The impact of indoor air quality on the transmission of airborne viral diseases in public buildings – NSTC advice to government

This document outlines advice from the National Science and Technology Council ('the Council') to the Australian Government on the impact of indoor air quality on the transmission of airborne viral diseases in public buildings based on the report commissioned by the Office of the Chief Scientist, on behalf of the Council.

The report prepared by the University of Wollongong Sustainable Buildings Research Centre, *The impact of indoor air quality on the transmission of airborne viral diseases in public buildings* ('the report'), was requested by the Assistant Minister for Health and Aged Care, the Hon Ged Kearney MP.

Context

The COVID-19 pandemic brought global attention to the transmission of airborne diseases and the impact of interventions to reduce this transmission.

The report, *The impact of indoor air quality on the transmission of airborne viral diseases in public buildings* (the report; Appendix A: Commissioned report scope), has synthesised available evidence relating to the impact of air quality interventions on the transmission of airborne viral diseases in indoor public environments. It also reviewed strategies to reduce the transmission of airborne viral diseases in indoor public settings in Australia and relevant findings related to the energy and economic impacts of these strategies.

The outcomes of the report provide an evidence base for government action, including via the COVID-19 Response Inquiry.

Improving air quality, reducing indoor bioaerosol concentrations and impacting airborne infection transmission risk requires a multifaceted approach, tailored to specific building types and scenarios of use. It is clear from the report there is not one discrete indoor air quality (IAQ) strategy that can be applied to all scenarios.

An Italian study investigating mechanical ventilation using heating, ventilation and air conditioning systems (HVAC) to reduce transmission of SARS-CoV2 in school settings has come a long way in establishing a strong epidemiological link between intervention and significant health outcomes. Broader questions remain about what amount of cleaner air (for recirculation) is needed to dilute potentially contaminated indoor air for optimal infection control purposes in a variety of indoor settings.

Government action to improve ventilation in public buildings should draw on the substantial body of evidence highlighted in the report commissioned to inform this advice. Several studies are ongoing, including a substantial project underway at the Australian Health Protection Principal Committee (AHPPC), which may provide further evidence to support decision-making around IAQ interventions in public spaces.

State governments have also developed evidence-based advice on ventilation strategies, including mechanical ventilation and behaviour standards.[1] These can be drawn on, where suitable, for national application.

Summary of advice

There is a limited number of studies linking indoor air quality interventions with health outcomes such as reduced infection transmission risk, morbidity and mortality. There is also limited evidence for the relationship between reduction in viral load and measured infection rates.

Nonetheless, a broad base of experimental literature, mostly using indirect proxy measurements, shows:

In healthcare settings:

- Negatively pressured rooms relative to corridors help prevent contaminated air from escaping.
- High efficiency particulate air (HEPA) cleaners reduce clearance time significantly, compared with the HVAC systems alone.
- Using two domestic HEPA cleaners on a ward removed 99% of all aerosols substantially faster than on wards with no air cleaners.

In educational institutions:

- HEPA cleaners and UVC lights are effective, especially when properly sized and positioned relative to the infected and susceptible persons.
- HEPA cleaners could reduce aerosol particle load by 85-95% within less than 20 minutes of operation.
- Implementing proper ventilation and air cleaning strategies can create safer environments for students and staff, reducing absenteeism and promoting better learning conditions.

In workplaces and public buildings:

- Improved IAQ is associated with enhanced worker productivity and reduced sick leave, but the magnitude of effect is variable and not well-defined in terms of scale of impact.
- Displacement ventilation systems have practical challenges which require further investigation before widespread implementation.

In hotels:

- Ensuite bathroom air extraction systems in hotels and buildings with multiple rooms help to maintain negative pressure relative to common corridors.

Evidence base and detailed advice

Mechanisms of airborne disease transmission

Identifying appropriate indoor air quality strategies to prevent the transmission of airborne diseases requires an understanding of the mechanisms involved in their transmission.

[1] Victorian Government, *Ventilation*, https://www.health.vic.gov.au/covid-19-infection-prevention-control-guidelines/ventilation, accessed 23/05/2024.

The three main stages of airborne transmission are:

1. Generation and emission of infectious particles by an infected person.
2. Transport of these particles to a susceptible person.
3. Inhalation and deposition of the particles in the respiratory tract of a susceptible person.

The transmission of airborne diseases in indoor public buildings

The transport of disease particles by indoor air is influenced by multiple factors, including ventilation. Historically, many viral diseases were thought to be transmitted only via direct deposition of expelled infectious particles. However, in recent years it became widely accepted that inhalation of airborne SARS-CoCV-2 virus was the main transmission mode in spreading COVID-19 at both short and long ranges.

The presence of infectious particles and subsequent risk of long-range airborne transmission has been verified by PCR air sampling (real time measurements detecting the presence of SARS-CoV-2 RNA in the air of hospitals), epidemiological analysis and genome sequencing during COVID-19 long-range transmission events. Similarly, long-range airborne transmission for other highly infectious diseases such as measles has been documented.[2] [3]

Transmission of airborne diseases through ventilation systems, including grilles, ducts and filters, has been investigated by a limited number of studies. The studies showed the presence of SARS-CoV-2 in the ductwork of ventilation systems **but no study, to date, has provided evidence on their viability (infectivity).**

Indoor air quality interventions

There are a range of IAQ strategies that could reduce the transmission of airborne viruses in indoor public environments by increasing the amount of clean air for building occupants.

Based on the available moderate to highest methodological quality evidence, the report identified two IAQ strategies as having the greatest potential to improve air quality, reduce indoor bioaerosol concentrations and according to a select few studies, reduce or increase airborne infection transmission risk. These include:

1. Dilution of contaminated indoor air via ventilation with cleaner air [through mechanical ventilation such as heating, ventilation and air conditioning systems (HVAC)].
2. a) Air cleaning technologies [such as high efficiency particulate air (HEPA) cleaners].
   b) Air disinfection technologies [such as ultraviolet-C (UVC) light disinfection].

Measuring the impact of IAQ interventions

Researchers face challenges establishing a direct link (cause and effect) between the transmission of airborne infection and IAQ strategies, due to the complexity of processes involved.

[2] Remington, P. L. Airborne Transmission of Measles in a Physician's Office. *JAMA* **253**, 1574 (1985).
[3] Bloch, A. B. et al. Measles Outbreak in a Pediatric Practice: Airborne Transmission in an Office Setting. *Pediatrics* **75**, 676–683 (1985).

Most studies examined in the report assumed no movement of infected or susceptible people; assumed one source and type of particle emission; and assessed exposure but not necessarily disease transmission.

The report found only a few rigorous epidemiological and controlled cohort studies and therefore limited high methodological quality evidence linking IAQ interventions with significant human health outcomes. Stronger evidence may emerge over the next 12 to 18 months as current studies conclude.

However, there is a good body of proxy (indirect) evidence based on indicators which are more straightforward to measure.

Effectiveness of IAQ monitoring

Monitoring IAQ can help reduce airborne viral disease transmission by identifying high-risk areas and informing appropriate mitigating actions.

There are multiple IAQ monitoring technologies which can provide valuable data for managing indoor environments, but all are affected by (i) constraints in feasibility, (ii) costs of use, and (iii) significant variability based on the time-point, the indoor location and the activity.

Measurement of carbon dioxide (CO_2) is the most promising proxy measure for ventilation effectiveness in IAQ studies. However, limitations around how CO_2 measurements are interpreted in the presence of other IAQ interventions must be taken into consideration.

Strategies to improve IAQ and reduce the transmission of airborne viral diseases in public buildings.

The report synthesised available research in the IAQ strategies detailed above. This section refers to key evidence reviewed in the report and rates this evidence in line with NHMRC guidelines (Appendix B: IAQ intervention body of).

1. *Dilution of contaminated air with cleaner air (mechanical and natural ventilation)*

There is **satisfactory evidence** that mechanical ventilation can reduce the relative risk of SARS-CoV2 transmission in school classrooms. A recent retrospective cohort study of more than 10,000 classrooms in Marche, Italy (of which 316 were equipped with HVAC units) showed a statistically significant **74% relative risk (RR) reduction in SARS-CoV-2 transmission among students using classrooms with mechanical ventilators fitted.** This result stands even after accounting for differences such as location or province, educational stage of students from preschool through to high school and number of students in the classroom from small to large.

Multiple review studies have shown mechanical ventilation can reduce total bioaerosol concentration in indoor spaces. A recent systematic review found areas with natural ventilation had the highest total bioaerosol concentrations compared to areas serviced by mechanical ventilation.

Review studies investigating the role of cleaner air supply for diluting indoor contaminants remain inconclusive on the optimum amount of cleaner air for infection control purposes. While empirical recommendations exist, the required amount of air for airborne infection control depends on the geometry of the space, the occupancy level, the HVAC characteristics and the installation of any other air cleaning technologies (e.g. filtering).

2. (a) ***Air cleaning – HEPA cleaners***

Experimental studies have shown that HEPA air cleaners have the potential to reduce bioaerosol concentration in the air by up to 99% across a variety of settings using proxy measurements, including CO_2 (especially if combined with UVC lights). It's difficult to generalise these findings outside of the laboratory, with in-situ studies producing mixed results.

There is **limited evidence** in the report demonstrating HEPA air cleaners alone are effective in reducing indoor infectious bioaerosol concentrations in hospitals and other non-healthcare settings. One study in ICUs in Turkey using air cleaners in addition to heating, ventilation and air conditioning systems in hospitals found a reduced microbial load in the air and on surfaces, and thus reduced hospital-acquired infections.

There is **limited evidence** in the report that HEPA air cleaners reduce the transmission of COVID-19.

The most important consideration in maximising the effectiveness of HEPA air cleaners is their size and position in relation to infected and susceptible people. Noise considerations from the use of HEPA air cleaners were raised in a number of studies and would need to be tested in noise sensitive spaces such as classrooms.

2. (b) ***Air disinfection via ultraviolet-C lights***

UVC light systems have been shown in experimental and laboratory settings to effectively reduce and inactivate infectious bioaerosols in a range of scenarios by up to 99%.

There is **limited evidence** from in-situ studies to show UVC lights alone are effective at reducing infectious bioaerosol concentrations in office spaces and hospital wards. Two experimental studies using UVC tubes and installed UVC in ventilation systems of office spaces had mixed results in reducing airborne microbial concentrations in the supply air streams.

There is **limited evidence** that UVC lights alone can reduce airborne viral disease infection transmission risk in kindergartens. One controlled cohort study using portable combined HEPA and UVC lights looking at the incidence of COVID-19 across 10 kindergartens did not find a reduction in COVID-19 transmission.

Optimal unit sizing, positioning and design are of paramount importance for effective operation of UVC lights. Direct exposure of people to UVC light is dangerous and some types of louvres installed in these systems for safety reasons were found to render them much less effective.

Impacts of strategies to improve air quality for reduction in disease transmission on the energy efficiency of buildings

Evidence shows that the impact of IAQ strategies on the energy efficiency of buildings is dependent on several factors, including the type of intervention, the building size, building characteristics, hours of operation and climate.

While relatively few studies have analysed the energy efficiency impact of interventions in the Australian context, international studies, particularly those in the US, suggest that while all interventions impact the building efficiency, there is significant variation in the size of the impact as these factors change.

A logical approach for the Australian government is to determine likely interventions, based on the findings outlined in this report. A detailed energy efficiency assessment of interventions in a specific setting can then be carried out.

With Australia committed to net zero by 2050, and in line with the National Energy Performance Strategy released in April 2024[4], all sectors will need to take action to reduce energy use[5]. This includes the operation of public buildings and the requirement to strike a balance between air quality interventions and carbon footprint. Equally, reductions in the contribution of fossil fuels to Australia's energy mix may mean that reducing electricity usage is less critical. With these changes in mind, the government should consider reviewing IAQ interventions regularly against Australian energy and built environment policies.

At the building planning stage, there is opportunity to consider how IAQ could be improved, to avoid the need to add interventions after construction is complete. The building industry should explicitly consider the ways in which the built environment could support natural ventilation as a lower cost intervention. The government could support this planning step with updated building policy settings, developed with consideration of current codes.[6]

Impact of the identified airborne viral diseases on human health and the economy

Significant direct and indirect socioeconomic impacts occur as a result of airborne disease transmission and outbreaks, including health and wellbeing, and economic impacts.

The report briefly reviews some of the reported direct (healthcare costs, testing, protective personal equipment) and indirect (lost productivity, lost years of life or lost years of healthy life) impacts across different socioeconomic categories. However, the economic losses are not well-defined at a population level in Australia. Impacts of respiratory virus transmission are likely to be reduced through improvement of IAQ but the magnitude of this effect has not been modelled. **Nonetheless, the government can build on the findings in this report by focusing action where the best return on investment is found.**

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[4] Department of Climate Change, Energy, the Environment and Water (2024). National Energy Performance Strategy. Available from: https://www.dcceew.gov.au/energy/strategies-and-frameworks/national-energy-performance-strategy

[5] Department of Climate Change, Energy, the Environment and Water (2023). Annual Climate Change Statement. Available from: https://www.dcceew.gov.au/climate-change/strategies/annual-climate-change-statement-2023

[6] Australian building codes board, *Indoor air quality verification methods handbook*, https://www.abcb.gov.au/resource/handbook/indoor-air-quality-verification-methods-handbook, accessed 23/05/2024.

Appendix A: Commissioned report scope

The report prepared by the University of Wollongong Sustainable Buildings Research Centre, *The impact of indoor air quality on the transmission of airborne viral diseases in public buildings: a systematic review of evidence* ('the report'), was requested by the Assistant Minister for Health and Aged Care, the Hon Ged Kearney MP.

The report focused on five areas:

1. Mechanisms involved in the transmission of airborne diseases in indoor public buildings.

2. What strategies to improve IAQ can reduce the transmission of airborne diseases in public buildings.

3. Whether IAQ monitoring can be used to support reduction in airborne disease transmission.

4. Impacts of these strategies to improve air quality for reduction in disease transmission on the energy efficiency of buildings.

5. Impact of the identified airborne diseases on the economy, and human health and wellbeing.

Appendix B: IAQ intervention body of evidence matrix

Table 1 is adapted from
https://www.mja.com.au/sites/default/files/NHMRC.levels.of.evidence.2008-09.pdf

IAQ Intervention BY NHMRC appraisal criteria	HEPA air filters 4 studies, 2 HEPA/UVC, 2 x interventions	UVC 4 studies, 2 HEPA/UVC cohort, 2 x experimental (1 x UVC and 1 x UVC+HVAC)	Mechanical Ventilation HVAC 1 large retrospective cohort during pandemic
Evidence base	D – level III-2 to III-3 studies with high risk of bias.	D – level III-2 to III-3 studies with high risk of bias. Unable to rate two experimental studies as could not find >2 meeting 111-3 criteria.	C – level III-2 study with low risk of bias.
Consistency	D – evidence is inconsistent.	C – Some inconsistency reflecting genuine uncertainty around question.	N/A as one study only.
Clinical impact	Unable to rate – study results varied due to unknown factors. One study showed a negative impact of HEPA on COVID transmission; two studies combined UVC/HEPA interventions with no separate analysis; one crossover intervention found a positive correlation between number of colonies detected and rate of hospital-acquired infections in ICUs in Turkey using HEPA in addition to HVAC.	Unable to rate – study results varied from 22% - 100% between studies. There were some unexplained anomalies and results could not be attributed to one specific intervention.	A- Large 74% relative risk (RR) reduction for transmission of COVID-19 in HVAC intervention Vs control. 12%-15% RR reduction for each unit of ventilation rate per person. Accounted for confounders; province in Marche-Italy; number of students in each classroom; and age range from kindergarten to high school.
Generalisability	B	D	C
Applicability	C	C	C
Overall Rating	D – Poor Body of evidence is weak, and recommendation must be applied with caution.	D – Poor Body of evidence is weak, and recommendation must be applied with caution.	C – Satisfactory Body of evidence provides some support for recommendation(s) but care should be taken in its application.

NSTC advice	Due to diverse opinions expressed by Expert Working Group (EWG) recommend using **'limited'.**	Due to diverse opinions expressed by EWG recommend using **'limited'.**	**Satisfactory**

Explanatory notes

- Studies in the report not meeting the NHMRC evidence hierarchy and criteria for 'interventions' on table 1 page 6 (https://www.mja.com.au/sites/default/files/NHMRC.levels.of.evidence.2008-09.pdf), were excluded from this appraisal. This included some experimental and all laboratory designs.
- Level III-2 studies include: comparative study with concurrent controls; non-controls; non-randomised, experimental trial; cohort study; case study; case-control study; study; and interrupted time series with a control group.
- Level III-3 studies include: comparative study without concurrent controls; historical control study; two or more single arm study; and interrupted time series without a parallel control group.
- The authors of the IAQ report pre-screened and included only moderate to highest methodological quality evidence (i.e. low level evidence was omitted) using professional judgement and principles of a medical research grading system (such as GRADE).
- All evidence included is available and published in relevant and established journals.