

INDOOR AIR

THE SCIENCE OF INDOOR AIR AND
PATHWAYS TO IMPROVE INDOOR AIR
QUALITY IN AUSTRALIA

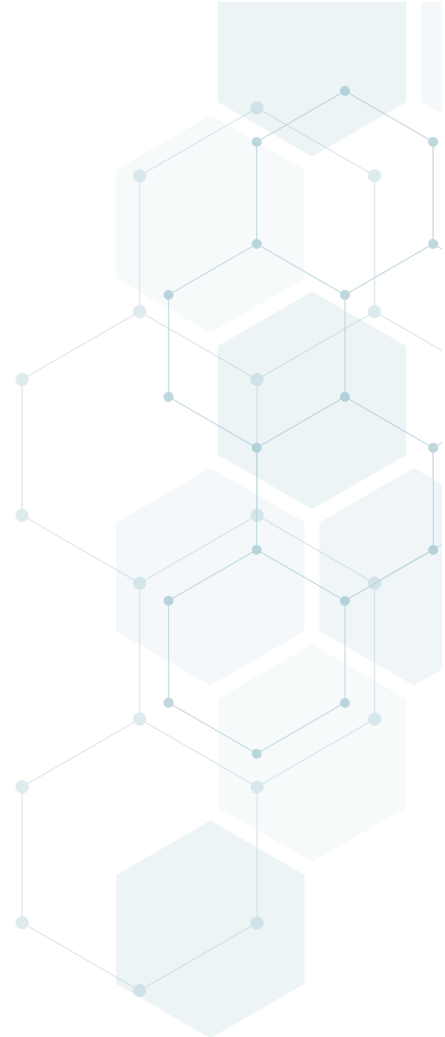
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Foreword

In this report, two clear themes emerge.

One, there is a robust and growing body of scientific evidence showing that poor indoor air quality has a negative impact on our health and wellbeing.

Two, there are known and available technological and policy solutions to address it.

In that light, it seems inconceivable that in 2025 in Australia – and in most places around the world – urgent action is not being taken to improve the air that we breathe in the places we spend around 90% of our time: indoors.

The Australian Academy of Science has a long-held interest in advancing actions to improve indoor air quality in Australia.

Through raising this issue with influential leaders including Australia's Prime Minister, submissions to government inquiries, and providing independent science advice to government, the Academy has collaborated with a growing network of stakeholders calling for action on indoor air quality.

Most recently, the Academy, in partnership with Burnet Institute, was proud to lead a global call to recognise clean indoor air as essential to health and wellbeing.

More than 300 global leaders gathered at the United Nations headquarters in New York on the sidelines of the 2025 UN General Assembly to declare that we consider indoor air quality a basic human right.

This report builds on the Academy's sustained advocacy to date and reflects our mission to bring evidence to decision-making and science to the service of the nation.

To do this, we lean on the extraordinary research effort across the nation and the globe, gathering evidence and translating it for use by decision-makers like ministers, policymakers, judges, teachers, and members of the public.

We especially lean on our Fellows – Australia's distinguished scientists elected to the Academy for their remarkable scientific achievements.

We gratefully thank Academy Fellow, and world-leading expert on indoor air, Professor Lidia Morawska FAA FTSE for her leadership and guidance as the Lead Expert for this report. We also thank the many expert contributors and reviewers involved in driving and shaping this endeavour.

As well as providing a primer on the scientific evidence base, this report explores the policy pathways to implement routine measurement and monitoring of indoor air in public buildings to an agreed set of standards and sensitivities.

Doing so will improve our health, performance and productivity. It will lower workplace absenteeism and better prepare us for future bushfires and pandemics. Our findings are clear, and there is enough evidence to act.

In Australia, we don't measure nor monitor indoor air according to scientific best practice. And so, we don't manage poor indoor air.

The responsibility and the opportunity sit with us all to work together across government, industry and academia to take heed of this knowledge and to deliver healthier indoor air for everyone.

Professor Chennupati Jagadish AC PresAA FRS FREng FTSE

President, Australian Academy of Science



Summary

Indoor air quality (IAQ) describes the composition of indoor air based on the degree to which it supports human health and wellbeing, including comfort and performance. In particular, it describes the presence of air pollutants including airborne pathogens.

Air pollution, both indoor and outdoor, is a significant risk to society. It negatively affects human health and wellbeing, as well as the accessibility of spaces, and the economy. Some groups, such as people with chronic illness or who are immunocompromised, children, and the elderly, are more vulnerable to poor IAQ.

The World Health Organization has published health-based global air quality guidelines (WHO AQG) applying to both indoor and outdoor air (WHO, 2021), as well as indoor air-specific guidelines for reducing risks and protecting health (WHO, 2010; WHO, 2014).

The majority of human exposure to air pollution occurs indoors, where people spend around 90% of their time (enHealth, 2012; Kim et al., 2025; Klepeis et al., 2001; Matz et al., 2014).ⁱ Moreover, the transmission of disease via airborne pathogens is almost exclusively an indoor problem.

There is a substantial and growing scientific understanding of:

- the sources contributing to indoor air composition and physicochemical processes occurring there
- the impact of indoor air pollution on human health and wellbeing
- the role of airborne pathogens in infection transmission in indoor air
- the burden of disease and associated economic impacts of indoor air pollution.

Despite decades of effort by many experts, and a large body of evidence about the scale of the problem, IAQ has attracted little attention (Morawska et al., 2024). Decision-making authorities have been slow to accept and use this scientific evidence and, in general, there is limited awareness by society, public health authorities, and policymakers about the need to improve IAQ.

There are three main approaches to improving IAQ: controlling pollutants at the source, ventilation, and air cleaning.

The way we design, build, operate, and use buildings impacts IAQ. Building design and operational practices, as well as advanced technologies, exist to ensure good IAQ, but have limited uptake. These include:

- an understanding of the critical factors that support human health and wellbeing given a building's purpose and local climate
- building management systems capable of incorporating equipment for monitoring, reporting and controlling IAQ
- an understanding of how to improve building ventilation systems to support IAQ and the opportunities for doing so
- the use of low-cost sensor technologies for monitoring IAQ at scale, including their calibration, location and maintenance
- the optimisation of the operation of the building management system to maintain good IAQ, including using continuous monitoring, automation, and machine learning approaches.

Managing IAQ does not need to be a trade-off with energy consumption. With flexible and responsive building systems, it is possible to optimise energy use in buildings by delivering ventilation to occupants only where and when it is needed.

ⁱ This figure includes time spent in enclosed transport.

Studies have estimated significant economic benefits from improving IAQ, for example, from increased productivity by reducing workplace absences and demands on the healthcare system (Boulanger et al., 2017; Facilities Management Association of & New Zealand, 2024; Liu et al., 2023; Royal Academy of Engineering, 2022; The Safer Air Project, 2024; Troeger et al., 2017; University of Wollongong, 2024).

A peer-reviewed consensus paper by international IAQ experts sets out the need to mandate IAQ standards in public buildings (Morawska et al., 2024). It provides a practical starting point for how to do this that is based on well-established scientific principles and available monitoring technology. This includes parameters for measuring IAQ, the setting of averaging or threshold values, and the scientific justification for these measures.

Australia lacks adequate enforceable IAQ performance standards with continuous monitoring and associated monitoring infrastructure and practices.

Policymakers have a range of mechanisms available to improve IAQ in Australia. The options provided in this document offer opportunities for immediate action and long-term strategic planning. These start with elevating IAQ as a national health and infrastructure priority and establishing a multidisciplinary taskforce to provide expert advice on IAQ to multiple government departments, developing a national reporting standard for workplace IAQ, and adopting the WHO AQG.

The establishment of a multidisciplinary taskforce, as recommended in the final report of the Inquiry into Long COVID and Repeated COVID Infections, would serve as a critical enabler to develop a government framework to address IAQ in Australia (Standing Committee on Health Aged Care and Sport, 2023).

Australia needs to develop clear and enforceable IAQ requirements. There are three key areas in which this could be addressed: building standards, workplace health and safety regulation and standards, and accessibility standards.

The most feasible starting point for government action is a phased approach to achieve clean indoor air in workplaces. It would consist of three phases beginning with a requirement to monitor without a reporting standard. This would be followed by a mandatory workplace reporting standard and finally an indoor air quality standard for all public buildings.

Public education will be vital to ensure that measures are effectively adopted by building owners, operators, and occupants. Policy measures should aim to address any existing inequities, especially in schools, aged care, and social housing. Maintenance will also be vital, including ensuring Australia has sufficient skilled labour for this industry.

Context

The 2019–20 Australian bushfire season and the COVID-19 pandemic brought IAQ into full focus in Australia. It became clear that there was a general lack of awareness of how to protect people from smoke coming indoors from outside, and from infectious respiratory particles generated indoors by infected individuals.

While Australia has a well-developed regulatory framework for outdoor air quality, IAQ is not regulated to the same degree in all settings and is rarely monitored. This is significant because human exposure to air pollution occurs predominantly indoors, where people spend around 90% of their time (enHealth, 2012; Kim et al., 2025; Klepeis et al., 2001; Matz et al., 2014).ⁱⁱ To establish and maintain good IAQ in public buildings, evidence-based performance standards are required.

For implementation, standards need to be supported by a framework that may include regulatory, voluntary, or other mechanisms. They also require standardised methods for measuring and reporting pollutant concentrations and other parameters. If it cannot be measured, it cannot be regulated.

This report provides an overview of the current scientific evidence on indoor air pollution and its impacts, as well as what policy pathways Australia could follow to improve IAQ. It is not a systematic literature review.

Studies on the health impacts of indoor air pollutants often focus on residential settings, where people spend a substantial portion of their time. While acknowledging this, the policy section of this report focuses on the implementation of performance standards to improve IAQ in public spaces as a feasible starting point for action. The airborne transmission of disease is of particular concern in shared spaces like hospitals, offices, schools, and residential aged care.



Bushfire smoke shrouds the town of Narrandera in NSW, January 2020.

ⁱⁱ This figure includes time spent in enclosed transport.

How advanced is indoor air science and technology?

Key terms

Indoor air is air in all enclosed spaces, including but not limited to homes, workplaces, education facilities, healthcare facilities, public buildings for retail and entertainment services, and transport.

Indoor air composition describes the chemical, biological and physical components in indoor air. The composition of indoor air may be impacted by other characteristics such as temperature and humidity.

Indoor air quality (IAQ) describes the composition of indoor air based on the degree to which it supports human health and wellbeing, including comfort and performance (Wargocki, 2016). Performance describes an individual's ability to perform mentally or physically demanding tasks, like learning at school or undertaking duties at work.

In this report, IAQ explicitly includes the airborne transmission of pathogens.

Indoor air pollution occurs when harmful components, collectively called pollutants, contaminate indoor air and pose a threat to human health and wellbeing. Whether or not components of the air are harmful depends on their concentration and the duration of a person's exposure.

World Health Organization (WHO) guidelines provide a uniform basis for the protection of public health from the adverse effects of indoor exposure to air pollution. This includes eliminating (or reducing to a minimum) exposure to those pollutants that are known or are likely to pose a threat (WHO 2010; 2021). Not included in these guidelines is protection against airborne viruses and bacteria, beyond a brief discussion in the *WHO guidelines for indoor air quality: dampness and mould* (WHO, 2009).

Indoor air pollution originates from both indoor and outdoor sources.

An *indoor source* refers to any origin of air pollutants that is located within a building or enclosed space. Indoor sources are often the result of people's presence and their activities. Among the most common and significant indoor pollutant sources are combustion (such as cooking and heating, smoking, and burning candles and incense), emissions from building materials, running electrical equipment, fragrances, cleaning products, mould (releases spores), and the resuspension of floor dust (Emmerson & Keywood, 2021; Goodman & Nematollahi, 2022; Spengler et al., 2001). The occupants of an indoor space are also a source of indoor air pollution; humans emit respiratory effluents (including pathogens) and body odours.

Outdoor sources include traffic emissions, industrial facilities, bushfires, surface dust, pollen emitted by plants, and fungi. Emissions from these sources enter buildings via natural or mechanical ventilation, as well as through unintentional air infiltration points such as gaps and cracks in the building envelope (Emmerson & Keywood, 2021; Spengler et al., 2001). Outdoor pollutants may also be carried in on occupants or items entering the space and be resuspended.

Indoor air pollutants include: particulate matter (PM, including PM_{2.5}, PM₁₀ and ultrafine particles (UFPs)),ⁱⁱⁱ inorganic and organic gases (CO, CO₂, NO₂, O₃, SO₂ and very volatile, volatile and semi-volatile organic compounds (VVOCs, VOCs and SVOCs) such as formaldehyde, benzene and toluene),^{iv} toxins, trace elements, fibres, microplastics, mould spores, and more (Emmerson & Keywood, 2021; Spengler et al., 2001; WHO, 2010).

Of particular importance are pollutants emitted from human respiratory activities, including exhaled CO₂ and particles emitted during all respiratory activities at a rate and size that is activity dependent (Morawska, Johnson, et al., 2009). These may contain pathogens (viruses and bacteria).

Physics and chemistry of indoor air processes

Pollutants in indoor air can undergo numerous physical and chemical processes that change their characteristics, remove them from the air ('sinks'), and result in formation of new pollutants. These processes include:

- chemical reactions between different components of the indoor environment which result in the formation of new pollutants (Morawska, He, et al., 2009; Nazaroff & Weschler, 2004) – for example, secondary organic aerosols form in the air from the VOC precursors emitted by laser printers during high-temperature fusing of toner on paper (Morawska et al, 2019)
- transport of indoor air pollutants within the space by diffusion and by airflow induced by natural or mechanical ventilation, occupant movement and activities, and temperature gradients
- deposition of particulate matter on indoor surfaces, transport of pollutants into indoor spaces, and removal out of the spaces by ventilation flows (Nazaroff, 2004).

As an example, pathogens (viruses or bacteria) present in the respiratory tract are emitted as a component of infectious respiratory particles (WHO, 2024a). The predominantly small size of these particles means that they can remain suspended in the air for long periods and travel considerable distances within an indoor environment transported by airflows. If a person inhales these pathogen-laden particles, they can become infected. This process is called airborne transmission of respiratory infections, which COVID-19 dramatically brought to our attention (Morawska & Milton, 2020).

ⁱⁱⁱ PM_{2.5} and PM₁₀ are particles with diameters less than 2.5 and 10 micrometres, respectively. UFPs are of nanoscale size (less than 0.1 micrometres). For regulatory purposes, based on health studies linking particle size to adverse health effects, they are usually measured in terms of mass concentration. Note: the standard analytical definition of PM_{2.5} and PM₁₀ differs slightly.

^{iv} NO₂ is nitrogen dioxide, SO₂ is sulfur dioxide, CO is carbon monoxide and O₃ is ozone. VVOCs, VOCs, and SVOCs encompass all analytically detectable organic compounds in the air. Their determination typically requires multiple analytical methods (Morawska et al., 2024a; WHO, 2021).

Factors impacting indoor air quality

Indoor air is a complex system dependent on numerous factors, including:

- a multitude of pollution sources that produce thousands of pollutants with different characteristics
- physical, chemical and biological processes that act on these pollutants
- the indoor environment, including building structure and type of ventilation system
- climatic factors which can influence the emission and transformation of indoor air pollutants – for example, relative humidity impacts the prevalence of mould and may affect viral stability, while temperatures can intensify reactions (WHO, 2009).

Because of the complexity of indoor air, without monitoring IAQ in indoor spaces, little conclusion can be drawn about the levels of air pollution in individual spaces, the dominant sources of the pollutants, and factors affecting them.

There is limited regulatory or voluntary monitoring of indoor air in Australia. Therefore, there is no comprehensive quantitative knowledge of the state of IAQ in the country.

A report documenting the state of indoor air in Australia was published by the ARC Training Centre for Advanced Building Systems Against Airborne Infection Transmission (THRIVE) in 2025 (Miller & Morawska, 2025). It is the first national report quantifying IAQ in Australian buildings and is based on the analysis of 106 peer-reviewed studies including data from more than 2,500 buildings. This report provides a baseline profile of 10 pollutants measured in different Australian building types – providing evidence that has never been collated and revealing data gaps.

Interventions to improve indoor air quality

The three general approaches for improving IAQ are source control, ventilation, and air cleaning. These approaches encompass a range of potential solutions with varying levels of effectiveness, feasibility and cost.

Source control

When it is feasible, source control is the most effective method to prevent exposure to pollutants and is the cornerstone of risk management. It is achieved by controlling indoor emission sources. For example, using low-emitting building materials, controlling moisture in the mechanical and built structures in a building, eliminating combustion processes indoors (e.g. switching from gas to electric cooking and removing solid fuel stoves), and managing reservoirs of indoor air pollutants. Reservoirs are places where indoor air pollutants settle or are absorbed, and may be transformed (e.g. the growth of biofilms in the cooling compartments of air conditioning systems can become more infective and resistant to antimicrobial treatment and later become airborne). Source control also includes the removal of pollutants at a source, such as using extractors and externally vented range hoods during cooking.

A range of source control regulations exist, for example bans on cigarette smoking and vaping indoors in public spaces, solid fuel heater standards, the regulation of asbestos and silica, and labelling schemes for building product emissions. Such regulations are limited to a few select products and are only implemented in some countries. However, they do not encompass the multiplicity of products used in building construction, fit-out, operation, and cleaning, and in products utilised by occupants for activities such as art (e.g. paints), ambience (e.g. candles), personal hygiene (e.g. deodorants) and beauty (e.g. nail and hair care products).

Humans are a source of indoor air pollutants – importantly, viruses and bacteria which can cause infection via airborne transmission. Controlling airborne pathogens at the source by requiring or encouraging everyone in public spaces to always wear respirators would not be feasible, sustainable or socially acceptable. Not everyone can or wants to wear a well-fitted mask at all times and such a requirement would be unlikely to be accepted in Australia. However, in some environments and under some circumstances – for example during a pandemic – public health orders may require or encourage the use of personal protective equipment to control human respiratory emissions to reduce risk.

When a person is infected, wearing respiratory protection to prevent spreading their infection to others – particularly in health and aged care settings – supports the protection of the right of others to breathe clean, unpolluted air.

Other interventions such as vaccination, treatment, and screening, testing and isolation strategies should also be used to control the source depending on the specific pathogen and circumstances.

Ventilation

Ventilation with outdoor air is the most prevalent method for improving IAQ (Wargocki, 2016; Wargocki, 2021).

Ventilation is achieved by supplying air to or removing air from a space. It requires proper distribution of air throughout the space or being delivered directly to a breathing zone of occupants. Some definitions of ventilation only include ventilation with outdoor air. In this report we also include the supply of appropriately sourced (away from outdoor sources, e.g. parking lots or air vents) and cleaned recirculated air (see air cleaning technologies below).

Bringing in outdoor air or recirculated air dilutes the pollutants, preventing unwanted accumulation in an indoor space. Depending on the specific context and environment, air cleaning (see below) may be required to ensure the outdoor or recirculated air being supplied is less polluted than the air in the room (for example, during a bushfire smoke pollution event). For some pollutants, where available air cleaning technology does not reduce their concentration, recirculated air may be insufficient.

Ventilation can be achieved through natural forces (by opening windows or designing openings to allow outdoor air to flow indoors) or mechanical forces (using fans to introduce and circulate air, such as in HVAC[▼] systems). Hybrid ventilation systems are a combination of natural and mechanical ventilation.

Natural ventilation may not be sufficient nor reliable. For example, it may require windows to be opened to their full extent and conflict with the thermal comfort requirements of occupants. Further, natural ventilation generally requires occupants to manually manage ventilation and is thus more reliant on individual knowledge and behaviour change.

▼ HVAC stands for heating, ventilation, and air conditioning.

Air cleaning

Air cleaning is achieved by removing or neutralising contaminants. The effectiveness of air cleaning technologies depends on many factors including, but not limited to, their design, the settings they are used in, how they are maintained, and where they are positioned. Many of these technologies do not have standardised methods to document efficiency or standardised operational guidance to ensure effective use. A notable exception is particle filters (see below), which have efficiency rating standards.

There are three main types of air cleaning: particle filtration, gas-phase air cleaning, and disinfection.

Particle filtration

Filtering the air is the best-established method to remove particulate matter.

Filters with different removal efficiencies are used in both fixed HVAC systems and in many portable air cleaners, and their effectiveness is reported by a filter's MERV rating (US)^{vi} or filter class (Europe).^{vii} Australia has adopted the ISO 16890 (AS 16890:2024) standard for air filtration which will be in full use by the end of 2026.^{viii} Media filters of different efficiency are used in all modern HVAC systems.

Portable air cleaners are devices placed in occupied spaces (not in ventilation systems) to remove pollutants by pulling air through a filter using a fan. To be effective, the device or devices used in a room must provide a clean air delivery rate appropriate for the size of that room. Other factors critical to the effectiveness of a portable air cleaner include:

- the type and rating of the filter
- the device settings used (such as fan speed)
- the appropriate sealing of the device
- replacement of the filters
- regular cleaning and maintenance of the unit
- placement of the unit in the space.

For example, poorly fitted filters that allow air to escape around their edges will not achieve their designed filtration efficiency.

Typically, public spaces do not require high efficiency particulate air (HEPA) filters to maintain particulate matter at a required particle mass or concentration level. A lower efficiency filter which air passes through multiple times can deliver the same pollutant removal results as a higher efficiency filter with a single pass. This can be quieter and more energy efficient. However, some environments, such as healthcare facilities, require the maximum protection provided by HEPA filters for vulnerable occupants.

^{vi} MERV rating is the Minimum Efficiency Reporting Values of each filter. The higher the MERV rating (from 1 to 16), the better the filter is at capturing smaller particles.

^{vii} Australia uses the European filter class system – G and F ratings – as articulated in EN 779/EN1882 and AS 1324 and AS4260. Ratings G1–4 are equivalent to MERV 1–8, and F5–F9 equivalent to MERV 1–15. F9 and MERV 16 filters are the start of the HEPA range of filters which, in Australia, has six grades of efficiency.

^{viii} *Air filters for general ventilation – Part 1: Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)* (ISO 16890-1:2016, MOD).

Gas-phase air cleaning

Particle filters do not remove gaseous pollutants. Gas-phase air cleaners encompass many technologies – such as activated carbon filters for VOCs and electrostatic filters – but their effects are less well documented than particle filters and their use is not as widespread. They are sometimes used alongside particle filters in portable air cleaning devices. Some gas-phase air cleaning may generate pollution by producing harmful byproducts.

Disinfection

Disinfecting the air with technologies that can deactivate pathogens is another approach. For example, germicidal ultraviolet-C (UV-C) lamps are commonly deployed in air conditioning systems to reduce biofilm and mould growth. Germicidal UV-C light is a long-established technology, but direct exposure poses risks to human skin and eyes at the conventional wavelength (254 nm) (Reed, 2010). For this reason, it is confined to upper-room locations (near a room's ceiling) or within HVAC systems and not at the level in the room where infectious aerosols are being generated by people. More recently, far-UV light has been deployed into the whole room; however, research is continuing into its success and safety – for example, in relation to the potential for secondary chemical products (Franklin et al., 2025).

Summary

Despite its complexity, the science of indoor air is well established. There is good understanding of pollutant sources and physiochemistry of indoor air process, and internal and external factors affecting indoor air systems. There are also well-established and advanced technological means to support good IAQ, as well as a pipeline of emerging technologies and solutions.

How does indoor air affect human health and wellbeing?

Global estimates place air pollution among the key risks affecting people. In 2021, around 8.1 million people died as a result of outdoor and indoor air pollution exposure, which was the second leading risk factor for death (Health Effects Institute, 2024). Of these, 38% were from household air pollution. Deaths from indoor transmission of airborne viruses (such as COVID-19) and bacteria are additional to this estimate.

Since people spend around 90% of their time indoors (enHealth, 2012; Kim et al., 2025; Klepeis et al., 2001; Matz et al., 2014),^{ix} exposure to indoor air pollution is an important determinant of health. Indoor air pollution exposure depends on the concentration of the pollutant in indoor air and how long someone is exposed to that pollutant (WHO, 2021). To assess the risk from exposure, scientists consider a chain of events including:

- the emission of the pollutant
- the concentration of the pollutant in the air
- how much of the population is exposed to the pollutant
- the body burden (the amount of the pollutant in a body)
- the dose of the pollutant at the organ or cellular level
- the health effects of the pollutant (WHO, 2021).

Health and wellbeing effects caused by exposure to indoor air pollution

Exposure to indoor air pollution leads to a wide range of negative health outcomes, both short term (acute) and long term (chronic). It affects respiratory, cardiovascular, reproductive and mental health, with possible health outcomes including an increased risk for lung cancer, diabetes, leukaemia and Parkinson's disease (Asikainen et al., 2016; Hänninen et al., 2014; Liu et al., 2023; Logue et al., 2012; WHO, 2010, 2021).

Short-term health impacts associated with indoor air pollution include irritation of the eyes, nose, throat and skin; exacerbation of asthma; and allergy symptoms (Australian Building Codes Board, 2023; Samet et al., 2022). Short-term impacts also include acute symptoms of airborne disease, such as fever, cough, runny nose, vomiting and headache.

Long-term health impacts include elevated cancer and cardiovascular disease risk (Samet et al., 2022; WHO, 2021; World Heart Federation, 2024). Chronic effects may take years to become noticeable, and the causes can be hard to identify since they are often associated with exposures to low pollutant concentrations over extended periods of time and in different environments (Samet et al., 2022; WHO, 2021; World Heart Federation, 2024).

Airborne diseases – including influenza, COVID-19, whooping cough and respiratory syncytial virus (RSV) – are also transmitted via indoor air. Pathogens enclosed in liquid-based particles are emitted from an infected person's nose or mouth when breathing, speaking, sneezing and coughing. Airborne transmission describes the process whereby these particles exhaled by an infected person are inhaled from the air by another person (Greenhalgh et al., 2021; Morawska et al., 2024).

People living with some health conditions may experience worsened symptoms due to indoor air pollution. Asthma, allergies and chronic obstructive pulmonary disease

^{ix} This figure includes time spent in enclosed transport.

(COPD) symptoms are exacerbated by indoor air pollution from sources such as gas and wood heaters, cooking, pollen from outside, perfumes and fragrance from consumer products, and dampness-associated mould and bacteria (Asthma Australia, 2022; Samet et al., 2022). For example, 12% of childhood asthma is associated with gas stove use in Australia (Knibbs et al., 2018).

People living with chronic health conditions are also at increased risk of poor health outcomes from exposure to airborne pathogens (Department of Health and Aged Care, 2025a, 2025b). For people living with chronic health conditions, poor IAQ may exclude them from accessing spaces equally (The Safer Air Project, 2024).

In addition, numerous studies have quantified the negative impacts of exposure to indoor air pollution on cognition, performance, comfort, learning, productivity, sleep quality, and neurobehavioural symptoms such as difficulty concentrating (Al Horr et al., 2016).

Linking exposure to indoor air pollution with health and wellbeing impacts

Typically, the impact of indoor air pollution on health does not manifest itself immediately, but days after exposure (in the case of airborne pathogens) or months or years after exposure (in the case of cardiovascular disease, stroke, or cancer). There are some exceptions. For example, PM_{2.5} exposure can contribute to the onset of acute cardiovascular events, and carbon monoxide (CO) poisoning can have health impacts up to and including death within minutes (Islam et al., 2025; Salthammer, 2024).

Only through epidemiological studies is it possible to associate health effects with indoor air pollution on a population scale. This involves monitoring population exposure to indoor air pollution by measuring the concentration of selected pollutants in indoor environments of interest. However, because limited routine monitoring of IAQ is in place, and only a small number of research and epidemiological studies have focused on this issue, it remains challenging to assess the scale of indoor air pollution impacts.

Assessment of the burden of disease from exposure to indoor air pollution

A relatively small number of studies have been conducted worldwide on the health burden of disease (BOD) attributable to indoor air pollution. Burden of disease may be reported using disability-adjusted life years (DALYs), which calculate the number of years lost to ill health, disability or death in a population.

Most existing studies of the health burden of air pollutants focus on the impacts of single pollutant exposures. However, in practice, people are exposed to multiple pollutants simultaneously and the combined effects are not fully understood. Multi-pollutant exposure is an emerging area of research that has implications for epidemiological studies on air pollutants. For example, PM_{2.5} and nitrogen dioxide (NO₂) often occur together, and it is challenging to separate their impacts (Z. Y. Chen et al., 2024; Mainka & Žak, 2022).

The chronic harm caused by indoor air pollution was assessed to account for 7% of the total global burden of diseases in residential settings (Morantes et al., 2023). This study accounted for multi-pollutant exposures by assuming all harm is additive, while acknowledging this approach may under or overestimate in some circumstances.

The Global Burden of Disease study (GBD) 2021 assessed the burden of disease of 88 risk factors from 1990 to 2021 in 204 countries and territories (Brauer et al., 2024). This included residential indoor air pollutants (radon and PM_{2.5} arising from solid fuel combustion inside a house), and occupational exposure pollutants (formaldehyde and benzene). However, the range of settings assessed by the GBD is fairly limited (with the focus primarily on residential environments) so the estimated IAQ health impacts are thus likely underestimated. The GBD estimates that indoor air pollution from burning solid fuels causes approximately 3.1 million premature deaths annually worldwide and contributes to respiratory diseases, cardiovascular conditions, and cancer, with the greatest health burden falling on people in low-income and middle-income countries who use solid fuels for cooking (Bennitt et al., 2025).

A recent study conducted on the annual exposure levels of specific indoor air pollutants in residences in China found that DALYs attributable to indoor air pollution accounted for 14.1% of China's total DALYs and ranked third among all risk factors, after tobacco and high blood pressure (Liu et al., 2023). The ranking of 10 specific indoor air pollutants in China in 2017 from highest to lowest impacts were: PM_{2.5} (88.5% of the total DALYs attributable to indoor air pollutants), CO, radon, benzene, NO₂, O₃, SO₂, formaldehyde, toluene, and *p*-dichlorobenzene. While the ranking of pollutants varies between Chinese provinces and between China, the US, France, Italy and Germany, the pollutant with the biggest impact for all countries is PM_{2.5}. Its impact in terms of burden of disease far exceeds the impacts of all other pollutants.

The HealthVent study was conducted for 26 European countries (Asikainen et al., 2016), and included indoor residential PM_{2.5}, CO, and indoor dampness. The study estimated that an annual loss of 2.1 million DALYs was associated with indoor and outdoor pollutants in 2010, with 1.28 million caused by exposures to outdoor air pollution indoors and 0.74 million caused by indoor-source pollutants. The study also found considerable variation between countries.

A WHO project on the environmental burden of disease in Europe for six countries (Hänninen et al., 2014) included assessment of the impact of benzene, dioxins, second-hand smoke, formaldehyde, lead, O₃, PM_{2.5} and radon. The study found that PM_{2.5} annually accounted for 4,500–10,000 DALYs per million people in the six participating countries.

The chronic health effects of 69 indoor air pollutants in US residences were estimated by Logue et al. (2012), assessing DALYs in the US at 400–1,100 per 100,000 people. The study used toxicological data from animal testing to estimate the attributable burden of most indoor air pollutants.



None of the studies analysed the impact of the presence of airborne viruses and bacteria emitted by occupants of buildings. Every year, acute respiratory illnesses, such as colds and influenza, cause an estimated 18 billion upper airway infections and 340 million lower respiratory infections (Troeger et al., 2017). Respiratory infectious diseases are spread mainly by airborne transmission, which is the inhalation from the air of virus- or bacteria-laden particles generated during breathing, speaking and all other human respiratory activities (Greenhalgh et al., 2021; Morawska, 2006; Morawska, Johnson, et al., 2009; Morawska & Milton, 2020).

Across 2023 to 2025, COVID-19 has been the leading cause of acute respiratory infection mortality in Australia (Australian Bureau of Statistics, 2025). In the year to June 2025, there were 1,230 deaths involving COVID-19 and 440 deaths involving influenza (Australian Bureau of Statistics, 2025)). In 2024, 43,950 DALYs were attributable to COVID-19 (0.8% of the total burden), and 46,968 DALYs were attributable to lower respiratory infections in Australia, including influenza and pneumonia (0.8%) (Australian Institute of Health and Welfare, 2024a).

Economic impacts of indoor air pollution

Indoor air pollution increases healthcare costs, workplace and educational absences, and productivity losses.

Studies show that there is a significant economic burden associated with indoor air pollution. The cost of exposure to indoor air pollution in residential buildings alone in China – and not including indoor airborne infection transmission – was calculated as equivalent to approximately US\$411 billion, representing 3.45% of the country's gross domestic product (GDP) (Liu et al., 2023). In France, indoor air pollution associated with six pollutants had an estimated annual cost of €20 billion in 2004, representing 1% of GDP (Boulanger et al., 2017).

Airborne transmission of diseases has socio-economic impacts, including workplaces and educational absences and reduced productivity at work (University of Wollongong, 2024). Globally, acute respiratory illnesses, such as colds and influenza alone, result in more than 2.7 million deaths and economic losses of billions of dollars a year (Troeger et al., 2017). A recent Australian study estimated the number of people who developed long COVID from SARS-CoV-2 infections during 2022–2023 based on survey data, and the associated economic costs. Based on the projected decline in labour supply and reduced use of other production factors (e.g. infrastructure and machinery), the study estimated that mean GDP loss was \$9.6 billion (0.5% of GDP) (Costantino et al., 2024).

Recent reports have also highlighted the potential economic benefits of improving IAQ. In Australia, based solely on the prevention of COVID-19 and subsequent long COVID cases, preliminary economic analysis suggests improving IAQ could deliver a benefit–cost ratio of 1.5–3.1 per year (The Safer Air Project, 2024). This indicates that benefits are likely to outweigh the costs for improving IAQ in public spaces.

In New Zealand, total benefits from reduced sickness in offices and productivity gains from improved IAQ are estimated to be between NZ\$776 million and NZ\$1.15 billion over 10 years (Facilities Management Association of New Zealand, 2024). Similarly, a 2022 social cost–benefit analysis estimated the total benefits of implementing improved ventilation for infection resilience in all buildings requiring improvements in the UK is around £3 billion per year or £174 billion over a 60-year period (Royal Academy of Engineering, 2022).

Indoor air and health in Australia

There are very few assessments of the impact of indoor air pollution in Australia. An estimated 728 deaths were due to wood heating PM_{2.5} in 2015 (Borchers-Arriagada et al., 2024) and 2.8% of annual deaths in Australia were attributable to air pollution in 2018 (based on PM_{2.5} levels) (Australian Institute of Health and Welfare, 2024a).

A 2024 report from the National Science and Technology Council – prompted by the challenges of the COVID-19 pandemic – reviewed the impact of IAQ on the transmission of airborne viral diseases in indoor public environments and presented strategies to reduce this transmission (University of Wollongong, 2024). The Australian Institute of Health and Welfare introduced a framework for environmental health indicators in 2024 (Australian Institute of Health and Welfare, 2024b). However, in general, Australia lacks a comprehensive assessment of the health and economic burden associated with multiple dimensions of IAQ, including infectious respiratory illness. Applying global averages or country-specific estimates from elsewhere to Australia is challenging given regional differences such as in the prevalence of cigarette smoking and the use of fossil fuels for home heating and cooking. Similarly, radon is a pollutant with generally lower exposure in Australia than in some other countries (ARPANSA, 2024).

Summary

Indoor air pollution has significant impacts on health and wellbeing. The scientific body of evidence reveals that indoor air pollution generates a high burden of disease both nationally and globally, and contributes to substantial economic losses. The number of studies investigating the burden of disease remains limited, and studies do not include all types of indoor spaces and rarely assess airborne infection transmission.

Comprehensive assessments have not been conducted in Australia, and IAQ is not yet a national decision-making priority. Despite the profound impacts of indoor air pollution, there has been insufficient global action on IAQ.

Health-based guidelines for IAQ

The most foundational guidelines and the only ones we focus on here are the WHO health-based guidelines, which are exclusively based on exposure–response relationships found in epidemiological, toxicological and environment-related studies conducted around the world.

The *WHO global air quality guidelines* (WHO AQG) published in 2021 provide recommendations for concentration levels of six pollutants and their averaging times (PM_{2.5}, PM₁₀, NO₂, SO₂, CO and O₃) and apply to both outdoor air and indoor air (WHO, 2021). See Supplement, Table 1 for a table summarising the guideline values. The WHO has also published *Guidelines for indoor air quality: selected pollutants* (WHO, 2010), which includes recommendations for: benzene, CO, formaldehyde, naphthalene, NO₂, polycyclic aromatic hydrocarbons, radon, trichloroethylene and tetrachloroethylene. WHO has not published health guidelines on CO₂. Concentration of CO₂ is commonly used as a proxy for ventilation. It is also used as a proxy for infection transmission, particularly in conjunction with infection risk models, for example the WHO airborne risk indoor assessment tool and CO₂ fitting algorithm (Aleixo et al., 2024; WHO, 2024b).

There are also two WHO guideline documents addressing impacts of specific pollutants on IAQ, which are *Dampness and mould* (WHO, 2009) and *Household fuel combustion* (WHO, 2014). They do not provide specific exposure limits, but rather guidance on:

- minimising exposure by prevention (or minimisation) of persistent dampness and microbial growth on interior surfaces and in building structures
- reducing emissions of pollutants as much as possible
- the importance of adequate ventilation
- information supporting households to ensure best use of technologies and fuels.

Summary

The WHO health-based guidelines were developed based on exposure-response relationships found in epidemiological, toxicological and environment-related studies conducted around the world. They are not mandated as the WHO does not have regulatory power over countries, and they do not prescribe measurement methods. However, they are considered the basis for national IAQ standards, meaning that individual countries do not have to repeat the rigorous WHO process to establish health-based guidelines but can base their regulations on the WHO AQG.

Regulatory and best-practice approaches for indoor air quality: Challenges in application and implementation

Globally, there is inconsistency in the scope and application of guidelines and standards for IAQ. Even the definitions of these terms vary. Analyses of current guidelines and standards for IAQ show diversity and variability between and within countries in terms of the purpose, objective and intended users of these documents; the rationale for the approaches taken in developing them; the number of pollutants covered; and the threshold guideline values assigned to the same parameter (Dimitroulopoulou et al., 2023; Morawska & Huang, 2022; Toyinbo et al., 2022).

Standards

Standards are criteria for IAQ set by industry organisations, standards authorities, and governments, and may be voluntary or enforceable. Guidelines – particularly the health-based WHO AQG – inform standards, but standards also account for additional factors such as social acceptability, economic efficiency, and the unique environments of specific locations or contexts. For example, building standards must meet multiple needs, ensuring both the safety of occupants and affordability of housing.

Voluntary standards set expectations in an industry or jurisdiction for IAQ but are not accompanied by enforcement or monitoring mechanisms.

Enforceable performance standards are compulsory, prescribe mandatory monitoring, and have consequences if not met through government regulation or industry governance. For outdoor air, legislation is based on prescribed performance standards that require meeting the concentration levels of pollutants monitored in real time. In contrast, IAQ is largely unregulated and unmonitored.

Standards may begin as voluntary but become enforceable when adopted into regulatory codes. For example, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 241, *Control of infectious aerosols*, addresses airborne disease transmission and was written to be code adoptable so that it can be integrated into legislation. The standard is designed to manage the spread of airborne pathogens during periods of elevated risk. It defines an 'equivalent clean airflow rate' considering space type, occupant density and occupant activities. The equivalent clean airflow rate is 'the flow rate of pathogen-free airflow into occupied areas of a building that would have the same effect as the total of outdoor air, filtration of IA [indoor air] and air disinfection by technologies' (ASHRAE, 2023). ASHRAE standard 241 offers an integrated approach where building operators can achieve equivalent clean airflow through optimal combinations of outdoor air ventilation, filtration, air cleaning technologies and occupancy levels, balancing IAQ objectives with energy efficiency, operational costs, and other building performance standards.

National building design standards prescribe ventilation parameters, and emissions from certain building materials in certain countries are regulated. Design factors include, for example, air exchange rate, filter specifications, or window size. Each factor is related to IAQ, but no single factor is solely responsible for it; therefore, without measuring the performance of the building management system, IAQ is unknown.

In many countries, IAQ is managed with national regulation specifying minimum ventilation requirements for different indoor space categories (Carrer et al., 2015), however, these are typically design (not performance) standards, which means ventilation rates are not monitored in real time in relation to number of occupants in the space.

Some countries, including South Korea and Taiwan, have written IAQ standards into law, which are monitored through periodic (but not real-time) assessments (H. L. Chen et al., 2024). In Europe, measuring and control devices for the monitoring and regulation of IAQ in non-residential buildings are required in the latest energy performance of buildings directive (The European Parliament & The Council of the European Union, 2024). This requirement must be implemented by EU Member States and is expected to lead to real-time monitoring of CO₂ as a proxy of ventilation.

However, most countries do not yet have enforceable IAQ performance standards (Morawska and Huang 2022).

Certification schemes

Certification schemes are programs that assess a building against a set of requirements to determine a rating or certification indicating IAQ.

Voluntary programs for the building industry, such as the WELL Building Standard provided by the International WELL Building Institute, include upper limits for certain indoor air pollutants (International WELL Building Institute, 2024). Other schemes include LEED (US Green Building Council), CASBEE (Japan Sustainable Building Consortium and Institute for Building Environment and Energy Conservation) and BREEAM (Building Research Establishment, UK).

Australia's National Australian Built Environment Rating System (NABERS) incorporates IAQ as an element of its indoor environment rating. IAQ only has a limited impact on the overall NABERS indoor environment rating, which also includes performance assessment of thermal comfort, lighting and noise, and an occupant satisfaction survey (NABERS, 2024). The Green Building Council of Australia also adopts a similar approach for its Green Star performance rating. Although voluntary, the prevalence of adoption of these certifications within the Australian commercial building market makes them pivotal when demonstrating accepted best industry practice that exceeds the baseline established by regulation.

The successful implementation of the mandatory Commercial Building Disclosure for energy efficiency, and the recognition of the Australian commercial building market as an early adopter of the International WELL Building Standard suggests a readiness to consider IAQ disclosure.

Challenges in application and implementation of regulatory and voluntary approaches to control IAQ

Multiple factors contribute to the legislative complexity in regulating IAQ.

First, in most countries, there is no single national government body responsible for IAQ. Environmental and health legislation is often left to the discretion of individual states or provinces, not the national government. In individual jurisdictions, there are no bodies directly responsible for IAQ, and responsibilities are spread between different organisations. For example, the education department is responsible for the indoor environment of schools, and the health department governs the indoor environment in care facilities. Similarly, different departments are responsible for hospitality venues, office buildings, and retail. Workplace health and safety regulators would also have a role in many of these environments. Occupational and residential environments are also generally treated differently. This means that IAQ is basically a regulatory 'no man's land', with no government body responsible for it (Corsi, 2000; Morawska, 2000).

The second challenge is that emissions from humans cannot be controlled in the same way we control emissions from other sources – which is by preventing or minimising the emissions from the source. Requiring people to wear masks in shared indoor spaces may not be socially acceptable in Australia as a long-term intervention. Ventilation can be used to control the concentration of particles from an infectious source by continually replacing polluted air with less polluted air (for example, outdoor air or filtered recirculated air). This is in addition to other public health interventions which may also be used to reduce the number of people in shared indoor spaces who are infectious sources including vaccination, testing and isolation, and occupancy limits. An in-depth discussion of these interventions is out of the scope of this paper.

Third, many buildings are not designed with an objective of securing good IAQ and most are not fitted with advanced building management systems able to manage IAQ in a flexible and responsive manner. Advanced building management systems can be designed respond to outdoor- and indoor-generated air pollution, to prevent ingress of pollutants from outside, or to efficiently remove those generated inside. Engineering technologies could be more widely deployed to help stay within parameters – adjusting to situations, occupancy levels, and outdoor meteorology and air quality. However, due to their current cost, these kinds of advanced building management systems will not be feasible in all kinds of buildings.

Times of crisis, such as pandemics or wildfires, expose the limitations of indoor environments to protect occupants. Many buildings fail to protect occupants from bushfire smoke (Borchers Arriagada et al., 2020; Brambilla et al., 2021) or from infection spread through indoor air (Hyde et al., 2021). There is an inequity between those who have access to good IAQ in adequately designed and maintained buildings and those who do not. The limitations of building management systems mean that operational practices are also critical for IAQ.

Finally, measures to reduce the carbon footprint of buildings may worsen IAQ – if IAQ is not factored into a building's design. For example, making building structures more airtight to improve energy efficiency can result in decreased ventilation rates, which in turn may result in worse IAQ. Addressing climate change and IAQ are both important to human health and wellbeing, and both should be accounted for in building regulations. The technologies and operational practices to address both exist; however, their implementation may increase the cost of constructing and managing a building.

Summary

While there is inconsistency globally in the use of guidelines and standards for IAQ, there are three well-defined regulatory and best-practice approaches, including:

- enforceable performance standards that are mandatory and prescribe mandatory monitoring
- voluntary standards
- certification schemes.

However, there are a number of factors contributing to legislative complexity in IAQ regulation, which must be considered and addressed pragmatically to make progress and ensure clean indoor air for communities in Australia and around the world.

Monitoring of indoor air quality: Challenges and proposed solutions

The ability to monitor an IAQ parameter is a key prerequisite to regulation via a performance standard. If technologies do not exist for routine monitoring of a parameter, a performance standard cannot be mandated for that parameter. An essential part of an IAQ regulatory framework is use of monitoring data to assess compliance with standards, and provide evidence that the regulation is achieving its objective.

Challenges

Outdoor versus indoor air monitoring

There is a fundamental difference between the approaches to indoor and outdoor air quality monitoring and data utilisation. Outdoor air pollution is monitored by a network of monitoring stations, usually operated by the government. For example, in Australia there are 211 monitoring stations (Emmerson & Keywood, 2021). While station locations are carefully chosen to provide data representative of the area in which they operate, this relatively small number of stations cannot provide air quality information at the individual building- or street-level scale. However, there are advanced modelling techniques that allow pollution assessment at a fine scale, using monitoring station and meteorological data.

Unfortunately, this approach cannot be applied to monitoring of IAQ, as indoor environments and their use differ greatly – not only between buildings, but also between individual spaces within buildings. Monitoring to provide information on compliance with IAQ standards must be undertaken in every space of the building. This means that the scale of monitoring will be a few orders of magnitude larger than outdoor monitoring. For example, there are more than 90,000 primary school classrooms in Australia.* Ideally, each of these spaces, together with other spaces in the school, should be monitored to demonstrate compliance with IAQ standards.

Monitoring technologies for IAQ

The challenge is not only the total number of the monitoring locations, but also the monitoring technology used to monitor WHO AQG's six pollutants. Current monitoring technology for regulatory compliance is optimised for monitoring these pollutants in outdoor spaces, meaning it is too big and too costly to simply deploy indoors.

However, this does not preclude monitoring in indoor spaces. For example, smoke alarms are already mandated in multiple spaces in all buildings, and temperature sensors can also be readily installed in each space of a building if desired.

The feasibility of monitoring IAQ parameters in buildings depends on the size, cost, and robustness and reliability of the monitor, as well as the ease of interpreting its readings and its maintenance and calibration over time. Indoor instruments must be smaller, lower cost and less complicated than instruments for outdoor regulatory monitoring to be viable at scale.

* The number of classrooms is an estimate based on the number of students enrolled in all primary schools divided by the average primary school class size in Australia in 2023 (ACARA, 2025; OECD, 2025).

Mature low-cost sensor technologies already exist for some pollutants, for example CO₂, PM_{2.5} and CO. They can be an effective quantitative monitoring tool if calibrated against lab-grade instruments, correctly located and installed in a building, and appropriately maintained. When accompanied by strict criteria for accuracy and sensitivity over time, such sensors can be part of robust monitoring protocols for IAQ.

As an example, a framework to use PM_{2.5} low-cost sensors for compliance monitoring of indoor air has been recently proposed by Morawska et al. (2025).

Low-cost PM_{2.5} sensors typically operate by optical detection of light scattered by particles. In contrast, traditional compliance monitors for PM_{2.5} use gravimetric testing – where particulate matter is collected on a filter and is weighed with very accurate tools. While gravimetric testing is more accurate to determine particle mass concentration, its cost and complexity mean it is less feasible for implementation of widespread monitoring of indoor air.

Low-cost PM_{2.5} sensors connected in a computer network can be used for compliance monitoring in indoor air. Morawska et al. (2025) describe the following requisite monitoring infrastructure:

- nomination of a reference sensor to act as the 'ground truth' for the other sensors in the computer network
- one sensor on the exterior to provide a reference for the local environment
- using low-cost sensors from of the same model, and ideally from the same batch
- connecting all sensors to the building management system.

With that base infrastructure in place, a calibration framework can be applied including:

- regular comparisons between the sensors in the network at times when they would be expected to read similar concentrations – for example, when the building is unoccupied
- collocation of the reference sensor and external sensor with reference instruments once a year (at minimum), either by taking them to the nearest ambient air quality monitoring station or by bringing reference instrumentation to the building.



Based on these calibration activities, correction factors can be established. These are numbers that can be used in calculations applied to the sensor readings to correct the readings to account for different optical properties of particles emitted from different sources in different environments. Morawska et al. (2025) recommends correction factors should be openly shared in a database alongside metadata like building type and occupancy levels. This database could be hosted by the relevant regulatory authority for use by the wider community where custom correction factors cannot be established.

We have sufficient knowledge and technology to begin rolling out implementation of IAQ monitoring now.

Ideally, IAQ monitoring data will be integrated with HVAC control systems to support automated responses based on real-time occupancy and IAQ levels. More advanced monitors incorporating low-cost sensors which connect with building management systems may be more expensive, while monitors manually read by a person may be less expensive.

Prices may refer to the cost of the sensor itself, or the full cost of a monitor device. The cost of the sensor will vary depending on the kind of sensing technology used. The cost of a monitor device will vary depending on the cost of the sensor, as well as whether it provides a simple value display, stores the data to be downloaded, transmits its readings by wi-fi or other means, and other features. For example, IKEA sells a PM_{2.5} monitor that costs A\$20 with a light indicating 'good', 'okay' and 'not good' through different colours. In contrast, PurpleAir's indoor air quality monitor costs approximately A\$320. It provides a more advanced colour scale and can connect to wi-fi to view real-time data.

Indoor pathogen monitoring

Currently, it is not technologically feasible to routinely monitor indoor pathogens in real time. Grab sampling measurements – where a single sample at a specific time and location is used to obtain a snapshot of a substance – are also complex and require subsequent laboratory analysis. While we can measure CO₂ emissions from humans respiring, we cannot easily measure, assess or meaningfully model human emissions of pathogens, nor their characteristics. For some pathogens like influenza, we understand the quanta of infectious matter emitted by infected people through laboratory-based testing. We do not have such information for new and emerging pathogens. It is also challenging to translate these quanta into a transmission risk as this depends on the environment, pathogen dose and distribution, and host susceptibility. Therefore, a different approach to routine indoor air monitoring must be developed, if a standard targeting indoor airborne infection risk is to be pursued.

Research is underway to explore the possibility of developing indoor air biosensors. For example, it is one of the objectives of the US Advanced Research Projects Agency for Health (ARPA-H) Building Resilient Environments for Air and Total HEalth (BREATHE) program (ARPA-H, 2024). However, this research is at a very early stage with no products viable for implementation at scale.

Proposed solutions

Currently, measuring all potential pollutants in a space – or even the pollutants recommended by WHO AQG 2010 and 2021 – is not technically or financially feasible; it may also be unnecessary. Routine real-time monitoring of specific pathogens is also not possible.

To address these challenges and to provide monitoring solutions and an initial pathway for feasible implementation of IAQ performance standards, a scientific consensus paper was published recommending real-time monitoring of four parameters: three pollutants (PM_{2.5}, CO, and CO₂ as a proxy for ventilation and infection transmission) and the ventilation rate in mechanically ventilated buildings (Morawska et al., 2024). These parameters were selected based on well-established scientific principles and available low-cost sensor technology. They offer policymakers a basis for establishing and monitoring compliance with IAQ standards. These could be expanded in the future as monitoring technologies advance.

See Supplement, Table 2 for a table of the parameter levels proposed in the paper.

In brief, the rationale for selecting these four parameters is as follows:

- **PM_{2.5} and CO.** Both pollutants have well-established health impacts and are identified as pollutants in the WHO AQG (WHO, 2021). Stable and robust low-cost sensors are available to measure concentrations of CO and PM_{2.5} (Morawska et al., 2024; Salthammer, 2024). While CO is naturally present in the atmosphere at very low concentrations, incomplete combustion indoors and outdoors can lead to harmful levels (Salthammer, 2024). Although rare in Australia, CO can cause serious or fatal poisoning. At lower levels, CO also has health impacts. Measuring PM_{2.5} together with CO provides a general indication of pollution sources when compared with outdoor air measurements (e.g. traffic combustion versus dust resuspension). It may be necessary to measure both indoor and outdoor PM_{2.5} to understand where and what the source is, to inform mitigation responses.
- **CO₂ levels** are proposed to be used as a proxy of ventilation adequacy in occupied space and as a proxy for infection transmission (Morawska et al., 2024; Wargocki, 2021). The accumulation of CO₂, which people exhale, signals inadequate ventilation with outdoor air. CO₂ levels can be monitored against a standardised level using readily available sensors. As a sole strategy, CO₂ minimisation will not eliminate spread of airborne infection, however scientists have demonstrated it has significant potential to reduce it (Morawska et al., 2024). Further, while a high CO₂ concentration indicates a potential risk, a lower CO₂ concentration does not indicate that there are no risks. It is also essential to consider the quality of the supply air, any air cleaning used, the density of people in the room, and occupants' vulnerability to indoor air pollution and activities (Morawska et al., 2024). CO₂ levels are not affected by air cleaning and disinfection methods so high CO₂ levels where cleaned recirculated air is used may not be indicative of infection risk. For example, the air in an aeroplane may be high in CO₂ but relatively safe in terms of airborne disease transmission risk because of the filtering used.
- **Ventilation rate in mechanically ventilated spaces.** The term 'ventilation rate' describes the volume of air supplied to a space over time. It may also be represented as a volume of air per second per person, meaning that if there are more people in a space, the required ventilation rate may need to be higher. When the outdoor air that is being used to ventilate a space does not pose a risk to the occupants, controlling the ventilation rate is an important method for improving IAQ (Wargocki, 2021).

Emerging opportunities

There are emerging opportunities to use smart building management systems to optimise IAQ. Data-driven automated control systems, informed by continuous monitoring of key IAQ parameters, could dynamically adjust ventilation to reduce indoor air pollution while also meeting the other requirements like energy efficiency and thermal comfort (Ogundiran et al., 2024). Recent research suggests there is potential to develop and implement AI and machine learning tools to improve IAQ prediction and management in buildings (Lató et al., 2025).

Summary

Real-time monitoring of four parameters offers a basis for developing IAQ performance standards. The parameters are:

- PM_{2.5}
- CO
- CO₂
- ventilation rate in mechanically ventilated spaces.

The four proposed parameters for monitoring IAQ are a starting point for what is possible now, rather than reflecting the only pollutants that should be mitigated. This list could be expanded or amended in the future as new approaches are developed. For example, the WHO AQG highlights a wider range of key pollutants of concern and associated guideline values, but they are not yet feasible for large-scale IAQ monitoring programs.

Current mechanisms and future pathways to manage indoor air quality in Australia

There are significant gaps in how IAQ is managed in Australia, including:

- very limited knowledge about IAQ across public and residential buildings in Australia
- available published research identifying IAQ issues in a sizeable fraction of indoor environments investigated (Miller & Morawska, 2025)
- absence of enforceable performance standards with continuous monitoring for IAQ in public indoor spaces and workplaces, as well as accompanying standards for reporting
- no agreed approach on how to establish continuous IAQ monitoring infrastructure.

As outlined in the sections above, these gaps present risks to public health and safety. They also present challenges for controlling frequent respiratory infections and pandemic preparedness.

Public policy interventions have a critical role in enhancing IAQ. Below we outline current approaches and challenges, and a proposed pathway for improving IAQ in Australia.

How is IAQ currently managed in Australia?

Responsibility and regulatory levers to manage IAQ are distributed across federal, state and territory, and local governments.

At the national level, policy relating to IAQ spans several portfolios, including environment, health, ageing, workplace relations, energy, industry, science, infrastructure, transport, planning, housing, finance, treasury, and education. Research and evidence from Australia's universities, medical research institutes, publicly funded research agencies, research councils, and advisory bodies – including the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the National Health and Medical Research Council (NHMRC), the ARC, and the Office of the Chief Scientist – support activities across these portfolios and are the source of limited information about IAQ in Australia.^{xi}

This dispersion of responsibility and authority is a challenge in managing IAQ at state and federal levels.

Existing national policy mechanisms

A range of policies, agreements, international commitments and legislation relate to IAQ at the national level, including the following:

- **Design standards** in the *National construction code* – which refers to Australian Standards – and accompanying guidance through the *Indoor air quality verification methods handbook* (Australian Building Codes Board, 2022, 2023). The *National construction code* is mandated through regulations at the state and territory level. It largely only applies at the design phase and not during building operation.

^{xi} Though a source of information on IAQ, the evidence and outputs of the various research projects and activities are not collated into a national repository to grow the body of evidence.

- **Australian Standards** are developed by Standards Australia, an independent non-governmental organisation. Standards are voluntary documents, however, when referred to in laws can become mandatory. For example, AS 1668.2 *The use of ventilation and airconditioning in buildings – part 2: mechanical ventilation in buildings* is required under the *National construction code*. The non-mandatory *Indoor air quality verification methods handbook* also refers to Australian Standards.
- **Restrictions on certain materials** focused on the construction supply chain and managing the presence and legacy of these materials in buildings (e.g. asbestos and silica).
- **NABERS indoor environment rating** (Miller & Morawska, 2025; NABERS, 2024). This rating is assessed based on the building's performance during operation.
- **Workplace health and safety obligations** under the *Work Health and Safety Act 2011* (WHS Act), with guidance from Safe Work Australia on *Workplace exposure standards for airborne contaminants* and COVID-19 information for workplaces (Safe Work Australia, 2024c, 2024a). While work health and safety is primarily regulated at the state and territory level, Safe Work Australia supports national harmonisation through model regulation and codes of practice.
- **Health and aged care infection prevention and control guidelines** published by the Australian Commission on Safety and Quality in Health Care.
- **Consumer rights regarding safety**, for example, the *Australian charter of healthcare rights*, which articulates the right of patients to 'be cared for in an environment that is safe and makes me feel safe'.
- **Disability discrimination laws**, which make it unlawful to discriminate against Australians with a disability. The *Disability Discrimination Act 1992* requires areas and facilities open to the public to be safely accessible for people with a disability. IAQ can be an accessibility barrier for people living with chronic conditions that increase risks associated with poor IAQ.
- **Regulation of outdoor air quality** via the National Environment Protection (Ambient Air Quality) Measure (National Environment Protection Council, 2022a).
- **Coordination on air quality** through the National Clean Air Agreement (Department of Climate Change Energy the Environment and Water, 2024b).
- **International commitments** including the following:
 - Australia's support for the 2022 UN General Assembly resolution on the Right to a clean, healthy and sustainable environment, which includes the right to clean air (UN General Assembly, 2022).
 - The *WHO pandemic agreement* adopted by the World Health Assembly in May 2025. It will establish a legally binding framework for global cooperation on pandemic prevention and response. Australia served as vice-chair of the Intergovernmental Negotiating Body for the Pandemic Agreement. While the agreement has been adopted, there are further steps to finalise its details and bring it into force.
 - The *Convention concerning prevention and protection against biological hazards in the working environment* adopted by the International Labour Organization in June 2025. Australia is a founding member of the International Labour Organization.
- **Knowledge generation**, such as funding for IAQ science and research initiatives at the federal and state level (e.g. the ARC Training Centre for Advanced Building Systems Against Airborne Infection Transmission (THRIVE) and the Pathway to Clean Indoor Air in Victoria project).

- **Commissioning advice on IAQ**, including the National Science and Technology Council report and advice, *The impact of IAQ on the transmission of airborne viral diseases in public buildings* (University of Wollongong, 2024).
- **National reporting frameworks**, including the *State of the environment* reports, the *Measuring what matters* wellbeing framework and the Australian Institute of Health and Welfare *Climate change and environmental health indicators: reporting framework* (Australian Bureau of Statistics, 2024; Australian Institute of Health and Welfare, 2024b; Emmerson & Keywood, 2021).

State and territory approaches to IAQ

State and territory governments also contribute to IAQ management through various mechanisms, including the following:

- **Adoption, implementation and enforcement of construction codes.** Each state and territory is responsible for building regulation.
- **Ambient air quality management.** State-based environmental protection agencies manage ambient air quality, which impacts indoor air environments, particularly in urban settings (Department of Climate Change Energy the Environment and Water, 2024a).
- **Residential tenancy regulations and public health legislation related to mould.** For example, Victoria's *Residential Tenancies Act 1997* requires adequate ventilation and structural mould-free conditions in rentals, while the *Public Health and Wellbeing Act 2008* enables councils to address severe mould infestations as public health nuisances.
- **Tobacco control measures.** Bans on tobacco smoking and vaping, implemented at various jurisdictional levels, help reduce indoor air pollution, particularly in public and enclosed spaces (Department of Health Disability and Ageing, 2025).
- **Combustion heating and cooking regulations.** Some jurisdictions have announced targeted policies addressing wood and fossil fuel heating and cooking. These proposed policies include restrictions such as phasing-out wood heater installations or mandating new residential and commercial buildings be built all-electric from a set date (Chief Minister Treasury and Economic Development Directorate, 2023; Department of Energy Environment and Climate Action, 2025).
- **COVID-19 ventilation guidance.** The Victorian Government first published ventilation guidance to stop the spread of COVID-19 and a ventilation and air purification policy for schools in 2021 (Department of Health, 2022; Victorian School Building Authority, 2024). Similar guidelines have been developed by other state and territory health departments, not only in relation to COVID-19, but also generally regarding the control of infectious pollutants in buildings (Government of Western Australia Department of Health, 2023).
- **State- and territory-level initiatives.** Projects like the Victorian Government's Pathway to Clean Indoor Air in Victoria reflect significant and proactive investment to enhance air quality in a range of settings, including schools, public spaces and other workplaces (Victoria State Government, 2024).

Policy pathways to improve IAQ in Australia

Australia has several policy pathways to improve IAQ. The options explored here focus on mechanisms available to the Australian Government to improve IAQ in public buildings that can be pursued concurrently.

Fostering national leadership and coordination

The Australian Government could elevate IAQ as a national health and infrastructure priority by appointing a minister specifically to champion and coordinate IAQ policy reform. This could also include integrating IAQ into national environmental health, climate resilience, workplace health and safety, and public health frameworks.

Establishing a multidisciplinary taskforce to support evidence-based decision-making

Expert scientific advice will be a critical input to all investments under a government framework for improving IAQ.

A multidisciplinary taskforce could be established to provide expert advice on the development and implementation of IAQ policy in Australia. Such a taskforce would support the other policy options explored below and could be overseen by an appointed minister.

A similar recommendation was made in the final report of the Inquiry into Long COVID and Repeated COVID Infections (Standing Committee on Health Aged Care and Sport, 2023). It recommended the Australian Government 'establish and fund a multidisciplinary advisory body' to '[o]versee an assessment of the impact of poor indoor air quality and ventilation on the economy' and '[l]ead the development of national indoor air quality standards for use in Australia' (Standing Committee on Health Aged Care and Sport, 2023).

Building the evidence base to underpin decisions

A strong evidence base is critical for prioritising investment, regulation, and public health action.

Opportunities to strengthen this evidence base include:

- commissioning an updated economic analysis for IAQ in Australia
- establishing large-scale implementation and feasibility projects to evaluate and optimise IAQ interventions in real-world Australian settings – for example, a nationwide IAQ monitoring feasibility study in schools, modelled after similar projects in the UK and the US (SAMHE 2024; Boston Public Schools, 2023)
- funding applied IAQ research and implementation science, including intervention effectiveness, monitoring technologies, system optimisation, and long-term health and economic impact modelling.

Adopting and applying health-based guidelines

The WHO AQG should be endorsed as Australian guidelines with additional clauses (if any) specifically relevant to Australia. The WHO AQG apply to both indoor and ambient air. Existing mechanisms, including enHealth and the NHMRC, can be leveraged to formally endorse WHO health-based guidelines as Australian guidelines. If adopted, these benchmarks could inform building standards, public health interventions, workplace health and safety regulation, and risk communication.

The mechanisms include:

- enHealth, the Environmental Health Standing Committee, aids governments and public health authorities in developing and implementing policies that address environmental health issues – including the health aspects of IAQ – in the 2024–2027 work plan (Australian Government Department of Health and Aged Care, 2024).
- The *National Health and Medical Research Council Act 1992* empowers the NHMRC to provide guidelines that inform the development of health and safety standards and health policies by providing a scientific basis for decision-making in government and healthcare sectors (National Health and Medical Research Council, 2024). This could be harnessed to endorse health-based IAQ guidelines. The NHMRC has previously worked on this issue, setting IAQ goals in the 1990s.
- The new Australian Centre for Disease Control (CDC) is in its interim phase and consulting on its final legislation at the time of drafting. The draft legislation would establish the Australian Centre for Disease Control as an independent agency. Its director-general would have functions including advising the Australian Government and other bodies on public health matters and developing, publishing and promoting guidelines and standards. The explanatory memorandum notes that its ‘initial priorities will focus on communicable diseases, pandemic preparedness and existing capabilities in environmental health and occupational respiratory diseases’ (The Parliament of the Commonwealth of Australia, 2025).

Establishing IAQ performance standards and enforcing other relevant standards

To translate health guidance into real-world protection, Australia needs clear, enforceable IAQ requirements.

New enforceable performance standards could be developed based on health-based guidelines. Existing standards could also be updated to reflect current evidence and improve enforcement.

Building standards

The *National construction code* provides minimum requirements for building design and construction, but does not cover building commissioning or post-construction verification (Australian Building Codes Board, 2022, 2023). Introducing mandatory requirements for building commissioning and ongoing building performance monitoring – such as ongoing IAQ checks during operation – would help improve IAQ. Ideally, this would be accompanied by maintenance requirements that ensure buildings continue to meet IAQ standards.

Workplace standards

The way IAQ is addressed by work health and safety (WHS) obligations could be strengthened. Safe Work Australia develops model WHS laws including the model WHS Act, the model WHS regulations, and model WHS codes of practice (Safe Work Australia, n.d.). Safe Work Australia does not enforce these laws. The Australian Government, states and territories may separately implement them as their own laws.

Under the model WHS Act, an employer must ensure ‘so far as is reasonably practicable’ the health and safety of their workers and others at their workplace (Safe Work Australia, 2023). The WHS regulations set specific requirements for managing hazards, including airborne contaminants, which do extend to aspects of IAQ. The regulations define an airborne contaminant as ‘a contaminant in the form of a fume, mist, gas, vapour or dust, and includes microorganisms’ (Safe Work Australia, 2024b). Division 7 of the model WHS regulations covers ‘Managing risks from airborne contaminants’, including ensuring exposure standards are not exceeded as set out in the

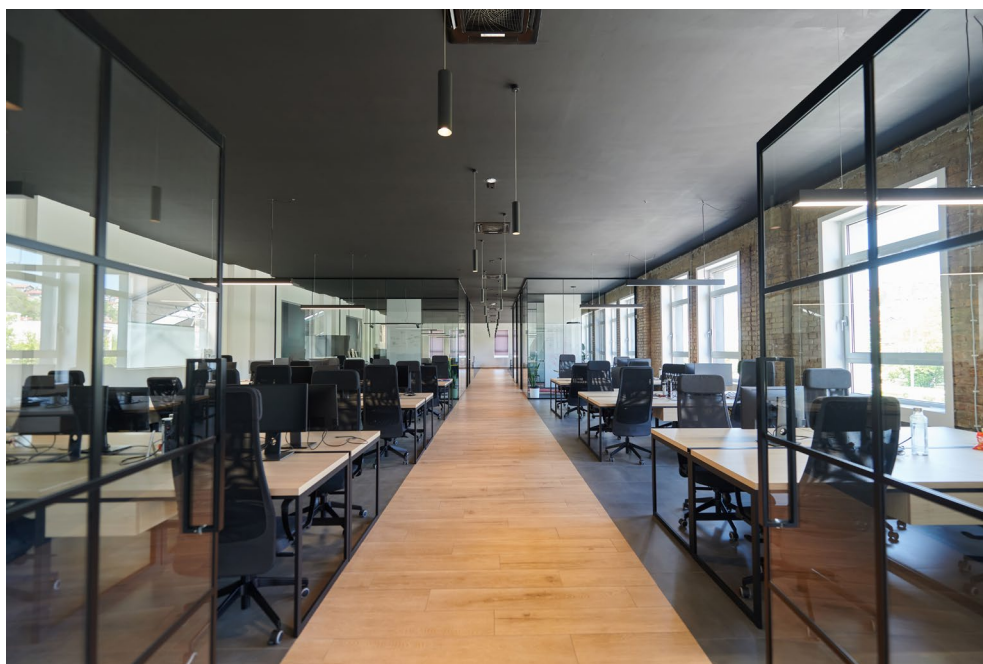
Workplace exposure standards for airborne contaminants (WES list)^{xii} (Safe Work Australia, 2019, 2024b). Some monitoring is conducted under certain conditions to ensure the workplace exposure standards are met.

While the workplace exposure standards set out requirements for airborne contaminants, in practice they are generally only relevant to settings like industrial workplaces that use or generate specific airborne hazards. They measure pollutant exposure over a day rather than continuous monitoring, and relate more to what personal protective equipment needs to be used in industrial settings. They don't meaningfully impact spaces like offices, schools, retail settings, and health and aged care. They also don't include pathogens, PM_{2.5} as a class, or appropriate CO₂ levels.

IAQ in all indoor workplace settings needs appropriate regulation. It could be more explicitly recognised as a WHS obligation for employers, accompanied by tailored guidance from Safe Work Australia.

Some of this work is underway through Safe Work Australia's development of codes of practice which provide practical advice on meeting the standards set out in the regulations (Safe Work Australia, n.d.). Safe Work Australia is developing a model code of practice on managing the risks of biological hazards at work, with a draft model published in July 2025 for consultation. Another relevant code is the new model code of practice for the healthcare and social assistance industry, which includes uplifting the attention given to IAQ in these settings. Safe Work Australia also provides guidance on the interpretation of workplace exposure standards for airborne contaminants and in 2021 provided guidance on improving ventilation in the context of COVID-19.

Under Australia's WHS regulation, a safe work environment must be provided. And in many workplaces, this cannot be assured when it comes to IAQ as key parameters are not measured.



^{xii} From December 2026, the *Workplace exposure limits for airborne contaminants* (WEL list) will replace the *Workplace exposure standards for airborne contaminants* (WES list).

A three-phase approach provides the most feasible path for governments to achieve clean indoor air in the workplace. The first phase would require monitoring in all workplaces. In this phase, no reporting requirements would be set. The second phase would involve a transition to a reporting standard, mandating specific parameters to be measured and reported. The final phase would be legislating IAQ standards for all public buildings. These legislated standards would require selected IAQ parameters to be monitored and controlled within designated safe levels.

The length of the phases may vary depending on the building class: buildings that already have advanced ventilation and air conditioning systems could advance to the third phase within a few years. On the other hand, naturally ventilated buildings, such as most schools in Australia, might require a longer period to reach the third phase.

The approach described would be a transitional pathway for existing buildings. New buildings would need to be designed and constructed to meet the standard, and this requirement could coincide with the end of the first phase for existing buildings: the knowledge generated from non-reporting monitoring would contribute to better design of new buildings.

A similar approach was taken in Australia in relation to ambient air monitoring. In 2003, the National Environment Protection (Ambient Air Quality) Measure in Australia was varied to include advisory reporting standards for PM_{2.5} (Commonwealth of Australia 2003). It then moved to compliance standards in 2016, when the country was deemed to have achieved readiness for compliance monitoring (Commonwealth of Australia 2016). The 13 years between these legislative instruments allowed jurisdictions to develop expertise in PM_{2.5} monitoring, and, in turn, an understanding of concentration levels, their trends, and the sources causing PM_{2.5} pollution at local and state levels. Therefore, at the start of compliance monitoring they were prepared to control PM_{2.5} concentrations at the required level. This example demonstrates that Australia is well prepared to take a phased approach to air quality control.

Such a measure could be achieved nationally with minimal cost compared to the consequences of not acting to improve IAQ. Some building management systems are already equipped to detect the concentration of pollutants of primary interest (in particular, CO₂, which is a proxy for ventilation and infection transmission).

The benefit case is clear, and Australia already has the scientific and technological know-how required.

Accessibility standards

IAQ could also be explicitly acknowledged as an accessibility issue, as recommended by The Safer Air Project which has observed that the 'lack of access to safe air spaces represents a potential breach of the *Disability Discrimination Act 1992*' (Safer Air Project, 2024). To address this, the Premises Standard under the Act could be updated to include IAQ as an accessibility feature.

Leveraging existing air quality mechanisms to address IAQ

A National Environment Protection Measure (NEPM), or similar measure, could be negotiated for IAQ with the states and territories. NEPMs, established under the *National Environment Protection Council Act 1994*, are regulatory instruments designed to manage and improve the environment by setting consistent national standards and goals for protecting air, water and soil quality (National Environment Protection Council, 2022b). The Act currently limits NEPMs to ambient air quality. NEPMs have been instrumental in establishing long-term monitoring systems for pollutants and addressing environmental issues.

The National Clean Air Agreement could be further leveraged to promote collaboration and coordinated action on IAQ across Australia. The most recent *National Clean Air Agreement work plan (2021–23)* addressed some IAQ-related issues including personal use of low-cost sensors and reducing pollution from wood heaters. The National Clean Air Agreement sets national standards, works with governments and industries to maintain consistency, and ensures guidelines are regularly updated and communicated to the public (Department of Climate Change Energy the Environment and Water, 2024b).

Incentivising industry improvements

Voluntary schemes can help accelerate improvements in commercial and public buildings. Australia's NABERS indoor environment rating could be updated and expanded to place greater emphasis on IAQ, or a new IAQ-specific rating could be developed to complement the existing tool (NABERS, 2024).

The quality and safety of IAQ products could be enhanced by establishing clear product safety and performance standards for IAQ technologies (e.g. filters, sensors, disinfection systems) and introducing a national certification or labelling scheme.

Enhancing public awareness and engagement

Education will be vital to ensure that other measures are effectively adopted by building owners, operators, and occupants.

A national public education campaign could promote clean indoor air, including the monitoring and displaying of IAQ data in public buildings.



Distinguished Professor Lidia Morawska FAA FTSE and colleagues at the THRIVE respiratory lab. Credit: Anthony Weate, QUT Media.

Engaging experts to inform decisions about Australia's management of IAQ

IAQ is a multidisciplinary challenge, requiring coordinated knowledge and expertise across science, engineering, architecture, medicine, environment, policy, law and economics. As such, Australia's management of IAQ will require input from a diverse array of experts, including but not limited to advice from:

- atmospheric aerosol and chemistry scientists on understanding how pollutants behave in indoor or enclosed spaces
- engineers on the design and maintenance of ventilation and filtration systems, as well as systems and sensors to control and measure indoor air pollutants
- architects on incorporating standards into building designs
- data and technology professionals on accurately capturing, monitoring and reporting IAQ in real time, and ensuring IT and building management system security and reliability
- epidemiologists on the role of IAQ in health and in the transmission of diseases
- environmental and medical microbiologists to advise on the role of monitoring for infection control and prevention, and dampness-associated mould and bacteria
- public health experts and health practitioners on the health impacts of poor IAQ
- lived experience representatives on ensuring policy delivers for those most affected
- environmental and climate change scientists on the state of ambient air quality and how it is changing
- infection prevention and control professionals
- occupational health and hygiene specialists, and facility managers on implementation of IAQ guidelines and monitoring in buildings and workplaces
- education experts on the cognition impacts in educational environments
- policy and law experts on developing, implementing and enforcing IAQ standards and regulations
- economists to advise on the economic costs and benefits of IAQ implementation and interventions, as well as opportunities for economic incentives
- social and behavioural scientists on occupant behaviour, effectiveness of awareness raising activities, and ensuring that people understand what and why changes are being made
- sustainability and energy efficiency experts on the long-term viability of IAQ management guidelines and regulations.

Summary

Policymakers in Australia have a wide range of mechanisms available to address IAQ. Evidence suggests that any current mechanisms in use to improve IAQ have been insufficient to ensure clean indoor air in Australia.

A more focused approach is necessary to allow Australia to take meaningful steps toward enhancing indoor environments and protecting public health. A proposed solution is a three-phase approach beginning with monitoring, followed by a workplace indoor air quality reporting standard, and finally enforceable IAQ performance standards for all public buildings. A reporting standard would involve the systematic measurement and collation of workplace IAQ to an agreed set of indicators and sensitivities and would provide a basis for mandating the standard in the future.

This will have an enormous impact on public health in general and will come at a relatively low cost to the Australian Government. It will result in cleaner workplace indoor air, making a profound contribution to the economic prosperity of the country by reducing costly work-related ill health, boosting productivity, and preventing future catastrophic losses from environmental and industrial hazards, as well as infectious diseases such as influenza and new pandemics.

The design and implementation of IAQ policy in workplaces and other settings would be strengthened by establishing a multidisciplinary taskforce which reports to a minister with responsibility for IAQ.

Abbreviations

ARC – Australian Research Council

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

CO – carbon monoxide

CO₂ – carbon dioxide

COVID-19 – coronavirus disease 2019

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DALYs – disability adjusted life years

GBD – Global Burden of Disease study

GDP – gross domestic product

HEPA – high-efficiency particulate air

HVAC – heating, ventilation and air conditioning

IAQ – indoor air quality

MERV – minimum efficiency reporting value

NABERS – National Australian Built Environment Rating System

NEPM – National Environment Protection Measure

NHMRC – National Health and Medical Research Council

NO₂ – nitrogen dioxide

O₃ – ozone

PM – particulate matter

PM₁₀ – particles with a diameter of 10 micrometres or smaller

PM_{2.5} – particles with a diameter 2.5 micrometres or smaller

SO₂ – sulfur dioxide

SVOC – semi-volatile organic compound

THRIVE – ARC Training Centre for Advanced Building System against Airborne Infection Transmission

UFP – ultrafine particle

UN – United Nations

VOC – volatile organic compound

VVOC – very volatile organic compound

WEL – workplace exposure limits

WES – workplace exposure standards

WHO – World Health Organization

WHO AQG – WHO global air quality guidelines

WHS – work health and safety

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Supplement

Table 1. WHO global air quality guideline values (WHO 2021)

Pollutant	Time period	Level
PM _{2.5}	Annual	5 µg/m ³
	24-hour ^a	15 µg/m ³
PM ₁₀	Annual	15 µg/m ³
	24-hour ^a	45 µg/m ³
O ₃	Peak season ^b	60 µg/m ³
	8-hour ^a	100 µg/m ³
NO ₂	Annual	10 µg/m ³
	24-hour ^a	25 µg/m ³
SO ₂	24-hour ^a	40 µg/m ³
CO	24-hour ^a	4 mg/m ³
^a 99th percentile (i.e. 3–4 exceedance days per year).		
^b Average of daily maximum eight-hour mean O ₃ concentration in the six consecutive months with the highest six-month running average O ₃ concentration.		

Table 2. Parameter levels proposed by Morawska et al. (2024)

Parameter	Time period	Level
PM _{2.5}	1 hour	15 µg/m ³
Carbon dioxide (CO ₂)	Threshold	800 ppm (absolute value)
	Threshold	350 ppm (difference between actual CO ₂ concentration and the CO ₂ concentration in the supply air)
Carbon monoxide (CO)	15 minutes	100 mg/m ³
	1 hour	35 mg/m ³
	8 hours	10 mg/m ³
Ventilation rate	When the space is occupied	14 litres/s per person