.v.

344 EZ Samsudin, SM Yasin, NH Ruslan, NN Abdullah, AFA Noor and AFA Hair, 'Socioeconomic impacts of airborne and droplet-borne infectious diseases on industries: a systematic review', BMC Infectious Diseases, 2024, 24(1):93, doi:10.1186/s12879-024-08993-y.

345 Access Economics, *The economic impact of allergic disease in Australia: not to be sneezed at* [PDF], Australasian Society of Clinical Immunology and Allergy website, 13 November 2007, accessed 10 April 2025. See also NHMRC, 'Airborne pollen and respiratory allergies: Case Study', NHMRC website, 1 August 2023, accessed 10 April 2025.

346 Boulanger et al, op. cit. n.6. See also ANSES et al, op. cit. n.6.

347 Liu et al, op. cit. n.7.

348 Phillips, op. cit. n.8.

349 Australian Institute of Health and Welfare (AIHW), 'Chronic respiratory conditions', AIHW website, 27 November 2024, accessed 10 April 2025.

350 NK Brusco, A Alafaci, J Tuckerman, H Frawley, J Pratt, AJ Daley, AK Todd, Y-M Deng, K Subbarao, I Barr and NW Crawford, 'The 2018 annual cost burden for children under five years of age hospitalised with respiratory syncytial virus in Australia', Communicable Diseases Intelligence, 2022, 46, doi:10.33321/cdi.2022.46.5.

351 Australian Bureau of Statistics (ABS), 'Causes of Death, Australia [TableBuilder]', ABS website, 10 October 2024, accessed 10 April 2025.

352 V Costantino, Q Grafton, T Kompas, L Chu, D Honeyman, A Notaras and CR MacIntyre, 'The public health and economic burden of long COVID in Australia, 2022–24: a modelling study', *Med J Aust*, 2024, 221 (4):217-223, doi:10.5694/mja2.52400.

353 Australian Bureau of Statistics (ABS), 'Causes of Death, Australia [TableBuilder]', ABS website, 10 October 2024, accessed 10 April 2025.

354 Ibid.

355 Australian Institute of Health and Welfare (AIHW), 'Health system spending on the response to COVID-19 in Australia 2019-20 to 2021-22', AIHW website, 29 November 2023, accessed 10 April 2025.

356 S Wright, 'COVID left us poorer, sicker and with a big financial headache, inquiry told', Sydney Morning Herald, 27 July 2024, accessed 10 April 2025.

357 JC Castillo, A Ahuja, S Athey, A Baker, E Budish, T Chipty, R Glennerster, SD Kominers, M Kremer, G Larson, J Lee, C Prendergast, CM Snyder, A Tabarrok, BJ Tan and W Więcek, 'Market design to accelerate COVID-19 vaccine supply', Science, 2021, 371(6534):1107–1109, doi:10.1126/science.abg0889.

358 Delgado-Saborit et al, op. cit. n.115.

359 MB Hadley, J Baumgartner and R Vedanthan, Developing a clinical approach to air pollution and cardiovascular health, *Circulation*, 2018, 137(7):725-742, doi:10.1161/CIRCULATIONAHA.117.030377.

360 Ibid; and Brauer et al, op. cit. n.61.

361 W Bloss, 'Air pollution: science shows there's no safe limit – here's how laws must change', The Conversation website, 8 September 2021, accessed 10 April 2025; and T Munzel, M Sorensen, J Lelieveld, O Hahad, S Al-Kindi, M Nieuwnhuijsen, B Giles-Corti, A Daiber and S Rajagopalan, 'Heart healthy cities: genetics loads the gun but the environment pulls the trigger', *European Heart Journal*, 2021, 42(25):2422-2438, doi:10.1093/eurheartj/ehab235.

362 MB Hadley, J Baumgartner and R Vedanthan, Developing a clinical approach to air pollution and cardiovascular health, *Circulation*, 2018, 137(7):725-742, doi:10.1161/CIRCULATIONAHA.117.030377; PM Ramos, 'Air pollution: a new risk factor for cardiovascular disease', European Society of Cardiology website, 3 August 2022, accessed 10 April 2025; and Y Wei and J Schwartz, 'Opinion. The updated WHO air quality guidelines are a big step forward but not a complete solution', *British Medical Journal*, 2024, 384:q542, doi:10.1136/bmj.q542.

363 National Science and Technology Council ,op. cit. n.27.

364 DP Wyon, 'The effects of indoor air quality on performance and productivity', *Indoor Air*, 2004, 14 Suppl 7:92-101, doi10.1111/j.1600-0668.2004.00278.x.

365 NERA Economic Consulting, *Infection Resilient Environments Social Cost Benefit Analysis* [PDF], June 2022, UK Royal Academy of Engineering website, accessed 10 April 2025.

366 M Neidell and N Pestel, 'Air pollution and worker productivity', *IZA World of Labor*, 2023, 236(2), doi:10.15185/izawol.362.v2.

367 T Chang, JS Graff Zivin, T Gross and MJ Neidell, 'Particulate Pollution and the Productivity of Pear Packers. Working Paper 19944' National Bureau of Economic Research, February 2014, doi:10.3386/w19944.

368 TY Chang, J Graff Zivin, T Gross and M Neidell, 'The Effect of Pollution on Worker Productivity: Evidence from Call Center Workers in China', *American Economic Journal: Applied Economics*, 2019, 11(1):151-172, doi:10.1257/app.20160436.

369 Allen et al, op. cit. n.13; and JG Allen, 'Research: Stale Office Air is Making You Less Productive', Harvard Business Review website, 21 March 2017, accessed 9 April 2025.

370 Organisation for Economic Co-operation and Development (OECD), *The economic cost of air pollution: Evidence from Europe* [PDF], OECD website, 26 August 2020, accessed 10 April 2025.

371 WJ Fisk and AH Rosenfeld, *Estimates of improved productivity and health from better indoor environments* [PDF], *Indoor Air*, 1997, 7:158-172. See also US EPA, *Energy Cost and IAQ Performance of Ventilation Systems and Controls* [PDF], US EPA website, January 2000, accessed 10 April 2025.

372 Pillay et al, op. cit. n.5, p.16.

373 JF Montgomery, CCO Reynolds, SN Rogak and SI Green, 'Financial implications of modifications to building filtration systems' *Building and Environment*, 2015, 85:17-28, doi:10.1016/j.buildenv.2014.11.005.

374 Z Zafari, PM de Oliveira, S Gkantonas, C Ezeh and PA Muennig, 'The cost-effectiveness of standalone HEPA filtration units for the prevention of airborne SARS CoV-2 transmission', *Cost Effectiveness and Resource Allocation*, 2022, 12,20(1):22, doi:10.1186/s12962-022-00356-1; and AY Chang, S Horton and DT Jamison, 'Benefit-Cost Analysis in Disease Control Priorities, Third Edition' in DT Jamison, H Gelband and S Horton (eds), *Disease Control Priorities: Improving Health and Reducing Poverty (3rd edition)*, The World Bank, Washington DC, 2017.

375 Wyon, op. cit. n.364.

376 D Davies, 'Billion-dollar boost for NZ if indoor air quality improved in offices and schools, new report unveils', FMANZ website, 25 September 2024, accessed 15 March 2025.

377 Note - infection resilience in terms of the use of engineering controls in the built environment and public transport to minimise the risk of transmission of infections to individuals. National Engineering Policy Centre, 'Infection Resilient Environments Phase 2', National Engineering Policy Centre website, 2024, accessed 10 April 2025, p.4; and The Engineer, 'Report calls on government to mandate infection-resilient buildings', The Engineer website, 13 June 2022, accessed 10 April 2025.

378 See J Boaz, 'Australia's air quality culture criticised as experts point to ventilation as key in COVID-19 fight', ABC News, 25 August 2021, accessed 10 April 2025.

379 See University of Wollongong, op. cit. n.4, p.57.

380 P Wargocki, O Seppanen, J Andersson, A Boersta, DJ Clements-Croome, K Fitzner, H Sten Olaf, 'REHVA Guidebook No.6 – Indoor Climate and Productivity in Offices – How to Integrate Productivity in Life-Cycle Cost Analysis of Building Services' in L Morawska, GB Marks and J Monty, *Healthy indoor air is our fundamental need: the time to act is now*, *Medical Journal Australia*, 217(11):578-581, doi:10.5694/mja2.51768.

381 P MacNaughton, J Pegues, U Satish, S Santanam, J Spengler and J Allen, 'Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings', *International Journal of Environmental Research and Public Health*, 2015, 18,12(11):22-14709, doi:10.3390/ijerph121114709; and JG Allen, 'Research: Stale Office Air is Making You Less Productive', Harvard Business Review website, 21 March 2017, accessed 23 July 2024. See also JG Allen, 'Where does the >10% net impact of #HealthyBuildings on the bottomline come from? …' *[Tweet]*, X (Twitter) website, 2024, accessed 31 July 2024.

382 R. Bruns, 'Cost-benefit analysis of ASHRAE Standard 241', *ASHRAE Journal*, October 2023, pp.14-16.

383 National Science and Technology Council, op. cit. n.27, p.5.

384 Ibid, pp.2,6.

385 Fisk and Rosenfeld, op. cit. n.371; and KW Ng, *Green healthcare facilities: assessing the impacts of indoor environmental quality on the working environment from the perspective of health care workers* [PhD thesis], University of New South Wales (UNSW) website, 2011, accessed 10 April 2025.

386 DK Milton, PM Glencross and MD Walters, 'Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints', *Indoor Air*, 2000, 10(4):212-221, doi:10.1034/j.1600-0668.2000.010004212.x.

387 H Settineri, 'Sick days weighing down Aussie businesses', RetailWorld website, 2022, accessed 10 April 2025; and B Roberts, 'Securing your environment from viruses and optimising resident and worker safety', AgedCareNews website, 2022, accessed 10 April 2025.

388 Food Magazine, 'The cost of absenteeism', Food Magazine website, 9 April 2018, accessed 10 April 2025; and D Taylor, 'Australians not using sick days effectively, workplace law expert says', ABC News website, 8 June 2015, accessed 10 April 2025.

389 Oxford Future of Real Estate Initiative (FoRE), 'The Future of Real Estate Occupation: Issues', Saïd Business School website, 2018, accessed 10 April 2025.

390 World Green Building Council (WGBC), *Health, Wellbeing & Productivity in Offices: The next chapter for green building* [PDF 2.89MB], WGBC website, 2014, accessed 10 April 2025; and Department of Environment, Water, Heritage and the Arts (DEWHA), *ESD Operations Guide for Owners, Managers and Tenants* [PDF], DEWHA website, 2009, accessed 10 April 2025.

391 Oxford Future of Real Estate Initiative, op. cit. n.389.

392 Wyon, op. cit. n.364.

393 Direct Health Solutions (DHS), *2023 Absence management and wellbeing report: 12th edition*, DHS website, 2023, accessed 10 April 2025.

394 Queensland University of Technology (QUT), *Indoor Environments: Design, Productivity and Health* [PDF 920KB], QUT website, 2004, accessed 10 April 2025; and EnVIE, *Co-ordination Action on Indoor Air Quality and Health Effects* [PDF 1.67MB], EnVIE website, 2009, accessed 10 April 2025.

395 Research and Markets, *Global Particulate Matter Monitoring Market*, Research and Markets website, 2024, accessed 10 April 2025.

396 Aclima, 'Aclima Comes Out of Stealth, Announces Partnerships with Google, EPA, and Lawrence Berkeley National Labs', Aclima website, 29 June 2015, accessed 24 July 2024.

397 Martin, op. cit. n.141. See also Google Sustainability, 'The journey toward healthier materials', Google website, September 2019, accessed 10 April 2025; and CETEC, 'Google – Indoor Air', CETEC website, n.d., accessed 10 April 2025.

398 JG Allen, 'It's Time for Companies to Monitor Workplace Air Quality', Harvard Business Review website, 9 November 2023, accessed 10 April 2025.

399 J LaPook, 'Indoor air systems crucial to curbing spread of viruses, aerosol researchers say', CBS News website, 29 October 2023, accessed 10 April 2025.

400 Ibid.

401 Honeywell, '2022 Healthy Building Occupant Survey Report', Honeywell website, 2022, accessed 10 April 2025.

402 Ibid.

403 The Safer Air Project, *Safer shared air: A critical accessibility and inclusion issue* [PDF], The Safer Air Project website, 20 November 2024, accessed 19 March 2025, pp.48-51.

404 NERA Economic Consulting, op. cit. n.365, p.3.

405 Australian Institute of Health and Welfare (AIHW), *Climate change and environmental health indicators: reporting framework* [PDF], AIHW website, 5 June 2024, accessed 10 April 2025.

406 Morawska et al, op. cit. n.123; and Morawska et al (2021), op. cit. n.179.

407 F McAndrew, RG Abeysuriya, R Sacks-Davis, M Sammann, DM Lister, D West, SS Majumdar and N Scott, 'Admission screening testing of patients and staff N95 respirators are cost-effective in reducing COVID-19 hospital acquired infections', *Journal of Hospital Infection*, 2024, 152:81-92, doi:10.1016/j.jhin.2024.06.015.

408 Department for Education (DfE), 'CO2 monitor and air cleaning unit survey responses and applications for air cleaning units', DfE website, 24 January 2022, accessed 7 April 2025.

409 Expert Panel, *Improving Outcomes for All: The Report of the Independent Expert Panel's Review to Inform a Better and Fairer Education System* [PDF], Department of Education website, December 2023, accessed 10 April 2025.

410 G Hanmer, 'It would cost billions, but pay for itself over time. The economic case for air conditioning every Australian school', *The Conversation*, 21 October 2024, accessed 17 March 2025.

411 R Bruns, 'Cost-Benefit Analysis of CT sSB 1198 (School Air Quality)', SSRN website, 18 May 2023, doi:10.2139/ssrn.4452172.

412 DL Robinson, 'Accurate, Low Cost $PM_{2.5}$ Measurements Demonstrate the Large Spatial Variation in Wood Smoke Pollution in Regional Australia and Improve Modelling and Estimates of Health Costs', Atmosphere, 2020, 11(8):856, doi:10.3390/atmos11080856, Table 1.

413 N Borchers-Arriagada, S Vander Hoorn, M Cope, G Morgan, I Hanigan, G Williamson and FH Johnston, 'The mortality burden attributable to wood heater smoke particulate matter ($PM_{2.5}$) in Australia', *Science of The Total Environment*, 2024, 921:171069, doi:10.1016/j.scitotenv.2024.171069; and Pillay et al, op. cit. n.5, p.iii. See also Centre for Safe Air, 'Data visualisation: Wood heater pollution', Centre for Safe Air website, n.d., accessed 10 April 2025.

414 Australian Council of Social Service (ACOSS), 'Retrofitting low-income homes a $17bn boon', ACOSS website, 19 July 2024, accessed 10 April 2025.

415 National Academies of Sciences, Engineering, and Medicine, 'Health Risks of Indoor Exposure to Fine Particular Matter and Practical Mitigation Solutions', The National Academies Press, Washington DC, 2024.

416 WJ Fisk and WR Chan, 'Effectiveness and cost of reducing particle-related mortality with particle filtration', Indoor Air, 2017, 27(5):909-920, doi:10.1111/ina.12371.

417 CL Gallagher and T Holloway, 'Integrating air quality and public health benefits in US decarbonization strategies', *Frontiers in Public Health*, 2020, 8:563358, doi:10.3389/fpubh.2020.563358.

418 Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), 'HVAC&R Building Services – About our industry', AIRAH website, n.d., accessed 10 April 2025.

419 O Jacques, 'Why a serious case of COVID could affect your insurance, even decades from now', ABC News website, 2022, accessed 10 April 2025; and D Bailey, 'Insurance industry coalition forms non-profit to study baffling excess mortality', InsuranceNewsNet website, 2023, accessed 10 April 2025.

420 Breeze Technologies, 'Future use cases for air quality data: air quality as a dimension of (re-) insurance', Breeze Technologies website, 2022, accessed 10 April 2025; and Ambee, 'How air quality data can help with better insurance underwriting?', Ambee website, 21 February 2025, accessed 10 April 2025.

421 Superannuation Industry (Supervision) Act 1993 (Cth), s. 52(2).

422 The Association of Superannuation Funds of Australia (ASFA), 'Looking At ESG Through a Super Lens', ASFA website, 2019, accessed 10 April 2025.

423 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'National Clean Air Agreement', DCCEEW website, 14 November 2024, accessed 10 April 2025; and Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'National Clean Air Agreement - Priority Setting Process', DCCEEW website, 2016, accessed 10 April 2025.

424 *National Environment Protection Council Act 1994* (Cth).

425 National Environment Protection Council (NEPC), 'Key Changes to the Ambient Air Quality Measure agreed by Ministers April 2021', NEPC website, n.d., accessed 10 April 2025.

426 National Environment Protection Council (NEPC), 'National Environmental Protection (Air Toxics) Measure', NEPC website, 2022, accessed 10 April 2025; and National Environment Protection Council (NEPC), 'National Environmental Protection (Air Toxics) EPHC Archive', NEPC website, 2022, accessed 10 April 2025.

427 Clean Air Society of Australia and New Zealand (CASANZ), 'Indoor Air Special Interest Group', CASANZ website, n.d., accessed 10 April 2025.

428 Department of Health and Aged Care (DoHAC), *Indoor Air Quality: a Report on Health Impacts and Management Options* [PDF], archived from DoHAC website, 2000; and Morawska et al, op. cit. n.123; and C Swannell, 'Indoor air quality: why are we ignoring it?', Medical Journal of Australia InSight+ website, 2022, accessed 10 April 2025.

429 Australian Building Codes Board (ABCB), 'National Construction Code', ABCB website, n.d., accessed 10 April 2025.

430 Australian Building Codes Board (ABCB), op. cit. n. 16.

431 Australian Building Codes Board (ABCB), 'Understanding the NCC', ABCB website, n.d., accessed 10 April 2025.

432 Ibid.

433 Australian Building Codes Board (ABCB), op. cit. n.16.

434 Australian Building Codes Board (ABCB), op. cit. n.16. See also F6V1 and F6V2 in NCC Volume One and H4V3 of NCC Volume Two.

435 Australian Building Codes Board (ABCB), op. cit. n.16.

436 Safe Work Australia (SWA), 'Workplace exposure standards for airborne contaminants', SWA website, 2024, accessed 10 April 2025.

437 Safe Work Australia, 'Exposure standards - airborne contaminants', SWA website, n.d., accessed 10 April 2025.

438 Safe Work Australia, *Interpretation of Workplace exposure standards for airborne contaminants. Guidance* [PDF], Safe Work Australia website, September 2024, accessed 10 April 2025.

439 Australian Building Codes Board (ABCB), op. cit. n.16, p.25.

440 Standards Australia, *AS 1668.2:2024 The use of ventilation and airconditioning in buildings, Part 2: Mechanical ventilation in buildings*, Standards Australia website, 2024, accessed 10 April 2025; and *AS 1668.4:2024 The use of ventilation and airconditioning in buildings, Part 4: Natural ventilation of buildings*, Standards Australia website, 2024, accessed 10 April 2025.

441 For building classes 2 to 9, see clauses F6D7 and F6D8 of the National Construction Code.

442 Morawska et al, op. cit. n.123; and Safe Work Australia, op. cit. n.436. See also M Vender, 'Need to know: key updates to AS 1668', Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) News website, 2023, accessed 10 April 2025.

443 Standards Australia, *Air-handling and water systems of buildings - Microbial control Operation and maintenance*, AS/NZS 3666.2:2011, Standards Australia, 2011, accessed 10 April 2025.

444 Standards Australia, *Routine service of fire protection systems and equipment AS 1851-2012 Amd 1:2016*, Standards Australia, 2016, accessed 10 April 2025.

445 See, for example, AS/NZS 5601 Gas installations; AS/NZS 5263 Gas appliances (including cooking appliances, water heaters and space heating appliances); AS/NZS 4012 Domestic solid fuel burning appliances (efficiency); AS/NZS 4013 Domestic solid fuel burning appliances (emissions); AS/NZS IEC 62471:2011 Photobiological safety of lamps and lamp systems; AS 1859.1:2017 Reconstituted wood-based panels - Specifications Particleboard; AS 1859.1:2017 AMD 1:2021 Reconstituted wood-based panels - Specifications Particleboard; AS/NZS 1859.2:2017 Reconstituted wood-based panels - Specifications Dry process fibreboard; AS/NZS 1859.3:2017 Reconstituted wood-based panels - Specifications Decorative overlaid wood panels; AS 3660 Termite management (new buildings, existing buildings, assessment criteria); AS 2985-2009 Workplace atmospheres - Method for sampling and gravimetric determination of respirable dust; AS 2986 Workplace air quality — Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography; AS/NZS 3580 Methods for sampling and analysis of ambient air; enHealth's Guidelines for Legionella control in the operation and maintenance of water distribution systems in health and aged care facilities; Safe design of structures Code of Practice; ANSI/IICRC S520 – an international standard from the Institute of Inspection Cleaning and Restoration Certification (IICRC) for the remediation of mould damaged structures and contents in residential, commercial, and institutional buildings; AS/NZS 3666:2011 – Air-handling and water systems of buildings – Microbial control; AS 1851-2012 Routine service of fire protection systems and equipment; AS 1324 Air filters for use in general ventilation and air conditioning; AS 4254.1:2021 Ductwork for air-handling systems in buildings Flexible duct; AS 1657:2018 Fixed platforms, walkways, stairways and ladders — Design, construction and installation; AS 2865-2009 Confined spaces ; Guideline SAA/SNZ HB32:1995 Control of microbial growth in air-handling and water systems in buildings.

446 For example, for mould and condensation, the National Construction Code has recently included additional provisions on condensation management to decrease health risks associated with condensation in new homes. Further measures will be considered for inclusion in the National Construction Code 2025. The Australian Building Codes Board has published an updated 'Condensation in Buildings' handbook to help practitioners use the new condensation management provisions in the code. enHealth has published guidance on the potential health effects of mould in the environment. State and territory health departments also offer fact sheets on the health effects of mould and dampness, suggested ways to prevent mould and advice on ways to safely remove mould. The Department of Health and Aged Care has recently published a biotoxins indoor damp and mould clinical pathway.

447 Australian Building Codes Board (ABCB), op. cit. n.16.

448 Waverley Council, *Waverley Development Control Plan 2022* [PDF], Waverley Council website, n.d., accessed 10 April 2025.

449 Australasian Health Facility Guidelines (AusHFG), 'Part D: Infection Prevention and Control', AusHFG website, 1 March 2016, accessed 12 March 2025.

450 Australian Commission on Safety and Quality in Health Care (ACSQHC), *Factsheet for health service organisations* [PDF], ACSQHC website, 2022, accessed 10 April 2025.

451 Ibid.

452 Department of Health and Aged Care (DHAC), *National Aged Care Design Principles and Guidelines*, DHAC website, 20 June 2024, last updated 25 March 2025, accessed 10 April 2025.

453 Safe Work Australia, op. cit. n.436.

454 *Model WHS Regulations* [PDF], Safe Work Australia website, 1 September 2024, accessed 19 March 2025, reg 49.

455 Safe Work Australia (SWA), 'Air Monitoring', SWA website, n.d., accessed 19 March 2025. See also *Model WHS Regulations* [PDF], Safe Work Australia website, 1 September 2024, accessed 19 March 2025, reg 50.

456 Safe Work Australia (SWA), 'Exposure standards - airborne contaminants', SWA website, n.d., accessed 10 April 2025.

457 Ibid.

458 Safe Work Australia, *Interpretation of Workplace exposure standards for airborne contaminants. Guidance* [PDF], Safe Work Australia website, September 2024, accessed 10 April 2025.

459 See, for example, regulation 40(e) of the model WHS Regulations (Cth).

460 Safe Work Australia (SWA), *Improving ventilation in indoor workplaces: COVID-19* [PDF], SWA website, 24 February 2021, accessed 23 July 2024; and Safe Work Australia (SWA), 'Improving ventilation in indoor workplaces: COVID-19', SWA website, 18 November 2021, accessed 10 April 2025.

461 WorkSafe Western Australia, 'Strategy at a glance', WorkSafe Western Australia website, 25 November 2024, accessed 27 February 2025. See also WorkSafe Western Australia, 'Indoor air quality', WorkSafe Western Australia website, 26 November 2024, accessed 28 February 2025.

462 SafeWork NSW, 'Managing respiratory conditions in the workplace', SafeWork NSW website, n.d., accessed 28 February 2025.

463 WorkSafe Victoria, 'Managing COVID-19 risks: Healthcare and social assistance industry – Respiratory Protective Equipment (RPE)', WorkSafe Victoria website, 21 October 2022, accessed 28 February 2025.

464 See 'The Safer Air Project', The Safer Air Project website, n.d., accessed 10 April 2025.

465 Facility Management (FM), 'ACT schools to monitor air quality with CO_2 sensors', FM website, 28 September 2021, accessed 10 April 2025; and S Lansdown, 'ACT rolls out air quality monitors before school return', *Canberra Times*, 27 September 2021, accessed 10 April 2025.

466 Australian Minister for Education, *Round 1 of Schools Upgrade Fund open* [media release], Australian Minister for Education, 2022, accessed 10 April 2025; and Department of Education (DoE), 'Schools Upgrade Fund', DoE website, 2023, accessed 10 April 2025.

467 NSW Department of Education – School Infrastructure (DESI), 'Asset review and ventilation', DESI website, n.d., accessed 10 April 2025.

468 S Dick, 'New COVID-19 rules will apply to NT government schools in term one. Here's what you need to know', *ABC*, 21 January 2022, accessed 10 April 2025.

469 Ibid.

470 SA Department of Education (SA DoE), 'Statement on ventilation in schools', SA DoE website, 2022, accessed 10 April 2025.

471 ABC, 'Tasmanian back-to-school plan for masks, air purifiers, as Premier defends Education Minister's holiday', 19 January 2022, ABC, accessed 10 April 2025.

472 Business Victoria, 'Small Business Ventilation Program – Ventilation Grant', Business Victoria website, n.d, accessed 10 April 2025.

473 Department of Education and Training, *2022-23 Budget Estimates general questionnaire* [PDF 4,544KB], Parliament of Victoria Public Accounts and Estimates Committee, 2022, accessed 10 April 2025.

474 A Raphael, 'WA Premier reveals plan for students to go back to school during Omicron', *News.com.au website*, 25 January 2022, accessed 10 April 2025.

475 THRIVE, 'Improving Indoor Air Quality For All', THRIVE website, n.d., accessed 10 April 2025.

476 World Health Organization (WHO), 'WHO Collaborating Centres Global database: WHO Collaborating Centre on Air Quality and Health', WHO website, n.d., accessed 10 April 2025.

477 International Laboratory on Air Quality and Health WHO Collaborating Centre, *Annual Report 2024* [PDF], Queensland University of Technology website, n.d., accessed 10 April 2025.

478 Centre for Safe Air, 'Everybody benefits from clean, safe air', Centre for Safe Air website, n.d., accessed 10 April 2025.

479 Healthy Environments And Lives (HEAL) Network, 'About HEAL Network', HEAL Network website, n.d., accessed 10 April 2025.

480 Premier of Victoria, *New Research Protecting Victorians From Poor Air Quality* [media release], Premier of Victoria website, 31 July 2024, accessed 10 April 2025; Burnet Institute, *Transformative $9.87m project to improve indoor air quality in Victoria* [media release], Burnet Institute website, 31 July 2024, accessed 10 April 2025; H Gleeson, 'Victoria's new 'clean air' project could help end the COVID pandemic and boost productivity', ABC website, 31 July 2024, accessed 10 April 2025.

481 NSW Government Chief Scientist and Engineer (NSW CSE), 'NSW Government provides $800,000 to inspire the next generation of natural hazards scientists', NSW CSE website, 31 July 2024, accessed 10 April 2025.

482 University of Queensland School of Electrical Engineering and Computer Science (EECS), 'Study Fresh', EECS website, n.d., accessed 8 Mary 2025; and 'Classroom Air Quality: UQ Study Fresh', in STEM Punks, *Future Learning Magazine*, STEM Punks website, May 2021, pp.16-17.

483 RMIT, 'Indoor Air Quality for Vulnerable Population - A Climate Change Innovation Grant', RMIT website, n.d., accessed 10 April 2025.

484 Homes Victoria, 'Energy Efficiency in Social Housing Program', Homes Victoria website, n.d., accessed 10 April 2025.

485 Green Building Council Australia (GBCA), 'Rating System', GBCA website, n.d., accessed 10 April 2025.

486 National Australian Built Environment Rating System (NABERS), 'About', NABERS website, n.d., accessed 10 April 2025.

487 Nationwide House Energy Rating Scheme (NatHERS), 'NatHERS News – October 2022', NatHERS website, 11 October 2022, accessed 10 April 2025.

488 Green Building Council of Australia (GBCA), 'Interiors – Design and construction of fitouts', GBCA website, n.d., accessed 10 April 2025.

489 International WELL Building Institute, 'The WELL Building Standard™ version 2 - AIR', International WELL Building Institute website, n.d., accessed 10 April 2025.

490 Fitwel, 'Resource Library', Fitwel website, n.d., accessed 10 April 2025.

491 Indoor Air Hygiene Institute, 'Get The Inside Advantage', Indoor Air Hygiene Institute website, n.d., accessed 10 April 2025.

492 P Wargocki, W Wei, J Bendžalová, C Espigares-Correa, C Gerard, O Greslou, M Rivallain, MM Sesana, BW Olesen, J Zirngibl and C Mandin, 'TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project)', Energy and Buildings, 2021, 244(111029), doi:10.1016/j.enbuild.2021.111029.

493 T Larsen, L Rohde, KT Jønsson, B Rasmussen, RL Jensen, HN Knudsen, T Witterseh and G Bekö, 'IEQ-Compass – A Tool for Holistic Evaluation of Potential Indoor Environmental Quality', Building and Environment, 2020, 172, 106707, doi:10.1016/j.buildenv.2020.106707.

494 Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), 'About the DGNB System', DGNB website, n.d., accessed 10 April 2025.

495 Global Real Estate Sustainability Benchmark (GRESB), 'Actionable ESG data and benchmarks for financial markets', GRESB website, 2024, accessed 10 April 2025.

496 Building Research Establishment (BRE) Group, 'A guide to how BREEAM works', BRE Group website, 2025, accessed 10 April 2025.

497 US Green Building Council (US GBC), 'LEED rating system', US GBCI, 2025, accessed 10 April 2025.

498 International Living Future Institute, 'Living Building Challenge,' International Living Future Institute, 2025, accessed 10 April 2025. See also Australian Government, 'Your Home: Building rating tools', Your Home website, updated 2023, accessed 10 April 2025.

499 AIRAH, 'DA26 Indoor Air Quality', AIRAH website, 2004, accessed 10 April 2025.

500 C Berger, A Mahdavi, E Azar, K Bandurski, L Bourikas, T Harputlugil, R T Hellwig, R F Rupp, M Schweiker, 'Reflections on the Evidentiary Basis of Indoor Air Quality Standards', *Energies*, 2022, 15(7727), doi:10.3390/en15207727.

501 World Health Organization (WHO), 'Roadmap to improve and ensure good indoor ventilation in the context of COVID-19', WHO website, 2021, accessed 10 April 2025.

502 Morawska et al, op. cit. n.123; and G R Zosky, S Vander Hoorn, M J Abramson, S Dwyer, D Green, J Heyworth, B-B Jalaludin, J McCrindle-Fuchs, R Tham, and G B Marks, 'Principles for setting air quality guidelines to protect human health in Australia', *The Medical Journal of Australia*, 2021, 214(6):254-256, doi:10.5694/mja2.50964; and P Carrer, E De Oliveira Fernandes, H Santos, O Hänninen, S Kephalopoulos, P Wargocki, 'On the Development of Health-Based Ventilation Guidelines: Principles and Framework', *International Journal of Environmental Research and Public Health*, 2018, 15(1360) doi:10.3390/ijerph15071360; and T Haahr, *Air pollution: MEPs want stricter limits to achieve zero pollution by 2050* [media release], European Parliament News website, 13 September 2023, accessed 10 April 2025; and A Barrett, Croakey Health Media, 'Push to improve indoor air quality at inaugural World Health Organization event', Croakey Health Media website, 5 October 2023, accessed 10 April 2025.

503 Haahr, ibid; and Barrett, ibid.

504 Belgium Federal Public Service (FPS) Health, Food Chain Safety and Environment, 'Legal framework regarding indoor air quality', FPS Public Health, Food Chain Safety and Environment website, 8 November 2024, accessed 10 April 2025; and M Hayashi, U Yanagi, K Azuma, N Kagi, M Ogata, S Morimoto, H Hayama, T Mori, K Kikuta, SI Tanabe and 5 more, 'Measures Against COVID-19 Concerning Summer Indoor Environment in Japan', *Japan Architectural Review*, 2020, 3(4):423–434, doi:10.1002/2475-8876.12183; and M Hayashi, K Kobayashi, H Kim and N Kaihara, 'The State of the Indoor Air Environment in Buildings and Related Tasks in Japan', Journal of the National Institute of Public Health, 2020, 69(1):63-72, doi:10.20683/jniph.69.1_63; and A Persily, *Challenges in Developing Ventilation and Indoor Air Quality Standards: The Story of ASHRAE Standard 62* [PDF], National Institute of Standards and Technology (NIST) website, 2015, accessed 10 April 2025.

505 National Institute for Occupational Safety and Health (NIOSH), 'How Much Ventilation Is Enough?', Centers for Disease Control and Prevention (CDC) website, 3 October 2024, accessed 10 April 2025.

506 ASHRAE, *Standard 241 – ASHRAE Standard 241, Control of Infectious Aerosols* [PDF], ASHRAE website, n.d., accessed 10 April 2025.

507 T Schley, 'Setting a breathable standard: Q&A with architectural engineer William Bahnfleth', Pennsylvania State University website, 28 July 2023, accessed 10 April 2025; and American Society of Heating and Air-Conditioning Engineers (ASHRAE), 'ASHRAE Standard 241: Control of Infectious Aerosols', ASHRAE website, 2023, accessed 10 April 2025; and J Gold, 'New ASHRAE Indoor Air Quality Standard Offers Reduced Virus Transmission Risk', Forbes website, 17 October 2023, accessed 10 April 2025.

508 M Vender, 'Australian views on US pathogen mitigation standard', HVAC&R News website, 25 May 2023, accessed 10 April 2025.

509 P Wargocki and O Seppänen, 'Principles of ventilation design to achieve high IAQ', REHVA Journal website, 2022, accessed 10 April 2025; Canadian Centre for Occupational Health and Safety (CCOHS), 'Indoor Air Quality', CCOHS website, 2024, accessed 10 April 2025; and The Lancet COVID-19 Commission Task Force on Safe Work, Safe School, and Safe Travel, *Proposed Non-infectious Air Delivery Rates (NADR) for Reducing Exposure to Airborne Respiratory Infectious Diseases* [PDF], Harvard T. H. Chan School of Public Health website, November 2022, accessed 10 April 2025.

510 Health New Zealand, 'Ventilation', Health New Zealand website, 23 December 2024, accessed 10 April 2025.

511 Morawska et al, op. cit. n.123. See also L Morawska, Submission 304 to House of Representatives Standing Committee on Health, Aged Care and Sport Inquiry into Long COVID and Repeated COVID infections, Parliament of Australia website, n.d., accessed 10 April 2025; L Morawska, 'Australia must get serious about airborne infection transmission. Here's what we need to do', *The Conversation*, 26 July 2021; and L Morawska and G Marks, 'Ventilation reduces the risk of COVID. So why are we still ignoring it?', *The Conversation*, 2 December 2022.

512 National Science and Technology Council, op. cit. n.27, pp.2-3.

513 Burnet Institute, the Australian Academy of Science and the University of Melbourne, *Clean Indoor Air: 2024 Collaboration and Global Action* [PDF], Burnet Institute website, n.d., accessed 16 March 2025; and The Safer Air Project, *Safer shared air: A critical accessibility and inclusion issue* [PDF], The Safer Air Project website, 20 November 2024, accessed 16 March 2025.

514 Morawska et al, op. cit. n.10.

515 Brown, op. cit. n.32.

516 World Health Organization, op. cit. n.337.

517 Department for Environment Food and Rural Affairs, 'Report: Indoor Air Quality', Department for Environment Food and Rural Affairs website, 2022, accessed 10 April 2025; and GOV.UK, 'Clean Air Strategy 2019', GOV.UK website, 2019, accessed 10 April 2025.

518 United States Environmental Protection Agency (US EPA), 'Federal Interagency Committee on Indoor Air Quality', US EPA website, 31 March 2025, accessed 10 April 2025.

519 United States Environmental Protection Agency (US EPA), 'About the Office of Air and Radiation', US EPA website, 26 March 2025, accessed 10 April 2025.

520 Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group, *Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places* [PDF], Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group website, 2019, accessed 11 April 2025.

521 Health Food Chain Safety Environment, 'Indoor Air Quality Platform', Health Food Chain Safety Environment website, 2023, accessed 11 April 2025.

522 Air Quality Expert Group United Kingdom (UK), *Indoor Air Quality* [PDF], Air Quality Expert Group UK, 2022, accessed 11 April 2025.

523 NZ Ministry of Education, *COVID-19 Response. Ventilation Guidance for New Zealand Schools* [PDF], NZ Government website, March 2023, accessed 11 April 2025.

524 Legislative Assembly Standing Committee on Public Works, *Report – Sick Building Syndrome* [PDF], NSW Parliament website, April 2001, accessed 11 April 2025.

525 Premier of Victoria Hon Jacinta Allan MP, *Following The Three Vs For A Safe Return To School* [media release], Premier of Victoria Hon Jacinta Allan MP website, 2021, accessed 11 April 2025.

526 Morawska et al, op. cit. n.123.

527 *National Environment Protection Council Act 1994* (Cth), s. 14(1).

528 National Science and Technology Council, op. cit. n.27. See, for example, Victorian Government Department of Health, 'Ventilation', Victorian Government Department of Health website, 6 March 2024, accessed 11 April 2025; and Premier of Victoria Hon Jacinta Allan MP, op. cit. n.525.

529 H Wykticky and M Skopec, 'Ignaz Philipp Semmelweis, The Prophet of Bacteriology', Infection Control and Hospital Epidemiology, 1983, 4(5):367–370, doi:10.1017/S0195941700059762.

530 Science Museum, 'Cholera in Victorian London', Science Museum website, 30 July 2019, accessed 11 April 2025.

531 National Research Council (US) Safe Drinking Water Committee, *Drinking Water and Health: Volume 1*, National Academies Press (US), 1977.

532 Melbourne Water (MW), 'History of Sewerage', MW website, 11 January 2023, accessed 11 April 2025.

533 S Brown, op. cit. n.32, p. 14 (Table 2) and p.48.

534 See L Teo, 'Australia's fresh approach to indoor air quality', 2 July 1999, ABC website, accessed 11 April 2025.

535 Australian Building Codes Board (ABCB), op. cit. n.16; and Green Building Council Australia (GBCA), *Exposure to Toxins certification scheme index* [PDF], GBCA website, 2021, accessed 11 April 2025.

536 Royal Society of Chemistry, *Indoor Air Quality Report* [PDF 3.69MB], Royal Society of Chemistry website, 2023, accessed 11 April 2025; and H Fletcher, 'Smog eating paint does more harm than good', Chemistry World website, 4 September 2017, accessed 11 April 2025.

537 Victorian Department of Energy, Environment and Climate Action, 'Gas heater safety', Victorian Department of Energy, Environment and Climate action website, 12 November 2024, accessed 9 April 2025; and Bunbury Mail, 'Open-flued gas heaters banned from sale in WA if they don't meet new standards', Bunbury Mail website, 27 October 2022, accessed 11 April 2025.

538 S Vardoulakis, FH Johnston, N Goodman, GG Morgan and DL Robinson, 'Wood heater smoke and mortality in the Australian Capital Territory: a rapid health impact assessment', The Medical Journal of Australia, 2024, 220(1):29-34, doi:10.5694/mja$_{2.5}$2176.

539 R Vassarotti, *ACT Government moves to phase-out wood heaters by 2045* [media release], ACT Government website, 24 August 2023, accessed 11 April 2025.

540 Asthma Australia, 'No new wood heaters, ACT Government first to commit to a phase-out in suburbs', Asthma Australia website, 2023, accessed 11 April 2025.

541 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'National Clean Air Agreement – work plan 2021-23', DCCEEW website, 22 August 2022, accessed 11 April 2025, p.3.

542 Kashtan et al, op. cit. n.90; and NSW Health, 'Unflued gas heaters,' NSW Health website, 19 July 2022, accessed 11 April 2025; and B Ewald, G Crisp and M Carey, 'Health risks from indoor gas appliances', Australian Journal of General Practice, December 2022, 51(12), doi:10.31128/AJGP-08-22-6535.

543 T Kelsall, 'Premier eyes hydrogen for home gas connections', InDaily website, 2023, accessed 11 April 2025; and Premier of Victoria, *Gas Substitution Roadmap Charts Path To Lower Bills* [media release], Premier of Victoria website, 2023, accessed 11 April 2025.

544 ACT Government, 'Switching from Gas', ACT Government website, n.d., accessed 11 April 2025.

545 Victorian Department of Energy, Environment and Climate Action, op. cit. n.537; and Bunbury Mail, op. cit. n.537.

546 Victorian Government, op. cit. n.21, p.2.

547 J Greber, 'Gas key to renewables transition, allies' energy security, says Chris Bowen', Australian Financial Review website, 30 November 2023, accessed 11 April 2025; and The Hon C Bowen MP, *Annual Climate Change Statement to Parliament* [Minister's speech], Department of Climate Change, Energy, the Environment and Water (DCCEEW) website, 2023, accessed 11 April 2025.

548 R Tang, R Sahu, Y Su, A Milsom, A Mishra, T Berkemeier and C Pfrang, 'Impact of Cooking Methods on Indoor Air Quality: A Comparative Study of Particulate Matter (PM) and Volatile Organic Compound (VOC) Emissions', *Indoor Air*, 2024, 6355613, doi:10.1155/2024/6355613. See also A Marlow, 'Exhausted by the debate? Rangehood strategies and indoor air quality', presentation at AIRAH IAQ24, Melbourne, 15 July 2024.

549 California Environmental Protection Agency Air Resources Board (ARB), *Residential Cooking Exposure Study Finds Unhealthful Levels* [PDF], ARB website, n.d., accessed 11 April 2025.

550 Australian Building Codes Board, *National Construction Code 2022*, Volume 1, 10.8.2 Exhaust systems.

551 LM Brosseau, CR MacIntyre, A Ulrich and MT Osterholm, 'COMMENTARY: Wear a respirator, not a cloth or surgical mask, to protect against respiratory viruses', The University of Minnesota website, 2023, accessed 11 April 2025; and LM Brosseau, A Ulrich, K Escandón, C Anderson and MT Osterholm, 'COMMENTARY: What can masks do? Part 1: The science behind COVID-19 protection', The University of Minnesota website, 2021, accessed 11 April 2025. See also T Greenhalgh, CR MacIntyre, MG Baker, S Bhattacharjee, AA Chughtai, D Fisman, M Kunasekaran, A Kvalsvig, D Lupton, M Oliver, E Tawfiq, M Ungrin and JO Vipond, 'Masks and respirators for prevention of respiratory infections: a state of the science review', *Clin Microbiol Rev*, 2024, 0:e00124-23, doi:org/10.1128/cmr.00124-23.

552 J Lai, KK Coleman, SHS Tai, J German, F Hong, B Albert, Y Esparza, D Rastogi, A Srikakulapu, P Kalliomäki and 10 more authors, 'Relative efficacy of masks and respirators as source control for viral aerosol shedding from people infected with SARS-CoV-2: a controlled human exhaled breath aerosol experimental study', *eBioMedicine*, 2024;105157, doi:10.1016/j.ebiom.2024.105157.

553 H Seale, M Trent, GB Marks, S Shah, AA Chughtai and CR MacIntyre, 'Exploring the use of masks for protection against the effects of wildfire smoke among people with preexisting respiratory conditions', BMC Public Health, 2023, 23:2330, doi:10.1186/s12889-023-17274-3.

554 E Batha, 'From drones to Harry Potter memes: how countries have convinced people to wear masks?', World Economic Forum website, 23 July 2021, accessed 11 April 2025.

555 Note recently proposed US legislation to improve indoor air quality in the USA would require the US EPA to establish and regularly update a list of significant indoor contaminants, and develop health-based voluntary guidelines to reduce exposure risks to these contaminants – see *Tonko, Fitzpatrick Introduce Bill to Improve Indoor Air Quality* [media release], Tonko website, 25 July 2024, accessed 11 April 2025.

556 For fire safety see, for example, Victorian Building Authority (VBA), 'Essential safety measures', VBA website, 2024, accessed 11 April 2025.

557 Work Health and Safety Regulations 2011 (Cth), reg 40(e). See also Australian Council of Trade Unions, *Hard lessons to learn: Managing COVID-19 and preparing for future pandemics – ACTU Submission on the COVID-19 Response Inquiry* [PDF], p.8, Prime Minister and Cabinet website, 22 December 2023, accessed 31 May 2024; and Safe Work Australia (SWA), 'Improving ventilation in indoor workplaces: COVID-19', SWA website, 18 November 2021, accessed 11 April 2025.

558 International Labour Organisation (ILO), 'Biological Hazards and Risks', ILO website, n.d., accessed 18 March 2025. See also See Safe Work Australia, *National Hazard Exposure Worker Surveillance: Exposure to Biological Hazards and the Provision of Controls Against Biological Hazards in Australian Workplaces* [PDF], Safe Work Australia website, March 2011, accessed 18 March 2025, p.5.

559 Commercial Building Disclosure (CBD), 'CBD Program expansion consultation FAQ', CBD website, n.d., accessed 11 April 2025.

560 Department of Industry, Science and Resources (DISR), 'Premises Standards', DISR website, n.d., accessed 11 April 2025, and The Safer Air Project, *Safer shared air: A critical accessibility and inclusion issue* [PDF], The Safer Air Project website, 20 November 2024, accessed 16 March 2025.

561 Burnet Institute, *National Indoor Air Quality Strategy: Burnet Institute 2025-26 Pre-Budget Submission* [PDF], Australian Treasury website, n.d., accessed 16 March 2025.

562 *National Environment Protection Council Act 1994* (Cth), s. 14(1).

563 National Environment Protection Council (NEPC), *Key Changes to the Ambient Air Quality Measure agreed by Ministers April 2021* [PDF], NEPC website, 2021, accessed 11 April 2025.

564 See also Goodman et al, op. cit. n.79.

565 Safe Work Australia (SWA), 'Hazardous Chemical Information System (HCIS). Exposure Standard Documentation. Carbon dioxide in coal mines', SWA website, n.d., accessed 14 March 2025.

566 World Health Organization (WHO), 'What are the WHO Air quality guidelines?', WHO website, 22 September 2021, accessed 11 April 2025.

567 Safe Work Australia (SWA), *WES Review 2018 - WES Methodology: Recommending health-based workplace exposure standards and notations - Australian workplace exposure standards and advisory notations* [PDF], SWA website, 2018, accessed 11 April 2025. See also Food Standards Australia New Zealand (FSANZ), 'General statement on the use of international standards and assessments', FSANZ website, April 2016, accessed 11 April 2025.

568 For more information on air pollution health risk assessments, see World Health Organization (WHO), *Health risk assessment of air pollution: General principles* [PDF], WHO website, 2016, accessed 14 May 2025.

569 Morawska et al, op. cit. n.10. See also LC Renaud Salis, M Abadie, P Wargocki and C Rode, 'Towards the definition of indicators for assessment of indoor air quality and energy performance in low-energy residential buildings', *Energy and Buildings*, 2017, 152:492-502, doi:10.1016/j.enbuild.2017.07.054.

570 World Health Organization (WHO), op. cit. n.12.

571 Department of Climate Change, Energy, the Environment and Water, op. cit. n.53; and Milman, op. cit. n.53; and Chen and Hoek, op. cit. n.53; and Orellano et al, op. cit. n.53.

572 See also Safe Work Australia, 'Hazardous Chemical Information System (HCIS) – Exposure Standard Documentation – Carbon monoxide', SWA website, n.d., accessed 11 April 2025.

573 European Standards, *BS EN 50291-1:2018 - Gas detectors. Electrical apparatus for the detection of carbon monoxide in domestic premises Test methods and performance requirements*, European Standards website, 26 January 2021, accessed 11 April 2025.

574 This is based on a scenario of one hour in a classroom with one infected student out of 25 students and one teacher - Morawska et al, op. cit. n.10, Supplementary Materials, section 3.

575 MR Laurent and J Frans, 'Monitors to improve indoor air carbon dioxide concentrations in the hospital: A randomized crossover trial', *Science of the Total Environment,* 2022, 806(151349), doi:10.1016%2Fj.scitotenv.2021.151349.

576 Department of Health and Aged Care, op. cit. n.452.

577 Belgium Federal Public Service Health Food Chain Safety Environment, op. cit. n.504.

578 The British Council for Offices (BCO), *BCO announces new recommendations for greener and healthier offices* [media release], BCO website, 2023, accessed 19 March 2024.

579 Indoor Air Hygiene Institute, 'Get The Inside Advantage', Indoor Air Hygiene Institute website, n.d., accessed 11 April 2025.

580 Standards New Zealand, *NZS 4303:1990 Ventilation for acceptable indoor air quality* [PDF], Standards New Zealand website, 13 September 1990, accessed 11 April 2025.

581 Health and Safety Authority (HSA), *Code of Practice for Indoor Air Quality* [PDF], HSA website, 2023, accessed 11 April 2025.

582 Mendell et al, op. cit. n.131.

583 Global Open Air Quality Standards (GOAQS), *White Paper: GO AQS* [PDF, v0.12], GOAQS website, February 2025, accessed 11 April 2025.

584 Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA), 'REHVA publishes Model IEQ regulation aligning with new provisions of the 2024 EPBD recast', REHVA website, 7 January 2025, accessed 14 March 2025.

585 World Health Organization (WHO), 'WHO unveils updated global database of air quality standards', WHO website, 26 February 2025, accessed 6 March 2025.

586 European Commission, Joint Research Centre, A Ruiz Moreno, FS Fumagalli, A Valsesia, C Desmet, F Roncari, P Colpo, D Ashour, A Prenner, A De Maleville, J Farinha and A Mochan, 'Suppressing indoor pathogen transmission: A Technology Foresight study,' Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/745765, JRC137325.

587 ARPA, 'BREATHE. Building Resilient Environments for Air and Total Health', ARPA website, n.d., accessed 11 April 2025. For information on the related Predictions for Real-time Optimization of MICRObiomes of Built Environments (PRO-MICROBE) Exploration Topic, see ARPA-H, 'ARPA-H launches Exploration Topic to develop a novel healthy building index', ARPA-H website, 5 July 2024, accessed 11 April 2025.

588 NABERS, 'The Rules Indoor Environment for Offices - Version 2.0 – September 2021', NABERS website, September 2021, accessed 11 April 2025.

589 National Institute for Occupational Safety and Health, About Ventilation and Respiratory Diseases, Centers for Disease Control and Prevention (CDC) website, 3 October 2024, accessed 11 April 2025.

590 T Schley, 'Setting a breathable standard: Q&A with architectural engineer William Bahnfleth', Pennsylvania State University website, 28 July 2023, accessed 11 April 2025; and American Society of Heating and Air-Conditioning Engineers (ASHRAE), 'ASHRAE Standard 241: Control of Infectious Aerosols', ASHRAE website, 2023, accessed 11 April 2025; and J Gold, 'New ASHRAE Indoor Air Quality Standard Offers Reduced Virus Transmission Risk', Forbes website, 17 October 2023, accessed 11 April 2025.

591 P Wargocki and O Seppänen, 'Principles of ventilation design to achieve high IAQ', REHVA Journal website, 2022, accessed 11 April 2025.

592 Morawska et al, op. cit. n.10.

593 World Health Organization (WHO), 'Roadmap to improve and ensure good indoor ventilation in the context of COVID-19', WHO website, 2021, accessed 11 April 2025.

594 The Lancet COVID-19 Commission Task Force on Safe Work, Safe School, and Safe Travel, op. cit. n.509. See also JG Allen, 'Recommitting to Ventilation Standards for Healthy Indoor Air Quality', *American Journal of Public Health*, 2024, 114:991-993, doi:10.2105/AJPH.2024.307809.

595 G Buonanno, L Ricolfi, L Morawska and L Stabile, 'Increasing ventilation reduces SARS-CoV-2 airborne transmission in schools: A retrospective cohort study in Italy's Marche region', *Front Public Health*, Dec 2022, 10:1087087, doi:10.3389/fpubh.2022.1087087.

596 National Science and Technology Council, op. cit. n.27, p.4.

597 NABERS, op. cit. n.588. See also Burnet Institute, op. cit. n.561.

598 Indoor Air Hygiene Institute, 'Get The Inside Advantage', Indoor Air Hygiene Institute website, n.d., accessed 11 April 2025.

599 Australian Bureau of Statistics (ABS), 'Australian System of National Accounts: Concepts, Sources and Methods', ABS website, 2021, accessed 11 April 2025.

600 Australian Building Codes Board (ABCB), op. cit. n.16.

601 World Health Organization and CERN, op. cit. n.172. See also Henriques et al, op. cit. n.172.

602 National Science and Technology Council, op. cit. n.27, p.4.

603 Ibid, p.4.

604 JV Puthussery, DP Ghumra, KR McBrearty, BM Doherty, BJ Sumlin, A Sarabandi, AG Mandal, NJ Shetty, WD Gardiner, JP Magrecki and 7 more authors, 'Real-time environmental surveillance of SARS-CoV-2 aerosols', *Nature Communications*, 2023, 14:3692, doi:10.1038/s41467-023-39419-z; and C Poltras, 'Wearable Air Sampler Detects Personal Exposure to SARS-CoV-2', Yale School of Public Health website, 17 January 2022, accessed 11 April 2025; and C Roquencourt, H Salvator, E Bardin, E Lamy, E Farfour, E Naline, P Devillier and S Grassin-Delyle, 'Enhanced real-time mass spectrometry breath analysis for the diagnosis of COVID-19', *European Respiratory Journal (ERJ) Open Research*, 9(5), doi:10.1183/23120541.00206-2023; and JL Santarpia, E Klug, A Ravnholdt and SM Kinahan, 'Environmental sampling for disease surveillance: Recent advances and recommendations for best practice', *Journal of the Air & Waste Management Association*, 2023, 73(6):434-461, doi:10.1080/10962247.2023.2197825; and M Osborne, 'New Device Can Detect Covid in the Air Within Five Minutes', Smithsonian Magazine website, 18 July 2023, accessed 11 April 2025. See also L Gutiérrez-Gálvez, N Seddaoui, L Fiore, L Fabiani, T García-Mendiola, E Lorenzo and F Arduini, 'Functionalized N95 Face Mask with a Chemical-Free Paper-Based Collector for Exhaled Breath Analysis: SARS-CoV-2 Detection with a Printed Immunosensor as a Case Study', *ACS Sensors*, 2 August 2024, doi:10.1021/acssensors.4c00981.

605 N Stanton, 'RAIsonance Launches the Air Quality Human Impact Program', RAIsonance website, 29 August 2023, accessed 11 April 2025.

606 JA Kingson, 'Your next phone may double as an air quality monitor', Axios website, 8 January 2024, accessed 11 April 2025.

607 L Morawska, C Asbach and H Patel, 'Application of $PM_{2.5}$ low-cost sensors for indoor air quality compliance monitoring', *Aerosol Science and Technology*, 2025, 1–11, doi:10.1080/02786826.2025.2457326. See also CE Ivey and J Ofodile, *Low-Cost Sensors for Healthier indoor Air Quality in Impacted Communities: Final Report* [PDF], California Air Resources Board website, March 2025, accessed 14 May 2025.

608 See archived version of Safe Work Australia (SWA), 'Improving ventilation in indoor workplaces: COVID-19', archived SWA website, 2021, accessed 11 April 2025.

609 An example of guidance around carbon dioxide monitor use is at Appendix C of *Building Regulations 2010 Approved Document F Volume 2, 2021 edition* [PDF], UK Government website, 2021, accessed 11 April 2025.

610 Innovative Instrument Company, 'Announcement of the Department of Health regarding air quality monitoring costs in public buildings, 2022', Innovative Instrument Company website, n.d., accessed 11 April 2025.

611 J Kagawa, 'Indoor Air Quality Standards and Regulations in Japan', *Indoor Environment*, 1993, 2(4):223-231, doi:10.1159/000463261.

612 T Yokoyama, 'National Health Promotion Measures in Japan Health Japan 21(the second term)', *Journal of the National Institute of Public Health*, 2020, 69(1):14-24, doi:10.20683/JNIPH.69.1_14.

613 Klinair, 'Japan is doing it right. CO2 and Indoor Air Quality …' [Tweet], X (Twitter) website, 2023, accessed 11 April 2025.

614 HLN, 'Government drops mandatory CO2 meter in high-risk sectors: "Working on a voluntary basis"', HLN website, 22 March 2024, accessed 11 April 2025.

615 Johns Hopkins Center for Health Security, *Model State Indoor Air Quality Act* [PDF 635KB], Johns Hopkins Center for Health Security website, 2023, accessed 11 April 2025.

616 LO Gostin, JG Hodge Jr and GK Gronvall. 'The Model State Indoor Air Quality Act', Journal of the American Medical Association, 2023, 330(16):1525–1526, doi:10.1001/jama.2023.17334.

617 Johns Hopkins Center for Health Security, op. cit. n.615.

618 Taiwan Ministry of Environment, 'Indoor Air Quality', Taiwan Ministry of Environment website, 2024, accessed 11 April 2025.

619 CP Hu and JH Cheng, 'Indoor Air Quality Certification and Consumers' Willingness: Taiwan's Experience and Survey', *Atmosphere*, 2021, 12(10):1320, doi:10.3390/atmos12101320.

620 Republic of Korea, 'Indoor Air Quality Control in Public-Use Facilities, Etc. Act', Korea Legislation Research Institute website, 2003, accessed 11 April 2025.

621 AirKorea, 'Indoor Air Quality Management', AirKorea website, 2006, accessed 11 April 2025.

622 Meersens, 'Indoor air quality in public buildings: Regulations are evolving in France', Meersens website, n.d., accessed 11 April 2025; and République Française, *Environmental Code: Sub-section 3: Indoor Air Quality Monitoring in Indoor Air Pollution (Articles R221-30 to D221-38)*, Légifrance website, 2022, accessed 11 April 2025.

623 The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group, *A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places* [PDF 3,408KB], The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group website, 2019, accessed 11 April 2025.

624 Australian Building Codes Board (ABCB), *Fire safety systems – Model guidance on BCR recommendation 19* [PDF 880KB], ABCB website, 2021, accessed 11 April 2025.

625 See 'Air quality monitor selection tool', Clean Air Stars website, n.d., accessed 11 April 2025.

626 Morawska et al, op. cit. n.10.

627 New Zealand Ministry of Education, 'Internal Environment Monitoring devices', New Zealand Ministry of Education website, 25 February 2025, accessed 11 April 2025. See also New Zealand Ministry of Education, 'Ventilation for school buildings', New Zealand Ministry of Education website, 16 December 2024, accessed 11 April 2025. See also BRANZ, *An overview of indoor air contaminants in New Zealand schools* [PDF], BRANZ website, October 2019, accessed 11 April 2025; and JS Loh and MM Andamon, 'A Review of IAQ Standards and Guidelines for Australian and New Zealand School Classrooms', in MA Schnabel (ed.), *Back to the Future: The Next 50 Years*, (51st International Conference of the Architectural Science Association (ANZAScA)), 2017, Architectural Science Association (ANZAScA), pp. 695–702.

628 New Zealand Ministry of Education, 'Portable CO2 monitor and air cleaner device support', New Zealand Ministry of Education website, 2024, accessed 24 July 2024.

629 United Kingdom (UK) Department of Education, 'CO2 monitor and air cleaning unit survey responses and applications for air cleaning units', UK Department of Education website, 2022, accessed 11 April 2025.

630 UNSW digital grid Futures Institute (DGFI), 'Rolling out air quality monitoring across NSW schools', DGFI website, n.d., accessed 11 April 2025.

631 Morawska et al, op. cit. n.123.

632 Morawska et al, op. cit. n.179.

633 Belgium Federal Public Service Employment, Labour and Social Dialogue, 'New Code of Well-being at Work', Belgium Federal Public Service website, 2017, accessed 11 April 2025.

634 The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group, *A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places* [PDF 3,408KB], The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group website, 2019, accessed 11 April 2025.

635 Victoria Department of Health, 'Cooling tower systems and the Public Health and Wellbeing Act 2008', Victoria Government website, 2022, accessed 11 April 2025.

636 MS Vlaskin, 'Review of air disinfection approaches and proposal for thermal inactivation of airborne viruses as a life-style and an instrument to fight pandemics', Applied Thermal Engineering, 2022, 202, doi:10.1016/j.applthermaleng.2021.117855.

637 For example, F Prehn, E Timmermann, M Kettlitz, K Schaufler, S Günther and V Hahn. 'Inactivation of airborne bacteria by plasma treatment and ionic wind for indoor air cleaning', *Plasma Processes and Polymers*, 2020, 17:e2000027, doi:10.1002/ppap.202000027.

638 F Masotti, L Vallone, S Ranzini, T Silvetti, S Morandi and M Brasca, 'Effectiveness of air disinfection by ozonation or hydrogen peroxide aerosolization in dairy environments', Food Control, 2019, 97:32-38, doi:10.1016/j.foodcont.2018.10.022.

639 Google Patents, 'A kind of lysozyme air cleaning filter', Google Patents website, 2017, accessed 11 April 2025.

640 M Malayeri, F Nasiri, F Haghighat and CS Lee, 'Optimization of photocatalytic oxidation reactor for air purifier design: Application of artificial neural network and genetic algorithm', Chemical Engineering Journal, 2023, 462, doi:10.1016/j.cej.2023.142186.

641 M Harper, 'Sorbent trapping of volatile organic compounds from air', Journal of Chromatography A, 2000, 885(1-2):129-151, doi:10.1016/S0021-9673(00)00363-0.

642 Kimmerling et al, op. cit. n.1; and Fondazione David Hume, op. cit. n.309.

643 World Health Organization (WHO), 'Roadmap to improve and ensure good indoor ventilation in the context of COVID-19', WHO Website, 2021, accessed 11 April 2025.

644 Morawska et al, op. cit. n.123.

645 National Science and Technology Council, op. cit. n.27, p.2.

646 Morawska et al, op. cit. n.179.

647 Australian Building Codes Board (ABCB), op. cit. n.16.

648 National Science and Technology Council, op. cit. n.27, p.3.

649 Health and Safety Authority (HSA), *Code of Practice for Indoor Air Quality* [PDF], HSA website, 2023, accessed 11 April 2025, pp.35-36.

650 See, for example, *Model Work Health and Safety Regulations* as at 1 September 2024, Safe Work Australia, clause 40(e).

651 Congressman D. Beyer, *Beyer Reintroduces Airborne Act* [media release], Beyer website, 11 July 2024, accessed 11 April 2025.

652 World Health Organization (WHO), op. cit. n.643.

653 S Brown, op. cit. n.32.

654 World Health Organization (WHO), op. cit. n.643.

655 Ibid.

656 Department of Health and Aged Care, 'Australian Health Protection Principal Committee (AHPPC) statement on the role of ventilation in reducing the risk of transmission of COVID-19,' DoHAC website, 2021, accessed 11 April 2025. See also Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH), *Building public confidence: COVID-19 transmission, indoor air quality, and ventilation* [PDF], AIRAH website, 2021, accessed 11 April 2025; and E Mundt, *Particles and Displacement Ventilation* [PDF], Air Infiltration and Ventilation Centre website, 2000, accessed 11 April 2025.

657 National Science and Technology Council, op. cit. n.27, p.4.

658 Mundt, op. cit. n.656.

659 City of Melbourne, 'Healthy and energy-efficient buildings', City of Melbourne website, n.d., accessed 11 April 2025.

660 J Flint, 'Dr Bronwyn King campaigns for clean indoor air in Australia to combat COVID, bushfire smoke', The West Australian website, 2023, accessed 11 April 2025.

661 S Alotaibi, W Chakroun, C Habchi, K Ghali and N Ghaddar, 'Influence of mixed and displacement air distribution systems' design on concentrations of micro-particles emitted from floor or generated by breathing', Journal of Building Engineering, 2019, 26:100855, doi:10.1016/j.jobe.2019.100855.

662 N Mingotti and AW Woods, 'On the transport of heavy particles through an upwards displacement-ventilated space', Journal of Fluid Mechanics, 2015, 772:478-507, doi:10.1017/jfm.2015.204.

663 University of Wollongong, op. cit. n.4.

664 P Schluter, 'Optimising Building Performance: Enhancing indoor air quality and energy efficiency through life cycle cost analysis', presentation at AIRAH IAQ 2024, Melbourne, 16 July 2024.

665 G Riese, 'Navigating the new ISO/AS16890 filter standard and knowing what is being installed in your HVAC system', Institute of Healthcare Engineering Australia (IHEA), IHEA website, 2 April 2024, accessed 11 April 2025.

666 A Barrett, 'Push to improve indoor air quality at inaugural World Health Organization event', Croakey Health Media website, 5 October 2023, accessed 11 April 2025.

667 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Trajectory for Low Energy Buildings', DCCEEW website, 22 February 2024, accessed 11 April 2025. See also Department of the Environment and Energy, 'Guide to best practice maintenance and operation of HVAC systems for energy efficiency', DCCEEW website, 1 September 2013, accessed 11 April 2025.

668 MD Ambrose and M Syme, *House Energy Efficiency Inspections Project – Final Report* [PDF], CSIRO website, December 2015, accessed 11 April 2025.

669 M Ambrose and S Maxwell, *Air Infiltration of New Dwellings in Australia* [PDF], June 2024, in A Dunne, 'Sealing the comfort in our new homes', CSIRO website, 14 August 2024, accessed 11 April 2025.

670 University of Wollongong, op. cit. n.4, p.39.

671 J. Stamkos, 'What lurks beyond: Inspecting HVAC systems' inner cleanliness', FM Media website, 14 January 2013, accessed 11 April 2025. See also AIRAH, 'DA19 HVAC&R Maintenance', AIRAH website, 2019, accessed 11 April 2025; and AIRAH, 'HVAC Hygiene Best Practice Guideline', AIRAH website, n.d., accessed 11 April 2025. See also S. McGowan, 'Coming Clean', *HVAC&R Nation*, May 2019, 121:20-23, AIRAH website, accessed 11 April 2025.

672 The Australian Building Codes Board (ABCB), op. cit. n.16, pp.51-52.

673 Department of the Environment and Energy, op. cit. n.667.

674 See, for microbial control, Australian Standard 3666.2.

675 Safe Work Australia, *Model Code of Practice: Managing the work environment and facilities* [PDF], SWA website, 20 March 2020, accessed 11 April 2025, p.17.

676 L Ekberg, 'Inspection of ventilation systems', *REHVA Journal*, April 2021, pp.14-18, accessed 11 April 2025.

677 ASHRAE, *ANSI/ASHRAE Standard 62.1-2022, Ventilation and Acceptable Indoor Air Quality* [PDF], ASHRAE website, n.d., accessed 11 April 2025.

678 National Collaborating Centre for Environmental Health (NCCEH), 'Do-it-yourself (DIY) air cleaners: Evidence on effectiveness and considerations for safe operation', NCCEH website, 18 January 2023, accessed 11 April 2025.

679 T Talhelm, 'What Combination of Air Filters Do I Need for my Home or Office?' Smart Air Filters website, 8 July 2023, accessed 11 April 2025.

680 SK Brown, 'Assessing the performance of room air cleaners using a room environmental chamber', *Proceedings of 8th International Conference on Indoor Air Quality and Climate*, Edinburgh, 1999, 2:647-652.

681 J Fox, 'Solving the HEPA Filter Noise Problem,' Medium website, 20 January 2023, accessed 11 April 2025. See also National Science and Technology Council, op. cit. n.27, p.5.

682 AJ Wheeler, F Reisen, CT Roulston, M Dennekamp, N Goodman and FH Johnston, 'Evaluating portable air cleaner effectiveness in residential settings to reduce exposures to biomass smoke resulting from prescribed burns', Public Health Research Practice, 2024, 34(1):33232307, doi:10.17061/phrp33232307. See also S Schmidt, *CSIRO study: HEPA filters a breath of fresh air in bushfire season* [media release], CSIRO, 31 July 2023, accessed 11 April 2025.

683 PK Barn, CT Elliott, RW Allen, T Kosatsky, K Rideout and SB Henderson, 'Portable air cleaners should be at the forefront of the public health response to landscape fire smoke', *Environ Health*, 2016, 15(1):116, doi:10.1186/s12940-016-0198-9.

684 University of Wollongong, op. cit. n.4.

685 National Science and Technology Council, op. cit. n.27, p.2. See also G Pei, P Azimi, D Rimb and JG Allen, 'A CFD study on the effect of portable air cleaner placement on airborne infection control in a classroom', *Environ. Sci.: Processes Impacts*, 2024, Advance Article, doi:10.1039/D4EM00114A.

686 C Wilson, 'Schools cut covid-19 sick days by 20 per cent using HEPA air filters', NewScientist website, 2023, accessed 11 April 2025; and CJ Noakes, HC Burridge, CB Beggs, S Botitsopoulos, CJ Brown, J Darling, RG Feltbower, S Relins, S Wood and M Mon-Williams, '901 Class ACT: the UK's trial on the feasibility and effectiveness of air cleaning technologies in school', *British Association of Child and Adolescent Public Health*, 2023, 180(2) doi:10.1136/archdischild-2023-rcpch.165.

687 Tampere Universities, 'Air purification reduces children's morbidity in the daycare', Tampere Universities website, 12 September 2024, accessed 11 April 2025.

688 J Gettings, M Czarnik, E Morris, E Haller, AM Thompson-Paul, C Rasberry, TM Lanzieri, J Smith-Grant, TM Aholou, E Thomas, C Drenzek and D MacKellar, 'Mask Use and Ventilation Improvements to Reduce COVID-19 Incidence in Elementary Schools – Georgia', Morbidity and Mortality Weekly Report, 70(21):779-784, doi:10.15585/mmwr.mm7021e1.

689 T Falkenberg, F Wasser, N Zacharias et al, 'Effect of portable HEPA filters on COVID-19 period prevalence: an observational quasi-interventional study in German kindergartens', *BMJ Open*, 2023, 13:e072284, doi:10.1136/bmjopen-2023-072284.

690 Ibid, Table 3. See also University of Wollongong, op. cit. n.4, p.26.

691 National Science and Technology Council, op. cit. n.27, p.2.

692 See section 6.2.4.

693 See, for example, ET Gall and WW Nazaroff, ' New directions: potential climate and productivity benefits from CO2 capture in commercial buildings', *Atmospheric Environment*, 2015, 103:378-380, doi:10.1016/j.atmosenv.2015.01.004.

694 E Bender, 'Disinfecting the air with far-ultraviolet light', Nature website, 2022, accessed 11 April 2025.

695 Q Ong, W Wee, JD Cruz, JWR Teo and W Han, '222-Nanometer Far-UVC Exposure Results in DNA Damage and Transcriptional Changes to Mammalian Cells', International Journal of Molecular Sciences, 2022, 23(16), doi:10.3390/ijms23169112.

696 Bender, op. cit. n.694.

697 Ong et al, op. cit. n.695.

698 VP Barber, MB Goss, LJ Franco Deloya, LN LeMar, Y Li, E Helstrom, M Canagaratna, FN Keutsch and JH Kroll, 'Indoor Air Quality Implications of Germicidal 222nm Light', *Environmental Science & Technology*, 2023, 57(42):15990-15998, doi:10.1021/acs.est.3c05680.; and D Chandler, 'Germicidal UV lights could be producing indoor air pollutants, study finds', Massachusetts Institute of Technology (MIT) News website, 17 October 2023, accessed 11 April 2025.

699 University of Wollongong, op. cit. n.4, pp.v-vi.

700 National Science and Technology Council, op. cit. n.27, p.5.

701 Ibid. See also Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 'UVC germicidal lamps for personal sterilisation', ARPANSA website, n.d., accessed 11 April 2025.

702 University of Wollongong, op. cit. n.4, pp.v-vi.

703 See SAHMRI, 'The PETRA Study', SAHMRI website; and PETRA, SAHMRI and Flinders University, *A study looking at preventing respiratory illnesses in aged care using ultraviolet light (PETRA)* [PDF], SAHMRI website.

704 Minister Ingrid Stitt, *Aged care study to test virus fighting technology* [media release], Victorian Premier's website, 20 May 2024, accessed 11 April 2025. See also Victorian Government Department of Health, 'Germicidal ultraviolet light – combatting airborne virus transmission', Victorian Government Department of Health website, 29 May 2024, accessed 11 April 2025.

705 MS Waring and JA Siegel, 'The effect of an ion generator on indoor air quality in a residential room', Indoor Air, 2011, 21(4):267-276, doi:10.1111/j.1600-0668.2010.00696.x. See also T Talhelm, 'Studies Find Ionizer Air Purifier Makes Particles Stick to Lungs and Cause Inflammation', Smart Air website, 19 July 2024, accessed 11 April 2025.

706 Western Australia Department of Health, *Information on air purifier/cleaners* [PDF], Healthy WA website, 2023, accessed 11 April 2025, and The University of Melbourne, 'Guide to air cleaners', The University of Melbourne website, n.d., accessed 11 April 2025.

707 Western Australia Department of Health, ibid.

708 United States Environmental Protection Agency (US EPA), 'Ozone Generators that are Sold as Air Cleaners', US EPA website, 2023, accessed 11 April 2025.

709 N Carslaw, 'To clean, or not to clean? That is the question', UK Clean Air website, 2022, accessed 11 April 2025; and Royal Society of Chemistry, *Indoor Air Quality Report* [PDF 3.69MB], Royal Society of Chemistry website, 2023, accessed 11 April 2025.

710 B Ham, 'Study: Indoor air cleaners fall short on removing volatile organic compounds', Massachusetts Institute of Technology MIT News website, 2021, accessed 11 April 2025.

711 Consumer Affairs Victoria, 'Rental properties - minimum standards', Consumer Affairs Victoria website, 5 June 2024, accessed 11 April 2025.

712 Tasmanian Government Consumer Building and Occupational Services (CBOS), 'Types of minimum standards for rental properties', CBOS website, 2022, accessed 11 April 2025; and Consumer Affairs Victoria, 'Rental properties - minimum standards', Consumer Affairs Victoria, 5 June 2024, accessed 11 April 2025; and NSW Government Fair Trading, 'Minimum standards for rental properties', NSW Government website, n.d., accessed 11 April 2025.

713 The State of Queensland Residential Tenancies Authority (RTA), 'Preparing for minimum housing standards', RTA website, 2023, accessed 11 April 2025.

714 New Zealand Government Ministry of Business, 'Ventilation standard', Tenancy Services website, 2024, accessed 11 April 2025. See also *Residential Tenancies (Health Homes Standards) Regulations 2019 (New Zealand)*, New Zealand Parliamentary Counsel Office website.

715 Australian Government Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Residential buildings', DCCEEW website, 2024, accessed 11 April 2025.

716 California Air Resources Board, 'Car & Bus Exposure Studies', California Air Resources Board website, n.d., accessed 11 April 2025. See also M Schöll, C Höhn, J Boucsein, F Moek, J Plath, M An der Heiden, M Huska, S Kröger, S Paraskevopoulou, C Siffczyk, U Buchholz and R Lachmann. 'Bus Riding as Amplification Mechanism for SARS-CoV-2 Transmission, Germany, 2021', *Emerging Infectious Diseases*, 2024, 30(4):711-720, doi:10.3201/eid3004.231299.

717 A Uteuova, 'Like a high-sodium diet: traffic pollution can cause rise in blood pressure – study', The Guardian website, 2023, accessed 11 April 2025; and MT Young, K Jansen, KE Cosselman, TR Gould, JA Stewart, T Larson, C Sack, S Vedal, AA Szpiro and JD Kaufman, 'Blood Pressure Effect of Traffic-Related Air Pollution: A Crossover Trial of In-Vehicle Filtration', *Annals of International Medicine,* 2023, 176(12):1577-1696, doi:10.7326/M23-1309; and S Liu, R Wu, Y Zhu, T Wang, J Fang, Y Xie, N Yuan, H Xu, X Song and W Huang, 'The effect of using personal-level indoor air cleaners and respirators on biomarkers of cardiorespiratory health: a systematic review', Environment International, 2022, 158:106981, doi:10.1016/j.envint.2021.106981.

718 A Schultz, 'Experts call for new laws after horror start to year on roads', Sydney Morning Herald website, 20 January 2024, accessed 11 April 2025.

719 For example, Government of Western Australia, 'Report a smoky vehicle', Government of Western Australia website, 22 February 2024, accessed 11 April 2025.

720 J Jovanović, M Jovanović and D Đorđević, 'Professional exposure of drivers to carbon monoxide as a possible risk factor for the occurrence of traffic accidents in the road traffic', *Vojnosanitetski pregled*, 1999, 56(6):587-592.

721 D Campagnolo, F Borghi, G Fanti, M Keller, S Rovelli, A Spinazzè, A Cattaneo and DM Cavallo, 'Factors affecting in-vehicle exposure to traffic-related air pollutants: A review', *Atmospheric Environment*, 2023, 295:119560, doi:10.1016/j.atmosenv.2022.119560.

722 New South Wales (NSW) Government Department of Planning, Housing and Infrastructure, 'Fire safety certification', NSW Government Planning Group website, 2024, accessed 11 April 2025.

723 Victorian Building Authority (VBA), 'Essential safety measures', VBA website, 2024, accessed 11 April 2025.

724 E de Oliveira Fernandes, M Jantunen, P Carrer, O Seppänen, P Harrison and S Kephalopoulos, 'EnVIE Co-ordination Action on Indoor Air Quality and Health Effects', EnVIE website, 2009, accessed 11 April 2025.

725 Legislative Assembly Standing Committee on Public Works, *Report – Sick Building Syndrome* [PDF], NSW Parliament website, April 2001, accessed 11 April 2025, p.ix.

726 S Cash-Goldwasser, AL Reingold, SP Luby, LA Jackson and TR Frieden, 'Masks During Pandemics Caused by Respiratory Pathogens—Evidence and Implications for Action', The *Journal of American Medical Association Network Open*, 2023, 6(10):e2339443, doi:10.1001/jamanetworkopen.2023.39443; and Y Bar-Yam, J Samet, A Siegenfeld and N Taleb, 'Quantitative errors in the Cochrane review on Physical interventions to interrupt or reduce the spread of respiratory viruses' [unpublished journal article], *Research Square,* 2023, doi:10.21203/rs.3.rs-3486610/v1; and WG Lindsley, DH Beezhold, J Coyle, RC Derk, FM Blachere, T Boots, JS Reynolds, WG McKinney, E Sinsel, JD Noti, 'Efficacy of universal masking for source control and personal protection from simulated cough and exhaled aerosols in a room', *Journal of Occupational and Environmental Hygiene*, 2021, 18(8):409-422, doi:10.1080/15459624.2021.1939879; M Ungrin, M Oliver, JM Wright, J Mesiano-Crookston, M Gasperowicz, D Fisman and C Nielson, 'Medical masks versus N95 respirators for preventing COVID-19 among health care workers: A secondary analysis of findings inconsistent with prior understanding reflects the expected inferiority of medical masks', (4 December 2023, last edited 10 July 2024), doi:10.31222/osf.io/ey7bj. See also Greenhalgh et al, op. cit. n.551.

727 JK Kodros, K O'Dell, JM Samet C L'Orange, JR Pierce and J Volckens, 'Quantifying the health benefits of face masks and respirators to mitigate exposure to severe air pollution', *GeoHealth*, 2021, 5:e2021GH000482, doi:10.1029/2021GH000482; Healthdirect Australia, 'Face masks', Healthdirect Australia website, November 2024, accessed 11 April 2025; and Victorian Government Department of Health, 'Face masks for environmental hazards', Victorian Government Department of Health website, 7 August 2024, accessed 11 April 2025.

728 World Health Organization (WHO), *NEW: COVID19 variant of interest JN.1* [media release], WHO website, 19 December 2023, accessed 11 April 2025.

729 National Center for Immunization and Respiratory Diseases, 'Find Free High-Quality Masks', Center for Disease Control and Prevention (CDC) Archive website, 23 January 2023, accessed 11 April 2025.

730 See, for example, S Galmiche, T Charmet, A Rakover et al, 'Risk of SARS-CoV-2 infection in professional settings, shops, shared transport, and leisure activities in France, 2020–2022', *BMC Public Health*, 2024, 24:2411, doi:10.1186/s12889-024-19651-y; and Dam et al, op. cit. n.25.

731 interim Australian Centre for Disease Control, COVID-19 CDNA National Guidelines for Public Health Units [PDF], Department of Health and Aged Care website, June 2024, accessed 11 April 2025.

732 CR MacIntyre and AA Chughtai, 'A rapid systematic review of the efficacy of face masks and respirators against coronaviruses and other respiratory transmissible viruses for the community, healthcare workers and sick patients', *International Journal of Nursing Studies*, 2020, 108:103629, doi:10.1016/j.ijnurstu.2020.103629. See also Greenhalgh et al, op. cit. 551; and R MacIntyre, AA Chughtai, D Fisman and T Greenhalgh, 'Yes, masks reduce the risk of spreading COVID, despite a review saying they don't', *The Conversation*, 7 February 2023.

733 ZM Most, B Phillips and ME Sebert, 'Healthcare-associated respiratory viral infections after discontinuing universal masking', Infection Control and Hospital Epidemiology, 2024, 45(2):247–249, doi:10.1017/ice.2023.200.

734 S Ehrenzeller, T Chen, V Vaidya, C Rhee, MA Baker and M Klompas, 'Impact of SARS-CoV-2 Prevention Measures on Non-SARS-CoV-2 Hospital-Onset Respiratory Viral Infections: An Incidence Trend Analysis From 2015–2023', Clinical Infectious Diseases, 2023, 77(12):1696–1699, doi:10.1093/cid/ciad451.

735 MM Andaman, P Rajagopalan, J Woo and R Huang, 'An investigation of indoor air quality in school classrooms in Victoria, Australia [conference presentation]', RMIT University, 2019, accessed 11 April 2025.

736 P Rajagopalan, M Andaman and J Woo, 'Enhanced Indoor Air Quality for Improving the Well-Being of Vulnerable Population in Victoria', report to the Victorian Department of Environment, Land, Water and Planning and Virtual Centre for Climate Change Innovation, Sustainable Building Innovation Laboratory, RMIT University, 2020.

737 S Haddad, A Synnefa, MA Padilla-Marcos, R Paolini, D Prasad and M Santamouris, 'Enhancing thermal comfort and indoor air quality in Australian school classrooms', 40th AIVC Conference, 15-16 October 2019, Ghent, Belgium, Analysis & Policy Observatory website, 10 July 2019, accessed 11 April 2025.

738 R Laiman, C He, M Mazaheri, S Clifford, F Salimi, LR Crilley, M Azman M Mokhtar and L Morawska, 'Characteristics of ultrafine particle sources and deposition rates in primary school classrooms', *Atmospheric Environment*, 2014, 94:28-35, doi:10.1016/j.atmosenv.2014.05.013. See also MM Andaman, J Woo and P Rajagopalan, 'Australian children are learning in classrooms with very poor air quality', *The Conversation*, 17 February 2021.

739 SE Jones, AM Smith, LS Wheeler and T McManus, 'School policies and practices that improve indoor air quality', Journal of School Health, 2020, 80(6):280–286, doi:10.1111/j.1746-1561.2010.00502.x.

740 N Rawat and P Kumar, 'Interventions for improving indoor and outdoor air quality in and around schools', Science of The Total Environment, 2023, 858, 159813, doi:10.1016/j.scitotenv.2022.159813.

741 BBC News, 'Air filters for London's polluted schools – mayor', BBC News, 20 February 2024, accessed 11 April 2025.

742 SAMHE, 'About SAMHE', SAMHE website, n.d., accessed 11 April 2025.

743 National Center on School Infrastructure (NCSI), 'Clean Air in Buildings Challenge for Schools', NCSI website, 4 February 2025, accessed 11 April 2025.

744 Boston Public Schools, 'Indoor Air Quality (IAQ) Sensor Dashboard', Boston Public Schools website, n.d., accessed 11 April 2025; and SGS Live View, 'Boston Public Schools Indoor Air Quality', SGS Live View, 2024, accessed 11 April 2025.

745 MESH, 'How to read the data displayed on the portal', MESH website, n.d., accessed 11 April 2025.

746 Australian Government Department of Education (DoE), 'Coronavirus (COVID-19)', DoE website, 2024, accessed 11 April 2025.

747 National Health and Medical Research Council (NHMRC), *Staying healthy: preventing infectious diseases in early childhood education and care services* [PDF], NHMRC website, 2024, accessed 11 April 2025.

748 Victorian Government Department of Education, 'COVID-19 — School Operations', Victoria Government website, 2023, accessed 11 April 2025.

749 Victorian Government Department of Education, 'Ventilation and Air Purification', Victoria Government website, 2023, accessed 11 April 2025.

750 S Lansdown, 'What schools could be doing to prevent COVID spreading this winter', *Canberra Times*, 7 June 2024.

751 B Prezant, *Guidance Document for Primary and Secondary Schools – COVID-19 Ventilation Optimisation* [PDF], AIRAH website, 17 November 2021, accessed 11 April 2025.

752 COVID Safety for Schools, 'About the COVID Safety for Schools Course', COVID Safety for Schools website, n.d., accessed 11 April 2025; and J Flint, 'COVID lessons for schools tackles myths and provides advice on keeping pupils and teachers safe', The West Australian, 20 February 2024, accessed 11 April 2025.

753 OzSAGE, 'Protecting children from COVID-19 and making schools and childcare safer', OzSAGE website, October 2021, accessed 11 April 2025.

754 A Pollock, *A Breath of Fresh Air: The importance of air quality in aged care design* [PDF], HammondCare website, 2021, accessed 11 April 2025.

755 Rajagopalan et al, op. cit. n. 736.

756 Department of Health and Aged Care, 'Improving accommodation in residential aged care', Department of Health and Aged Care website, 7 November 2024, accessed 11 April 2025; and Department of Health and Aged Care, op. cit. n.452.

757 Department of Health and Aged Care (DHAC), *National Aged Care Design Principles and Guidelines. Factsheet for residential aged care providers and staff* [PDF], DHAC website, n.d., accessed 11 April 2025.

758 Australian Commission on Safety and Quality in Health Care (ACSQHC), 'The Aged Care Infection Prevention and Control Guide', ACSQHC website, 21 January 2025, accessed 11 April 2025.

759 Australian Commission on Safety and Quality in Health Care (ACSQHC), 'Australian Guidelines for the Prevention and Control of Infection in Healthcare', ACSQHC website, 14 November 2024, accessed 27 April 2025.

760 H Forehead, J Barthelemy, B Arshad, N Verstaevel, O Price and P Perez, 'Traffic exhaust to wildfires: $PM_{2.5}$ measurements with fixed and portable, low-cost LoRaWAN-connected sensors, *PLoS ONE*, 2020, 15(4):e0231778, doi:10.1371/journal.pone.0231778.

761 Victoria Department of Environment, Land, Water and Planning, *Clean Air for All Victorians – Victoria's Air Quality Strategy Report* [PDF], Victoria Department of Environment, Land, Water and Planning website, 2022, accessed 11 April 2025.

762 Australian Institute of Health and Welfare (AIHW), 'Benefits of the environment to health. A literature review of health benefits derived from 3 ecosystem services: air filtration, local climate regulation, and recreation', AIHW website, 2022, p. 24.

763 National Science and Technology Council, op. cit. n.27, p.6.

764 Asthma Australia, op. cit. n.231.

765 See AJ Wheeler, RW Allen, K Lawrence, CT Roulston, J Powell, GJ Williamson, PJ Jones, F Reisen, GG Morgan and FH Johnston, 'Can Public Spaces Effectively Be Used as Cleaner Indoor Air Shelters during Extreme Smoke Events?' *International Journal of Environmental Research and Public Health* , 2021, 18(8):4085, doi:10.3390/ijerph18084085; CSIRO, 'CSIRO, ACU, UTAS and DEWLP working together to understand indoor smoke in public spaces', CSIRO website, 7 February 2020, accessed 11 April 2025; Standing Committee on Environmental Health, 'enHealth guidance - Guidance for public health agencies - Managing prolonged smoke events from landscape fires', Department of Health and Aged Care website, 19 August 2024, accessed 11 April 2025; Australian Building Codes Board (ABCB), *Information Handbook: Design and Construction of Community Bushfire Refuges* [PDF], ABCB website, 2014, accessed 11 April 2025; R Blanchi, J Whittaker, K Haynes, J Leonard, K Opie, M Holland and S Dreyfuss, *Sheltering practices during bushfire, CSIRO report to the Department of Justice* [PDF], 2015; ACT Government, *Bushfire Smoke and Air Quality Strategy 2021-2025* [PDF], ACT Government, November 2021, accessed 11 April 2025, p.20; G Goldrick, 'Escaping underground: the eerie new age of bushfire bunkers', *The Guardian*, 29 October 2023, accessed 11 April 2025; Country Fire Authority of Victoria (CFA), 'Community Fire Refuges', CFA website, 17 August 2021, accessed 11 April 2025; California Air Resources Board (CARB), 'California Clean Air Centers', CARB website, 2024, accessed 11 April 2025.

766 See, for example, Safe Work Australia, *Interpretation of Workplace exposure standards for airborne contaminants. Guidance* [PDF], Safe Work Australia website, September 2024, accessed 11 April 2025.

767 The Australian Building Codes Board, op. cit. n.16.

768 See, for example, WorkSafe Western Australia, 'Indoor air quality', WorkSafe Western Australia website, 26 November 2024, accessed 11 April 2025.

769 Department of Climate Change, Energy, the Environment and Water (DCCEEW), *National Clean Air Agreement – work plan 2021-23* [PDF 323KB], DCCEEW website, 2022, accessed 11 April 2025, Project 1.1.

770 World Health Organization (WHO) Regional Office for Europe, op. cit. n.337, pp. 42-43.

771 Ibid, pp. 42-43.

772 Coroner P Barlow, *Annex A. Regulation 28: Report to prevent future deaths (1)* [PDF], UK Judiciary website, 20 April 2021, accessed 11 April 2025.

773 S Holgate, J Grigg, H Arshad, N Carslaw, P Cullinan, C Dimitroulopoulou, A Greenough, M Holland, B Jones, P Linden and 7 more authors, 'Health Effects of Indoor Air Quality on Children and Young People', *Environmental Pollutant Exposures and Public Health*, Royal Society of Chemistry 2020, doi:10.1039/9781839160431-00151, p. 16.

774 World Health Organization Regional Office for Europe, op. cit. n.337, pp. 42-43.

775 University of Tasmania Menzies Institute for Medical Research, 'Bushfires And Your Health', University of Tasmania Menzies Institute for Medical Research website, n.d., accessed 11 April 2025.

776 See Australian Curriculum, Assessment and Reporting Authority, 'Curriculum Connections', Australian Curriculum website, 2024, accessed 11 April 2025. See also, for example, Australian Curriculum, Assessment and Reporting Authority, 'Explore this content description, Health and Physical Education, Years 3 and 4, Personal, social and community health: making healthy and safe choices', Australian Curriculum website, 2024, accessed 11 April 2025; and Australian Curriculum, Assessment and Reporting Authority (ACARA), 'Understand this Curriculum connection 'Food and wellbeing', Australian Curriculum website, 2024, accessed 11 April 2025.

777 Australian Curriculum, Assessment and Reporting Authority, 'Explore this organising idea. Sustainability – Systems', Australian Curriculum website, 2024, accessed 11 April 2025.

778 World Health Organization Regional Office for Europe, op. cit. n.337, pp. 42-43.

779 Australian Building Codes Board, op. cit. n.16, pp. 85-93.

780 Green Building Council Australia (GBCA), *Responsible Products Guidelines – Version A* [PDF], GBCA website, 21 November 2024 revision, accessed 11 April 2025.

781 Bureau of Environment Tokyo Metropolitan Government, 'Introduction to Eco-labeling', Bureau of Environment Tokyo Metropolitan Government website, 10 May 2021, accessed 11 April 2025; and Ministry of Land, Infrastructure, Transport and Tourism, 'Architecture: Measures against sick house syndrome based on the Building Standards Act', Ministry of Land, Infrastructure, Transport and Tourism website, n.d., accessed 11 April 2025.

782 Rakennustieto, 'Emission Classification of Building Materials', Rakennustieto website, n.d., accessed 11 April 2025.

783 Dansk Indeklima Mærkning, 'About Danish Indoor Climate Labelling', Dansk Indeklima Mærkning website, n.d., accessed 11 April 2025.

784 R Jäckh, E Annys, B Heinzow, T Witterseh, M Glöckner, S Kephalopoulos, R Coutalides, D de Lathauwer, M Uhl, K de Brouwere and 13 more authors, 'Harmonisation framework for health based evaluation of indoor emissions from construction products in the European Union using the EU-LCI concept', Europa website, 2013, accessed 11 April 2025.

785 United States Environmental Protection Agency (US EPA), 'Learn About the Safer Choice Label', US EPA website, 2023, accessed 11 April 2025. See also Google Sustainability, 'The journey toward healthier materials', Google website, September 2019, accessed 11 April 2025.

786 The University of Melbourne, School of Geography, Earth and Atmospheric Sciences, 'Guide to air cleaners', The University of Melbourne website, n.d., accessed 11 April 2025.

787 California Air Resources Board (CARB), 'List of CARB-Certified Air Cleaning Devices', CARB website, n.d., accessed 11 April 2025. See also T Grundig, N Köksal and A Singh, 'Is an $800 purifier best to clean your home's air? Marketplace tested 5 top brands and their claims', CBC News website, 12 February 2021, accessed 11 April 2025.

788 Belgium Federal Public Service Health, Food Chain Safety and Environment, op. cit.504; and Belgium Federal Public Service (FPS) Health Food Chain Safety Environment, 'Loi du 21 DECEMBRE 1998 normes produits', FPS website, 10 December 2013, accessed 11 April 2025.

789 Australian Building Codes Board, op. cit. n.16, pp. 85-93.

790 Ibid, pp. 6-9.

791 Morawska et al, op. cit. n.10.

792 Safe Work Australia, op. cit. n.436.

793 Safe Work Australia, 'Exposure standards - airborne contaminants', SWA website, n.d., accessed 11 April 2025.

794 Australian Building Codes Board, op. cit. n.16.

795 Note – not sourced directly from NHMRC, as document rescinded. S Brown, 'Summary of indoor air quality in Australia: a strategy for action. Indoor Air Quality Special Interest Group, CASANZ', CASANZ, ResearchGate website, October 2002, accessed 11 April 2025.

796 Standards Australia, *AS 1668.2:2024 The use of ventilation and airconditioning in buildings, Part 2: Mechanical ventilation in buildings*, Standards Australia website, 2024, accessed 11 April 2025; and *AS 1668.4:2024 The use of ventilation and airconditioning in buildings, Part 4: Natural ventilation of buildings*, Standards Australia website, 2024, accessed 11 April 2025.

797 Department of Health and Aged Care, op. cit. n.452.

798 M Hayashi, K Kobayashi, H Kim and N Kaihara, 'The State of the Indoor Air Environment in Buildings and Related Tasks in Japan', *Journal of the National Institute of Public Health*, 2020, 69(1):63-72, doi:10.20683/jniph.69.1_63.

799 Innovative Instrument Co, 'Announcement of the Department of Health regarding air quality monitoring costs in public buildings', Innovative Instrument Co website, n.d., accessed 11 April 2025.

800 The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group, *A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places* [PDF 3,408KB], The Government of the Hong Kong Special Administrative Region Indoor Air Quality Management Group website, 2019, accessed 11 April 2025.

801 Government of Canada, 'Residential indoor air quality guidelines', Government of Canada website, 9 December 2022, accessed 11 April 2025.

802 World Health Organization, op. cit. n.86.

803 World Health Organization, op. cit. n.12.

804 National Environment Protection Council (NEPC), 'National Environmental Protection (Ambient Air Quality) Measure', NEPC website, 2022, accessed 11 April 2025. Note also that the *National Environment Protection (Air Toxics) Measure* aims to collect data on five priority air toxics in outdoor air – benzene, formaldehyde, polycyclic aromatic hydrocarbons, toluene and xylene – to facilitate the development of standards.

805 See also Safe Work Australia, 'Hazardous Chemical Information System (HCIS) – Exposure Standard Documentation – Carbon monoxide', SWA website, n.d., accessed 11 April 2025.

806 French Government, *Order of 27 December 2022 setting the conditions for carrying out the direct reading measurement of the concentration of carbon dioxide in indoor air as part of the annual assessment of ventilation means*, Légifrance website, n.d., accessed 11 April 2025.

807 See also Safe Work Australia, 'Hazardous Chemical Information System (HCIS) – Exposure Standard Documentation – Carbon monoxide', SWA website, n.d., accessed 11 April 2025.

808 French Government, *Monitoring of indoor air quality in certain establishments open to the public (Articles R221-30 to D221-38)*, Legifrance website, n.d.; accessed 11 April 2025.

809 French Government, Decree No. 2012-14 of 5 January 2012 relating to the evaluation of ventilation systems and the measurement of pollutants carried out as part of the monitoring of indoor air quality in certain establishments open to the public, Légifrance website, n.d., accessed 11 April 2025.

810 Innovative Instrument Co, 'Announcement of the Department of Health regarding air quality monitoring costs in public buildings', Innovative Instrument Co website, n.d., accessed 11 April 2025.

811 Asbestos and Silica Safety and Eradication Agency (ASSEA), *Communicating asbestos facts and figures to the public guide* [PDF], ASSEA website, 2021, accessed 11 April 2025; and Safe Work Australia (SWA), op. cit. n.22.

812 Prockop and Chichkova, op. cit. n.112.

813 J Domenech and R Marcos, 'Pathways of human exposure to microplastics, and estimation of the total burden', *Current Opinion in Food Science*, 2021, 39:144-151, doi:10.1016/j.cofs.2021.01.004.

814 Environmental Health Standing Committee (enHealth), op. cit. n.199.

815 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Oxides of Nitrogen', DCCEEW website, 30 June 2022, accessed 11 April 2025.

816 DJ Jarvis, G Adamkiewicz, ME Heroux, R Rapp and FJ Kelly, 'Nitrogen oxide', in WHO guidelines for indoor air quality: selected pollutants, National Library of Medicine website, 1 January 2010, accessed 11 April 2025.

817 United States Environment Protection Agency (US EPA), 'Particulate Matter (PM) Basics', US EPA website, 20 June 2024, accessed 11 April 2025.

818 Expert Health Panel for PFAS, 'Expert Health Panel for PFAS - Report', Department of Health and Aged Care website, 14 Jun 2024, accessed 29 April 2025.

819 Department of Climate Change, Energy, the Environment and Water, op. cit. n.106.

820 Department of Climate Change, Energy, the Environment and Water (DCCEEW), 'Sulfur dioxide', DCCEEW website, 15 August 2022, accessed 11 April 2025.

821 Wang et al, op. cit. n.174.

822 'Chemicals in e-liquids and e-cigarette aerosols' in 'Tobacco in Australia. Facts & Issues. A comprehensive online resource', Tobacco in Australia website, August 2024, accessed 11 April 2025.


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