ENGINEERS AUSTRALIA

The COVID-19 pandemic and HVAC

Problem and opportunity analysis

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The COVID-19 pandemic and HVAC: problem and opportunity analysis

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1. Background

1.1 Purpose of this paper

This paper is designed to elicit feedback that will inform decisions by Engineers Australia on its potential role regarding improving engineering practice for management of air in the built environment, especially in the context of COVID-19 and future pandemics.

1.1.1 Providing feedback

Feedback can be provided via email to policy@engineersaustralia.org.au

Engineers Australia members are asked to provide their member number with the feedback.

People who are not Engineers Australia members are requested to provide a CV which demonstrates the professional or academic background which informs their feedback.

The closing date for feedback is Tuesday 16 November 2021.

1.2 Introduction to the problem and opportunity analysis

The state of knowledge about the characteristics of COVID-19 has evolved considerably since emerging as a global threat in late 2019 and early 2020. Although case studies and research have indicated the potential airborne nature of the virus for some time (e.g. Lu et al July 2020), it wasn't until April/May 2021 that the US Centers for Disease Control and Prevention (CDC, 2021) and the World Health Organisation (WHO, 2021) formally acknowledged that COVID-19 was spread through inhalation of aerosolised particles.

Public health controls for the risk of COVID-19 have primarily consisted of administrative controls, (such as physical distancing, hand washing, contact tracing, self-isolation, and health screening) and Personal Protective Equipment (PPE) controls (primarily masks). The effectiveness of these controls relies heavily on voluntary compliance of most individuals and, after more than year of restrictions and uncertainty, the general public has grown weary and, in some places, complacent.

Some jurisdictions, including Australia and New Zealand, have sought to avoid the risk through heavy restriction of incoming travellers and mandatory hotel quarantine. More than 20 "breaches" of hotel quarantine have occurred in Australia (Grout et al, 2021), a number of them in more recent times are thought to have arisen through ventilation and air flows. The resulting lockdowns when outbreaks occur are economically, socially and politically costly, albeit not as costly as suppression strategies (Abraham, 2021).

Vaccination offers the potential for a more robust control environment, however, in Australia, herd immunity is still months away. Even once herd immunity has been achieved, ongoing mutation of the virus, less than 100 per cent effectiveness of vaccines, uncertainty over the longevity of immunity and a growing sense that the virus has become endemic means that ongoing vaccine maintenance and other controls less reliant on human behaviours and less economically costly are likely to be necessary in the long run.

From a longer-term perspective, the causes and effects of climate change are associated with an increased risk of pandemics like COVID-19, and more severe illness for individuals (Bernstein, 2021). The current pandemic comes after a series of significant epidemics over the last 20 years, including SARS (2003), H1N1 Influenza (2009-2010) and MERS (2012). When determining the cost-benefit of engineering controls and updates to standards and other formal requirements, the increased likelihood of these types of events should be considered.

1.3 Recommendations

The work undertaken by Engineers Australia to develop this problem and opportunity analysis has led to the following recommendations:

1. Collect case studies and data on exposure events where ventilation is a factor, including both super spreader events and the cases where significant spread does not occur. Develop advice about what can be learned about the design of buildings from these case studies. It is critical that this data is collected contemporaneously for future reference in the development and improvement of regulation, standards and other guidance.

2. Provide leadership to bring the broad cross section of relevant professionals and trades together, to share lessons, data, research, questions, industry experience, new technology, and specific challenges that could be solved better together. This work should be supported by influencers and other advocates to drive change.

3. Engineers Australia to provide leadership on the promulgation of specific, actionable advice to critical actors in the control of COVID, and on the promulgation of knowledge, science and data to facilitate informed community discourse on the topic.

4. Actively advocate for meaningful changes to the content of both regulation and standards, as well as structural issues that limit the effectiveness, resilience and sustainability of regulation and standards.

2. The challenge and opportunity

There are four broad categories of impact to be considered:

1. The immediate crisis
2. Future-proofing buildings for pandemics, ongoing emergence of new variants and general occupant health
3. Developing infrastructure and tools to enable the engineering community to more swiftly, cohesively and cooperatively respond to emerging and dynamic crises
4. Ensuring that systemic challenges highlighted by the current crisis are remedied.

The acceptance of the airborne spread of COVID-19, coupled with the need to strengthen the resilience of the infection control environment, presents an opportunity for the engineering community to play an important role in providing expert advice on the design, maintenance and operation of heating, ventilation and air conditioning (HVAC) systems in public, commercial and multi-unit residential buildings. Opportunities to improve the performance of built environment indoor air quality are apparent across the life cycle of multi-occupancy buildings.

Some of these opportunities focus on the community's long-term needs for indoor air quality, and some relate to the current crisis (highlighted in red):

Table 1 Life-cycle issues and opportunities for action

Life-cycle issues	Opportunities for action
Policy and Standards	• Advocating policy change with respective Departments of Health to require building owners to deliver better indoor air quality for occupants • Ensuring the maintenance of regulations, standards and guidance materials is adequately resourced to ensure they are keeping pace with changing needs • Working with government to understand the risk associated with the existing pool of assets from a public health perspective
Project Development	• Advocate for the adoption of benchmarking schemes that seek to achieve high occupant health performance, such as GBCA, WELL and NABERS Indoor Environment ratings • Advocate for government to seek good performance regarding air quality of public assets, such as public housing, schools, hospitals and prisons.
Design	• Undertake building designs that are capable of minimising spread of illness between occupancy
Construction	• Ensure that the building is built to the design and that lower performance HVAC components are not substituted during construction
Maintenance and Operation	• Advocating for the setup of an advisory panel to develop guidance for building owners, workplaces, and immediate/urgent actions as we rely less on lockdown for future control. • Advocating for building owners to get an engineering assessment of their buildings in relation to prevention of COVID-19 spread • Advocate for the maintenance of "as-built" drawings by property managers to enable rapid assessment for modifications in the event of a crisis • Support development of retrofit technologies that enable older buildings to minimise the spread of disease between occupants • Work with other aligned stakeholders to identify common adjustments to building operations and maintenance practices to reduce the risk of spread within buildings
End of Life	• Advocating for the appropriate disposal of filters

2.1 Meta observations

2.1.1 Lessons from COVID-19

Beyond the immediate COVID-19 concerns, there are some meta-level observations and lessons arising from the current pandemic.

1. Readiness to respond quickly with aligned stakeholders in a crisis is important. For example, the pre-existence of Construction Health and Safety New Zealand *a non-profit in which industry, government, Engineering New Zealand are participants enabled the NZ construction industry to very quickly come together to develop standards, practices and guidance material and continue operating in response to COVID-19.*
2. There is a role for Engineers Australia to connect groups (e.g. industry, academic, experts) who are working an issue from different angles, or who might be able to collaborate/share funding
3. An immediate review of the resilience of engineering profession "infrastructure" (e.g. standards, online platforms, software) may be needed when new threats emerge.
4. Some sovereign capability is at risk when the ongoing performance and maintenance on essential infrastructure has a significant reliance on overseas experts and overseas-sourced spare parts, etc.

2.1.2 Stakeholders

- State Departments of sustainability, health and education
- Australian Building Codes Board (ABCB)
- WorkSafe: what does 'so far as is reasonably practicable' (SFAIRP) mean in the context that an employer is a tenant and has limited ability to get better performance out of building managers?
- High rise commercial building managers.
- Residents and tenants of multi-occupancy buildings and their representative associations
- Allied associations including the Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), The Australian Institute of Occupational Hygienists (AIOH), The Association of Consulting Architects, Property Council Australia
- Academia in engineering and related disciplines

2.1.3 Indoor air quality in general

The issue of indoor air quality and performance of buildings in Australia appears to be complex and somewhat opaque. Some observations from this research process indicate that this is a topic worth exploring further to understand the ranging perspectives and aspects, given its importance to human health:

- The 2011 State of the Environment Report (DoE, 2011) identifies the importance of indoor air quality on human health and notes the lack of objective data and that "the absence of specific guidelines for indoor air quality in Australia prevents an objective assessment of the quality of observed indoor air". Commentary in the most recent State of the Environment Report (2016) is limited to a reference to a 2015 paper, stating "Indoor air quality and occupational exposure may also be increasing pressures [defined as events, conditions or processes that result in degradation of the environment], but these remain poorly measured and monitored".
- Sustainability of HVAC systems including energy efficiency is critical given the energy consumption of these systems, the relative inefficiency of ageing assets.
- A proposal to amend the National Construction Code (NCC) as part of the 2022 amendments from an Engineers Australia member regarding fire safety/smoke spread risks "would be reviewed at a later date as part of the 2025 amendments (Johansson, 2021). How transparent are the review processes and prioritisation of issues for resolution?
- Who is responsible for indoor air quality? For tenants, the ability to improve indoor air quality is limited, and the incentives for building owners are difficult to see (e.g. WHS would be a very long bow for work places, and it's hard to see anything in the residential space).

2.2 Exposure contexts

When considering COVID-19 transmission in indoor environments, it's important to note that there are several different contexts to consider, each with their own risk profile and available set of controls. Table 2, below, describes a selection of contexts, noting there will be more that are not listed here, such as shopping centres and sporting complexes.

Table 2 Exposure contexts

Exposure context	Risk profile	Control environment	Indoor air quality regulatory context
Hospitals	Exposure arises through presentation/admission of infected persons for treatment, admission and testing, visitors carrying the infection in/out and staff. Risk is higher where special treatment wards have been established (e.g. COVID wards) and in particular through Intensive Care Unit (ICU) use due to need to maintain positive pressure in the treatment room, particularly when patients are ventilated.	Infection control standards for operation; highly trained staff; high performance standards for air quality in particular areas of hospitals particularly operating theatres; negative pressure isolation rooms (e.g. high efficiency particulate air filter (HEPA) or similar) and special manufacturing/pharmacies.	Australasian Health Facility Guidelines (voluntary). State based engineering and technical guidelines from relevant health department. NCC requirements for these classes of building, note Victorian Department of Health report (Sara, 2021) on isolation wards ventilation failures.
Single family home	Close living quarters often leads to spread between household members. Visitors and gatherings in the home have been a source of super spreader events.	Limited ability to restrict air flow between rooms; limited knowledge in general public of infection control practices; can open the windows.	NCC requirements generally assume natural ventilation and openable windows.
Residential Apartment Complex- low to mid rise	Common areas including foyers, lifts, stairwells and amenities (laundry, gym, pool) can allow infection between apartments, even in casual contact (e.g. Southbank, Vic). Stack effect can enable air to travel between apartments above and below each other through naturally ventilated bathrooms.	Different class of building to high rise towers; improvements to indoor air quality. Older buildings/complexes and converted office buildings will also have a different risk profile.	Construction: NCC (may rely on natural ventilation for living areas). Operation: depends upon the individual owner and the Owners Corporation for common areas.
Residential Apartment Tower	Common areas including foyers, lifts, stairwells and amenities (laundry, gym, pool) can allow infection between apartments, even	Different class of building to low/mid-rise.	Construction: NCC (may not have openable windows)

Exposure context	Risk profile	Control environment	Indoor air quality regulatory context
	in casual contact (see the cases below in China, Canada). Stack effect can enable air to travel between apartments above and below each other through naturally ventilated bathrooms.		Operation: depends upon the individual owner and the Owners Corporation for common areas.
Commercial Office Tower	Common areas including foyers, lifts, stairwells, bathrooms, amenities, meeting rooms, between people working together.	Inability to open windows for fresh air; limited incentives for building owners to improve air quality (outside NABERS, where adopted).	NCC, NABERS for operation.
Hotel Tower/ Hotel Quarantine	Interstate/international arrivals coming from higher risk locations and/or during the travel itself. Infection between guests within one room, infections between rooms (perhaps via the corridor) and infection to staff supporting hotel operations.	Often cannot open windows; positive pressure in rooms leads to air from rooms being pushed into corridors; heavy government support on infection control measures in quarantine hotels, but otherwise limited experience in hotel industry.	NCC; similar to high rise office towers. Operation: relevant health code in jurisdiction.
Schools	Within classrooms, but also in shared use spaces such as assembly halls, libraries and hallways.	Ability to open windows is typically pretty good, however, during winter and hot weather days this may not be an option. Additionally, the efficacy of mask wearing requirements for younger children is unclear.	Relevant Department of education guidelines or requirements, including the NCC.

Questions for feedback and discussion

What are other indoor environments in which air quality management should be explored?

For those additional indoor settings, what are their specific risk profiles, control environments and indoor air quality regulatory contexts?

3. Supporting Professional Practice

3.1 Technology and research

The building system industry (including researchers, designers and manufacturers of HVAC systems, filters, control system and air purifiers) has responded to the emergence and growing body of knowledge of COVID-19 with a range of new and improved technologies and applications of existing technologies (e.g. Connolly, 2021, Aitchison and Evans, 2021, Buising et al 2021).

Conversations informing this paper indicated that there was a lack of visibility of researchers, potential industry partners and collaborators working in this space. Engineers Australia, (with membership that crosses a range of relevant disciplines, including mechanical engineering, building services engineering, biomedical engineering, electronics/control systems, and relationships that includes range of government entities, professional bodies, industry and university stakeholders) is in a potentially unique position to support connections across these disciplines and sectors.

Questions for feedback and discussion

How can could Engineers Australia facilitate sharing of emerging technology and novel applications and support collaborations on applications research?

What additional structures are needed to enable this? What other relationships are important here?

How could Engineers Australia engage with members to identify and ideate problems and solutions? (For example, a case competition with university students to retrofit HEPA filter bathroom ventilation fans for high rise apartments?)

3.2 Standards

The engineering community relies heavily on standards and guidance material in the design, maintenance, and operation of HVAC systems. However, the complexity of the standards landscape potentially impedes their effectiveness as tool to mitigate airborne illness spread in the short-medium term. For example:

- Competing requirements and trade offs arise from the range of applicable standards and guidance, for example adapting HVAC installations to achieve health outcomes will impact compliance with energy efficiency and fire performance requirements.
- Some standards are very specialised and may not contemplate the interconnected nature of other standards, particularly where they are managed by different organisations.
- The length of update cycles for critical regulatory standards such as the NCC may be several years, which makes it unsuitable to respond to immediate issues.
- Updates generally require robust industry and stakeholder consultation, which impacts the quantum of change or number of issues resolved that can be achieved at any given time.
- Standards are not always applicable to existing assets, which reduces the potential impact of any change.

Questions for feedback and discussion

How could Engineers Australia map the standards landscape is it applies to HVAC systems and indoor air quality to inform further understanding of the issue?

How could Engineers Australia work with standards owners to improve the coordination and agility of standards, and ensure they are well maintained into the future?

3.3 Achieving benefit for the community

Engineering practice exists in a broader eco system, and both constraints and opportunities to improve indoor air quality appear when broader context is considered. For example, while engineers may have the knowledge to make buildings safer from an HVAC perspective, this can only occur when they are tasked to do so. The lack of awareness/ knowledge of health-related HVAC considerations for multioccupancy buildings from strata and other building managers (particularly outside of A class buildings), may mean they are unlikely to seek this advice or work.

Similarly, the existence of as-built drawings is inconsistent, severely hampering any ability for buildings to be assessed and recommendations for improvements made. While plan drawings are lodged with the relevant local council, as-built drawings are usually delivered to individual building owners/managers, and are at risk of being misplaced, damaged or never actually delivered.

Questions for feedback and discussion

How can Engineers Australia work to repair underlying systemic issues with the building sector, to enable better, more timely response to future issues?

On the other hand, there is an opportunity for Engineers Australia to engage with allied professionals to support engineering practice, perhaps through understanding the underlying science, new and emerging understanding of the behaviour of COVID-19 and related issues. For example, working with epidemiologists, the Australian Institute of Occupational Hygienists or aerosol physicists.

Questions for feedback and discussion

How can Engineers Australia work with allied professionals to:

- Deliver fundamental and contextual knowledge CPD for engineers?

- Collectively advocate for shared positions?

- Close any gaps in existing knowledge of the issue by professionals as a whole?

- Support collaboration on research and technology development to achieve a multidisciplinary approach?

3.4 Public engagement and communications

The topic of COVID-19 and ventilation is an opportunity for Engineers Australia to further its strategic objective to increase recognition of engineering value to the community. As ventilation becomes increasingly important to the control of COVID, so too does the education of the community the roles of both the general and engineering communities in using ventilation as a control.

Engineers Australia should collaboratively consider how best to communicate with the community about the importance of ventilation as a control, how ventilation can act to reduce the spread of airborne illnesses, what considerations are relevant to their situation and how and when to engage with the engineering community to obtain specialist advice. This can be achieved in several ways, for example:

- The production of explainer products, aimed at the community, on the importance of and science behind ventilation in indoor air quality
- Guidance targeted particularly for asset owners and decision makers such as bodies corporate, building managers, schools and hospitals
- Guidance for individuals such as apartment residents.

Questions for feedback and discussion

What kinds of information/considerations should be incorporated in material to help engage the public?

Who should Engineers Australia collaborate with in its development?

What other opportunities are there to promulgate information?

3.5 Data and lessons learned

A key feature of the approach to incident response (as articulated in the Australian Interagency Incident Management System, AIIMS) is the capturing of lessons and information during the response that will enable better prevention, mitigation and recovery from similar future hazards.

In the wake of the Newcastle Earthquake in 1989, which resulted in 13 deaths and $1.974b damage in today's dollars, Engineers Australia commissioned a report by CSIRO and the University of Newcastle (Mel hers 1990). This report documented evidence of how buildings in the affected region performed during the earthquake and was produced only months after the earthquake incident. In commissioning this work, Engineers Australia recognised that valuable evidence would be lost during the reconstruction effort.

Similarly, where transmission occurs in multioccupancy buildings, there is an opportunity to gather contemporaneous evidence of the building, for example:

- The arrangements and setting of the ventilation system in relevant areas of the building at the time, both where transmission took place and where transmission was apparently prevented
- Any local arrangements, including temporary settings that were in place in the building, such as placement of and setting of air purifiers, DNAs, dehumidifiers, door stops and filters operating at the time
- The movement of elevators
- The nature of the cases in the building, their viral load and vaccination status and other considerations.

A particular focus might be considered for buildings that are representative of a general class of common buildings of high risk, such as public housing towers.

Questions for feedback and discussion

How could Engineers Australia work with academia, research organisations, industry and government to:

- Create case studies of multi occupancy buildings (e.g. residential, commercial, health and hotel quarantine) with data about the performance of buildings in the Australia?

- Identify common practices or HVAC system features that correlate with transmission events, or the apparent prevention of transmission in outbreak events?

What should be included in the scope of this data collection?

Who could Engineers Australia work with?

4. Literature review and references

4.1 Relevant cases in the literature

A brief survey of cases of coronavirus spread in multi-occupancy apartment buildings reveals intervention opportunities in the design of bathroom and general ventilations:

235 Rebecca, Hamilton, Canada COVID-19 outbreak: In this case, an outbreak in a 17-storey, 164-unit apartment building in the city of Hamilton, Canada led to 55 cases and one fatality. Tenants rejected claims by health officials that the outbreak was the result of socialising, and capacity limits were introduced into elevators and shared laundry facilities (Mitchell, 2021a; Mitchell 2021b)

Seoul, South Korea Apartment building COVID-19 outbreak: An outbreak in an apartment building in Seoul, South Korea, led to 10 cases of COVID19. A study of the outbreak (Hwang et al, 2020) identified that "[a]ll infected cases were found along two vertical lines of the building, and each line was connected through a single air duct in the bathroom for natural ventilation" and contends this is an example of "(reverse) stack effect, which explains air movement in a vertical shaft".

Amoy Gardens, Hong Kong SARS outbreak: An outbreaks of SARS in a large private apartment complex in Hong Kong, home to 15,000 residents, led to 321 cases and 42 deaths. An analysis of the outbreak identified a range of possible routes of transmission relating to bathroom ventilation and hydraulic action of flushing toilets.

Guangzhou, China COVID-19 outbreak: An outbreak in an apartment building in Guanzhou, China, led to nine cases in three families. The cases occurred across three vertically aligned flats in a 29-storey building. A study (Min Kang et al, 2020) contends that bioaerosols spread via dry u-shaped water traps and bathroom ventilation arrangements.

Questions for feedback and discussion

How are engineers educating themselves about this emerging research?

4.2 References

The following resources were utilised in the development of this paper:

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Sally Sara, *Almost half of Victorian isolation wards failed to meet all ventilation guidelines, leaked report reveals* (1 July 2021) ABC News <https://www.abc.net.au/news/2021-07-01/ventilation-in-victorian-hospitals-audit-leaked/100258586> at 2 July 21

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Questions for feedback and discussion

Are there other references that are recommended for review in this work?

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