CLEAN INDOOR AIR

2024 COLLABORATION AND GLOBAL ACTION

CONTENTS

GLOBAL MOVEMENT

Indoor air quality has recently emerged as a 'hot topic' driving significant global attention. In Australia, multiple high-level events have been held recently, bringing together key stakeholders, to share knowledge, explore collaboration opportunities and accelerate action.

Indoor Air Quality Collaboration

Proudly hosted by the Australian Academy of Science, Burnet Institute and CSIRO, the *Science of Clean Indoor Air* event was held at Parliament House, Canberra, in March 2024. Australian and international experts, from the public and private sectors, delivered presentations and engaging interviews, sharing insights and global best practice.

Dr Doug Hilton AO – CEO Commonwealth Scientific and Industrial Research Organisation, Ms. Anna-Maria Arabia – Chief Executive Australian Academy of Science, and Professor Brendan Crabb AC – CEO Burnet Institute, spoke at the Science of Clean Indoor Air event, Parliament House, Canberra, 2024

COLLABORATION ACROSS DISCIPLINES

Australians spend 80-90% of the time indoors. The air we breathe during this time has significant impacts.

- Clean indoor air policies will future-proof buildings for climate change and future pandemics. Resilient buildings need to be energy-efficient and have excellent indoor air quality to allow people to thrive.
- Better indoor air quality improves physical and mental health, cognitive function, academic achievement and business productivity.
- Airborne hazards – **Pollutants** (like bushfire smoke, vehicle emissions and pollens) and **Pathogens** (airborne viruses, bacteria and fungi/mould) – have dramatic impacts on health, the economy and society.
- Access to clean air is a fundamental human right, as per the 2022 United Nations General Assembly resolution on the Right to a Clean, Healthy and Sustainable Environment.
- The science concerning the negative health impacts of poor air quality is clear, amounting to a significant burden of acute and chronic disease affecting the lungs, heart, brain, and other organs. Cancers may be induced, the immune system damaged, and mental health harmed.
- Improving indoor air quality is a key opportunity to reduce multiple significant risks and deliver a range of impactful benefits in the short- and long-term. Transformational change is the goal.
- Solutions are multi-faceted and require a suite of interventions, a broad range of skillsets, and engagement with many stakeholders.

> We have made air – the thing that keeps us alive – the number one threat to our health. By formalizing our right to clean air, this resolution is an important step towards protecting both people and planet."
>
> **Martina Otto, Head of Secretariat, Climate and Clean Air Coalition, United Nations Environment Programme**

KEY ACTIONS FOR CONSIDERATION

Appoint a **Multi-Disciplinary Taskforce** to develop a pathway to clean indoor air throughout Australia. Key steps on the pathway include:

1 Set indoor air quality standards

- The consensus guidelines for indoor air quality standards, published in Science by Morawska et al in March 2024, could serve as a blueprint for indoor air quality standards.
- When thresholds for unsafe air are clearly defined and understood, leaders will have targets to drive action.

2 Educate the community

- Increase public awareness of the importance of clean indoor air by developing a *Clean Indoor Air* campaign.
- Empower Australians with knowledge to better protect themselves and take action to improve indoor air quality.

3 Monitor and display indoor air quality data

- Install CO2 monitors in shared indoor spaces, starting with high priority settings, like hospitals, schools, early childhood education, aged care, disability services, public transport, workplaces and retail.

OPPORTUNITY

A clean indoor air transformation will provide generational benefits.

- Future-proof buildings for climate change and future pandemics
- Guard against harmful impacts of air pollution (bushfire smoke, vehicle exhaust, pollens etc.)
- Protect from current and future pathogens (airborne diseases)
- Maximise economic productivity
- Uplift academic achievement and ensure children are safe at school
- Enhance occupational health and safety standards
- Improve transparency
- Promote inclusivity
- Build safe and health-promoting buildings
- Empower individuals and society
- Improve health and wellbeing for all
- Deliver a generational legacy by addressing a key public health gap.

RATIONALE FOR ACTION ON INDOOR AIR QUALITY

1. **Indoor air quality** has significant impacts on health, cognitive function, and productivity.
2. **There are many well recognised indoor air hazards** including air pollution (bushfire smoke, vehicle exhaust, pollen etc.) and airborne diseases.
3. **Addressing indoor air quality is a foundational element** of preparing for the next pandemic, to guard against catastrophic pandemic impacts on health, the economy and society.
4. **In most countries, including Australia, people spend the vast majority of time indoors.** A significant proportion of exposure to outdoor air pollution (like bushfire smoke) occurs when *indoors*, as air flows from the outside to the inside of homes, offices, schools, and other indoor spaces.
5. **Legal risks are escalating: Australian workplaces have an obligation to provide a safe workplace for employees.**
   - Air quality is not excluded from Australian occupational health and safety regulations.
   - In 33 European countries, several US states including Arizona and Colorado, and in Peru, courts have concluded that COVID-19 can be an occupational disease, with a range of compensation obligations including long-term sick leave, disability benefits, treatments, rehabilitation and pensions for surviving family members. Long-COVID is recognised as an occupational disease in 27 European countries.
   - Courts in the UK and New Zealand are currently hearing cases that focus on this issue.

> People spend large periods of time indoors and many indoor places are public, where individuals have little control over the quality of air they breathe. These two factors should be recognised in the planning and development of public indoor spaces."
>
> **Professor Chris Witty, Chief Medical Officer for England,**

"Clean indoor air is a workplace health and safety issue. Unlike asbestos, there is no specific regulation, there is no specific code of practice for clean indoor air, to help employers understand how they can discharge their positive duties, which are imposed on them under work health and safety legislation. At the moment, we're failing them by not providing that type of information."
Kate Cole OAM, Certified Occupational Hygienist

"Occupational Health and Safety frameworks place positive obligations on parties, on employers and people who design, build, manage and own buildings, to ensure health and safety so far as is reasonably practicable. The missing link there, to enable those parties to do that, is compliance codes. Regulators can put in place compliance codes dealing with ventilation and that will be a very quick win."
Louise Houlihan, Managing Principal HMB Employment Lawyers

6. **Indoor public spaces should be safe and accessible for all; thus, clean indoor air is a fundamental requirement for an inclusive society**. Poor indoor air quality disproportionately impacts children, the elderly, those who are immunocompromised and those in marginalised communities. Millions of Australians fit into a 'higher risk' category, demonstrating the large portion of the population for whom indoor air quality is a key health determinant.

"One thing that is very clear is that indoor air quality is yet another area where there are pretty big disparities across most societies. With higher socioeconomic status, kids generally have better indoor air quality in their schools, and consequently all those better outcomes that come from better indoor air quality."
Jeffrey Siegel, Professor in the Department of Civil and Mineral Engineering, Toronto Canada

"Clean air is a social justice issue". Like in the US, in Australia, poor air quality impacts marginalised communities the most.
Professor Deborah Lupton, SHARP Professor, Faculty of Arts, Design & Architecture, University of New South Wales.

Ella's Story

"Ella Roberta Adoo Kissi Debrah was born happy and healthy. By the age of seven she had been diagnosed with asthma. At the age of nine she suffered a fatal asthma attack. It took her mother years of campaigning for the role of air pollution to be recognised: **Ella is the first person in the world to have air pollution listed as a cause of death on her death certificate**." **The Ella Roberta Foundation.**

"We believe in a world where everyone can breathe air that is free from toxic pollution, regardless of where they live, their economic status or their ethnic background." **Rosamund, Ella's mum**

"

150 years ago, we decided, as a community, that everyone had the right to clean, safe water. With the guidance of engineers, this has been delivered. It is now time to do the same for clean, safe air."

Prof. Guy Marks AO, Respiratory Physician, President, International Union Against Tuberculosis and Lung Disease

7. **Climate change, Net Zero and indoor air quality:** In the context of a rapidly changing climate, with more frequent and severe natural disasters, epecially bushfires in the Australian context, and well-established challenges associated with current and future pandemics, there is urgent need for action. Indoor air quality iniatives and energy efficiency efforts should align to reduce systemic risk within the built environment.

"A critical engineering challenge is getting the best solution for maximising ventilation, while keeping buildings warm in winter and cool in summer, and minimising energy and therefore carbon use."
UK Chief Medical Officer's Annual Report 2022: Air Pollution

The trilogy of goals for climate resilient buildings

8. **Human Right to breathe clean air:** Enshrined by the United Nations General Assembly in 2022 as a human right, everyone on the planet has a right to a healthy environment, including clean air, water, and a stable climate. **Australia was one of 160 UN Member States that voted in favour.**

"

Clean air is not an optional policy objective. It's a fundamental human right."

David R. Boyd, the United Nations Special Rapporteur on human rights and the environment

Photo by Mathias Reding on Unsplash

CURRENT STATUS OF INDOOR AIR QUALITY

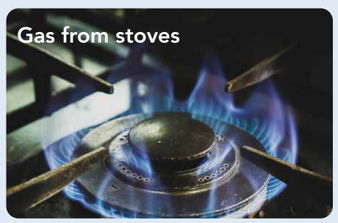
There is a gap in public health frameworks in terms of a lack of standards governing indoor air quality.

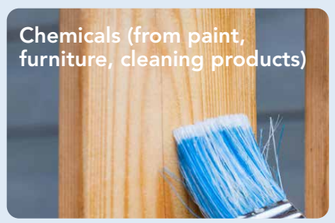
- Australians spend 80-90% of the time indoors.
- Each day we breathe 25,000 times and inhale 11,000 litres of air.

Indoor Air Quality Hazards

PATHOGENS

POLLUTANTS





1. Pathogens (airborne disease)

Infectious respiratory particles are breathed into the air by people infected with airborne diseases including influenza, respiratory syncytial virus (RSV), measles, tuberculosis, whopping cough and SARS-CoV-2 (COVID-19).

The COVID-19 pandemic is ongoing, with the majority of disease transmission occurring in indoor settings. A key element of reducing the incidence and severity of COVID-19 – a stated objective of the Australian Government – is to review and reform ventilation and air quality standards, alongside efforts to improve vaccination and community understanding of protective behaviours and public health measures.

Improving indoor air quality is a cornerstone requirement to prepare for future pandemics and will revolutionise the response to airborne threats. Robust indoor air quality systems would allow buildings (including schools and workplaces) to remain open and functional and be regarded as safe havens during pandemic conditions.

In April 2024 the **World Health Organisation** published the *Global technical consultation report on proposed terminology for pathogens that transmit through the air*, introducing new terminology such as:

- **Infectious Respiratory Particle** (IRP)
- **Puff Cloud** – describing air breathed out during exhalation
- **Through The Air Transmission** (TTAT) – a term encompassing both **Airborne Transmission** of IRPs over any distance, and **Direct Deposition** of IRPs into the eyes, mouth or nose

> As we entered the back end of the emergency phase of the pandemic it became clearer that this was an aerosol-based coronavirus, and that **clean air was an important protection against infection**."
>
> **The Hon Mark Butler MP, Australian Minister for Health, and Aged Care**

CURRENT STATUS OF INDOOR AIR

The majority of your exposure to outdoor air pollution actually occurs from *the air you're breathing indoors*"

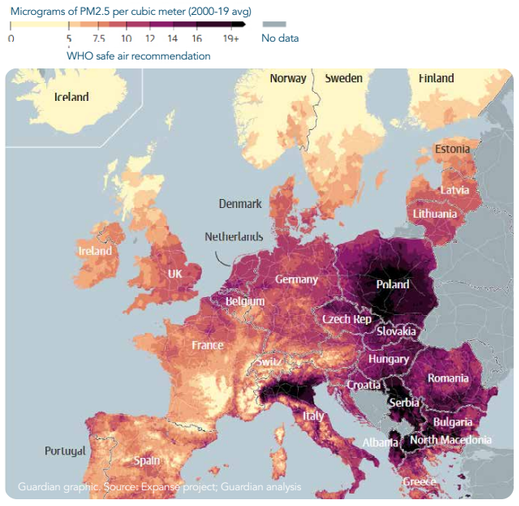
A/Prof Joseph Allen, Director, Harvard Healthy Buildings Program

2. Pollution

- **While the majority of air pollution originates outdoors, the majority of exposure occurs indoors** as pollutants move freely through windows, doors and vents and are drawn in via mechanical ventilation systems.
- Air pollution is the world's greatest environmental risk to health, affecting the air both indoors and out, and is a cause of significant mortality and reduced life expectancy globally. **Impacts are not distributed equally amongst populations, with the young, the elderly, those with existing health conditions and those in marginalised communities bearing the greatest burden**.
- **The UN estimates air pollution is responsible for around seven million deaths each year. In 2021, the WHO estimated that 3.8 million people die annually from indoor air pollution alone**, noting this figure only relates to exposure to household wood-fire smoke and gas stoves, thus the real statistic would be vastly higher should all pollutants as well as airborne diseases be included. A 2021 Harvard study estimated that that pollution from burning fossil fuels was associated with 8 million, or 1 in 5 annual deaths worldwide.
- Dangerous airborne pollutants include:
  - Nitrogen dioxide (NO_2) – a gas produced by vehicles.
  - Fine particulate matter ($PM_{2.5}$) produced by vehicles, wood burning, industry, farming and bush fires. A 2024 Dutch study of 161 primary school children living near Schiphol airport found that aviation-related ultra-fine particles caused an increase in respiratory symptoms.
- The US-based Health Effects Institute, published State of Global Air 2024, which estimated that in 2021, over 700,000 deaths in children under 5 years were linked to air pollution.
- **While acute health impacts of air pollution are well recognised, somewhat less appreciated is the risk of chronic health conditions**, including lung disease, heart disease, diabetes, cataracts and hearing loss, as outlined in a 2024 Danish study that researched over three million Danes for 18 years.

The World Health Organization (WHO) maintains an air quality database covering thousands of cities. In 2022, WHO reported that billions of people were breathing unhealthy air.

- In 2021, the World Health Organization (WHO) published the *Global Air Quality Guidelines* which include recommended limits for key pollutants in outdoor and indoor air.
  - A world first study published in 2023 by Monash University determined that 99% of the world's population breathes air that does not meet these WHO guidelines, including in Australia.
  - A 2024 study published in the British Medical Journal found that there was no safe threshold for exposure to $PM_{2.5}$ particles, with even minimal exposure causing an increase in hospital admission for cardiovascular disease, suggesting the WHO should consider reducing the recommended limit for this pollutant.
  - Many countries including China and India report outdoor air pollution that vastly exceeds recommended limits.



A 2023 study revealed that "almost everyone in Europe is breathing toxic air"

Industrial sources	Environmental sources	Household sources
Electricity generation	Bushfire smoke	Gas stoves
Industrial processes	Dust storms	Wood-fire heaters
Mining and agriculture	Pollens and allergens	Chemicals from carpets, paints etc.
Transportation		Dust mites and allergens
Waste management		Mould and dampness

AUSTRALIAN CONTEXT

- **Bushfires** are experienced during most Australian summers and are likely to increase in the context of climate change. Hazard reduction burns, like several in Sydney in 2023 and in Victoria in 2024 can cast smoke over major cities with little public information or instruction to protect against harmful inhaled pollutants. In response to the 2019-2020 Black Summer Bushfires, the ACT Government developed a Bushfire Smoke and Air Quality Strategy 2021-2025. **This strategy acknowledges the need for air quality monitoring and improved ventilation systems in public buildings and recommended the use of air purifiers.**


Photo: James Brickwood


Photo: AAP- Lukas Coch

Football players surrounded by bushfire smoke during a game at the Melbourne Cricket Ground (MCG) in March 2024 (top). Parliament House, Canberra, and Sydney Harbour (above) during the January 2020 Australian bushfires.

- **The Australian landscape is vast.** Indoor air quality solutions depend on the state of the outdoor air. For example, while it makes sense to encourage people to open windows and doors to increase ventilation in Sydney in milder months, the same plan would not suit the Hobart community during winter. Solutions need to be tailored to the local climate, considering many natural factors like temperature, humidity, wind, and noise, and building features like existing structural features, proximity to major roads, room usage and number of occupants. A suite of solutions will be required to accommodate all scenarios.
- **The Australian National Science and Technology Council** released a report in August 2024 – The impact of indoor air quality on the transmission of airborne viral diseases in public buildings. Key findings included that:
  - Ventilation plays a role in the transport of disease particles indoors.
  - Disease transmission can occur indoors at short and long ranges.
  - A range of strategies could reduce transmission of airborne viruses in indoor public environments, such as increasing the amount of clean air indoors via mechanical ventilation, using air purifiers with HEPA filters and/or using ultra-violet light disinfection.
- **Vehicle emissions** are a major air hazard in Australian cities, where over 70% of populations live. These emissions pass into nearby indoor spaces, including schools, offices, businesses, and homes.
- **High pollen** levels occur in many parts of Australia, causing allergy reactions, hay fever and rarely, thunderstorm asthma – as occurred in 2016 in Victoria, resulting in thousands of people simultaneously developing severe asthma symptoms, with a surge in demand for emergency services and hospital care. Sadly, there were ten deaths (age range 18-57 years).
- **Dust storms and bushfire smoke** inflict substantial impacts on remote communities.
- Collectively, **all forms of air pollution** inflict a substantial burden on Indigenous Australians causes an estimated 12% of strokes and 12% of coronary heart disease.
- **Floods** occur frequently in Australia. Affected communities risk impacts of poor indoor air quality from dampness and mould.
- **Gas stoves** are widely used across Australia, in homes and commercial kitchens, yet cause significant health impacts, including an estimated 12% of childhood asthma. Many experts encourage switching to safer alternatives. In Victoria, from 1 January 2024, gas connections for new dwellings are being phased out.
- **Particulate matter from wood heaters** caused an estimated 728 Australian deaths in 2015, according to a recent study. In 2023 the ACT government announced a phasing out of wood heaters in Canberra by 2045.

> Australia has an enviable history of world-leading public health community campaigns, including for road safety, sun protection and tobacco control. This history of expertise and know-how can be leveraged for clean indoor air."
>
> **Prof Bronwyn King AO, Professor (Hon.) Melbourne School of Population and Global Health, University of Melbourne**

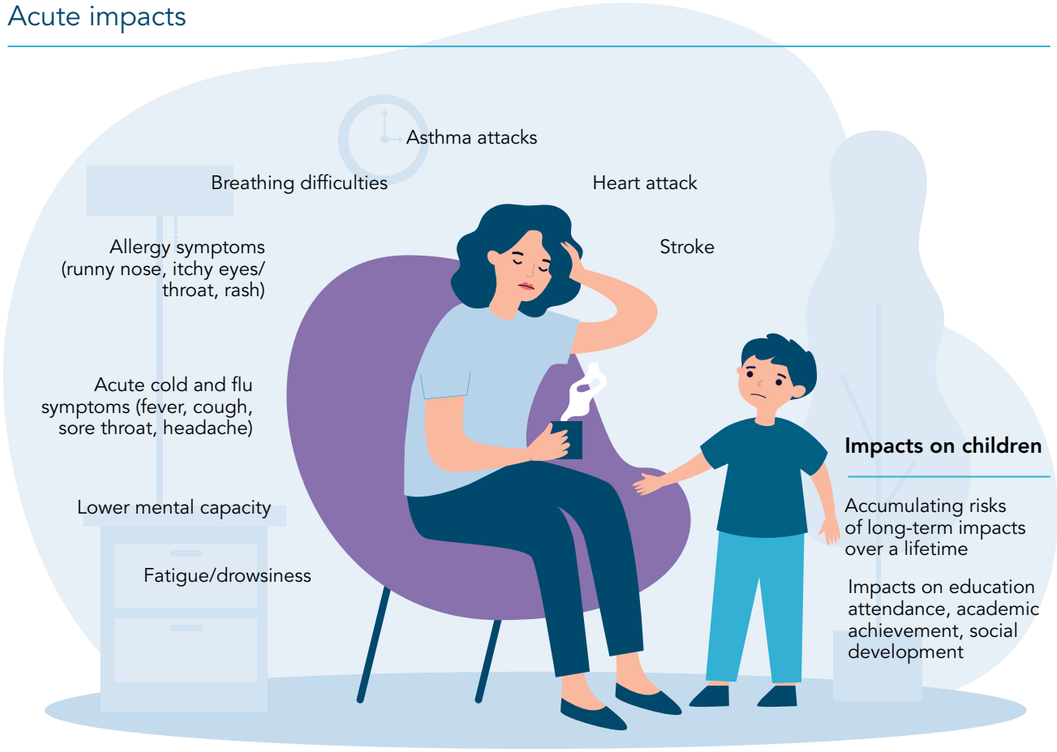
HEALTH IMPACTS OF POOR INDOOR AIR QUALITY

The health impacts of indoor air hazards accumulate over a lifetime, amounting to a significant burden of acute and chronic disease.

Recent studies find association between poor air quality and **all** 10 leading causes of death in Australia in 2022.

Coronary heart disease	**18,643 deaths**
Dementia, inc Alzheimer's	**17,106**
COVID-19	**9,859**
Cerebrovascular diseases	**9,829**
Lung cancer	**9,048**
Chronic lower respiratory diseases	**8,580**
Diabetes	**6,050**
Bowel cancer	**5,410**
Blood cancers	**5,168**
Urinary diseases	**4,571**

Acute impacts



Chronic impacts of poor air quality can be substantial

COVID-19 ACUTE INFECTIONS

LONG COVID AND CHRONIC DISEASES

A 2024 study estimated that during the Omicron-era, COVID-19 infections cause long COVID in 3.5% of vaccinated adults and 7.7% of unvaccinated adults.

A growing body of evidence details concerning cognitive effects of COVID-19 infection, including brain shrinkage, fusion of brain cells, IQ drop (by 3-9 points, depending on acute disease severity), memory decline up to three years post infection (see here and here), accelerated brain aging (see here and here), increased risk of dementia and mental health disorders.

Long-term impacts

Lung disease – asthma, bronchitis, pneumonia, lung cancer.	Heart disease, vascular function and blood pressure.	Mental health impacts including anxiety, depression and even suicide	Dementia
Exacerbation of pre-existing diseases	Interference with treatment of other diseases, including cancer	The World Health Statistics 2024 report, shows the COVID-19 pandemic eliminated a decade of progress in global life expectancy.	Post-infection long-term impacts – Long COVID in adults and children, including fatigue, brain dysfunction (Drop in IQ, reduced memory, brain shrinkage) and heart damage

COGNITIVE AND PERFORMANCE IMPACTS OF POOR INDOOR AIR QUALITY

Indoor air quality impacts are broader that health alone. For almost a decade, high quality studies, including from Harvard University have demonstrated superior cognitive function in buildings and indoor spaces with better air quality.

- The CogFX Study was conducted in 2014 by Harvard, Syracuse and SUNY Upstate Universities, to investigate the impact of buildings with better air quality on cognitive function. **On average, cognitive function test scores doubled in buildings with enhanced ventilation and low levels of exposure to dangerous chemicals** (volatile organic compounds) commonly found in products used in offices and homes (like paint, glue, cleaning products, printers etc.).
- A 2018 study of commercial airline pilots flying in simulators, demonstrated optimized air quality (specifically: lower CO2 levels on the flight deck), resulted in **significantly better advanced maneuvers**, suggesting a direct effect of air quality on cognitive performance.
- There are many studies that investigate the impact of improved ventilation and indoor air quality on productivity in the workplace, with **productivity uplift estimates ranging from 1–4%**.
- In 2023, an article in Time, The Business Case for Better Air Quality concluded that "whether you look at an individual level, a business level, an investor level, owner level, a societal level, there's a business case to be made."

Indoor air quality uplift potential in schools, early learning centres and universities

- Academic achievement improves
- Enhanced inclusivity for students with asthma or immune system disorders
- Absenteeism reduced
- Reduced long-term risks for students and teachers

Indoor air quality uplift potential for businesses and the economy

- Cognitive function improves
- Productivity improves
- Absenteeism reduced
- Reduced workforce loss due to chronic illness

PRIORITY AREAS

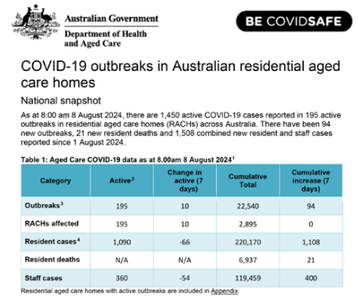
Healthcare

Healthcare facilities should be safe. It is standard practice for hospitals to aim for zero hospital-acquired infections, implementing strict infection control policies, mandatory reporting and immediate uplifting of protections and staff education when an incident occurs. **These policies and processes should be extended to include all significant infections, including those that are airborne**.

In Victoria, several reports, including by The Age in 2023 and by ABC news in 2024, note that thousands of Victorian patients acquired COVID-19 in hospital, while being treated for other conditions. The ABC news report states that at least 6212 patients caught COVID-19 in hospital from the start of 2021 until the end of 2022, and 586 (9.4%) died. In 2024 Queensland Health reported that from January 2022 to June 2023 an average of 14 patients per day caught COVID-19 while in Queensland hospitals, with one patient dying daily as a result.

Aged care

As of 9 August 2024, 198 Australian aged care facilities reported COVID-19 outbreaks, with 1197 residents and 437 staff testing positive.



Australian Government
Department of Health and Aged Care

BE COVIDSAFE

COVID-19 outbreaks in Australian residential aged care homes

National snapshot

As at 8:00 am 8 August 2024, there are 1,450 active COVID-19 cases reported in 195 active outbreaks in residential aged care homes (RACHs) across Australia. There have been 94 new outbreaks, 21 new resident deaths and 1,508 combined new resident and staff cases reported since 1 August 2024.

Table 1: Aged Care COVID-19 data as at 8.00am 8 August 2024[1]

Category	Active[2]	Change in active (7 days)	Cumulative Total	Cumulative increase (7 days)
Outbreaks[3]	195	10	22,540	94
RACHs affected	195	10	2,895	0
Resident cases[4]	1,090	-66	220,170	1,108
Resident deaths	N/A	N/A	6,937	21
Staff cases	360	-54	119,459	400

Residential aged care homes with active outbreaks are included in Appendix.

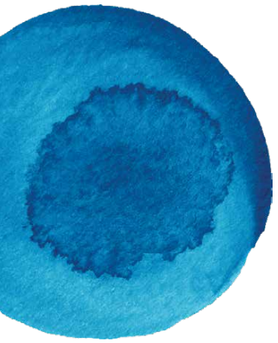
Educational settings

A 2023 US study found >70% household COVID spread started with a child, with in-person school resulting in substantial spread.

The Australian Health Protection Principal Committee notes that the contribution schools make to COVID-19 outbreaks is unknown, but based on prior experience, is likely to be considerable. In term 4 in 2022, **22% of COVID-19 cases across Victoria were linked to school outbreaks**. The committee notes this is likely an underestimate.

In 2021, data began to emerge demonstrating significant transmission of COVID-19 at schools. A 2021 study of 181 teachers, parents and students at a Belgian primary school suggested that most COVID-19 transmission events originated within the school.

> Currently we do not have any comprehensive indoor air quality controls or standardised policies for schools to protect children's and teachers' health inside school buildings. Our research shows that in classrooms with no windows or doors open, in less than ten minutes CO2 levels are high enough to affect learning and enable the transmission of airborne viruses."
>
> **A/Prof Donna Green, Environmental scientist, Associate Investigator NHMRC Centre for Safer Air**



Workplaces

Workplaces have an obligation to provide a safe workplace for employees. Air quality is not excluded from Australian occupational health and safety regulations and 33 European countries, several US states and Peru formally recognise COVID-19 as an occupational disease.

There are many studies that investigate the impact of improved ventilation and indoor air quality on productivity in the workplace, with **productivity uplift estimates ranging from 1–4%**.

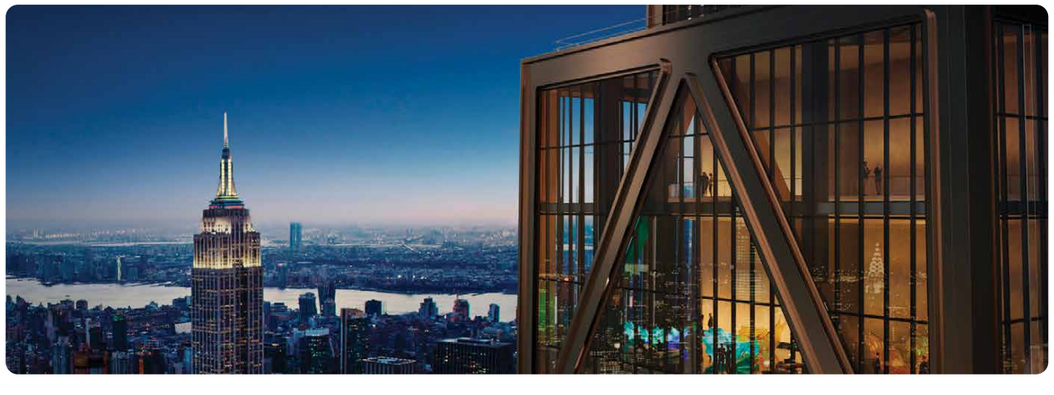
Some companies are actively addressing indoor air quality:

In 2023, Amazon rolled out a real-time air quality monitoring network across its global commercial office portfolio, to uplift worker productivity and to align action with occupational health and safety requirements.

In 2023, JP Morgan Chase, the largest bank in the US, unveiled its new global headquarters in New York. The 60-story skyscraper has net zero operational emissions and exceptional indoor air quality that 'exceeds the highest standards in sustainability, health, and wellness'. The stated aim of this design is to 'champion occupant health, wellness and productivity'.

Retail/Hospitality/Commercial enterprises

The 2023 'Ruby Princess' lawsuit in Australia, serves as an example of how **a commercial enterprise is obliged under Australian consumer law to make a reasonable attempt to offer services safely**. The lead applicant in the class action was the wife of a gentlemen who acquired COVID-19 during the cruise and became gravely ill, but thankfully survived. The court upheld her claim that Carnival (the company that chartered the cruise ship) breached the consumer protection provisions of the Australian consumer law and awarded damages for 'distress and disappointment' as a result of acquiring COVID-19 during the cruise.



Public Transport

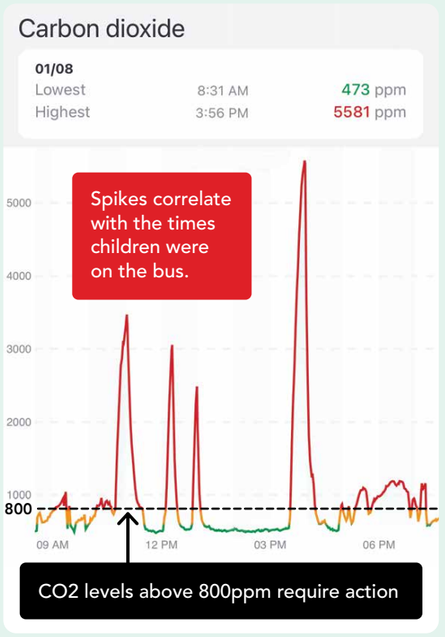
In recent years, many studies have noted the need to improve air quality on public transport, buses in particular.

It is widely recognised that buses and trains have poor ventilation, increasing the risk of passengers being exposed to airborne disease. Professor Nick Wilson from University of Otago, New Zealand suggests that air quality standards for public transport "…are a very basic requirement for a safer transport system."

A 2021 study by Germany's national public health institute investigated a COVID-19 Delta variant outbreak in elementary students. The study demonstrated how local bus transportation amplified a COVID-19 outbreak. Although students spent only 9–18 minutes on the bus, twice a day, **74% of COVID-19 infections in the outbreak were attributed to bus riding**.

In 2024, Italian high-speed trains promoted their installation of new sophisticated air quality systems, including HEPA filters, vertical flow ventilation and complete air refreshment every three minutes.

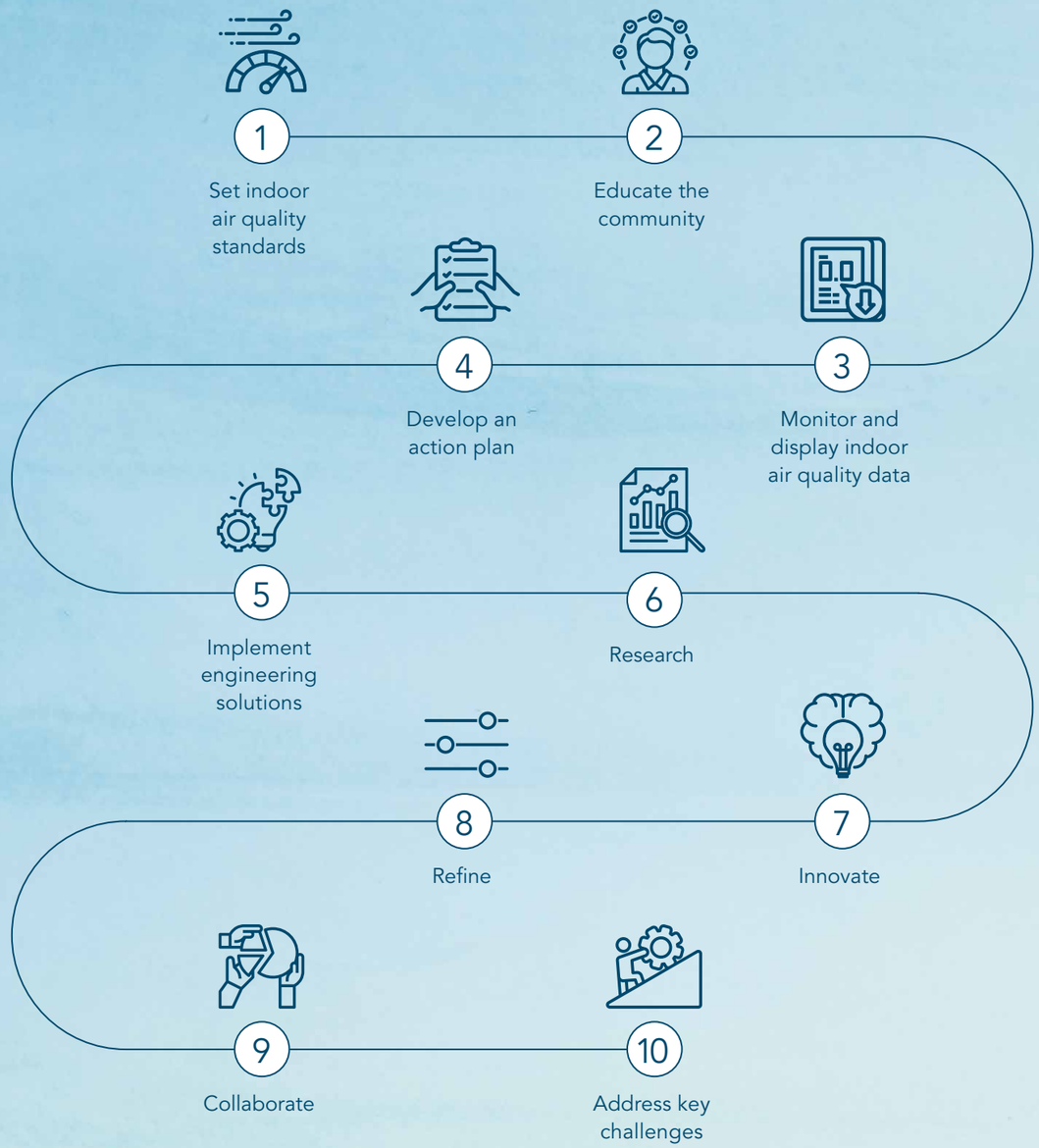
A 2024 systematic review of COVID-19 transmission during commercial flights, before vaccines were available, showed that compared to shorter flights, medium flights (3-6 hours) had 4.66 times the risk of infection and long flights (over 6 hours) 25.93 times the risk. Long flights with mandatory masking had no transmission reported. This study highlights that risk of airborne disease on flights can be high (especially for Australians who often take long flights) and collective masking on planes is very effective.



Hazardous CO2 levels recorded during a school excursion where students were transported by bus from venue to venue throughout the day. **These CO2 levels indicate extremely poor air quality as a result of inadequate ventilation**, exposing students and staff to very high risk of transmission of airborne diseases like influenza, COVID-19, RSV and whooping cough, as well as impacting cognitive function for all occupants, including the driver.

MULTI-DISCIPLINARY TASKFORCE TO DEVELOP PATHWAY TO CLEAN INDOOR AIR

Pathway will involve many elements, some of which can proceed concurrently.



1. Set indoor air quality standards

The 2024 landmark paper published in Science by Morawska et al, calling for mandatory indoor air quality standards, responds to a growing global call for policy to drive change. As per the paper, the metrics to be measured are:

Metric	Sources/ definition	Proposed standard
PM2.5	Smoke Vehicle exhaust	Maximum of 15 micrograms per cubic metre, averaged over one hour
CO2	Respiration Burning coal, oil, gas	Maximum of 800 parts per million (absolute value) (or maximum of 350 parts per million higher than the CO2 level outside)
CO	Vehicle exhaust	Maximum of 100 milligrams per cubic metre over 15 mins Maximum of 35 milligrams per cubic metre over 1 hour Maximum of 10 milligrams per cubic metre over 8 hours
Ventilation	Replacement rate of indoor air with clean air	14 litres per second per person

Pathways forward

- A comprehensive public policy approach will be required to drive transition to indoor air quality policy governing new buildings and renovations, in addition to a retrofitting program.
- A range of instruments is available to governments to promote adoption of and adherence to new standards. These include supportive and capacity-building instruments such as the development of guidance, advice, and support, as well as more directive instruments such as regulation and legislation for building design and operations. Such instruments are increasingly being adopted internationally to guarantee indoor air quality.
- Examples of successful policy transitions in the built environment include installation of smoke alarms, fire sprinklers and pool safety fences.

"Every drop of water we drink from the tap – its quality is highly regulated. Every piece of food we take to our mouths – its quality is highly regulated. Indoor air – which we take into our lungs twelve times a minute – is not regulated at all. That needs to change."

Distinguished Professor Lidia Morawkska, Director of the International Laboratory for Air Quality and Health at Queensland University of Technology

"The National Construction Code is limited to new buildings which are growing at 1-2% per annum, so that's a very slow scale of change, Retrofitting will also be a key element'."

Gary Rake, CEO Australian Building Codes Board

2. Educate

Knowledge, awareness, and behaviour change across the community will need to be strengthened, so indoor air quality monitoring, understanding and management becomes routine practice.

Culturally appropriate public education campaigns, covering traditional and social media will be required to engage the community, uplift awareness, and empower all to take simple actions. An excellent example is this educational video from the New Zealand government. Innovative communication methods should also be explored.

> Information and guidance and communication is key and should be the first thing we need to do and really amplify. It's one thing putting something on a website, it's another thing to have that reach the community and people who need it."
> **A/Prof Suman Majumdar, Chief Health Officer – COVID & Health Emergencies, Burnet Institute.**

3. Monitor and display data

Real-time publicly available data enhances education, builds trust, and engages and empowers the community. Employees, students, consumers and the public would be informed, and better able to manage risks.

Low CO2 levels (under 800 parts per million) indicate good ventilation.

- This means lots of outdoor air is being brought inside, keeping the air fresh and diluting contaminants (like pathogens and pollutants).
- Low CO2 levels protect health and allow optimal cognitive function and performance.

High CO2 levels (over 800 parts per million) indicate poor ventilation.

- This means that action needs to be taken to improve air quality.
- High CO2 levels impact health, cognitive function and performance.
- Research published in 2024 demonstrates that the virus that causes COVID-19 survives longer and remains infectious when CO2 levels are high – an additional reason to keep CO2 low.

Live indoor air quality monitoring is being increasingly adopted.

- In 2022, the Belgian government introduced a new legal framework, mandating CO2 monitoring and display in all public indoor spaces.
- In 2021, Boston Public Schools commenced a world-leading indoor air quality program, by installing air quality sensors in all classrooms, hallways and nurses stations, in 4322 classrooms in over 120 schools. A dashboard was built to display data in real time, to engage the whole school community. Similar program are active in 2200 schools in Lubeck, Germany, 687 schools in Berkeley California and 875 Latvian schools.

> We designed our CO2 monitor to be fun and playful. Birdie drops down when air quality is poor, and a window must be opened to bring it back to life!"
> **Andreas Sørensen, Co-founder of Birdie**

Jasper announces the CO2 level in French!

4. Develop an action plan

Developing effective and practical response plans is a crucial step to derive maximum benefit from monitoring indoor air quality.

Actions may include:

Immediate	Medium-term	Longer-term
Open windows and/or doors	Install more windows or windows that allow better ventilation (louvre windows for example)	Install new mechanical ventilation systems
Turn on an air purifiers	Better match of activities to specific rooms, depending on air quality	Redesign ventilation and air purification systems
Vacate the room momentarily to allow air to refresh	Modify or replace existing mechanical ventilation system	

Over the past 200 years, some of the most significant improvements in health have resulted from engineering, and many still do. Engineering is often as important as biomedical science in reducing major infections."

National Engineering Policy Centre 3.8

5. Implement or enhance engineering solutions

- A 2022 article published by the American Society of Mechanical Engineers noted that "Good engineering can create robust public health. In fact, mechanical engineers have been responsible for many of the most significant advances in health", including water and sewer systems that prevent waterborne disease and food storage and refrigeration systems that reduce food-borne disease.

"Engineered solutions are so critical, because it doesn't have to rely on us being mindful of behavioural interventions each and every moment of each and every day."
Prof Brett Sutton AO, Director of Health and Biosecurity, CSIRO

Ventilation

- **Natural Ventilation** includes opening existing windows and doors, or redesigning buildings to increase window number, size, style, opening capacity and placement. Windows on opposite sides of a room allow *cross ventilation*. Natural ventilation, on its own, is insufficient when outdoor air quality is poor, for example, when bushfire smoke or vehicle exhaust is present.

"In our love affair with new technology, we've kind of forgotten the window!"
Dr Ian Longley, Principal Air Quality Scientist, National Institute of Water and Atmospheric Research, New Zealand

- **Mechanical ventilation** is airflow that is controlled by devices, most commonly Heating, Ventilation and Air-Conditioning (HVAC) systems. Some HVAC systems have integrated air purification. *Displacement ventilation* – where the air travels in only one direction (usually from the bottom of a room, moving up towards the ceiling) rather than mixing randomly, can keep fresh and polluted air separate and is a promising technique for protecting occupants from airborne pathogens.

A suite of solutions can be tailored to accommodate:

Building style and design

Building purpose and usage

Geographical location and local environment

Air Purification

- Air purifiers (often called air cleaners) typically clean the air by passing it through several layers including:
  - A pre-filter to remove dust and dander.
  - A HEPA filter (High Efficiency Particulate Air filter) to trap very small particles like viruses, bacteria, and particles in smoke. HEPA filters have proven to be very effective at removing such particles. For example, a 2023 study showed 30-74% reduction in indoor PM2.5 particles when HEPA filers are used during hazard reduction fires.
  - A charcoal filter to remove dangerous gases and odours.
- Air purifiers can be portable or integrated into mechanical ventilation systems. There are a number of online tools that recommend suitable air purifiers according to room size and number of occupants. Portable air purifiers are easy to use and an excellent interim solution while building infrastructure is upgraded over time.
- Air purifiers can be used in combination with other solutions.
  - A 2022 study in two UK hospital wards, using portable air purifiers with combined HEPA filters and ultraviolet light sterilisation, showed that SAR-CoV-2 viral particles were undetectable in air samples when air purifiers were in use.
  - In 2023, researchers from University of NSW investigated indoor air quality strategies in classrooms through real-life tests, concluding that **the combination of natural ventilation plus air purifiers (with HEPA filters), was the most effective way to improve indoor air quality**.

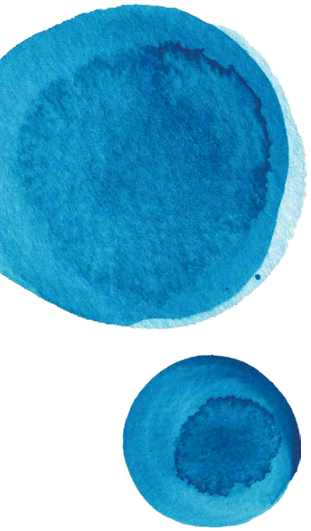
There are many portable air purifiers available, including some that are integrated into furniture.

An increasing body of data demonstrates ventilation and air purification systems can reduce transmission of airborne pathogens in real-world settings:

- A 2022 study of 10,000 Italian schools showed classrooms with **mechanical ventilation reduced the risk of COVID-19 infections in students by at least 74%**, compared with natural ventilation.
- A 2024 study of 100 classrooms at a school for students with intellectual and developmental disabilities in Rochester USA, demonstrated that **classrooms with better ventilation (lower CO2 levels) had fewer COVID-19 cases** and ventilation systems that also purified air using high quality filters had lower rates of COVID-19.

Other technologies

Germicidal ultraviolet light (GUV) has been shown in laboratory studies to successfully inactivate bacteria and viruses, preventing infections. A 2024 study proved the efficacy of GUV in removing pathogens in a real-world setting. Conducted by researchers from Columbia University Irving Medical Center, this study showed that far-UVC removed 99.8% of airborne pathogens in an occupied indoor location. Many other studies are underway globally, researching the safety, feasibility, and efficacy of GUV, including in Victoria.



6. Research

There is evidence that engineering interventions including air purifiers and germicidal ultraviolet light are effective, but there is a ‘knowledge gap’ in terms of the magnitude of benefits, how to optimise implementation in real-world settings, and how to best educate and engage the community. These elements form a research priority for those studying indoor air quality.

7. Innovate

Innovation in indoor air quality monitoring systems, data management, AI applications and real-world implementation is rapidly evolving and opens up many new business opportunities.

8. Refine

Continuous iteration and deployment of the most efficient and user-friendly solutions will accelerate and amplify progress.

9. Collaborate across disciplines

Many disciplines, sectors and portfolios are key stakeholders in indoor air quality improvement pathways. Good-spirited collaboration will foster knowledge transfer, an uplift in skills, thoughtful workforce and resource planning and a smoother, faster journey to a clean indoor air society.

10. Address key challenges

Temporary vs. Systemic solutions

In the short- to medium-term, temporary solutions are important, like asking room occupants to open windows and doors, and to turn on air purifiers. In the longer-term, systemic solutions will be required. This will see indoor air quality monitoring, ventilation and purification systems embedded into buildings, ideally with automatic settings that can scale up and down to accommodate different occupant numbers.

Indoor air quality and thermal comfort

> “Thermal comfort is an immediate thing, but the possibility of infection is a distant thing. Thermal comfort always wins. If you go into a naturally ventilated school and it’s cold, the windows will be shut and consequently there will be no ventilation. We’re never going to get decent indoor air quality without also guaranteeing thermal comfort.” **Prof Geoff Hanmer, Professor of Architecture, University of Adelaiden**

> “A critical engineering challenge is getting the best solution for maximising ventilation, while keeping buildings warm in winter and cool in summer, and minimising energy and therefore carbon use.
> **UK Chief Medical Officer’s Annual Report 2022: Air Pollution**

Indoor air quality improvements and the impact on energy efficiency

> “I want to create healthier environments *and* reduce energy. In our study on a building in the City of Melbourne, we reduced energy consumption by 20% and demonstrated 83% reduction in virus transmission (a proxy for air quality).”
> **Dr Dominique Hes, Former Zero Carbon Building Lead at City of Melbourne**

Skills gap

> “From an implementation level, we found that industry expertise was limited outside of the HVAC engineers, and there is an implementation or a technical assistance gap that needs to be filled.”
> **A/Prof Suman Majumdar, Chief Health Officer – COVID & Health Emergencies, Burnet Institute**

> Do we have the technology to provide clean air? Yes, we do. We don’t need decades of research to figure out how to clean the air. Do we have the technology available that the market wants? We don’t. We need to figure out how to get that technology to the market.”
>
> **Prof Jason Monty, Head of Department of Mechanical Engineering, University of Melbourne**

THE ECONOMIC CASE FOR CLEAN INDOOR AIR

A critical step to galvanise action is demonstrating the value of improved indoor air quality, and quantifying the economics and investment case.

Cost of the status quo

There is no current comprehensive estimate of the impacts of poor indoor air quality – incorporating the full suite of pollutants and airborne diseases – on health and the economy. Drawing from the following data – each study focusing on just one or a selection of indoor air quality impacts, **the cost of NOT addressing indoor air quality is substantial**.

AU$12 billion per annum, nationally, due to health impacts and lost productivity

- Estimate from 1998 CSIRO report, noting in the press release "…a clear need for Australia to improve indoor air quality…".

AU$1.6 billion per annum

- Economic burden from all lower respiratory infection in Australia in 2018-2019, as per the Australian Institute of Health and Welfare.

In August 2024, a study published in Nature Medicine estimated that 400 million have had long COVID since the beginning of the pandemic, with an estimated **annual economic impact of US$1 trillion**.

AU$211 million per year for health impacts of bushfire smoke (yearly average from 2000 to 2019) and AU$1.95 billion for 2019/2020 bushfire season

- Annual cost of health impacts of bushfire smoke in Australia, calculated in a 2020 study by University of Tasmania.

A cost benefit analysis produced by the Royal Academy of Engineering in the UK in June 2022, found the annual expected costs of influenza-type pandemics are £15 billion, plus £8 billion for seasonal influenza. The combined total of £23 billion equated to 1% of the UK's GDP in 2020.

The economic benefits of improving indoor air quality:

In October 2023, the Journal of the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) published a piece by public health economist, Dr Richard Bruns, estimating a **cost-benefit ratio of 1:10 for investment in improved indoor quality**. Bruns estimated US$4 billion would be required to improve indoor air quality in all US buildings for 16 weeks each year (to coincide with the coldest weather, when people spend most time indoors) resulting in an estimated US$40 billion benefit from COVID-19 infection risk reduction alone. Bruns also estimated an additional US$20-40 billion in value of other benefits, including reduction of other airborne diseases and increased productivity.

The *Indoor Air Quality Scientific Findings Resource Bank*, run by Lawrence Berkeley National Lab in the US, published a summary – The National Benefits of Increased Ventilation Rates, estimating **increasing ventilation rates in 30-40% of US offices (those with the worst ventilation) would result in an annual benefit of US$13.5 billion** through enhanced productivity, reduced absence rate and better health.

"Just for Melbourne **if we reduce building carbon impact and improve air quality, it will contribute AU$2.7 billion to the Victorian economy** over the next 18 years, provide 12,000 jobs by 2040 and reduce energy costs by around AU$184 million per year."
Dr Dominique Hes, Former Zero Carbon Building Lead at City of Melbourne.

"What we find is **if you make these (indoor air quality) improvements, it leads to reductions in absenteeism, better cognitive function, and leads to 10% gains to the bottom line**…whether you look at an individual level, a business level, an investor level, owner level, a societal level, there's a business case to be made."
Associate Professor Joseph Allen, Director, Harvard University Healthy Buildings Program"

"Ventilation is seen as a negative cost to the market. But that's not true. Our research shows better indoor air quality can reduce energy use. There's a payback period for the capital cost, which is 10-15 years at February 2022 energy prices – which were less than half of what they are now. **So, the payback period is short.**"
Prof Jason Monty, Head of Department of Mechanical Engineering, University of Melbourne

"The Australian economy is ~AU$2 trillion. If we can improve productivity by 1% across the economy, through better indoor air quality, we would deliver an **AU$20 billion** payoff per year, in perpetuity."

The Hon. Robin Scott, Former Victorian Minister (Finance, Assistant Treasurer and Multicultural Affairs)

INTERNATIONAL DEVELOPMENTS

International action on clean indoor air is gaining momentum with major initiatives taking place in multiple jurisdictions.

- In 2024, an international group of experts from 40 universities published a landmark paper in Science: *Mandating indoor air quality for public buildings*, documenting consensus guidelines proposing four key aspects of indoor air quality, to form the cornerstone of indoor air quality standards.
- In 2024, the World Health Organization, in partnership with the European Organisation for Nuclear Research (CERN) published an online tool that enables users and building managers to assess the risk of COVID-19 airborne transmission in residential, public, and healthcare settings.
- In 2024, Our Common Air was launched, an independent commission led by high profile co-chairs – the Right Hon Helen Clark, former Prime Minister of New Zealand, and Dr Soumya Swaminathan, former World Health Organization Chief Scientist. The commission aims to catalyse global action on clean air.
- Following the International Labour Organization's (ILO) introduction of Technical Guidelines on Biological Hazards in the Working Environment, Member States resolved in 2024 to continue work on this topic, with view to adoption of a formal Convention in 2025.
- In 2022, the United Nations General Assembly adopted a resolution recognising the human right to a clean, healthy and sustainable environment, including clean indoor air.
- In 2022, the *Evidence Driven Indoor Air Quality Improvement* project was launched, led by Lisbon Council. It is a European funded research project, that will study indoor air pollution in European cities, aiming to understand the sources and health effects of indoor air pollution, and to assist in development of sustainable strategies to improve indoor air quality.
- In 2021 the World Health Organization published Global Air Quality Guidelines outlining recommendations for both outdoor and indoor exposure limits for six key pollutants (PM2.5, PM10, NO2, SO2, CO and O3). Additional pollutant limits have been specified in subsequent guidelines. These guidelines represent a key foundation for global action on indoor air qualityw.
- In 2024 the European Union tightened outdoor air quality limits but still fell short of adhering to the 2021 WHO guidelines.
- In 2021, at the United Nations Climate Change Conference (COP26), the World Economic Forum (WEF) launched the Alliance for Clean Air, with a focus on reducing air pollution. Multiple WEF articles have since focused on action required to improve indoor air quality.

World Health Organization

International Labour Organization

European Organisation for Nuclear Research

EU

United Nations General Assembly

School-focused actions

New Zealand

- In 2023, the New Zealand Government launched a public awareness campaign video to educate the public about the importance of ventilation in reducing the risk of COVID-19 transmission. New Zealand's highly awarded *Unite Against COVID-19* communication platform was used.
- In 2022, New Zealand schools were supplied with CO2 monitors and air purifiers.

Australia

- In August 2024, the Australian National Science and Technology Council released a report – The impact of indoor air quality on the transmission of airborne viral diseases in public buildings.
- In July 2024, the Victorian Government announced funding of $9.87 million for a two-year project – the Pathway to Clean Indoor Air in Victoria – to evaluate indoor air quality and mitigation measures in public spaces, including schools and workplaces.
- In July 2024, Thrive was launched – the Australian Research Council Training Centre for Advanced Building Systems against Airborne Infection Transmission. Hosted by Queensland University of Technology, the $5 million training centre brings together academic and industry experts to develop sophisticated building systems.
- In June 2024, the Victorian Department of Health announced a new clinical trial, the ELUCIDAR study, trialling ultra-violet light technology in aged care homes, aiming to reduce transmission of COVID-19 and other airborne diseases.
- In 2023, Air Quality was listed as a key indicator in Measuring What Matters - Australia's First Wellbeing Framework.
- In 2022, Western Australia's Department of Health released building ventilation guidelines for COVID-19 mitigation. The guidelines were updated in 2023.
- In 2021 in Victoria, public schools received air purifiers for each classroom. The Victorian Government regularly updates detailed guidance regarding optimal Ventilation and Air Purification for schools.
- Indoor air quality was discussed in the 2021 Department of Climate Change, Energy, the Environment and Water's 'Australia State of the Environment' report.
- In 2021, University of Queensland School of Electrical Engineering and Computer Science developed the Study Fresh Project, monitoring indoor air quality in classrooms and educating students.

"Ensuring that the air the children in our community and nationwide are breathing at school is clean and safe is a fundamental priority"

Congressman Brian Fitzpatrick

School-focused actions

USA

- In July 2024, the *Indoor Air Quality and Healthy Schools Act* was introduced to US congress. The bipartisan legislation would require the US Environmental Protection Authority to establish a list of significant indoor contaminants, develop health-based, voluntary guidelines to reduce exposure risks, develop or recognise voluntary indoor air certifications for buildings, establish a national assessment of IAQ in schools and childcare facilities, and support development of technical assistance, guidelines, and best practices to improve IAQ in these facilities.
- In July 2024, Congressman Beyer reintroduced the Airborne Act into US congress, legislation that proposes tax credit incentives for non-residential building owners to do indoor air quality assessments and upgrade ventilation and air filtration.
- In April 2024, the USA government's Advanced Research Projects Agency for Health (ARPA-H) launched the Building Resilient Environments for Air and Total HEalth (BREATHE) program, which is a platform aiming to improve indoor air quality across the country. BREATHE aims to spark the generation of smart buildings that can continually assess, measure, and report indoor air quality and deploy real-time interventions, such as extra ventilation or disinfection, to reduce airborne threats to human health.
- In 2024 the US Environmental Protection Authority announced grant funding to address indoor air pollution at schools.
- In 2024 the White House held a *Summit for Sustainable and Healthy Schools*, and released the White House Toolkit for Sustainable and Healthy K-12 Schools which details guidance and available grants to support schools to uplift building infrastructure, including attention to indoor air quality.
- In 2024 the second round of funding for US public schools will be distributed, as part of the Renew America's Schools Program, a US$500 million program aiming to help schools make energy upgrades, improve indoor air quality, and foster healthier learning environments.
- In 2023, the US standard setting organisation – American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) published a new Indoor Air Quality Standard – Standard 241 – for new and existing buildings, explicitly to mitigate risk of airborne disease.
- In 2023, John Hopkins University published a *Model Clean Indoor Air Act*, for consideration by state legislatures to help improve indoor air quality in public buildings.
- In 2023, the US Centre for Disease Control (CDC) determined a health-based ventilation target for indoor air (at least five air changes per hour) and issued guidance on Ventilation in Buildings.
- In 2023, the US Environmental Protection Agency published a suite of online resources to help schools improve indoor air quality.

School-focused actions

- In 2023, the Illinois Government announced a program to provide 20,000 air purifiers to improve air quality in day care centres.
- In 2023, the California Department of Public Health – issued guidance on Improving Air Quality in Schools, covering monitoring with CO2 devices (noting 800ppm as the level required for action), uplifting natural and mechanical ventilation and use of air purifiers.
- In 2023 the City of Philadelphia announced a program to supply air purifiers to early childhood education centres and schools.
- In 2023 a Bill was introduced into the Massachusetts Senate for legislation to improve student and staff attendance and performance by ensuring CO2 monitoring in schools.
- In 2023, the Colorado Department of Health and Environment and University of Colorado Boulder, commenced a study to determine the impact of live CO2 monitoring and air purifiers in schools.
- Connecticut invested US$200 million to install mechanical ventilation units into school buildings between 2022 and 2024, to 'ensure clean and healthy air, which not only is good for health, of course, but also better for learning'.
- In 2022, the New York City Senate and Assembly passed the Schools Impact by Gross Highways Act, prohibiting the construction of new schools near highways, to protect children from air pollution.
- In 2022 the White House, in collaboration with the United States Environmental Protection Agency (EPA), the Department of Energy and other federal agencies, launched the *Clean Air in Buildings Challenge*, calling on organisational leaders and building owners and operators to create a clean indoor action plan, optimise ventilation and air filtration and educate occupants. Organisations are being encouraged to publicly Pledge their commitment.
- In 2022 the White House held a Clean Indoor Air Quality Summit.
- In 2021, Boston Public Schools In 2021, Boston Public Schools commenced a world-leading indoor air quality program, by installing air quality sensors in all classrooms, hallways and nurses stations, in over 120 schools.
- 687 schools in Berkeley California have live indoor air quality monitoring systems installed.
- In Albuquerque, 35 public schools are replacing HVAC units at a cost of over $16 million, to improve indoor air quality.
- Denver's public schools have IAQ monitoring sensors in classrooms, with data publicly available.
- In 2024, two Illinois schools implemented indoor air quality monitoring, in collaboration with the American Society of Heating, Refrigerating and Air Conditioning Engineers. The project includes data collection, education and hands-on workshops.

Canada

- A Bill - Improving Air Quality for Our Children Act, 2023 – is currently being considered by the Legislative Assembly of Ontario. The Bill calls for indoor air quality measurements, standards, and action plans to be implemented by publicly funded schools and childcare providers.
- Schools in British Columbia and Ontario have received significant funding to uplift air quality in recent years.
- In 2022, the Ontario Society of Professional Engineers formed the Indoor Air Quality advisory group and has since published a suite of educational resources.

School-focused actions

Ireland

- In 2023, Ireland's Health and Safety Authority published a Code of Practice for Indoor Air Quality, applying to all places of work, covering CO2 monitoring, ventilation and air filtration.
- The Code of Practice requires employers to develop policies, conduct risk assessments and implement control measures to address indoor air quality and ventilation in the workplace.

UK

- In 2024, Sadiq Khan – Mayor of London announced a new pilot program of installing air filters in 200 schools across London.
- In 2023, the UK's SAMHE project (Schools' Air quality Monitoring for Health and Education) was launched, placing indoor air quality monitors into over 1000 schools.
- In 2023, the British Standards Institution, the UK's national standards body, published a new code of practice regarding health and well-being and indoor environmental quality, covering four key factors, one of which is air quality.
- In 2023, the UK Parliament's Environmental Audit Committee launched an inquiry into outdoor and indoor air quality targets. The report is soon to be delivered.
- In 2022, the UK's National Engineering Policy Centre delivered a comprehensive report *Infection resilient environments: time for a major upgrade*, noting the lessons of COVID-19 called for an uplift in clean indoor air measures to ensure healthier indoor environments.
- In 2022, a Clean Air (Human Rights) Bill was introduced into the UK parliament, to establish the right to breathe clean air. The Bill – referred to as 'Ella's Law', in honour of Ella Adoo Kissi Debrah, the first person in England to have air pollution named as cause of death by a coroner – has completed passage through the House of Lords and is now in the House of Commons.
- In 2022, Chief Medical Officer Sir Chris Whitty published his Annual Report on air pollution, with five of 15 recommendations concerning indoor air, including a call for prioritisation of indoor air quality research.
- In 2021, the UK Government announced that 300,000 CO2 monitors would be provided to all state-funded education settings, to enable staff to identify when ventilation required improvement.

School-focused actions

France

- In 2023, indoor air quality monitoring, and limits requiring action were embedded in the French Environmental Code, with focus on schools and childcare. This code will expand to cover elderly care and nursing facilities in 2025.
- From July 2023, regulation prohibits the construction of new schools near heavily polluted roads in Paris, to preserve indoor air quality for students and staff and in recent years, Paris has closed over 200 school streets to fight air pollution, as part of its *Rue aux Écoles* program.

Belgium

- In 2022, the Belgian government introduced a new legal framework to improve indoor air quality in all enclosed areas accessible to the public.
- This includes a CO2 monitor display being mandatory in all public indoor spaces, the development of a new certification system and notification that more rigorous obligations will follow, after a transition period.

Netherlands

- Legislation governing ventilation in schools and workplaces came into force in 2023, obliging employers to guarantee air quality and, if necessary, take measures to improve it.
- In 2023, the €4.3 million Clean Air for Everyone (CLAIRE) project was launched – a collaboration between 17 universities, research institutes, companies and industry associations, working together to study the impact of improving indoor air quality in schools and nursing homes.
- In 2022, the Dutch Minister for Primary and Secondary Education announced a package to uplift ventilation in schools, including a CO2 monitor for every classroom, a ventilation hotline and subsidised air purifiers.

School-focused actions

Germany

- 2200 schools and 28 nurseries in Lubeck, Germany are fitted with real-time indoor air quality monitoring systems.

Italy

- In 2024, Italo, a provider of Italian high-speed train announced installation of a new innovative ventilation and air purification system including HEPA filters, vertical air flow and complete air changes every three minutes, to reduce pollution, bacteria, allergens and viruses in the air.

Latvia

- In 2022, 14,000 classrooms in 875 Latvian schools were fitted with air quality monitors displaying CO2, temperature and humidity, in a €4.3 million program to improve health of pupils and educators, and to reduce risk of spreading infections. Data is displayed on a public dashboard.

Serbia

- In 2023 the Secretariat for Environmental Protection of the city of Belgrade announced a tender for 11,500 air purifiers, to install in pre-school and school facilities, to reduce exposure to outdoor air pollution.

Estonia

- In 2023, Estonian researchers developed DigiAUDIT, a digital platform that monitors CO2 concentration, room temperature and energy use in real time, to better inform analysis and action on indoor air quality.

Switzerland

- In 2023, Switzerland hosted the first WHO/European Indoor Air Quality Conference.

School-focused actions

South Korea

- South Korea was the first country in the world to introduce an Indoor Air Quality Control Act, which it did in 2005, with the most recent amendments adopted in 2023.
- Before the COVID-19 pandemic, Seoul Metro already used air quality monitors and air purifiers. In 2020, Seoul Metro installed additional high-performance air purifiers on subway platforms to improve ventilation for the underground environment.
- The Seoul Metropolitan Government has a policy for Indoor Air Quality Control at Public Use Facilities, including a *Clean Indoor Air Certification System* and an Indoor Environment Management System that publicly discloses air quality data in all public use facilities.
- In 2020 the Seoul Global Challenge was launched to encourage innovative solutions to improve air quality in subways, to reduce exposure to pollutants and viruses.

Japan

- In 2020, a variety of Japanese businesses, including concert venues, restaurants, and airports, installed large CO2 monitor displays to inspire public confidence in adequate ventilation.

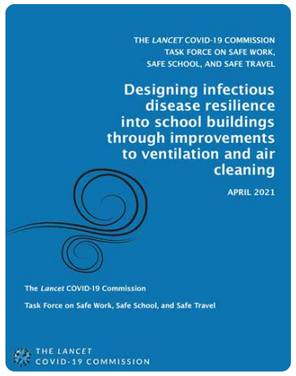
Taiwan

- The Taiwan Government began regulating indoor air quality in 2012 (the second country to do so after South Korea) and implemented a self-managed indoor air quality certification in 2021.

Hong Kong

- Many major hotels in Hong Kong, including the Dorsett, Fullerton, Renaissance, Langham and Best Western, have deployed air purifiers in hotel rooms and hallways.
- In 2023, a 'Clean Air for Schools and Beyond' Forum was held in Hong Kong, highlighting data that revealed concerning levels of CO2 and pollutants in schools, and reviewing potential corrective strategies.
- Prior to the pandemic, Hong Kong employed a self-regulation approach through publication of resources including Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places.

CASE STUDIES OF EARLY ADOPTERS



The broad range of positive health and academic impacts from improved indoor air quality was detailed in the 2021 Lancet COVID-19 Commission: Designing infectious disease resilience into school buildings through improvements to ventilation and air cleaning

Case Study 1: Schools

Globally, schools have been early movers for researching, innovating, piloting, regulating and embedding indoor air quality into standards, guidelines and in some places law, addressing both air pollution and infection control.

> "I want every single child to breathe clean air in and around their school. In those vital early years, the difference to young people's health and well-being can be life changing."
> **Mayor of London, Sadiq Khan**

Indoor Air Quality Research in Schools

- A 2024 study of 100 classrooms at a school for students with disabilities in Rochester USA, demonstrated that **classrooms with better ventilation (lower CO2 levels) had fewer COVID-19 cases** and ventilation systems that also purified air using high quality filters had lower rates of COVID-19.
- A 2024 US study found when sized and placed adequately, portable air cleaners supplement existing ventilation systems to help remove airborne pathogens and mitigate disease transmission in learning environments.
- In 2023, preliminary results of the CLASS-ACT study (Classroom Air Cleaning Technology Study), which researched 30 schools in Bradford, UK, showed that **schools randomised to using air purifiers with HEPA filters had a reduced rate of absences due to illness compared to schools without them and a 48% reduction in exposure to particulate matter**.
- A 2023 study of 144 US classrooms, showed higher ventilation rates significantly reduced student illness-related absences.
- A 2022 study of 10,000 Italian schools showed classrooms with **mechanical ventilation reduced the risk of COVID-19 infections in students by at least 74%**, compared with natural ventilation.
- A 2022 US study of five schools within seven miles of an international airport showed that portable air purifiers effectively lowered the concentration of ultra-fine particles in classrooms, from ~50% to ~10% of outdoor levels.

CLEAN AIR MAKES CLEVER KIDS!

Benefits of improved indoor air quality in schools, in addition to reducing infectious disease

Impact	Context	Findings
↑ Test scores	Ventilation renovations were completed to improve IAQ in all school buildings within a single Texas school district	Math and reading test scores significantly improved, with an increased probability of passing by 2% and 3%, respectively.
↑ Cognitive function	CO2 concentrations were measured as a proxy for ventilation rates in classrooms.	Cognitive testing of students shows a 5% decrease in 'power of attention' in poorly ventilated classrooms. Researchers equate this to the effect of a student skipping breakfast.
↑ Math, reading, and science scores	Classroom ventilation rates were measured in 140 fifth grade US classrooms.	Mean mathematics scores increased by up to 0.5% per each liter per second per person increase in ventilation rate, with similar effects on reading and science scores.
↓ Asthma symptoms	Exposure factors were measured in 100 primary and secondary school classrooms with and without new ventilation systems.	Pupils who attended schools with new ventilation systems reported fewer asthmatic symptoms.
↓ Respiratory symptoms ↓ Missed school days	Over 4,000 sixth graders from 297 schools participated in a survey of indoor environmental quality in schools	Lower ventilation rates, moisture, and dampness were all independently associated with a higher incidence of respiratory symptoms. Inadequate ventilation was also associated with more missed school days.
↓ Child absenteeism	Increased ventilation rates and child sick days were studied for 635 children attending 20 daycare centers in Denmark.	A 12% decrease in sick days was found per hour increase in the air exchange rates.
↓ Missed school days	CO2 as a proxy for ventilation was studied in 60 naturally ventilated primary school classrooms in Scotland.	For each 100 ppm increase in time average CO2 concentration, student attendance decreased by about 0.4 days per year.
↓ Illness absence	CO2 concentration was measured continuously over two years in 162 US primary school classrooms with a mixture of mechanical and natural ventilation	For each 1 L/s (2.2 cfm) per occupant increase in ventilation rate, illness absence decreased 1.6%.

2021 Lancet COVID-19 Commission: Designing infectious disease resilience into school buildings through improvements to ventilation and air cleaning

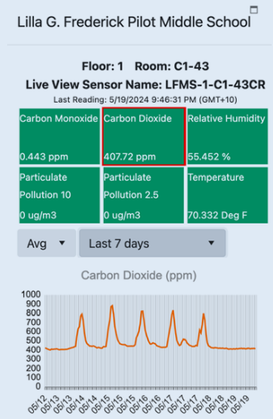
Repeated infectious diseases in children result in significant school absences and increase the risk of long-term health problems including long COVID. In addition the cognitive and IQ impacts of COVID-19 are concerning.

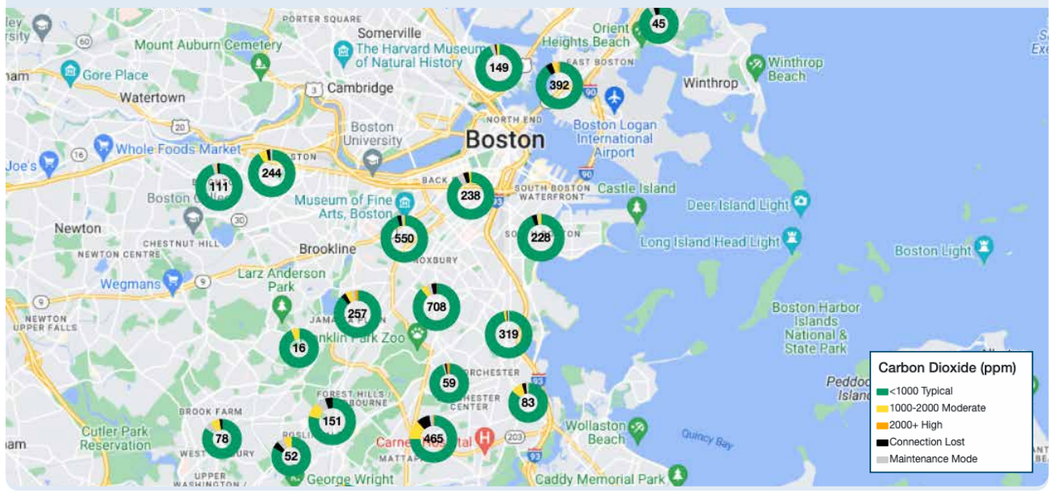
Best practice in schools

In 2023, the **UK's SAMHE project** (Schools' Air quality Monitoring for Health and Education) was launched, a collaboration between five UK universities and the UK Health Security Agency. The project involves establishing a network of air quality monitors in schools across the UK, to generate data for scientists studying school indoor air quality. **More than 1000 schools have joined, benefiting from free air quality monitors, linked to an interactive App**.

In 2021, **Boston Public Schools** commenced a world-leading indoor air quality program, by installing air quality sensors in all classrooms, hallways and nurses stations, in over 120 schools:

- Sensors report information in real-time on six key measures of indoor air quality.
- A roof-top monitoring unit was also installed in every school building to measure outdoor air quality as a baseline per location.
- A dashboard was built to display data in real time, to engage the whole school community.
- Data collected helps identify and respond to indoor air quality issues, and advocate for building investments.
- Boston Public Schools partnered with Boston University to conduct research regarding the implementation and impacts of the program.
- Details on the standards, response actions, and strategies for achieving optimal ventilation in classrooms can be viewed on the school Boston Public Schools website.





Science curriculum activities:

The Corsi-Rosenthal box, a do-it-yourself, highly effective air purifier, made from inexpensive materials, was created in August 2020 to remove airborne virus and prevent COVID-19 infections. Dr Richard Corsi, Dean of Engineering at University of California, Davis, and Jim Rosenthal, CEO of Tex-Air Filters, devised the concept, which has now been embedded into science curriculums in hundreds of schools across the US. See this instruction video to learn more.

Making Corsi-Rosenthal Boxes is a fun and engaging student activity

School infrastructure is commonly suboptimal for indoor air quality:

- In 2022, it was reported that two thirds of schools assessed in a Queensland University study, recorded high carbon dioxide levels consistent with high-risk of airborne disease transmission.
- The US Government Accountability Office surveyed schools in 2020 and estimated that 41 percent of districts needed to update or replace heating, ventilation and air conditioning (HVAC) systems in at least half of their schools, representing 36,000 schools nationwide that needed HVAC updates.

Studies in New Zealand also show improved student performance and lower absenteeism with lower CO2 levels in classrooms

INDOOR CO2 LEVEL PPM	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000
INDICATIVE EFFECT ON NORMALISED STUDENT PERFORMANCE			110%	105%			100%					95%		90%
INDICATIVE EFFECT ON TOTAL SCHOOL ABSENCE				5%										15%

Adapted from New Zealand Ministry of Education: Designing Quality Learning Spaces – Indoor Air Quality and Thermal Comfort, 2022

Case Study 2:
The White House seeks collective action through a Pledge

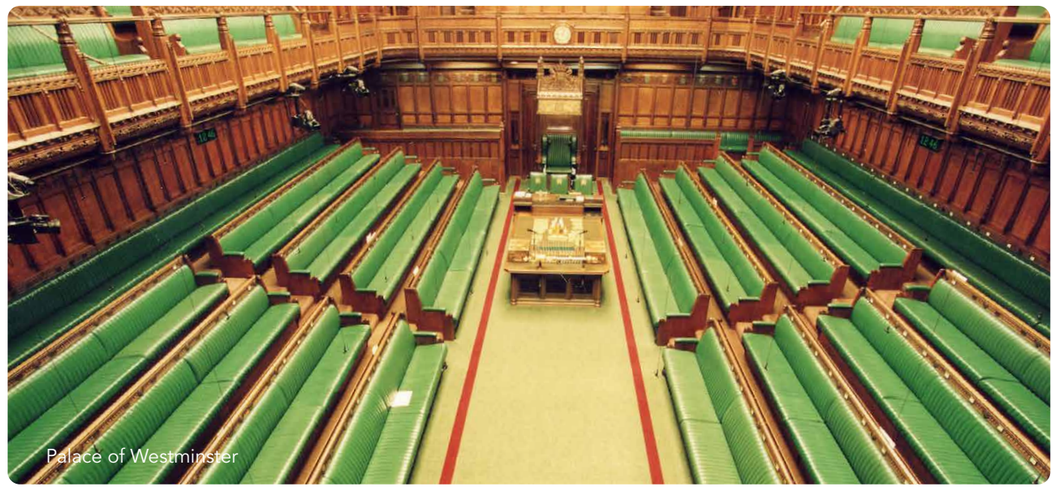
In 2022 the White House, in collaboration with the United States Environmental Protection Agency (EPA), the Department of Energy and other federal agencies, launched the Clean Air in Buildings Challenge, calling on organisational leaders and building owners and operators to create a clean indoor action plan, optimise ventilation and air filtration and educate occupants. Organisations are being encouraged to publicly Pledge their commitment.

Case Study 3:
Private sector action: Amazon

In 2023, Amazon rolled out a real-time air quality monitoring network across its global commercial office portfolio, to uplift worker productivity and to align action with occupational health and safety requirements.

Case study 4:
Palace of Westminster (UK Houses of Parliament)

In 2021, air filtration solutions in the Palace of Westminster were incorporated into existing HVAC systems, to improve indoor air quality so airborne viruses and bacteria would be kept to an absolute minimum, and wellbeing and productivity would be enhanced.



Palace of Westminster

Case study 5:
City of Melbourne

City of Melbourne conducted a pilot study called BREATH, evaluating three different ventilation systems in a vacant building. The study found that *displacement ventilation air conditioning* proved the most effective and energy-efficient system of those tested. Modelling suggested these methods would reduce virus transmission by 83% and reduce energy consumption by 20%.

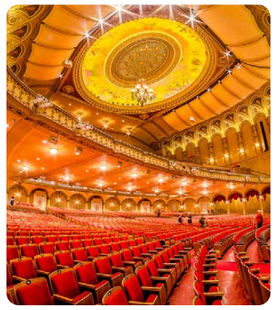
> "BREATH is a world-first collaboration between local government, industry and academics, which has given us the knowledge to predict the best type of retrofit to simultaneously reduce carbon footprint and infectious disease transmission."
> **Professor Jason Monty, Head of Mechanical Engineering, University of Melbourne**

Researchers investigated the best way to simultaneously improve indoor air quality and energy efficiency

Melbourne, Australia

Case study 6:
The Orpheum theatre, Vancouver

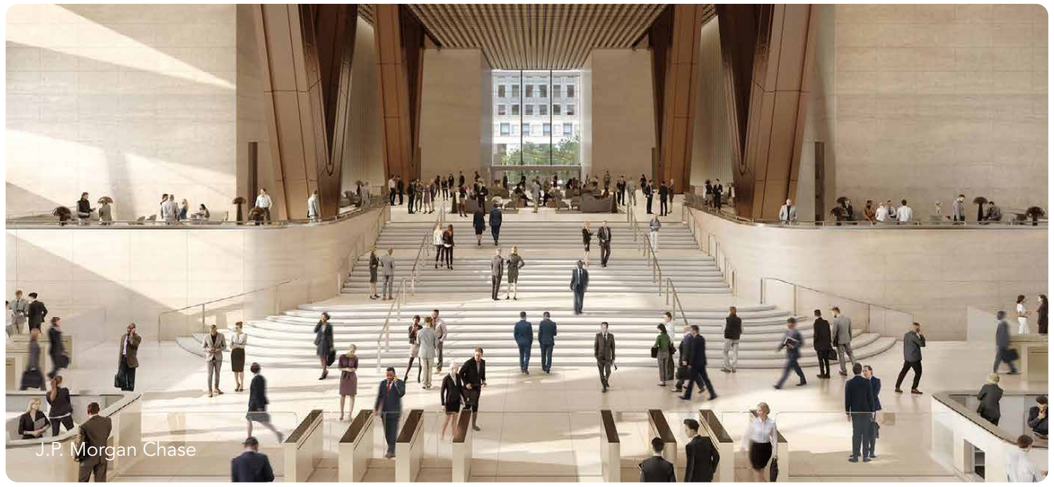
Built in 1927, following the Spanish Flu pandemic, this theatre was built with the explicit aim of being 'pandemic proof'. Air was brought from the outside and blown through a series of water sprays or screens, heated, then forced through a series of ducts that opened beneath each seat. Recent CO2 measurements by members of the public, during live performances, appear to demonstrate that the ventilation system remains fit for purpose to this day.



Fresh air is delivered by a pipe opening beneath each seat in the Orpheum theatre. The ventilation system, installed in 1927, remains fit for purpose in 2024, ensuring excellent ventilation, despite large audiences.

Case Study 7:
Private sector action: J.P. Morgan Chase

In 2023, JP Morgan Chase, the largest bank in the US, unveiled its new global headquarters in New York. The 60-story skyscraper has net zero operational emissions and exceptional indoor air quality that 'exceeds the highest standards in sustainability, health, and wellness'. The stated aim of this design is to 'champion occupant health, wellness and productivity'.



J.P. Morgan Chase

IMPROVED INDOOR AIR QUALITY FRAMEWORK

Hazard	**Pathogens** e.g. Flu, COVID, TB, Measles, Whooping cough	**Pollutants** e.g. bushfire smoke and pollutants (PM2.5), allergens
Detection	Real Time Air Quality Measurement	Real Time Air Quality Measurement
Mitigations	Reduce number of people in a room Natural ventilation – open windows/doors to let fresh air in Mechanical ventilation – increase air changes Germicidal UV Light	Portable air cleaner/ HEPA N95/P2 masks Close windows/doors to keep contaminants out Mechanical ventilation – reduce outdoor air leaks
Outcomes	↓ Infections ↑ Health ↑ Mental Capacity ↑ Productivity ↓ Allergies ↓ Pollutants	

SELECTED RECENT ARTICLES

Global articles:

Title: Mandating indoor air quality for public buildings
Authors: Prof Lidia Morawska et al
Publication: Science, 2024

Title: Lessons from the COVID-19 pandemic for ventilation and indoor air quality
Authors: Prof Lidia Morawska et al.
Publication: Science, 2024

Title: Global technical consultation report on proposed terminology for pathogens that transmit through the air
Authors: WHO
Publication: WHO website publications, 2024

Title: It's time to clean the germs out of our indoor air
Author: Blake Murdoch
Publication: Edmonton Journal, 2024

Title: Mounting research shows that COVID-19 leaves its mark on the brain, including significant drops in IQ scores
Author: Dr Ziyad Al-Aly
Publication: The Conversation, 2024

Title: Predicting building ventilation performance in the era of an indoor air crisis
Authors: Yuguo Li, Pan Cheng, Li Liu, Ao Li, Wei Jia and Nan Zhang
Publication: Tsinghua University Press, 2023

Title: WHO's departing chief scientist regrets errors in debate over whether SARS-CoV-2 spreads through air
Author: Kai Kupferschmidt
Publication: Science, 2022

Title: The First Four Healthy Building Strategies Every Building Should Pursue to Reduce Risk from COVID-19
Co-author: Prof Lidia Morawska as part of the Safe Work, Safe School, and Safe Travel Task Force
Publication: The Lancet COVID-19 Commission, 2022

Title: A paradigm shift to combat indoor respiratory infection
Authors: Prof Lidia Morawska et al.
Publication: Science 2021

Title: Indoor Air Quality in Buildings: A Comprehensive Review on the Factors Influencing Air Pollution in Residential and Commercial Structure
Authors: Mehzabeen Mannan, Sami G Al-Ghamdi
Publication: Int J Environ Res Public Health, 2021

Australian articles:

Title: Evaluating portable air cleaning effectiveness in residential settings to reduce exposures to biomass smoke resulting from prescribed burns
Authors: Amanda Wheeler et al
Publication: Public Health Research and Practice, 2023

Title: Indoor air is full of flu and COVID viruses. Will countries clean it up?
Author: Dyani Lewis (Australia)
Publication: Nature, 2023

Title: Getting off gas – Why, how and who should pay?
Authors: Tony Wood, Alison Reeve and Esther Suckling
Publication: Grattan Institute, 2023

Title: Majority of Queensland classrooms record higher carbon dioxide levels increasing COVID-19 risk, study shows
Authors: Janelle Miles and Emma Pollard
Publication: ABC News, 2023

Title: Healthy indoor air is our fundamental need: the time to act is now
Authors: Prof Lidia Morawska, Prof Guy B Marks and Prof Jason Monty
Publication: The Medical Journal of Australia, 2022

Title: Australia must get serious about airborne infection transmission. Here's what we need to do
Author: Prof Lidia Morawska
Publication: The Conversation, 2021

Title: Beating the $12 Billion Cost of Polluted Air
Author: Steve Brown
Publication: CSIRO Media release, 1998

New Zealand article:

Title: Airborne transmission: a new paradigm with major implications for infection control and public health
Authors: Anna Stevenson, Joshua Freeman, Mark Jermy, Jason Chen
Publication: The New Zealand Medical Journal, 2023

UK articles:

Title: Hidden harms of indoor air pollution – five steps to expose them
Co-author: Prof Chris Whitty, Chief Medical Officer of England
Publication: Nature, 2023

Title: Indoor Air Quality (IAQ) monitoring should be 'standard practice' says Whitty
Author: Building Engineering Services Association
Publication: FM Business Daily, 2023

Title: Good ventilation a public health priority
Author: Sandra Rossi
Publication: Climate Control News, 2023

European articles:

Title: Air pollution 'aged' hospital Covid patients by 10 years, study shows
Author: Damian Carrington
Publication: The Guardian, 2023

Title: Infectivity of exhaled SARS-CoV-2 aerosols is sufficient to transmit covid-19 within minutes
Authors: Malin Alsved et al
Publication: Scientific Reports, 2023

Title: Belgium imposes ventilation rules for businesses to combat new Covid surge: Carbon dioxide monitors must be on public display so customers can see level of fresh air
Author: Naomi O'Leary
Publication: Irish Times, 2021

USA articles:

Title: A healthy building starts with better ventilation
Author: Prof Joseph G. Allen
Publication: Harvard Public Health, 2023

Title: We might be on the verge of an indoor air quality revolution
Author: Prof Joseph G. Allen
Publication: The Washington Post, 2023

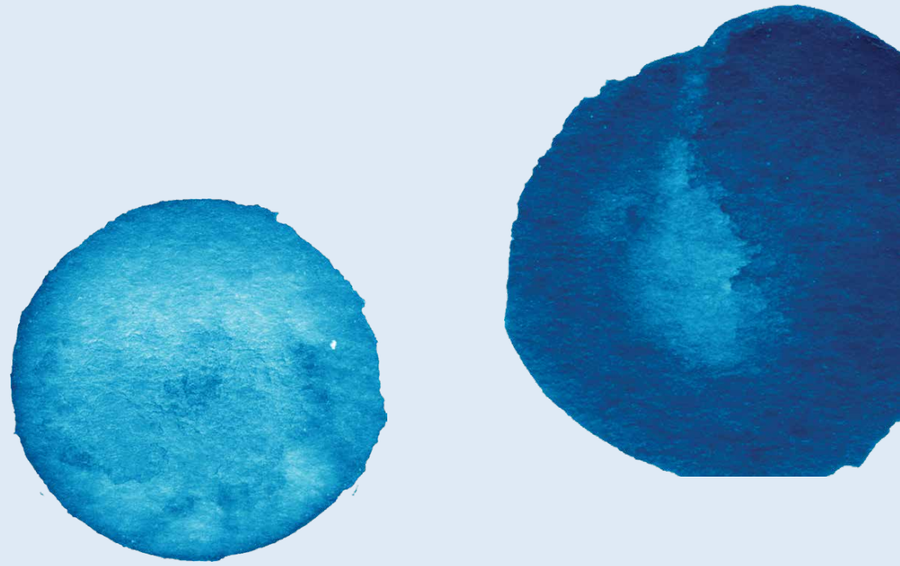
Title: The CDC takes a step toward virus-free air in schools and offices
Authors: Washington Post Editorial Board
Publication The Washington Post, 2023

Title: Making the Air in the Office Cleaner
Authors: Devabhaktuni Srikrishna, Abraar Karan, and Ranu S. Dhillon
Publication: Harvard Business Review, 2023

Title: 270 Park Avenue: The largest all-electric, 97% up-cycled tower on New York City's skyline
Author: Emily Bagshaw
Publication: Material Source, 2023

Title: Designing Buildings that Are Both Well-Ventilated and Green
Author: Prof Joseph G. Allen
Publication: Harvard Business Review, 2023

Title: Investing in indoor air quality improvements in schools will reduce COVID transmission and help students learn
Authors: Patricia Fabian, Johnathan Levy
Publication: Boston university School of Public Health, 2022



"CLEAN INDOOR AIR IS THE LOWEST HANGING FRUIT FOR TRANSFORMATIONAL PUBLIC HEALTH CHANGE"

Professor Brendan Crabb AC, CEO Burnet Institute

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