NSW Legislative Council's Portfolio Committee No. 2 – Health

Inquiry – Indoor Air Quality

THRIVE welcomes the invitation to provide a submission to this committee regarding indoor air quality. THRIVE, the Australian Research Council Training Centre for Advanced Building Systems Against Airborne Infection Transmission, was established in 2023 with the aim of engineering building systems whose elements work together to reduce airborne infection transmission by improving indoor air quality while maintaining comfort and efficiency. THRIVE's Director is Distinguished Professor Lidia Morawska, a world-leading expert in indoor air quality, a Fellow of the Australian Academy of Science, International honorary Member of the American Academy of Arts and Sciences, advisor to the World Health Organisation, and recipient of the 2025 Prime Minister's Prize for Science.

THRIVE's submission is presented under the headings used in the Inquiry's Terms of Reference. For more in-depth information on any of the issues raised below, please refer to the provided reference list.

Impacts of poor IAQ

'*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*.' Air pollution is a significant societal risk that negatively affects health and wellbeing, accessibility and the economy, and most human exposure occurs indoors. Disease transmission via airborne pathogens is also an almost exclusive indoor problem. [2]

Exposure to indoor air pollution (IAP) is linked with respiratory, cardiovascular, reproductive and mental health impacts, and health outcomes including lung cancer, diabetes, leukaemia and Parkinson's disease. IAP impacts human health, wellbeing and productivity; infection transmission via airborne pathogens; and subsequent burden of disease and economic impacts. The risks are higher for vulnerable groups such as the very young, the elderly, and those with chronic diseases.

As an example, children (22% of Australia's population) are especially vulnerable because their developing physiology places them at higher exposure risk and the impacts on their body systems can remain for life. Acute (high levels of pollution over a short period of time) and chronic (relatively low pollution levels over prolonged periods) exposure to indoor air contaminants in schools impacts pre-school and school level children in three main ways: respiratory effects (wheeze, allergies, asthma etc), dermatological effects (eczema, dermatitis, conjunctivitis etc), and cognitive and behavioural effects (greater hyperactivity, impulsiveness and inattention; reduced cognitive performance, difficulty sleeping) [3]. In Australia, asthma affects 10% of 0-14 year olds, and was the leading cause of total Burden of Disease for that age group. Eczema and ADHD also place considerable economic and social burden on Australia.

IAQ standards and monitoring

THRIVE's *State of Indoor Air in Australia 2025* [4] (the first national report to quantify airborne pollutants in Australian buildings) summarises the two national bodies that currently provide 'model' codes or standards relating to indoor air:

- The National Construction Code (NCC) of the Australian Building Codes Board (ABCB) requires, as part of its mandatory performance requirements, that occupied spaces maintain 'adequate air quality' and control the circulation and accumulation of harmful contamination by micro-organisms, pathogens and toxins; and
- Safe Work Australia sets exposure standards (or limits, from 2026) and requires enterprises to manage the risk of airborne contaminants, monitor concentrations and health, implement a hierarchy of controls and keep records relating to these actions.

The level of compliance with, or enforcement of, these existing codes / standards is questionable, in the absence of public monitoring and reporting.

THRIVE's report summarises 106 peer reviewed scientific publications that measured pollutants in residential, commercial and public buildings nationwide in the last 25 years (since 2000). The measured pollutants included carbon dioxide (CO_2), carbon monoxide (CO), respirable particles (PM_{10}, $PM_{2.5}$, Ultrafine particles UFP), nitrogen dioxide (NO_2), ozone (O_3), formaldehyde (CH_2O), Total Volatile Organic Compounds (TVOC) and sulfur dioxide (SO_2). NABERS Indoor Environment Quality (IEQ) ratings were also analysed, bringing the total number of buildings involved in IAQ measurement studies to approximately 2,500 – less than 0.03% of Australia's building stock. (Note that studies focusing on quantifying mould/mildew and airborne pathogen (e.g. COVID 19) were generally excluded from this inaugural report, partly because biological contaminants are not yet covered in the ABCB's Indoor Air Quality Verification Methods Handbook.)

The Executive Summary of the State of Indoor Air in Australia 2025 report is included at the end of this document.

At a state level, monitoring of indoor air in NSW buildings is scarce, as summarised in Table 1. This information is presented according to the building classifications of the NCC, enabling IAQ to be examined and addressed for different occupancy modes, pollutant risks, exposure limits, health and economic consequences, and policy responses. The studies referenced in this table highlight that:

- Very few buildings on NSW have monitored and reported IAQ, and no studies have quantified IAQ in NSW healthcare or residential care buildings (or in clubs / bars / sporting venues).
- Only 22 classrooms have reported IAQ monitoring (from > 3,000 schools).
- Measurement timeframes were very short (i.e. a point in time, not long term or continuous).
- The focus of each study was varied (e.g. pollutant measurements and variability, health impacts, technology effectiveness, and policy effectiveness), and influenced the pollutants measured, the measurement timeframe and the data analysis / findings.
- Results are often generalised as mean pollutant concentration values, with minimal discussion on peak concentrations or exposure rates that could impact acute or chronic health conditions.

Table 1 Peer-reviewed scientific publications measuring IAQ in NSW buildings

Building class	Author, Year	Number of buildings	Purpose / focus of study	Measurement timeframe	Pollutants measured
1 and 2 (residential)	Sheppeard et al [5-7] 2006	140	Prevalence, sources and concentrations of indoor air pollutants in homes	Passive sampling over one week (winter)	NO_2, PM_{10}, CH_2O, nicotine
			Comparison of smoking / non-smoking homes		
			Estimate NO_2 exposure based on indoor and outdoor concentrations		
	Sercombe et al [8] 2014	39	Inhalable fungal aerosols in homes of people diagnosed with chronic fatigue		Fungal aerosols
	Pettit et al [9] 2019	1 (1 room)	Efficiency of green wall in reducing air pollutants		TVOC, PM
	Xiong et al [10] 2020	48 (bedrooms only)	Association of bedroom temperature and ventilation with sleep quality	5 consecutive days	CO_2
Class 3 (other residential)	He et al [11] 2016	1 (correction facility)	Impact of smoking ban on IAQ	48 hrs pre and post smoking ban	$PM_{2.5}$, UFP, VOCs
Class 5 (offices)	Irga et al [12] 2016	11	Impact of different ventilation types on indoor / outdoor pollutant ratios	1 year	CO_2, CO, NO_2, TVOC, SO_2, PM_{10}, $PM_{2.5}$, airborne fungi
Class 6 and 7 (retail / w'sale)	No studies				
Class 8 (Factories)	Hawchar et al [13] 2022	1 (brewery)	Test Internet-of-Things sensor network	2 months	CO_2
Class 9a (healthcare)	No studies				
Class 9b (public assembly)	Mohsen et al [14] 2018	4 (train stations)	Measure PM in underground and ground level platforms	15 min sampling over 6 weeks	PM_{10}, $PM_{2.5}$, dust samples
	Wheeler et al [15] 2021	1 (library)	Effectiveness of library as a 'cleaner indoor air shelter'; efficacy of portable air cleaners	5 months	$PM_{2.5}$
Class 9b (education)	Marks et al [16] 2010	22 schools (20 classrooms)	Compare respiratory health effects of exposure to unflued gas heaters	6 periods of 1 week	NO_2, CH_2O
	Haddad et al [17] 2021	1 school (2 classrooms)	Demand control ventilation and thermal comfort	1 year	CO_2, TVOC
	Ulpiani et al [18] 2021	1 university (1 building)	Spatial and temporal variability in environmental quality	Short term sampling	CO_2, TVOC
	Samandi et al [19] 2023	1 university (1 building)	Effect of hazard reduction burning and vehicular traffic	5 months	$PM_{2.5}$
Class 9c (Residential care)	No studies				

Solutions to improve IAQ

Staged approach for public buildings

Immediate action and long-term strategic planning is required, especially in relation to public buildings, according to international experts [1] and the Australian Academy of Science [2] . Fundamentally we need to address how we design, build, operate and use buildings. This will require clear and enforceable IAQ requirements being embedded into building codes, workplace health and safety regulations and accessibility legislation. Public buildings (classes 9a, 9b and 9c) are an obvious starting point for a phased approach to the implementation of continuous monitoring that would eventually require reporting against, and compliance with, mandatory exposure limits. A phased approach enables the development of monitoring infrastructure and practices, including skills development and reporting processes.

Some solutions for consideration for specific building types are summarised below.

Schools

Key findings about indoor pollutants in education facilities (childcare, school, university) can be found on Table 16 of THRIVE's State of Indoor Air report [4], with key considerations listed on page 76. Mould in schools was not part of that report, but needs urgent addressing, considering NSW's experiences in schools in recent years (e.g. Broken Hill, Fort Street High School in Petersham, and Main Arm Upper Public School) that seem to suggest that there are short-comings in knowledge and understanding of ventilation systems in schools to inform the safe and healthy operation of ventilation (and air conditioning) systems and appropriate maintenance and cleaning procedures. Education department messaging gives the perception that mould is an inevitable part of life (and hence not a serious health issue?) and that existing workplace health and safety processes and regulations are robust [20]. However, short-comings in current mould assessment and remediation processes in Australia (albeit from the perspective of residential buildings) were revealed in a recent peer-reviewed publication [21].

Office buildings

NABERS (National Australian Built Environment Rating System) is managed by the NSW government for the Australian government. In accordance with the national Commercial Building Disclosure Program, a NABERS energy rating is required for all office buildings with a net lettable area equal to or greater than 1000 m². The rating must be disclosed at point of sale or lease. NABERS also has an Indoor Environment Quality (IEQ) rating, of which air quality is a component. THRIVE's State of Indoor Air report analysed all NABERS IEQ rating data and key considerations for building certification schemes such as NABERS can be found on page 47 of that report [4].

Residential buildings

First, smoke alarms are already mandatory in residential buildings, to protect occupants from fire risks. A similar approach could be used to protect occupants from the acute and chronic health risks of exposure to pollutants (e.g. asthma) resulting from combustion within the home, for example mandating CO sensors in all dwellings (and rooms in dwellings) with combustion appliances could be an extension of existing approaches to safety. The UK introduced such legislation in 2022 (Smoke and Carbon Monoxide Alarm (Amendment) Regulations 2022).

Second, mould was not specifically included in THRIVE's inaugural State of Indoor Air report, however recent peer-reviewed publications characterise the multi-system characteristics of mould-related illness (high similarity with

long-COVID) [22], and the industry's self-reported lack of regulated national indoor air quality standards or regulations for the investigation, assessment, hazard management, remediation and post verification of mould repairs or remediation works (for residential buildings) [21].

Third, a significant number of Australian families are transitioning to rooftop solar and battery storage systems in response to affordability, resilience, environmental or ideological considerations. Thought should be given to policies that enable vulnerable cohorts to transition away from combustion appliances (e.g. gas or wood stoves and heaters) to electric appliances.

Implications for climate resilience and pandemic preparedness

Addressing indoor air pollution in our buildings is fundamental not only to general health, wellbeing and productivity, but can also provide additional co-benefits.

Moving towards mandatory monitoring of public buildings has multiple benefits. For example, CO_2 monitoring is a good proxy for ventilation effectiveness, and can be used as a reliable indicator of the transmission rate of infectious respiratory diseases (such as seasonal flu or RSV, or future pandemic related viruses).

Climate resilience also requires a better understanding of how outdoor air infiltrates into buildings (i.e. the leakiness of buildings) and the extent to which indoor environments provide safe havens during events such as bushfires, controlled burning, dust storms etc. Air quality sensors (e.g. $PM_{2.5}$) are required in addition to CO_2 sensors to assist with this knowledge and ventilation management.

Policies that promote electrification of households can have the multiple benefits of improving energy affordability, increasing household resilience (if energy supplied by rooftop solar and battery storage), improve indoor air quality and hence reduce respiratory illness, and reduce carbon emissions. The co-benefits for IAQ, health, affordability, resilience and carbon reduction of electrification should be comprehensively addressed in benefit-cost analyses for targeted policies (e.g. buy back schemes, minimum standards for rental properties, electricity rebates, solar and battery rebates etc).

If you have any questions or need further clarification about this research, please do not hesitate to contact me directly at the email below.

Yours Sincerely,

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References

1. Morawska, L., et al., *Mandating indoor air quality for public buildings.* Science, 2024. **383**(6690): p. 1418-1420.
2. Australian Academy of Science, *Indoor air: the science of indoor air and pathways to improve indoor air quality in Australia*. 2025, Australian Academy of Science: Australia.
3. Royal College of Paediatrics and Child Health (RCPCH) and Royal College of Physicians, *The Inside Story: Health effects of indoor air quality on children and young people*. 2020, RCPCH: London.
4. Miller, W. and L. Morawska, *State of Indoor Air in Australia 2025*. 2025, THRIVE - Australian Research Council Training Centre for Advanced Building Systems Against Airborne Infection Transmission: Brisbane Australia,.
5. Sheppeard, V., G.G. Morgan, and S. Corbett, *New South Wales Indoor Air Survey: Part III Particulate Matter Concentrations in Homes in New South Wales.* Environmental Health, 2006. **6**(3).
6. Sheppeard, V., G. Morgan, and S. Corbett, *New South Wales Indoor Air Survey: Part II Concentrations of Nitrogen Dioxide in Homes in New South Wales.* Environmental Health, 2006. **6**(3): p. 25-33.
7. Sheppeard, V., G. Morgan, and S. Corbett, *New South Wales Indoor Air Survey: Part 1 Sources and Concentrations of Pollutants in Homes in New South Wales.* Environmental Health, 2006. **6**: p. 15-24.
8. Sercombe, J.K., et al., *Domestic exposure to fungal allergenic particles determined by halogen immunoassay using subject's serum versus particles carrying three non-fungal allergens determined by allergen-specific HIA.* Indoor Air, 2014. **24**: p. 438-45.
9. Pettit, T., et al., *An assessment of the suitability of active green walls for NO2 reduction in green buildings using a closed-loop flow reactor.* Atmosphere, 2019. **10**(12): p. 801.
10. Xiong, J., et al., *Associations of bedroom temperature and ventilation with sleep quality.* Science and Technology for the Built Environment, 2020. **26**: p. 1274-1284.
11. He, C., et al., *Unexpected increase in indoor pollutants after the introduction of a smoke-free policy in a correctional centre.* Indoor Air, 2016. **2016**(26): p. 623-633.
12. Irga, P.J. and F.R. Torpy, *Indoor air pollutants in occupational buildings in a sub-tropical climate: Comparison amoung ventilation types.* Building and Environment, 2016. **98**(March 2016): p. 190-199.
13. Hawchar, A., S. Ould, and N.S. Bennett, *Carbon Dioxide Monitoring inside an Australian Brewery Using an Internet-of-Things Sensor Network.* Sensors, 2022.
14. Mohsen, M., M.B. Ahmed, and J.L. Zhou, *Particulate matter concentrations and heavy metal contamination levels in the railway transport system of Sydney, Australia.* Tranportation Research Part D: Transport and Environment, 2018. **62**(July 2018): p. 112-124.
15. Wheeler, A.J., et al., *Can Public Spaces Effectively Be Used as Cleaner Indoor Air Shelters during Extreme Smoke Events?* Int. J. Environ. Res. Public Health, 2021. **18**(8): p. 4085.
16. Marks, G., et al., *Respiratory Health Effects of Exposure to Low-NOx Unflued Gas Heaters in the Classroom: A Double-Blind, Cluster-Randomized, Crossover Study.* Environmental Health Perspectives, 2010. **118**(10): p. 1476 - 1482.
17. Haddad, S., et al., *On the potential of demand-controlled ventilation system to enhance indoor air quality and thermal condition in Australian school classroom.* Energy and Buildings, 2021. **238**(May 2021): p. 110838.
18. Ulpiani, G., et al., *Towards a Living Lab for Enhanced Thermal Comfort and Air Quality: Analyses of Standard Occupancy, Weather Extremes, and COVID-19 Pandemic.* Frontiers in Environmental Science, 2021. **9**.
19. Samandi, E., A. Shirazi, and S. Newton, *Measuring the fine particulate exposure levels of building occupants using localized sensors.* Building and Environment, 2023. **242**(15 August 2023): p. 110403.
20. NSW Department of Education, *Main Arm Upper Public School - Works notification* 2024.
21. Coulburn, L., et al., *Field practitioners' perspectives of challenges and practices that hinder effective mould assessment and remediation in Australian residential buildings.* Building and Environment, 2026. **290**(15 February 2026): p. 114132.
22. Coulburn, L., W. Miller, and C. Susilawati, *Onset characteristics and breadth of occupants' long-lasting building-related symptoms attributed to living in damp housing conditions in Australia: Qualitative insights.* Building and Environment, 2024. **255**(May 2024): p. 111432.

Executive Summary

Australia has been producing State of the Environment (SoE) reports for more than two decades, yet it has not, until this report, undertaken to quantify the state of indoor air. The scientific evidence of the importance of indoor air quality for occupant health is unequivocal, as is the evidence quantifying the health, social and economic costs of poor indoor air quality. Translating this evidence into policy and practice is challenging in the absence of data about the current status of air inside Australian buildings of all types.

A systematic literature search strategy identified 106 peer reviewed publications that have reported on measurements of some indoor air pollutants within residential, non-residential and public buildings in Australia since 2000. Over three quarters of these studies were conducted in Queensland (41%) and Western Australia (37%), and most (77%) were conducted since the introduction of energy efficiency requirements in the building code in 2003.

These publications collectively measured pollutants in about 2000 buildings. The geographic and temporal distribution of these publications are shown in Figures 1 and 2 respectively. NABERS Indoor Environment Quality (IEQ) ratings were also analysed, bringing the total number of buildings involved in IAQ studies to approximately 2,500 - less than 0.03% of Australia's building stock.

Residential dwellings account for 68% of the buildings, followed by offices (22%) and public assembly buildings, including schools (9%). Healthcare, residential care and factories each represent about 2% of the total buildings studied.

Chapter 1 provides the context for the report, including a summary of existing regulations relating to indoor air. Each of the following chapters, focused on a specific building class, provides an overview of the relevant studies, a summary of key pollutant measurement ranges, and key findings.

While each study individually was subject to each scientific journal's respective peer review process, as a collective it is not possible to generalise the findings to all buildings within each class or to assume that these 'snap-shots in time' indicate the current state of indoor air. Different building types (e.g. housing, offices, factories, public buildings), in different urban and climate contexts, have different occupancy modes, pollutant risks, exposure limits, health and economic consequences, and policy response options. The impact that indoor air has on individual and population health and wellbeing depends on the pollutants that may be present in the air, the respective concentration levels of those pollutants, and the exposure of occupants to those pollutants.

The data presented in this report is helpful in

- providing insights into the range of indoor air quality (IAQ) conditions in different building classes over time;
- highlighting some of the key contributors to, and impacts of, poor air quality;
- quantifying the importance of source control, ventilation and filtration as strategies for improving IAQ;
- presenting multi-disciplinary approaches in study design and implementation; and
- providing solutions or strategies that could be applied to buildings of the same class, or between buildings in different classifications.

The shortcomings of the studies as a collective include

- the short measurement timeframes (from a few hours up to, in a few instances, one year).
- the small number of rooms or zones that were included in each building study.
- a generalised focus on mean pollutant concentration values, with minimal discussion on peak concentrations.
- a generalised absence of analysis of the duration of concentrations at different levels. This is important because health risks, in simple terms, are a combination of pollutant concentration levels multiplied by duration of exposure at different pollutant concentrations.
- a generalised omission of important building data such as occupant density.

This report acts as a baseline report for indoor air quality and as a catalyst for multi-jurisdictional and transdisciplinary discussion and debate that leads to the development and implementation of a national strategy for indoor air quality. It is hoped that this report will be augmented periodically with more data as it becomes available, enabling improvements in indoor air quality to be tracked over time, and the impact of interventions to be evaluated.

Figure 1 Geographic distribution of IAQ studies (excluding NABERS IEQ ratings)

WA Studies
Perth : 24

SA Studies
Adelaide : 25

VIC Studies
Melbourne : 7
Regional : 5

TAS Studies
Hobart : 0
Regional : 1

QLD Studies
Brisbane : 39
Regional : 4

NSW Studies
Sydney : 12
Regional : 6

ACT Studies : 4

Climate Zone 1
High humidity summer, warm winter

Climate Zone 2
Warm humid summer, mild winter

Climate Zone 3
Hot dry summer, warm winter

Climate Zone 4
Hot dry summer, cool winter

Climate Zone 5
Warm temperate

Climate Zone 6
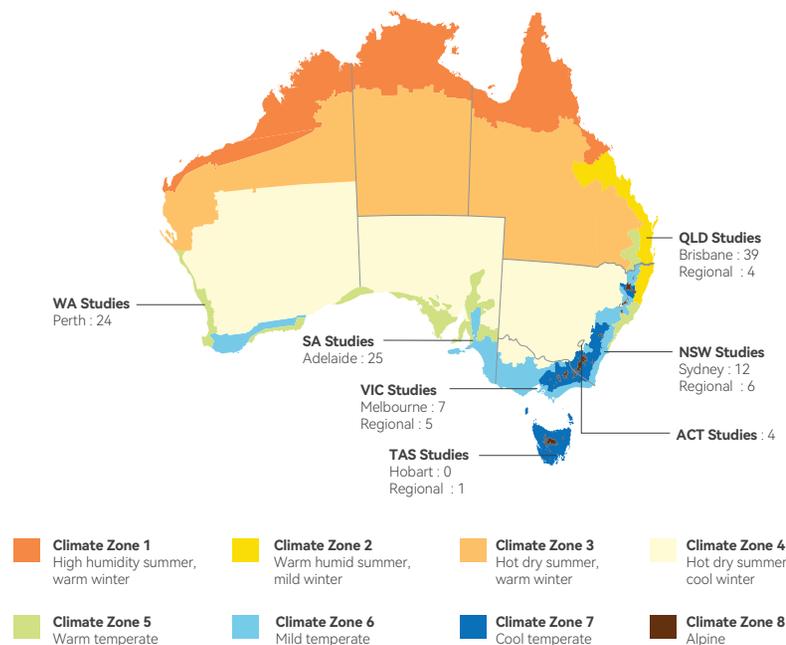Mild temperate

Climate Zone 7
Cool temperate

Climate Zone 8
Alpine

Figure 2 Temporal distribution of IAQ studies

Key Industry Milestones

1998 Ambient Air Quality Standards

2003 Energy Efficiency requirements in National Construction Code

2016 Enhanced stringency of energy efficiency requirements

3 papers

22 papers — 1998 – 2003

47 papers — 2004 – 2016

35 papers — 2017 – 2025