Parliament of Australia

Submission to the Inquiry into Long COVID and Repeated COVID Infections

Submission from: Professor Geoffrey Hanmer

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Image Cover: Classroom in regional NSW, photo from the Author.
Image Back: Aged Care Facility in regional NSW, photo from the Author.

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This submission primarily addresses Question 4.

“The health, social, educational and economic impacts in Australia on individuals who develop long COVID and/or have repeated COVID infections, their families, and the broader community, **including for groups that face a greater risk of serious illness due to factors such as age, existing health conditions, disability and background**;”

Summary

The COVID-19 pandemic has highlighted the critical role that building ventilation and Indoor Air Quality (IAQ) play in the control of airborne infectious disease. Most transmission of airborne diseases occurs indoors where ventilation, or dilution with fresh outdoor air, is limited by the characteristics of the building.

In Australia, high occupancy buildings such as schools, community centres, restaurants, pubs, shops, and aged care are often Designed to Satisfy (DTS) Naturally Ventilated under Section F in Volume 1 of the National Construction Code (NCC). This requires that ventilation openings, such as operable external windows and doors, are designed into and provided in the completed building.

Unfortunately, there is no requirement for these devices to be opened when the building is operational. There are no national or state standards for Indoor Air Quality (IAQ) that are enforceable, nor are there any agencies that are tasked to enforce them. Observation shows that during periods of hot and cold weather, windows in high occupancy DTS Naturally Ventilated buildings are often shut to maintain thermal comfort, resulting in very poor ventilation and consequently increased risks that airborne diseases will be transmitted.

Most high occupancy community buildings in Australia are DTS naturally ventilated. For example, of the 2,220 public schools in NSW, only about 40 are mechanically ventilated.

Nearly all childcare centres, community centres and ACF are DTS naturally ventilated. **These buldings accommodate some of the groups in the community most vulnerable to the impact of COVID sequelae**; children because the long-term impacts of COVID infection are uncertain and old people because the case fatality rate for COVID-19 increases rapidly for people over 65.

In other countries, high occupancy community buildings are often mechanically ventilated. This appears to be the case in the US, Canada and in many countries in Europe.

Buildings in Australia that should and could play a critical role in reducing the spread of airborne diseases such as COVID and its sequelae amongst vulnerable groups are a key reason why transmission is higher in Australia than it would be if IAQ was properly regulated.

The consequences of high transmission in Aged Care Facilities (ACF) were obvious during the second wave in Victoria, when about 700 residents died, but they have also been very evident during 2022. The total number of people dying in ACF in 2022 to date is not easy to ascertain accurately, but it is clearly more than 4,000 people.

Disruption to learning and teaching caused by repeated COVID-19 infections and sequalae in schools has become a serious issue in most states with insufficient relief teachers available to assure continuity of education. [1]

Deemed to Satisfy Mechanically Ventilated buildings under the NCC must comply with AS/NZS 1668.2. This Standard requires a minimum amount of fresh air ventilation, generally 10 litres per second per person which should give adequate ventilation in most circumstances.

Unfortunately, measurements in real buildings over the past two years demonstrates that many mechanically ventilated buildings have ventilation levels that suggest AS 1668.2 air volume levels are not being delivered. This means that ventilation will not be adequate to minimise the risk of airborne disease transmission.

The most probable reason for this situation is because building owners are operating mechanical systems with reduced amounts of fresh air to manage operating costs. As with DTS Naturally Ventilated buildings, there are no IAQ Standards for mechanically ventilated buildings and no agencies responsible for enforcing ventilation provisions.

Solutions

The three key solutions to reducing the transmission of airborne infections are; 1) increasing natural or mechanical ventilation to dilute the concentration of pathogens in internal air or 2) the use of HEPA filters to remove them or 3) the use of UV-C irradiation to inactivate them.

These solutions will result in improvements to Indoor Air Quality (IAQ) that will deliver a range of benefits to health and wellbeing, including a reduction in the transmission of airborne infectious diseases including COVID-19, influenza and diseases caused by other pathogens.

Improvements in ventilation need to go together with provisions to deliver thermal comfort. Without arrangements to deliver satisfactory levels of thermal comfort, it is practically impossible to ensure that ventilation levels will be maintained at satisfactory levels.

The National Construction Code (NCC) requirements for ventilation should be harmonized with new National Standards for IAQ for high occupancy buildings, including schools and aged care facilities.

Operation of high occupancy buildings accessed by the public in a manner that breaches the National Standards for IAQ should be an offence.

Compliance with national IAQ standards could be enforced through a partnership with the Australian Building Codes Board (ABCB), state and local authorities in a similar way in which the National Food Standards Code is now enforced.

The use of CO2 monitoring to activate fall back mechanical ventilation systems, or the use of permanent mechanical supplementary ventilation systems in high occupancy naturally ventilated buildings may be required to achieve complying IAQ. Improved provisions for natural ventilation through advanced systems could also play an important role.

The provision of publicly visible CO2 confidence monitoring in public venues, as in Belgium and the Netherlands, should also be considered.

The research and development of practical methods to rapidly retrofit existing building stock is vital, particularly in schools and aged care facilities. This should be a central focus of the recently established ARC ITCC for Advanced Building Systems Against Airborne Infection (ADVANCE).

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Introduction

Pre COVID, respiratory illnesses around the world, including colds and influenza, caused an estimated 18 billion upper airway infections and 340 million lower respiratory infections every year, resulting in more than 2.7 million deaths and economic losses measured in billions of dollars. [2]

Respiratory infectious diseases are spread mainly by airborne transmission, which is the inhalation from the air of virus or bacteria-laden particles generated during breathing, speaking and other human respiratory activities. [3]

A single airborne viral disease, COVID-19, has now claimed between 17 million and 25 million lives worldwide [4]. The COVID pandemic has focussed attention on the role buildings can play in reducing the transmission of airborne diseases and by promoting health, either by improved ventilation (dilution), filtration of internal air or sanitising internal air using UV radiation.

There are several other key causes of poor respiratory health associated with IAQ and buildings:

1. Tiny airborne particles with widths as small as small as 2.5 microns (PM 2.5) are responsible for more than four million deaths worldwide each year. Most of these particles are generated by combustion of fossil fuels or natural products such as timber and dung, but recent research has shown that vehicle tyres also contribute to this problem. PM 2.5 particles are small enough to penetrate deep into the lungs and can transit to the blood and lodge in organs including the heart, gut, and liver, causing cancer and other diseases. Most of this pollution is generated in outdoor air, with key sources being traffic, industry, wood burning stoves and bushfires.
2. Other pollutants, including carbon monoxide and nitrogen oxides from cooking and heating appliances, formaldehyde from adhesives and certain building materials, ozone from the operation of electrical equipment and volatile organic compounds from common furniture and insulation materials can all have detrimental impacts on human health in indoor environments unless ventilation is sufficient to dilute them to harmless concentrations, or they are removed by other means. Some of these pollutants can be eliminated by choosing materials and equipment with low emissions and others can be minimised by ensuring that appliances have extraction direct to outside air, which is now required by the NCC for residential kitchens in apartment buildings, for instance. Some gaseous compounds can be removed by filtration through activated carbon.
3. Carbon dioxide, which is a product of human respiration can accumulate in densely occupied naturally ventilated buildings to levels that will negatively impact cognitive functions if ventilation is low. This is a particular concern in education environments such as schools and universities where natural ventilation is common, room occupancy is high, and windows are often shut or only partially open to maintain thermal comfort or to exclude rain and wind. Carbon dioxide cannot be removed by filtration.
4. In some locations in Australia, radon gas, which is a daughter product of the decay of radium found in building materials or in the ground can accumulate in unhealthy quantities. ARPANSA estimate that around a thousand houses in Australia may be impacted, but this assumes normal (leaky) levels of ventilation. Buildings that are tightly sealed may be more vulnerable to effects from radon because it cannot be filtered out. [5]
5. Biological agents, including mites, mould spores, fungal spores, pet dander, pollen and plant material can also cause a significant impact on health if they are able to accumulate indoors. Some people are vulnerable to different biological agents, and spores from black mould can be particularly hazardous. Eliminating biological agents from outside air used as a ventilation source requires filtration, but biological agents generated indoors can be controlled by managing water ingress and condensation to ensure that conditions are not favourable to indoor growth. The most common causes of biological growth are leaks caused by inadequate construction detailing, poor mechanical designs and condensation caused by inadequate construction detailing and ventilation. This impact is often manifest in kitchens and bathrooms of Class 1 and 2 buildings, but can also be problematic in non-residential buildings, particularly where they are DTS Naturally Ventilated. [https://www.abcb.gov.au/resource/handbook/condensation-buildings-handbook]
6. Bushfires produce enormous amounts of particulates including PM 2.5 plus toxic gases and other bioactive compounds. Bushfire smoke has been observed to cause a range of impacts, particularly

on pregnant women, people with asthma, immuno-compromised people, and those with pulmonary diseases, such as COPD. Practically, smoke from prolonged bushfires cannot be kept out of conventional buildings, but particles and some gaseous products can be filtered out, either by an installed mechanical system or by portable air purifiers using HEPA and activated carbon filtration.

While these are important subjects in themselves, this submission will concentrate on the impacts of COVID, in part because the ventilation and filtration that will reduce the probability of airborne disease will have a beneficial impact on most of the other factors listed above, aside from bushfire smoke.

Improving IAQ may have an impact on building energy consumption. This can be mitigated using heat recovery equipment and other techniques, but nevertheless this is an issue that must be confronted. Total carbon impact will of course depend on how energy is generated.

The energy used to deliver clean air must be considered in context. Developed countries expend a considerable amount of energy to deliver clean potable water, remove waste, provide facilities for hygiene, refrigerate food to reduce contamination, and to provide thermal comfort, all to improve human health and welfare.

Every time people pay a domestic water bill, they are paying to preserve their health. Every time they heat water for washing, they are paying to preserve their health. Their refrigerator helps to ensure that they do not suffer from food poisoning and their stove delivers food that has been cooked to remove pathogens.

The supply of clean water, removal of sewage and sullage and the provision of other hygiene and sanitation services incur a significant economic and energy cost on the community, but the benefits of this are well established.

Up to now, relatively little energy has been used to deliver acceptable IAQ in Australia. Given that the pandemic has reminded us how important clean air is to human health, a recalibration is required in our thinking on IAQ and its regulation.

Disease Control in Developed Economies

For all recorded history, humans have suffered from debilitating infectious diseases that have reduced their life expectancy and productivity. Around 1870, life expectancy and population in advanced economies began to increase more rapidly due to improvements in sanitation and hygiene. This included the construction of sewer systems in cities, the provision of clean drinking water, control of vermin and insects plus improvements in personal hygiene driven by the availability of affordable soap, public bathhouses, housing incorporating bathing facilities, disinfectants, detergents, and pest controls.

These measures sharply reduced the incidence of plague, cholera, typhoid, malaria and many other diseases. In western Europe, there have been no cholera epidemics since 1892 and the last outbreak of typhus in Europe was at the end of WWII. Malaria or 'quartan auge' was endemic to the Thames Estuary and in many parts of Australia but was eliminated towards the end of the nineteenth century by control of mosquitoes. Only in 1981, Malaria was declared eradicated from Australia. [6] [7]

Food borne infectious diseases have been reduced by the introduction of Pasteurisation, effective preservation processes, cold chains and in developed countries, domestic refrigeration.

It took about 300,000 years for the human population to reach one billion in the early nineteenth century but in the 200 years since then, world population has grown to over 8 billion, largely because of the elimination or control of infectious diseases.

In Australia, life expectancy has nearly doubled since 1870, from 48 years to almost 84.[8]

The most dangerous infectious diseases historically were plague, smallpox and influenza. Smallpox was controlled using the first vaccine, discovered by Edward Jenner in 1796. By 1979 it became the first infectious disease to be declared eliminated by WHO. Other potentially fatal infectious diseases such as measles, diphtheria, rubella, mumps and polio were also controlled by vaccines. Plague, which has killed over 200 million people, the deadliest infectious disease in recorded history, was spread by fleas and lice from an animal reservoir of infected rats. Eliminating the rats and the insects manages this disease, which continues to exist in parts of the world.

As vectors for disease transmission have been reduced through sanitation, hygiene, pest control, food safety and vaccination, airborne infections and sexually transmitted diseases now dominate the pandemic landscape in developed economies. The most recent pandemic involving a non-airborne disease was HIV-AIDS. There is still no vaccine or cure for HIV-AIDS, although management of the disease has improved substantially, but the availability of these treatments is mainly confined to developed economies. HIV-AIDS has now killed more than 32 million people over the last 40 years, most of them in developing countries. [9]

The threat of pandemics comes from zoonotic diseases, which jump unpredictably from animals to humans because humans have limited immunity to new pathogens. Although there are many zoonotic diseases around, including some dangerous ones such as the flaviviruses that cause West Nile Fever and Zika, filoviruses that cause Ebola, and alphaviruses that cause some human encephalitis diseases, most of these are transmitted by insect vectors or primarily through direct contact, both of which are vulnerable to physical controls.

The most serious pandemic threats to developed countries come from viruses that can be effectively transmitted as aerosols through the air. These includes the Orthomyxoviridae family (influenza), the Morbillivirus family (measles) and the Coronaviridae family, which includes SARS CoV, MERS and SARS CoV2, the virus that causes COVID-19.

Unlike influenza or many other respiratory infections, COVID is a multi-system disease. In a currently unknown percentage of infections, it causes complications that result in strokes and heart attacks. There is also evidence of memory loss and cognitive problems, including aphasia (speech impediment), brain fog, nerve damage plus loss of smell and taste.

Long COVID impacts at least four percent of people infected with COVID-19 and the implications of this condition are still unclear, particularly for people who experience repeat infections. Typically, the impact of long COVID includes fatigue, cognition problems, nerve pain, immune system disorders leading to parasitic infections and psychosis. The impact on individual productivity can be catastrophic.

There is currently no certainty that impacts of repeated COVID infection on children will be trivial, even though the severity of the disease experienced is in most cases mild. For older people, the Case Fatality

Rate (CFR) for COVID is directly related to age. Arguably, these two vulnerable groups should be the focus of protection efforts.

In Australia, outdoor air quality has been significantly improved since the 1970's, and is now classified under the Air Quality Index (AQI) system as mostly 'good', except near major roads, during bushfires and in some regional areas where wood burning fires produce high levels of particulates, including PM 2.5's.[10]

Clean, safe indoor air is the final frontier for sanitation and hygiene in developed economies. Given the threat posed by airborne pandemics including COVID-19, the sooner that this gap can be plugged, the better. If governments do not act, they are ignoring a long-term vulnerability to airborne disease. As a result, Australians will need to deal with levels of sickness, disability and economic impacts that could be avoided if IAQ were to be improved.

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The Transmission of COVID-19

At the start of the COVID pandemic, there was an emphasis on controlling transmission by sanitising fomites (contaminated surfaces) hand hygiene and distancing to prevent droplet transmission. Unfortunately, this was a mistake:

"This is likely the most egregious public health error in modern history. The cognitive dissonance that goes with making this mistake must make it very hard for those responsible to acknowledge the error in order to protect others. There must have been an element of "we'll just get through this wave and we'll be okay" but then the waves just kept coming."

Dr Joe Vipond [11]

During the COVID-19 pandemic, the significance of indoor airborne transmission of disease was fully exposed by scientists [12] and eventually recognised by public health authorities, but the implications of the airborne nature of COVID-19 are still not fully understood or acted upon in a rational way by governments. [13]

Both WHO [14] and the Australian Department of Health now acknowledge that COVID-19 is primarily an airborne disease transmitted as an aerosol. Nevertheless, other diseases can be acquired from fomites, so hand hygiene, particularly after visiting the toilet, is still important.

In 2020, the Centers for Disease Control (CDC) in the US estimated that the chance of catching COVID outdoors was at least 18.7 times less than catching it indoors. The derivation of these figures is problematic because they are affected by so many variables, including the characteristics of the room, but in outdoor locations, evidence shows that probability of COVID-19 transmission is extremely low providing social distancing is maintained and dwell time is short. Although transmission has been recorded at outdoor music festivals, this may have been associated with enclosed spaces such as food and beverage facilities and toilets, plus of course the close mixing of people over a long period of time. [15] It is possible that COVID can be acquired walking down a street, but the probability is low. [16]

At its most basic, the transmission of COVID-19 is facilitated by the poor ventilation characteristics of buildings.

Since about mid 2021, governments in Australia have been encouraging people to eat and gather in outside settings because there was a growing awareness that COVID-19 was airborne. Unfortunately, there has been little action by those same governments to improve regulations or ventilation of buildings housing vulnerable populations, including ACF and schools.

Part of the problem inherent to viral pandemics is the rate of mutation due to the aggregate number of infections, which for COVID-19 now exceeds 600 million worldwide. Every infection and particularly prolonged infections are opportunities for a mutation to emerge. As a result, new strains of COVID-19 are being detected at a rate proportional to infections. Given that strains become dominant because they outcompete previous strains, it is likely that established new strains are more infectious, either because they are inherently fitter or they are better at evading the human immune system.

Whether a new strain is milder or more severe is a matter of chance; either is possible. While some people hope COVID will become less severe, either because of mutation or because our immune systems evolve to be better able to cope with it, there is no guarantee that this will be the case. Polio, a virus, was only controlled by a vaccine, and AIDS, another virus, is only controlled by treatment. They have not mutated to be milder.

In a room, exhaled virus particles accumulate in the air and appear to build up over time. Singing and exercise are clearly factors that can add to the viral load in the air, as has been shown in several research papers. [17] The rate of virus build up is influenced by the nature of the activity, the number of people per sq m, the amount of virus shed by individual infectious people and the number of infectious people.

Virus and pathogens can be removed from the air by:

1. Diluting the air in the room by ventilating with fresh air and directing the spill air outside.
2. By recirculating the air in the room through a filter which is fine enough to remove viral particles. Only a Grade 1 HEPA filter (H13) can remove over 99.9 percent of COVID virus particles, but a F8 or MERV 15 filter can remove up to 95 percent of them.

3. Sterilising virus particles by using UV-C light. [18]

The higher the dilution or filtration rate, or the more effective the sterilisation process is, the lower the probability of infection.

Ventilation is measured as the number of air changes per hour, or the equivalent number of air changes if filtration is involved. ASHRAE recommend between 6 and 12 air changes per hour to control airborne infections, and similar figures are recommended by CIBSE and OzSAGE. [19]

The length of time that pathogens in the air remain active depends on the pathogen and the physical conditions in the room. Measles, which is one of the most contagious airborne viruses, can persist in air for two hours after an infected person has left the room, according to the CDC. [20]

The Omicron variant of SARS-CoV2 is highly contagious, but not as infectious as measles, and the persistence of SARS CoV2 in air is still under study. Clearly, it is capable of persisting in air for at least 15 minutes and probably longer, based on evidence from infections acquired in lifts.

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Infection Control and Buildings

In the late nineteenth and early twentieth centuries tuberculosis (TB), which is caused by an airborne bacterium, Mycobaterium tuberculosis, was one of the most concerning of the infectious diseases that posed a threat to health in developed economies. Prior to 1945, there was no vaccine for TB and no medical cure, but it was believed that rest and exposure to benign climatic conditions and the sun would lead to remission. Partly because of this belief, Coco Chanel among others was responsible for pioneering the adoption of suntanned skin by fashion models as a sign of health, ironically the cause of many skin cancers in subsequent years. [21]

During the Crimean War of 1853-56, Florence Nightingale used simple statistical analysis to show that patients in well ventilated rooms fared better than those in badly ventilated rooms. Her book 'Notes on Hospitals' still makes fascinating reading and as some have observed, the air supply rates she proposes are close to those we see in modern codes. [22] The UK Royal Commission on Contagious Disease of 1871 subsequently identified ventilation as a key requirement for healthy living.

From the late nineteenth century and up to WWII, there was considerable interest among the population of developed economies in the improvement of ventilation and hygiene, both to reduce infection by TB and as a potential cure for it. Modernist architects and engineers were significantly influenced by the ideas of the Sanatorium movement and the Garden City movement, both of which were inspired by a vision of a healthier future, one without slums and smoke [23].

Since 1945, when TB treatment with antibiotics began in developed countries, and the use of antibiotics to counter bacterial infections became more common, concern about building ventilation appears to have abated, and this is reflected in Australian building regulations progressively permitting lower residential ceiling heights and the deletion of compulsory high-level wall ventilation in all types of buildings.

The current NCC permits windowless bedrooms to 'borrow' ventilation from an adjacent space in Class 2 Apartment buildings. In Melbourne in particular, this has resulted in many recent two-bedroom apartments with one of the bedrooms having no external windows and consequently extremely poor ventilation.

It is also clear that ventilation provisions in recent schools have become less demanding than was the case prior to WWII, with reduced attention to cross ventilation and the design of windows to allow them to remain open during rain. The current trend for very deep plan K-12 school buildings, DTS naturally ventilated, with no effective ventilation to the collaboration spaces in the centre of the building demonstrates how far we have regressed from the typical nineteenth century school design that placed windows on both sides of classrooms in buildings with narrow plans and high ceilings.

The natural ventilation provisions in the NCC date back to the aftermath of the Great Fire of London in 1666 and do not have a scientific basis. The current DTS rule at Section F of the NCC is as follows:

F4.6 Natural ventilation

a) *Natural ventilation provided in accordance with **F4.5(a)** must consist of permanent openings, windows, doors or other devices which can be opened—*

1. *(i) with an aggregate opening or **openable size** [my emphasis] not less than 5% of the floor area of the room required to be ventilated; and*
2. *(ii) open to—*
    1. *(A) a suitably sized court, or space open to the sky; or*
    2. *(B) an open verandah, carport, or the like; or*
    3. *(C) an adjoining room in accordance with **F4.7**.*

This is completely unacceptable. Awning and hopper windows give far less free area than double-hung sash or sliding windows for openable elements of the same size, yet all types are regarded equally under the NCC. While every architect and designer knows that cross ventilation will deliver higher levels of ventilation than a room with openings on one side only, the NCC has no requirements to ensure or even encourage the use of techniques that could increase the probability that natural ventilation will achieve an adequate level of ventilation.

Analysis carried out in response to the NSW Department of Education's audit of natural ventilation in NSW state schools in 2020 showed that on the most optimistic assumptions, the NCC DTS regulations would deliver about one-third of the ventilation area required to meet WHO target air change requirements if awning windows were used, or restrictors were in place to hold sliding or double hung windows to a 125 mm opening to comply with the fall protection requirements of the NCC. [24]

The five percent of floor area requirement has never been altered to acknowledge the deletion of high-level vents, or other changes to common building practice, including the reduction in the provision of open-hearth fires for heating and the use of modern well-sealed door and window units, which have reduced ventilation.

Reducing Airborne Disease Transmission in Buildings

The COVID pandemic has so far killed over 15,000 Australians, with most transmission occurring via indoor air. We need to ensure indoor air is clean and safe to reduce the probability that another pandemic will cause the level of disruption experienced during COVID.

To protect building occupants from airborne disease, indoor air quality must be improved by removing pathogens. This must apply to both naturally ventilated and mechanically ventilated buildings and should be considered in relation to their level of occupancy, or the number of people per sq m. Any building with more than approximately one person per 10 sq m of Usable Floor Area (UFA) should be considered a high occupancy building.

This type of objective has never been envisioned in Australian building regulations except for specialised sections of health care facilities. There are no requirements for DTS naturally ventilated buildings, particularly schools and aged care facilities that have high density of occupation and vulnerable occupants. A typical school classroom will accommodate one person for every 3 sq m of UFA.

Studies clearly show that improving indoor air quality is associated with reduced respiratory infections and better health. [25]

Despite this, the Australian Building Codes Board (ABCB) in their recent draft Indoor Air Quality Handbook have concluded that it is impossible to measure and control biological contaminants. Instead of considering this issue more carefully, they have simply given up on considering appropriate regulations:

Biological contaminants – Contaminants such as moulds and fungi are known air contaminants that can degrade indoor air quality. However, the methodology for the accurate modelling, sampling, testing and measurement of many biological species is not universally agreed. Biological contaminants including house dust mites, moulds and fungi, allergens, bacterial and viral pollutants, are all not covered by the IAQ Verification Methods. (Note: The inclusion of biological contaminants and the extension of the Verification Method to Performance Requirements ***FP4.4(b)*** *and* ***P2.4.5(b)(ii)*** *may be considered for a future edition of the NCC as knowledge in the area increases.)*

Maintaining thermal comfort while achieving sufficiently high rates of ventilation may increase energy consumption, but the priority must be to protect human health.

Contaminants can be removed by dilution, filtration or sterilization and this submission discusses each method in turn. These systems can be combined in different ways to achieve different results and combination treatments and costs will be discussed in the conclusion.

Dilution

The simplest and most direct way to reduce the risk of transmitting an airborne disease is to dilute the air within a room using fresh air. This reduces the concentration of pathogens and therefore lowers the probability of breathing in the pathogenic particles exhaled by an infected person in that room. Dilution will not prevent all infections from occurring, but it will substantially lower the probability. The closer the air is to the quality of outdoor air, the lower the risk of infection.

Studies have shown that an air change rate between 6 and 12 per hour (ACH) is the most effective in combatting SARS-CoV2, according to ASHRAE and WHO recommendations. Both the NSW and the Federal Parliamentary chambers have adopted 8 ACH, which must now be regarded as the gold standard. Unfortunately, ACH does not account for the number of people in the room, or the number of infectious people in the room. A room with a low density of people will present a quite different risk profile to a room with a high density of people, particularly as the opportunity to adequately physically distance is reduced or eliminated as it is in an audience for a theatrical performance, a nightclub or possibly the worst case, a choir singing loudly towards an audience close by.

In situations where distancing is impossible or the activity is inherently likely to produce a lot of virus particles (shouting or singing) or the number of infectious people is large, the capacity to dilute virus before it is breathed in will be compromised. At some point, the only solution will be the use of masks. This is one of the key reasons why it is sensible to try to reduce the number of infections in the community. The more infectious people there are in circulation, the greater the probability that air in a room will be infected.

The ACH rate approach is most appropriate to rooms with a reasonably stable number of inhabitants, such as offices. Where the load changes significantly over time, as it does in schools, entertainment venues, lecture theatres or the common areas of ACF, a method that adjusts ventilation levels to the risk may be more appropriate. One way of doing this is to measure the CO2 level in the air. Humans breathe out concentrated CO2 because of metabolic processes that produce energy in the body. The amount of CO2 breathed out is proportional to the level of physical activity and the amount of air being exchanged in the lungs. A small volume room with low ventilation will have a large rise in CO2 as the population increases, and it will rise faster if people are involved in energetic activity. The CO2 level in outside air is about 410 ppm at 2022, so the level of CO2 above background is a good indicator of whether ventilation in a room is adequate to deal with the load or not.

The level of CO2 in a room is a product of its volume, air change rate and the number of people in the room. In a classroom, for instance, where occupancy can alter throughout the day as different activities take place, CO2 readings will rise and fall with load. The gold standard for CO2 is less than 800 ppm. Below that level, risk of rebreathing expired air is very low, but above that, it rises sharply. The closer a room gets to the outside air CO2 level, the more effective the dilution and the probability of rebreathing other people's expired air is reduced. My research shows it is common to measure classrooms with CO2 levels above 1,500 ppm, some above 2,500 ppm, levels which will markedly increase the risk of infection. Similarly, measurements by RMIT in Aged Care Facilities have shown levels above 2,000 ppm in common spaces.

Several manufacturers make CO2 sensors that can provide a signal to a mechanical ventilation system or to a mechanism that will automatically open windows. In this way, a trigger level of 800 ppm can be selected to increase ventilation. When CO2 levels fall to a set level, possibly 600 ppm, ventilation can be reduced again, depending on the circumstances. In this way, ventilation levels can be adapted to varying loads, potentially reducing cooling and heating energy input. While CO2 is not a perfect measure of ventilation and load, it is the best available technology, given that we cannot detect pathogens in the air in anything like real time.

Good ventilation with low CO2 levels has other benefits than reducing the probability of infection, including improved mental acuity, better concentration. improved reasoning and higher productivity. [26]

Filtration

Another way or removing pathogens of fine particles including bushfire smoke is to filter the air in a room using a High Efficiency Particle Air (HEPA) filter. A HEPA filter operating correctly will remove over 99.9 percent of pathogens, including those as small as SARS-CoV2, the virus that causes COVID-19. High Efficiency Particulate Air (HEPA) filters were originally developed for the removal of contaminants in nuclear facilities during WWII but were quickly adapted for use in several applications, notably operating theatres, ICU's, the electronics industry and other environments where fine particulates are problematic.

Unfortunately, HEPA filters require higher static pressures than fans for most existing mechanical systems will deliver, so it is normally impossible to retrofit them into existing air conditioning systems. Where is it not possible to fit a HEPA filter, it may be possible to upgrade existing filters to the highest grade supported by the fan. While an F8/MERV 15 filter is not as good as HEPA, it can remove over 90 percent of pathogen particles. Combined with dilution or sterilisation, this may reduce the risk of infection to tolerable levels.

The use of standalone 'air purifiers' or 'air cleaners' has become popular during the pandemic, and where dilution is limited by practical considerations or there is no existing mechanical system to upgrade, these are a perfectly viable solution. It is important to match the capacity of the filter to the room size and to ensure that the filter is run as the setting necessary to achieve the designed Clear Air Delivery Rate (CADR). Unfortunately, most manufacturers measure CADR at the highest fan speed and the noise level at the lowest fan speed, so caution is needed to select the correct equipment.

In a school classroom, one big unit is unlikely to be as successful as several small units. Units should be positioned away from the openable windows as the purifier will do more in this location to clean the atmosphere than to clean the air in the room.

Sterilisation Using UV-C Light

In Europe, sterilisation of pathogens using narrow band UV-C light has been used for many years. The system is generally confined to the upper volume of a room with the lights not visible to the room population. Studies show that these systems can be effective in inactivating pathogens and can be used in combination with dilution and filtration to deliver acceptable IAQ.

There are potential issues in using UV-C light in naturally ventilated environments as the air in the lower portion of the room may stratify, negating the benefit of sterile air at the upper level, but relatively simply mechanical mixing devices, such as ceiling fans, can overcome these limitations.

As a part of a solution involving filtration, UV-C appears very promising.

Conclusion and Costs

Australian governments need to take the final step in improving human sanitation and hygiene, which is to improve indoor air quality. This will improve human health and performance, but also it will provide additional security against the next pandemic.

In Australia, it would be logical in the first instance to concentrate improvements on schools and ACF, the vast majority of which are DTS naturally ventilated and which accommodate vulnerable populations.

There are 9,581 schools with 4,030,717 students in Australia in 2021. The cost of upgrading IAQ in all these facilities would be approximately AUD$10 billion in today's dollars, or $2 billion per year over five years.

Similarly, there are 180,900 Australians in 2,695 aged care facilities. The cost of upgrading these would be about AUD$3 billion in today's dollars, or $600 million per year over five years.

The total cost of ensuring the provision of clean air in both schools and aged care facilities would be less than AUD$15 billion in total in today's dollars– $3.0 billion per year over five years. These estimates could be improved by competitive tendering among mid-size contractors.

Not all the money would come from government. For-profit aged care operators and high-fee private schools may be expected to contribute.

$3.0 billion per year is about five percent [27]of the money Australian governments already spend on infrastructure every year, mostly on roads and railways.

It is less than the cost of the AUD $16 billion Building the Education Revolution program, and the benefits would be more widespread, particularly as it will necessitate improvements in thermal comfort as well as IAQ.

Improved indoor air quality would better prepare Australians for the next pandemic and help Australian children and workers learn and work more effectively. It would be value for money and a positive legacy for all Australians.

About the Author

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