Figure 1 Photo credit Grant Skidmore, University of Melbourne

AIR CLEANING TEST FACILITY SCOPING REPORT

International testing best practice – exploring requirements for an Australian facility

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1 Human Right to a Healthy Environment - Air

On the 28th July, 2022 the United Nations declared the human right to clean, healthy and sustainable environment (United Nations, 2022). We would survive just 3 minutes without air, yet relative to food and water there are very few regulations to protect and ensure excellent air quality of communal air. Our lungs have the surface area of a tennis court, and we breathe 8 litres of air every minute. 99% of the world's population breathes air that is below the WHO guideline standards. Of the 7.3 million global premature deaths annually due to poor air quality – 3.2 million deaths were estimated in 2020 to be caused by poor indoor air (with an estimated 86 million healthy life years lost in 2019) – mostly due to insufficient ventilation when using coal and biomass for cooking[1].

The wildfires that were experienced by the East coast of Australia resulted in 417 deaths from smoke exposure over December 2019 and January 2020, with 120 in Victoria (Arriagada et al., 2020). Outdoor air pollution in our urban environments is largely due to wood-heaters, transport and control burns in winter and transport/shipping and industry in the summer months. The 2021 State of the Environment began its Air Quality report with 'Australia generally experiences good air quality'[2], however when there is no threshold below which health benefits aren't seen, and the socio-economic inequity of air across our urban airsheds means most people under-estimate the benefits of cleaning up the air. It is estimated that 3236 Australians died prematurely in 2018 due to Air Pollution (AIHW, 2021), with the most recent estimate of 2,616 annual premature deaths due to $PM_{2.5}$ (Hanigan et al., 2021), making it the dominant Environmental risk factor – it is essentially equivalent to the combined deaths of Sun exposure and the road toll in Australia. With the value of a statistical life estimated at $AUD 5.3M, the annual death rate due to Air Pollution equates to an economic cost of $AUD 13.9 - 17.1 billion a year. It is worth noting that current Australian assessments of air pollution mortality inadequately account for NO_2 with a recent government report[3] highlighting 3,300 annual deaths in New Zealand with a population slightly less than the state of Victoria.

The pandemic highlighted the role that poor ventilation played in the spread of airborne pathogens – the economic cost of regulatory neglect of indoor air in our built environment is yet to be determined. To date 15,569 people have lost their lives to CoVID-19 in Australia, this alone is a cost of $AUD82.5 billion – without considering the cost of disability affected life years due to Post-Acute COVID-19 Syndrome or Medium/Long COVID. Most of the transmission of SARS-CoV-2 has occurred in indoor environments.

1.1 Indoor Air Quality

Australians spend 90% of their time indoors and poor indoor air quality has previously been estimated to cost the Australian economy $12 Billion a year – mainly in presenteeism and absenteeism – i.e. lost work and educational productivity[4].

In Victoria in 2011 40 homes were tested as outlined in the Chief Health Officer's publication on Indoor Air, but this comprised simply a contrast of indoor/outdoor air. The lack of indoor

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[1] https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health
[2] https://soe.dcceew.gov.au/air-quality/key-findings
[3] https://environment.govt.nz/publications/health-and-air-pollution-in-new-zealand-2016-findings-and-implications/
[4] https://www.dcceew.gov.au/environment/protection/air-quality/indoor-air

air guideline values means that there is little incentive for a more comprehensive assessment or ongoing monitoring and tracking programs to improve the health of our indoor environments[5].

1.1.1 Defining 'Safe' Indoor air

There are three controls on the quality of air in a space, these are:
- Ventilation and filtration
- Pollution sources
- Chemical processing

When considering air within a space, and viral transmission primarily, all three processes are important. Ventilation is key to removing contaminants, and refreshing the air in a space. Filtration of outside air ensures outdoor pollution has limited impact on indoor air quality and recirculated air removes particles. Air cleaning devices can augment ventilation via filtration to remove aerosols (but not gases, usually) when ventilation is insufficient or when the outdoor air contains high aerosol loads (smoke, pollen etc). Indoor pollution sources can be human bio-effluents including pathogens within expired air – i.e. SARS-CoV2 viral aerosols or pollution from cooking, but there are also lots of materials and other pollutant sources indoors for which air cleaners are used. Some air cleaners introduce conditions that chemically change the air (i.e. electronic devices containing ionizers / UV / PAC), or make claims to reduce concentrations of some chemical species, and the materials of the air cleaners themselves can also off-gas. Ozone, formaldehyde, nitrogen oxides are all of concern.

1.1.1.1 Ventilation

There are three metrics that are useful in defining safe air shared in an indoor space, in terms of ventilation - these are i) Air Changes per Hour (ACH), ii) the room clearance time and iii) number of air change times (ACT).

1.1.1.1.1 Air Changes per Hour (ACH)

The number of air changes per hour is the most commonly used metric to describe ventilation, a minimal and optimal *ACH* are prescribed for hospital design, with between 6 and 10 commonly recommended. In public buildings there is no such design standard – though educational settings recognize that 6+ is best practice[6]. *ACH* is defined as the ratio of the ventilation rate (*Q)* to volume of the room (*V*).

$$ACH = \frac{Q}{V}$$

Although ACH is the most commonly discussed metric, Memarzadeh & Xu, (2012) note ACH is not the dominating control of airborne contaminant transmission. In their view the path from the patient's head to the ventilation exhaust is the most important contributor in work force infections of airborne pathogens.

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[5] https://www.health.vic.gov.au/chief-health-officer/healthy-indoor-environments

[6] https://assets.education.govt.nz/public/Documents/Primary-Secondary/Property/Design/Indoor-Air-Quality-and-Thermal-Comfort-V2-v2.0-2022.pdf - figure 5, p21

1.1.1.1.2 Room clearance time

The clearance time is the time it takes to completely remove a certain percentage of the air in a room – the Centres for Disease Control define 'safe' as 99% and 99.9% (CDC, 2003). Assuming well mixed space the time to clear a room to 99% or 99.9% efficiency is given by the following equation (CDC, 2003):

$$t_2 - t_1 = -\frac{ln\left({}^{C_2}/_{C_1}\right)}{\left({}^{Q}/_{V}\right)}$$

Where:

t_1, t_2 are the initial and final times

C_1, C_2 are the initial and final concentrations and ($1- C_2/C_1$) is the removal efficiency

Q/V is ACH is the ventilation rate (Q) divided by the volume (V) of the space

With this equation 99% or 99.9% removal efficiencies do not need to be achieved in observations if the absolute concentration is measured. The times can be calculated for 99% and 99.9% for some other observed removal efficiency. 12 ACH means that after 5 minutes (1/ACH x 60 = 60/12 = 5 minutes) 63% of the contaminant will be removed (we can state that it is 'likely' that contaminant will be removed after this time). 99% clearance means it is 'virtually certain' that the contaminant is removed – for 12 ACH this occurs at 23 minutes – assuming well-mixed and a non-continuous source.

A standard already used in operating theatres to define 'safe air space' is one where 99% of the potentially contaminated air is removed. A relevant tolerable time frame needs to be applied – we recommend under 10 minutes for an occupied space – though this is arbitrary for continual sources such as people breathing.

1.1.2 Pollution Sources

Air cleaners – like all new appliances / materials - can off-gas, usually this is a volatile organic compound (VOC) of which formaldehyde is one, and as a known carcinogen, is most often of concern. Some air cleaners use electronic filters and these aim to chemically alter the air intentionally, introducing, ozone or hydrogen oxides (negative ions of some description), or unintentionally nitrogen oxides or other by-products.

1.1.3 Chemical Processing

When hydrogen oxides (hydroxyl, hydroperoxyl radicals), nitrogen oxides or hydrogen peroxide or ozone are introduced to a space, usually by ionization or photocatalytic oxidation then the oxidizing capacity of the air is altered. Ozone chemistry is initiated which when ethanol (i.e. alcohol wipes etc) or other VOCs are present, formaldehyde and higher order aldehydes can form. Radicals and oxidative air chemistry is detrimental to lung and skin health and can trigger asthma / allergies in the short-term; longer term exposures to formaldehyde is carcinogenic.

UV lamps and devices can either create or destroy ozone, or participate in hydrogen / nitrogen / halogen oxide radical air chemistry. ARPANSA can test UV products, particularly lamps for their UV spectra and have issued a product warning for the rise in personal UV lamp use for sterilisation[7]. UV germicidal irradiation lamps require professional installation, but most concerns are for skin and eye health concerns – ozone is also a concern and air cleaner testing protocols for ozone exist. Other air chemistry concerns with UV / electronic air treatment devices is outlined by Collins & Farmer, (2021), testing for just ozone is insufficient to understand the chemical processing of the air, which is why NO_2 and HCHO are also recommended alongside as a minimum to assure safe air delivery by the products (VOCs, HOCl and HONO are also interesting research observables).

2 Regulatory landscape

Without indoor air quality guideline values or standards for operational buildings there is limited incentive to monitor the air within a given space. However, it is recognized by building owners and managers there is significant value to providing fresh and safe air for workforce comfort, health and wellbeing. The air is monitored by many businesses for energy efficiency and this is done automatically in many new builds for building management, despite this is not being a regulatory requirement.

2.1 Australian Building Codes Board – IAQ Handbook

Design standards for new construction and air supply for proposed occupancy exist through the IAQ handbook of the Australian Building Codes Board[8]. This handbook is currently under review, with the consultation process now complete and the update is due to be released in December 2022[9]. In the appendix the submission made to the consultation made by Robyn Schofield is provided – this provides an overview of pollutants of concern in the indoor air environment, and existing guideline thresholds both nationally and internationally.

2.2 Health care settings

In health care settings the number of air changes per hour specified is usually greater than 6 ACH, but in infectious wards / operating theatres negative pressure or 20+ ACH are specified – viz the Victorian Engineering guidelines for healthcare facilities Volume 4: Heating, Ventilation and Air Conditioning (HVAC), in particular.

2.3 Mould

When indoor air is too humid or there is water leakage, mould, a type of fungi, can form, with many adverse health effects. In addition to climate or flooding, building structural issues or occupant behaviours / activities can lead to conditions that promote mould growth. Adequate ventilation minimizes humidity issues in Victoria's mostly dry climate.

2.4 Air Cleaner/Purification device regulation

The US has regulatory and testing standards for Portable Air Cleaners. Almost all other testing facilities internationally are based off these standards – this evaluates the Clean Air Delivery Rate (CADR) of Air Cleaning devices and the standard is the "ANSI/AHAM AC – 1 Standard – Method for Measuring Performance of Portable Household Electric Room Air Cleaners".

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[7] https://www.arpansa.gov.au/our-services/testing-and-calibration/ultraviolet-radiation-testing

[8] https://www.abcb.gov.au/sites/default/files/resources/2022/Handbook-indoor-air-quality.pdf

[9] https://www.abcb.gov.au/news/2022/planned-update-indoor-air-quality-iaq-handbook

Particles of smoke, dust and pollen are introduced and well mixed in a small room, and the rate at which the air cleaner can clean the air is assessed.

The Chinese Air Cleaning test standard GB/T18801-2015 describes the CADR test for particulates, and also has provisions for gaseous pollutants. For the gaseous pollutants formaldehyde and methylbenzene are supplied to the chamber at 10 times the guideline concentrations (i.e. 1.00 mg/m^3 for formaldehyde and 2 mg/m^3 for methylbenzene, mixed using the ceiling fan for 10 minutes before operation of air cleaners begin. Then the decay curves are monitored.

The Canadian and Chinese standard allow the use of optical particle counters, which rely on calibration to a size distribution and provide mass concentrations i.e. PM2.5. The AHAM use particle size resolved number counters – which are more expensive instruments, but provide a comprehensive size resolved CADR.

2.4.1 Clean Air Delivery Rate (CADR)

CADR is calculated from the decay rate particles (where these are number of particles of the challenge smoke, dust or pollen – not mass concentrations):

$$C = C_0 e^{-kt}$$

Where C = minimum number of particles, and C_0 is the maximum initial number of particles, and t is the time over which the decay occurs (hours).

$$CADR = V \times k$$
$$CADR = V \times (k_e - k_n)$$

Where k the decay due to the portable air cleaner is made up of the total measured decay k_e less the decay of the room alone k_n (losses to walls, deposition/absorption and air leakage). V is the volume of the chamber (~30m^3).

An approximation to CADR is sometimes made when the air flow through the filter Q_f and the single-pass filtration efficiency η is known:

$$CADR = Q_{fan} \times \eta \times E \times \varepsilon$$

For HEPA 13 or 14 initially the η is 99.97%. In air cleaners there is always some leakage around the filter (or short-circuit of the filter which is accounted for by E, where E =1 means no short-circuit) and ε is an indication how well the room is mixed (i.e. ε =1 means the room is well-mixed, and the air cleaner is not simply cleaning already clean air etc) (ANSI/AHAM, 2020; Ren & Liu, 2019). The AHAM standard provides for additional room mixing with fans – it would be prudent for the test to provide CADR with and without additional room mixing as this introduces an artificial advantage to air cleaners that are designed poorly and entrain clean air (so don't clean as effectively as advertised).

Operationally as filters become loaded, the air flow resistance increases and the CADR will decrease. This is why the pre-filter needs regular maintenance, but also can be used to determine the filter lifetime (or lifespan).

Alongside the CADR, products usually display a floor area - this is calculated as:

$$Floor\ Area\ (m^2) = CADR_{Smoke}\ \times\ 0.144$$

2.4.2 Filter Lifespan

Within the Chinese Air Cleaning test standard GB/T18801-2015 one protocol for the filter lifespan is described. This Cumulative clean mass (CCM) method which defines the lifespan of the filter as the amount of material required to be accumulated for the CADR to drop to 50%. Elsewhere when the filter efficiency to remove smoke particles drops from 99.97% to below 90% it is considered time to replace the filter. The equivalence of these two measures hasn't been evaluated in the literature.

2.4.3 Electronic Cleaners and Ozone testing

A test method for evaluating ozone emissions from air cleaners described in ANSI/UL Standard 867 (UL 2011), which is also similar to the method described in IEC 60335-2-65 (IEC 2015). And this test has been adapted by the standard AS/NZS 60335.2.65:2015 (Household and similar electrical appliances - Safety, Part 2.65: Particular requirements for air-cleaning appliances).

For in ANSI/UL Standard 867 (UL 2011) testing rooms should be 26.9-31.1 m^3 (maximally 3m high, and minimum floor side dimension of 2.4m). Walls are to be covered by polyethylene or aluminium. The floor is to be non-porous (vinyl tile or aluminium).

The Air Cleaning appliance should be located in the centre of the room, elevated to 750-762 mm above the floor if required to be situated on a table. Ozone air sampling tube should be located 50mm from the air outlet of the appliance in the clean air stream of the device. Observations should be monitored for 24 hours, all fan settings should be tested, and with various filters removed sequentially. Room temperature should be 25^{o}C+/-2^{o}C and relative humidity 50% +/- 5% - note the indoor AQ recommendations for thermal comfort list the temperature range as 21-24^{o}C and RH 40-60%.

The background ozone level of the room needs to be measured before the device is operating and then subtracted from the test. No ozone test is required now for devices that use UVGI lamp (in the US). **Ozone in the room shouldn't exceed 5 x 10^{-6} percent (50 ppbv) over a 24 hour period for the CARB test pass.**

The standard AS/NZS 60335.2.65:2015 (Household and similar electrical appliances - Safety, Part 2.65) requires UV-C emitting devices (100-280nm) to carry notification and warning about UV-C dangers, which primarily concern skin/eye damage concerns, but also sometimes ozone generation potential. ARPANSA[10] has concerns about UV-C lamp use (outside of a device) – and are able to perform the ozone tests upon request.

ARPANSA[11] provides information concerning ionizing energy – this is the only official guidance on ionization that is available in Australia at present.

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[10] https://www.arpansa.gov.au/understanding-radiation/sources-radiation/more-radiation-sources/uvc-germicidal-lamps-personal

[11] https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/ionising-radiation-and-health

2.4.4 Microbial removal

AHAM has recognized the need for standardisation of methods that measure the performance of air cleaners with respect to removal of bioaerosols, including viable airborne viral and bacterial pathogens and airborne allergens, including mould and pollen (AHAM, 2022).

Similar to the three aerosol size challenges for CADR testing, the standard, AHAM-AC-5-2022 measures the rate at which an air cleaner reduces small, non-enveloped viruses (<50 nm), large, bacteria and mould.

Table 2-1: Recommended virus, bacteria and mould challenges for testing air cleaning of bioaerosols (AHAM, 2022)

Challenge	Type	Size	Properties
Virus	Non-enveloped bacteriophage MS2	30nm	Biosafety level 1. More resistant to chemical inactivation. Useful influenza surrogate, considered as SARS-CoV-2 surrogate.
Bacteria	Gram-positive coccus Staphylococcus epidermidis	500nm – 1μm	Biosafety level 1. Part of the microflora of the human skin
Mould	Aspergillus brasiliensis	3.5 – 5μm	Biosafety level 1.

For a test facility to be able to test air cleaning devices for bioaerosol deactivation the testing facility would need to meet Biosafety Level 1 regulations[12] based on the challenge biological material challenge agents provided in Table 2-1.

The air cleaner operates within the test room as outlined below for the standard CADR testing.

Table 2-2 Bioaerosol testing controlled conditions

	Range	Controlled	Notes
Temperature	20 +/- 3°C	Monitored continuously	
Relative Humidity	50 +/- 10 %	Monitored continuously	Will increase due to nebulization
Air Exchange Rate	<0.05 ACH	Yes	
Room volume	30 m^3	N/A	International harmonization
Recirculation fan	100-400 cfm	Yes	
Nebulization	6-jet nebulizer	N/A	24-jet harsh on microbes
Duration of test	60 minutes		Natural decay occurs within 60 minutes

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[12] https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/biosecurity/import/arrival/approved-arrangements/class-5.1-informative.pdf

Instrument	Impinger		Natural decay occurs within 60 minutes

2.4.5 Clean Air Delivery Rate (CADR) testing

The Association of Home Appliance Manufacturers AHAM provides a certification seal (fee charged quarterly) of the clean air delivery rate (CADR) of tobacco smoke, dust and pollen under standard test conditions for all portable electric room air cleaners sold in the United States. The test protocol[13] can only provide CADR for devices that clean between a certain range provided in table 1 below using the ANSI/AHAM AC – 1 Standard – Method for Measuring Performance of Portable Household Electric Room Air Cleaners. AHAM accepts independent testing from accredited facilities that adhere to the testing protocols outlined by the ANSI/AHAM AC-1 2020 standard – it is the manufacturers responsibility to obtain these tests for certification of their products, and therefore enabling sale on the US market.

Table 2-3: CADR range for testing under ANSI/AHAM AC-1 standard

CADR Range	Cubic feet per minute, cfm		m^3/h	
	minimum	maximum	minimum	maximum
Tobacco Smoke	10	450	17	765
Dust	10	400	17	680
Pollen	25	450	42	765

The chamber and aerosol observing equipment is defined precisely by the standard.

Room dimensions – 3.2m x 3.7 m x 2.4 m giving a volume of 28.5m^3
Walls – 1.3cm thick plasterboard over 0.9 cm plywood
Floors – smooth, full width, seamless linoleum or vinyl
Filtration – Prefilter (60%) and HEPA
Paint – White, washable latex semi-gloss
Ceiling fan, motor and blower for reconditioned, recirculating air operating at 21.5 m^3/h loop.
Table – top: 0.36 m x 0.56 m x 0.03m and 0.74m high
Humidification / cooling etc
Aerosol sizing – Aerodynamic Particle Sizer (APS) Spectrometer – Model 3321
Ultra high Sensitivity Laser Aerosol Spectrometer Probe PMS Model TSI LAS 3340

These aerosol instruments require annual manufacturer (TSI) cleaning and calibration. The test chamber walls require annual painting and the watt meter requires annual standardisation (via NIST in the US).

Pollen generator, Dust Neutralizer, Dust generator and fans etc all specified.

The smoke is generated by cigarettes (using a cigarette smoke generator), dust using test dust and pollen using paper mulberry pollen.

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[13] https://www.aham.org/DownloadableFiles/pdf/Air%20Cleaner%20procedural%20guide%20Ver%204_1e.pdf

The Chinese test standard room is similarly designed – though with different wall/floor surface materials are used i.e. GB/T18801-2015:

Table 2-4: Chinese standard GB/T18801-2015 Chamber test facility

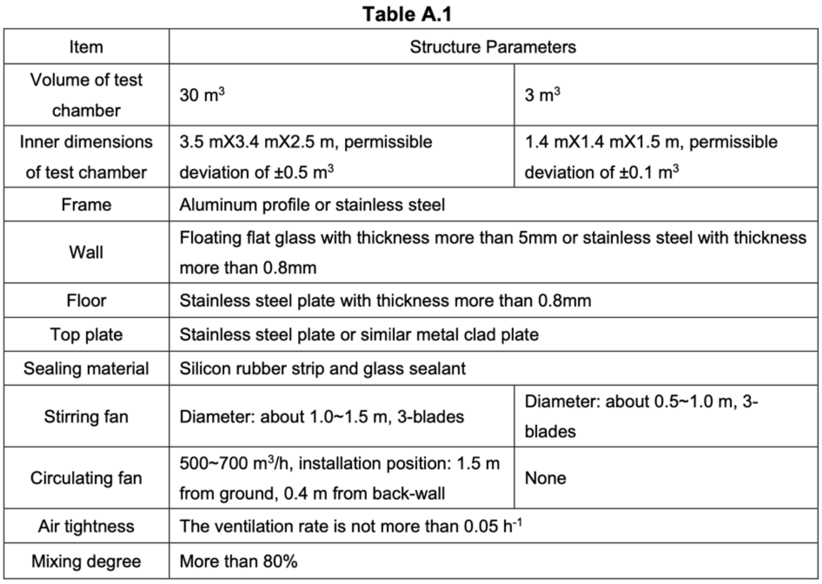

Table A.1

Item	Structure Parameters	
Volume of test chamber	$30\ m^3$	$3\ m^3$
Inner dimensions of test chamber	3.5 mX3.4 mX2.5 m, permissible deviation of ±0.5 m^3	1.4 mX1.4 mX1.5 m, permissible deviation of ±0.1 m^3
Frame	Aluminum profile or stainless steel	
Wall	Floating flat glass with thickness more than 5mm or stainless steel with thickness more than 0.8mm	
Floor	Stainless steel plate with thickness more than 0.8mm	
Top plate	Stainless steel plate or similar metal clad plate	
Sealing material	Silicon rubber strip and glass sealant	
Stirring fan	Diameter: about 1.0~1.5 m, 3-blades	Diameter: about 0.5~1.0 m, 3-blades
Circulating fan	500~700 m^3/h, installation position: 1.5 m from ground, 0.4 m from back-wall	None
Air tightness	The ventilation rate is not more than 0.05 h^{-1}	
Mixing degree	More than 80%	

2.4.6 Noise

AHAM, (2016) provides a standard for testing of noise of the air cleaner devices. Testing is performed at a distance of 1 meter from the device, with the device 1.5-2 m from the walls, in a corner of a room. One-Third Octave Band Sound Pressure Levels are recorded for the frequency bands from 100 to 10,000 Hz in accordance with ANSI S12.51.

In Australia, for outside noise Victoria EPA specify that Sound level meters must meet the specifications for Class 1 as specified in Australian Standard AS IEC 61672.1 *Electroacoustics - Sound level meters* and must be NATA calibrated at least every 2 years (Vic EPA, 2021).

The Vic EPA, (2021) note where the noise exceeds the background noise by 5dB it is defined as unreasonable. This could be a guideline threshold adopted for tolerable public building air cleaner noise – i.e. classrooms and libraries. An absolute noise guideline though is perhaps more useful. WHO Regional Office for Europe has developed Noise guidelines, in recognition that noise is an important and growing public health concern. These guidelines recommend that outside road noise be reduced to below 53dBA during the day, and 45dBA at night, to avoid health impacts (WHO, 2018). 53dBA could be therefore seen as a maximum tolerable guideline noise value for an operating air cleaner to avoid environmental noise health impacts.

For noise testing AHAM standard for Air Cleaner noise testing reports two loudness parameters are to be measured (AHAM, 2016):

- A-Weighted Sound Power Level, LWA (unit: dB re 1 pW) - dBA
- Loudness, s_t (unit: $sone_o$ – Stevens)

From these a sound rating is then determined.

3 Aerosol Chamber testing

In the United States, and in parts of Asia all portable air cleaners are required to be tested. Verifide is a certification program run by AHAM that provides facilities to perform testing in the United States[14], energy ratings are evaluated at the same time (Energy stars are provided as CADR / W). The first year is covered by the initiation fee and there-after a participation fee for accreditation of products to carry the AHAM seal is paid on an annually based on the total sales volume. All new filters and other modifications are required to be re-tested within 45 days for the seal to be valid, 60 days to re-rate. A tolerance of CADRs within 90% of the test results is required for products sold, withdrawal from market occurs within 30 days for non-compliance.

Annual fees for AHAM members are $USD 720 per unit or $USD 1,040 plus 0.1% of the annual sales amount for members and 0.58% for non-members. Appendix I below provides some preliminary costings for the instrumentation and build of a facility. It also provides a fee model which would be cost-neutral for running such a facility and protect consumers by quality assuring air cleaning devices sold into the Australian market.

3.1 International Testing facilities

In California air cleaning testing is performed by the California Air Resources Board (CARB) to limit the amount of ozone produced over a 24 hour period by devices to protect the public. The Air Cleaner Regulation (AB 2276) regulations found here.

3.2 National Testing facilities

Australia currently has no accredited chamber facility for air cleaner testing. The University sector has some facilities i.e. QUT has test facilities for biofuel / emissions testing, Monash has a sleep lab biosecurity bacteriophage testing facility, Swinburne has clean room facilities and the University of Melbourne has tested air cleaners using smoke decay rates. CSIRO's pyrotron[15] chamber facility is for bush-fire and smoke research.

Choice performs testing of home appliances, however while their methods are based off the AHAM standard for air cleaners their tests are not traceable to national or international calibration standards with experimental protocols clearly outlined with calibrated instrumentation details provided[16]. Their use of wood chips is interesting for their smoke test, but details are not provided. Choice doesn't consider air health / safety standards explicitly and they don't contribute to consumer standard developments – i.e. many of the devices promoted contain electronic cleaning i.e. ionization which directly produces harmful products or by-products as explained by the FAQ of the SGEAS Air Cleaning guide[17].

Sensitive Choice created by National Asthma Council Australia seeks to provide consumer assurance certification for air treatments. Their system for certification is based on an expert panel review of manufacturer provided information, they do not conduct independent testing.

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[14] https://www.aham.org/DownloadableFiles/pdf/Air%20Cleaner%20procedural%20guide%20Ver%204_1e.pdf Accessed 1st October 2022

[15] https://www.csiro.au/en/work-with-us/use-our-labs-facilities/Bushfire-laboratory

[16] https://www.choice.com.au/home-and-living/cooling/air-purifiers/articles/how-we-test-air-purifiers

[17] https://sgeas.unimelb.edu.au/engage/air-cleaner-guide/frequently-asked-questions

Funding relies on partners' paying a fee to display the butterfly logo. Some devices promoted contain ionizers or plasma technologies.

For Air Quality testing: consultants, air quality professionals, occupational health and safety, state EPAs and DPIE(NSW) all rely on the National Association of Testing Authorities (NATA) accreditation of equipment and testing standards. Air quality data used in legal action, state and national state of environment reporting and international data compilation relies on traceable and reproducible testing.

3.3 Value to Industry

The Australian air purifier market was estimated to be worth $32M a year in 2019. It was projected to grow to $46M by 2025 in a market report written pre-pandemic[18]. With the use of air cleaners in schools, hospitals and care settings for COVID-19 transmission suppression the value of the Air Cleaner market is much larger now – i.e. the Victorian Education Department bought 111,000 devices in 2021- 2022 for schools – probably well in excess of $130M in Victoria alone. The number of Air Cleaners available to consumers has grown significantly from ~20 HEPA devices available in 2021 to the >70 HEPA devices available now.

Independent testing, research and industry data is supported by the Association of Home Appliance Manufacturers in the United States, providing reputable reports and a single voice of leadership and advocacy. Their trusted commitment to consumer safety, efficiency, sustainability and innovation helps industry deliver the best products to the market, policies and standards. Setting up independent testing and verification for Air Cleaners in Australia would enable:

- Competitive and quality assured devices with the ability to access the US / Asian markets without additional testing
- Raising the standard of devices – promoting best and safe products and practices
- Building of consumer confidence, and provide a 'quality assurance' seal for these health delivering products (just as medical appliances are rigorously and independently tested by TGA, consumers expect verified health benefits of air cleaners)
- Support the Australian Competition and Consumer Commission in accessing marketing claims
- Support research and innovation, building expert capacity and facilitation of training of air/ventilation professionals
- Ability to test germicidal UV-C (traditional 254nm) and emerging (222nm) as well as ionizing, POC, plasma air cleaning devices including portable, wearable and fixed devices for unintended indoor air quality consequences
- Building a manufacturing industry to support world class indoor clean air guidelines / creation of clean air havens and to avoid supply chain issues -> resilient public health and educational systems
- Enable and encourage cheaper filter production / recycling / reduced waste/life cycle of filtration products
- Support the achievement of Sustainable Development Goal 12 – Responsible Consumption and Production

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[18] https://www.techsciresearch.com/report/australia-air-purifiers-market/1709.html accessed 24th October

4 Recommendations

Air quality is the dominant environmental risk for health and Australians spend 60-90% of their time indoors without protections of IAQ standards. All devices that seek to treat, modify and clean indoor air therefore are relevant for health. To support the industry that provides clean air to our built environment and to assure consumers of clean indoor air, we need rigorous product testing for air equivalent to what we expect for water and food.

Testing needs to traceable, reproducible and scientifically rigorous and robust to withstand legal challenge. An air cleaning test facility would support innovations in filtration, air conditioning and ventilation required to support indoor air guideline monitoring and compliance.

A test facility should:

- Be a NATA accredited facility, instrumentation and testing
- Work with ACCC / TGA for consumer confidence
- Be Compliant with and traceable to AHAM testing conditions and protocols
- Support and develop IAQ guidelines and standards

And testing for all device operating settings should:

- Provide CADR for viral, bacterial and mould biological challenges
- Provide CADR for smoke, dust and pollen challenges
- Provide CADR for formaldehyde, NOx and ozone (extend to VOCs in line with IAQ guidelines)
- Provide device noise testing
- Provide energy efficiency / energy star rating information
- Provide UV/ionization irradiance where UV/ionization used as air treatment technology

5 References

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6 Appendix I – Approximate Costings and Possible Funding Model

Table 6-1: Appendix I - Approximate costs associated with test facility instrumentation, ongoing maintenance and operations

Description	**Supplier / model**	**Purpose**	**Price (Excl. GST)**
Instrumentation cost			
Aerodynamic Particle Sizer Spectrometer (includes Aerosol Instrument Manager Software for APS Instruments)	TSI - 3321	Size distribution aerosol monitor providing aerosol counts for dust/pollen	$129,242
Ultra-high Sensitivity Laser Aerosol Spectrometer Probe	TSI - LAS 3340A	Size distribution aerosol monitor providing aerosol counts for smoke	$126,000
Dust Neutralizer	TSI - 3012 Aerosol Neutralizer	Electrostatically charges aerosols for sizing	$30,000
Dust Generator	TSI - Model 3400 Fluidized Bed Aerosol Generator	Aerosolizes dry powders and dusts	$60,141
Filtered Air Supply	Model 3074B	Supplies clean air	$7,466
Temperature and relative humidity probe	Vaisala	Temperature and relative humidity	$466
Ozone monitor	ThermoFisher 49i Ozone generator calibration, zero-air + logger	Ozone Calibration equipment + logger	$20,000 $40,000
Nitrogen Oxides monitor	ThermoFisher 42i-TL and calibration gases	NO-NO_2-NO_x-NH_4 analyser	$30,000
Formaldehyde, methane and water monitor	Picarro G2307 Gas Concentration Analyzer	HCHO, CH_4 and H_2O	$100,000
Occupational Sound Level 1/3 Octaves + calibration unit	NoiseMeters Australia CEL632C-K	Logging 1/3 Octaves 12.5Hz to 20kHz dB weightings A, C and Z	$7,803
SKC biosamplers	SKC Glass Midget Impinger Trap	$190 each x 50	$9,500
5 x pumps	Edwards style pumps	$1000 each	$5,000
Total Instrumentation			**$565,618**

Chamber Build Cost			
Costed to specifications	Approximate Estimate – room, autoclave + biosecurity level 1	Approximate Estimate	$200,000
Ongoing Costs			
Technician – HEW 5.8 (fully costed)	Professional salary scale technical support	Scheduling, logistics, customer liasing and conducting testing	$172,316 p.a.
Annual APS and LAS calibration and clean	Kenelec Melbourne – shipping to US return	Compliance calibration	$9,932 p.a. (APS) $9,119 p.a. (LAS) Return shipping airfreight to US $2,500 p.a.
3 monthly calibrations of ozone and NOx monitors	Calibration gases	Compliance calibration	$5,000 p.a. (NOx)
Total Build cost			**$765,618**
Total Operational costs – per annum			**$198,867**

Table 6-2: Appendix I - Potential funding model - based on AHAM fee structure and Australian market value

Base fee per year – non-member #Units on Market	55-100 @ $1600 per unit base fee	$88,000 - $160,000
Sales per year – non-member	$32,000,000 (2019) @ 0.58% $46,000,000 (2025) @ 0.58%	$185,600 - $266,800
Annual income from fees		**$273,600 - $426,800**

7 Appendix II – Submission to Australian Building Codes Board IAQ Handbook Update

Australian Building Codes Board Indoor Air Quality Handbook – Review and Update

https://consultation.abcb.gov.au/engagement/indoor-air-quality-handbook-review-and-update/

Consultation Response by A/Prof Robyn Schofield, School of Geography, Earth and Atmospheric Sciences, University of Melbourne.

7.1 Indoor gas cooking and heating installations

7.2 Need for mandated rangehoods and flues to exhaust air to outside as well as mandated IAQ monitoring for public buildings

There should be a requirement if combusting for cooking or heating within a building that the air is exhausted externally – to remove PM, NOx and CH_4. Lebel et al., 2022[19] show that even without having the gas ovens operating significant levels of methane leakage inside buildings occurs (3/4 of domestic methane emissions are from gas oven installations is from leaking while not operating) – this constitutes a large health and climate risk in buildings. When operating under usual cooking circumstances, emissions of 21.7 [range: 20.5 - 22.9] ng NO_x J^{-1} is being produced and the 1 hour US standard of 100 ppb (Australia's 1 hour NEPM NO_2 standard is 80 ppb) is surpassed in minutes - when there is no exhausting of air to outside.

Current kitchen building codes allow gas cooktops to be installed without consideration or requirement to exhaust the air containing fumes/gases to outside. i.e. rangehood products such as https://www.bunnings.com.au/bellini-60cm-white-slimline-rangehood_p0195633 just recirculate the cooking fumes and gases, such as NOx, back into the room.

Installation of gas ovens and gas cooktops should only be possible with mandated outside exhausting rangehood installation, and an education program on the dangers of cooking with gas in unventilated kitchens should be undertaken.

Installation of gas heaters and cooking (i.e. whenever gas in piped through a building) within public buildings requires that VOCs, $PM_{2.5}$, CO and NO_2 are monitored for IAQ purposes.

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[19] **Lebel, E. D.**, Finnegan, C. J., Ouyang, Z., and Jackson, R. B. (2022). Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*. DOI: 10.1021/acs.est.1c04707

7.3 Mercury

Mercury is not currently a criteria outdoor air pollutant, but its production and use is now controlled under the Minamata convention on Mercury (ratified by Australia in 2021).

Reporting under the Minamata convention for Australia will now follow reporting requirements expected of all Parties (who ratified after the 2013 adoption) – i.e. conducting full life-cycle analyses of mercury use. Coal power stations in Japan are noted to emit 1.3t of Hg per year to the air, and 0.75 t of Hg within coal fly ash is used in cement production[20]. Australia coal electricity generators emitted 1.8t of Hg in 2020/2021 to the air (NPI[21]), without quantities (or quality) of coal fly ash used in Australia building construction being reported, it is conceivable that a similar quantities areis being used here in Australia i.e. 0.75t of Hg is ending up in cement in the building sector. Exposed cement in buildings (i.e. carparks) could potentially represent a large mercury (and other heavy metals) source to the air and water ways. A review study of fly ash leeching by Kurda et al.[22], notes that "avoiding the use of Fly Ash concrete for drinking water tank and architectural concrete applications." A Fly Ash white paper notes: "California's Collaborative for High-Performance Schools (CHPS) has put limits on the mercury content for fly ash in concrete under their green building rating system, and the recently released LEED™ for Healthcare also has a credit that limits mercury levels in supplemental cementitious materials" – this should be considered here in Australia also[23]. There are no regulation protections in Victoria or Western Australia on the toxic composition of fly ash, NSW has protective legislation which AGL noted some of its products exceeded which caused their withdrawal of fly ash products from the market[24].

US EPA calculated mercury exposure for a room constructed with fly-ash concrete[25] to be 100 ngm^{-3} (for reference background outside air mercury levels[26] are ~1 ngm^{-3}). US EPA (in 2001) concluded this is considered 'safe' because it is lower than the US EPA reference standard (also established in 2001[27] and not revised since the Minamata convention 2013) of 300 ngm^{-3}. These values are certainly well below the Australian workplace 8-hour standard[28] for exposure to mercury of 0.003 parts per million (0.025 mg/m^3 or 25,000 ngm^{-3} which is extra-ordinarily high). Indoor air levels generally range from 2 -10 ngm^{-3} in a recent, well conducted study in Basel[29].

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[20] https://www.mercuryconvention.org/sites/default/files/documents/submission_from_government/Japan_Article14.pdf (accessed 8 September 2022)

[21] National Pollution Inventory: mercury emission to air from electricity generators http://www.npi.gov.au/npidata/action/load/emission-by-source-result/criteria/destination/ALL/industry-source/261/substance/55/source-type/INDUSTRY/subthreshold-data/Yes/substance-name/Mercury%2B%2526%2Bcompounds/year/2021

[22] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5968176/

[23] https://assets.ctfassets.net/t0qcl9kymnlu/1Tx57nRsWYYMEC824CkOaI/38239c5e0fb2044af10bc2b1fac38cf8/FlyAsh_WhitePaper.pdf`

[24] https://www.envirojustice.org.au/wp-content/uploads/2019/06/EJA_CoalAshReport.final_.pdf

[25] https://www.epa.gov/sites/default/files/2014-12/documents/ccr_bu_eval.pdf

[26] Schofield, R, et al. 2021. Atmospheric mercury in the LatrobeValley, Australia: Case study June 2013. Elem Sci Anth,9: 1. DOI:https:// doi.org/10.1525/elementa.2021.00072

[27] Carpi, A.; Chen, Y. Gaseous elemental mercury as an indoor air pollutant. *Environ. Sci. Technol.* **2001**, *35*, 4170– 4173, DOI: 10.1021/es010749p

[28] https://www.dcceew.gov.au/environment/protection/npi/substances/fact-sheets/mercury-compounds

[29] Wohlgemuth, L., et al., *Environ. Sci. Technol. Lett.* 2020, 7, 4, 234–239

WHO 2021[30] provides an updated guideline of a tolerable concentration of 0.2 µg/m^3 (200 ng/m^3) for long-term inhalation exposure to elemental mercury vapour. This represents 200 times outdoor mercury concentrations in Australia, and would be indicative of serious indoor ventilation / emission issues representing an intolerable indoor health risk. IAQ standards should adopt 200 ng/m^3 as a reference standard for Hg(0) in air.

7.4 Asbestos

Indoor air within buildings without specific asbestos sources have concentrations generally below 1000 Fibres/m^3; with rural / clean urban having just 10-30 Fibres/m^3 (counted via electron microscopy)[31]. For comparison the current Australian workplace TWA for Asbestos[32] is 0.1 f/ml or 10,000 Fibres/m^3.

“Asbestos is a proven human carcinogen (IARC Group 1). No safe level can be proposed for asbestos because a threshold is not known to exist. Exposure therefore should be kept as low as possible.” [12]

Any elevations of Asbestos within buildings above outside air levels is therefore intolerable. 200 Fibres/m^3 is considered a high urban exposure level. Construction workers can experience 1000-10000 Fibres/m^3 (but will have appropriate PPE made available to them).

Indoor air quality within buildings should be investigated and mitigated when inside air Asbestos levels exceed 200 Fibres/m^3 – particularly in sensitive settings such as childcare, schools, and healthcare.

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[30] https://www.who.int/publications/i/item/9789240023567

[31] https://www.euro.who.int/__data/assets/pdf_file/0015/123072/AQG2ndEd_6_2_asbestos.PDF

[32] https://www.safeworkaustralia.gov.au/system/files/documents/1912/workplace-exposure-standards-airborne-contaminants.pdf

Suggested Health based Guideline Indoor Air Quality Standards for Public Buildings

Public Buildings such as Schools, Universities, Sports facilities are Class 9b buildings under the Australian Building code[33]

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[33] The Building code of Australia has the following classes of buildings:
Class 1 – Houses or dwellings of a domestic or residential nature
Class 2 - Apartment buildings
Class 3 - A residential building, other than a Class 1 or 2 building, which is a common place of long term or transient living for a number of unrelated persons.
Class 4 - Part of a building that is a dwelling or residence within a non-residential building (Class 5 to 9), such as a caretaker's residence in a hospital.
Class 5 - Office buildings for professional and/or commercial purposes
Class 6 - Shops, restaurants and cafés
Class 7 - Buildings including carparks, warehouses or storage buildings
Class 8 - Factories—buildings used for production, assembling, altering, repairing, finishing, packing, or cleaning of goods or produce.
Class 9 - Public buildings - with three sub-classifications:

- **class 9a** - healthcare buildings such as hospitals and day surgery clinics
- **class 9b** - buildings where people assemble for social, political, theatrical, religious or civic purposes, e.g. churches, schools, universities, sports facilities, night clubs
- **class 9c**—aged care facilities.

Class 10 - Non-habitable buildings or structures. This class includes three sub classifications:

- **class 10a**—non-habitable buildings including sheds, carports, and private garages.
- **class 10b**— structures such as fence, mast, antenna, retaining wall, swimming pool
- **class 10c**—private bushfire shelter associated with, but not attached to, a class 1a building.

Table 7-1: Appendix II - IAQ pollutant threshold values - current and recommended

Pollutant	**Existing Current Recommendations**	**WHO**[34,35]	**Recommended Indoor Air Threshold Guidelines for Public buildings**[36]	**Australian Occupational exposure limit (2019)**[37] TWA – Time Weighted Average STEL – Short Term Exposure Limit
Carbon Dioxide CO_2	ASHRAE 62.1 – 1000ppm AS 1668.2 for mechanical ventilation control – 600-800 ppm NCC IAQ design standard – 850ppm Review of All IAQ Standards[38]: <750-1000ppm = Good; >1500 ppm = Poor		• 1500 ppm 15 minute maximum (99th percentile limit) • 800 ppm (1 hour average)	TWA - 5000 ppm (8 hours) STEL – 30000 ppm (15 minutes)
Carbon Monoxide CO [1 ppm = 1.145 mg/m^3]	NEPM – 9 ppm NCC (Class 9b): • 90 ppm (15 minute average) • 50 ppm (30 minute average)	100 mg/m^3 (87.3 ppm) 15 minute average 35 mg/m^3 (30.5 ppm) 1 hour average 10 mg/m^3 (8.7 ppm) 8 hour average	• 90 ppm (15 minute average) • 50 ppm (30 minute average) • 25 ppm (1 hour average) • 9 ppm (8 hour average)	TWA - 30 ppm (8 hours)

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[34] World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329. License: CC BY-NC-SA 3.0 IGO

[35] https://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

[36] Where conversion required: the general equation is $\mu g/m^3$ = (ppb)*(12.187)*(M) / (273.15 + °C); using 25°C and 1013.25hPa.

[37] https://www.safeworkaustralia.gov.au/doc/workplace-exposure-standards-airborne-contaminants-2019

[38] Lowther,S.D.; Dimitroulopoulou, S.; Foxall, K.; Shrubsole, C.; Cheek, E.; Gadeberg, B.; Sepai, O. Low Level Carbon Dioxide Indoors—A Pollution Indicator or a Pollutant? A Health-Based Perspective. *Environments* **2021**, *8*, 125. https://doi.org/10.3390/ environments8110125

	- 25 ppm (1 hour average) - 10 ppm (8 hour average)	4 mg/m^3 (3.5 ppm) 24 hour (99th percentile limit)		
Nitrogen Dioxide NO_2 [1 ppb = 1.88 µg/m^3]	NEPM: - 80 ppb Averaged over 1 hour - 15 ppb Averaged over 1 year NCC: - 40 µg/m^3 (0.0197 ppm) Averaged over 1 year; and - 200 µg/m^3 (0.0987 ppm) Averaged over 1 hour	200 µg/m^3 (106.3 ppb) 1 hour averaging time 25 µg/m^3 (13.3 ppb) 24 hour (99th percentile limit) 10 µg/m^3 (5.3 ppb) Averaged over 1 year	- 80 ppb 1 hour maximum (99th percentile limit) - 13 ppb 24 hour / daily maximum (99th percentile limit) - 5 ppb Averaged over 1 year	TWA - 5.6 mg/m^3 (3 ppm) (8 hours) STEL - 9.4 mg/m^3 (5 ppm) (15 minutes)
Ozone O_3 [1 ppb = 2.00 µg/m^3]	NEPM - Outdoor: - 0.065 ppm Averaged over 8 hours NCC - 100 µg/m^3 (50.0 ppb) 8 hour daily maximum limit Indoor levels known to be 10-50% of outdoor due to deposition onto surfaces[39]	100 µg/m^3 (50.0 ppb) 8 hour daily maximum (99th percentile limit) 60 µg/m^3 (30.0 ppb) 6 month average of 8 hour daily maximum (99th percentile limit)	- 50 ppb - 8 hour daily maximum (99th percentile limit)	TWA - 0.2 mg/m^3 (0.1 ppm) Peak limit (8 hours)
Sulfur Dioxide SO_2 [1 ppb = 2.62 µg/m^3]	NEPM: - 100 ppb Averaged over 1 hours - 20 ppb Averaged over 1 day NCC – None listed	500 µg/m^3 (190 ppb) 10 minute averaging time 40 µg/m^3 (15 ppb) 24 hour (99th percentile limit)	- 190 ppb 10 minute averaging time - 100 ppb 1 hour averaging time	TWA - 5.2 mg/m^3 (2 ppm) (8 hours) STEL - 13 mg/m^3 (5 ppm) (15 minutes)

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[39] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1626413/

			• 15 ppb 24 hour (99th percentile limit)	
Lead Pb	NEPM: • 0.50 $\mu g/m^3$ 1 year average • US EPA[40]: 0.15 $\mu g/m^3$ (3 month average) • NCC - 100 $\mu g/m^3$ (50.0 ppb) 8 hour daily maximum limit	0.50 $\mu g/m^3$ 1 year average	• 50 $\mu g/m^3$ (8 hours) • 0.15 $\mu g/m^3$ 3 month average	TWA - 50 $\mu g/m^3$ (8 hours)
Particulate Matter less than 10 µm PM_{10}	NEPM: • 25 $\mu g/m^3$ averaged over 1 year • 50 $\mu g/ m^3$ averaged over 1 day NCC: • 20 $\mu g/m^3$ averaged over 1 year • 50 $\mu g/ m^3$ 24 hour (99th percentile) limit	• 15 $\mu g/m^3$ averaged over 1 year • 45 $\mu g/m^3$ 24 hour (99th percentile) limit	• 15 $\mu g/m^3$ averaged over 1 year • 45 $\mu g/m^3$ 24 hour (99th percentile) limit	No current recommendations
Particulate Matter less than 2.5 µm $PM_{2.5}$	NEPM: • 8 $\mu g/m^3$ averaged over 1 year • 25 $\mu g/ m^3$ averaged over 1 day NCC: • 10 $\mu g/m^3$ averaged over 1 year • 25 $\mu g/ m^3$ 24 hour (99th percentile) limit	• 5 $\mu g/m^3$ averaged over 1 year • 15 $\mu g/m^3$ 24 hour (99th percentile) limit	• 5 $\mu g/m^3$ averaged over 1 year • 15 $\mu g/m^3$ 24 hour (99th percentile) limit	No current recommendations

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[40] https://www.govinfo.gov/content/pkg/FR-2008-11-12/pdf/E8-25654.pdf

Elemental Mercury Hg(0)	No current recommendation	200 ng/m^3	• 200 ng/m^3 (1 hour averaging time)	25,000 ngm^{-3} TWA (8 hours)
Nickel	No current recommendation	25 ng/m^3 (annual average)	• 25 ng/m^3 (1 year averaging time)	25,000 ngm^{-3} TWA (8 hours)
Cadmium	No current recommendation	5 ng/m^3 (annual average)	• 5 ng/m^3 (1 year averaging time)	25,000 ngm^{-3} TWA (8 hours)
Arsenic	No current recommendation	6.6 ng/m^3 (annual average)	• 6.6 ng/m^3 (1 year averaging time)	25,000 ngm^{-3} TWA (8 hours)
Total Volatile Organic Compounds TVOC	NEPM – Xylene, Toulene, PAH and Benzene all have independent investigation limits[41]: Benzene – 3 ppb (annual average) Toulene – 1 ppm 24h average Xylene – 250 ppb 24h average BaP – 0.3 ng/m^3 (annual average) NCC – TVOC 500 µg/m^3 (250.0 ppm) 8 hour daily maximum limit	Benzene[42] – No safe limit - threshold 1.7 µg/m^3 Benzo(a)pyrene BaP[24] – threshold 0.012 ng/m^3	• TVOC: 500 µg/m^3 (250.0 ppm) 8 hour daily maximum limit • Toulene – 1 ppm 24 hour average • Xylene – 80 ppb 8 hour average • Benzene – 1.7 µg/m^3	Benzene - TWA 3.2 mg/m^3 (8 hours) Xylene - TWA 80 ppm (8 hours)

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[41] https://www.legislation.gov.au/Details/F2011C00855

[42] No safe limit threshold values for 1/1,000,000 risk of excess lifetime cancer risk

			• Benzo(a)pyrene BaP – 0.12 ng/m^3	
Formaldehyde HCHO	NEPM (investigation level)[2] – 40 ppb 24h average NCC - 0.1 mg/m^3 (80.1 ppb[43]) Averaged over 30 minutes	0.1 mg/m^3 (80.1 ppb[44]) Averaged over 30 minutes	• 80 ppb 30 minute average • 40 ppb 24 hour average	TWA - 1 ppm (8 hours) STEL - 2 ppm (15 minutes)
Asbestos and < 1% crystalline silica	No current recommendation	No safe limit. 200 Fibres/m^3 is a high urban exposure.[13]	• 200 Fibres/m^3	0.1 f/ml or 10,000 Fibres/m^3
Radon	ARPANSA[45, 46]: • 200 Bqm^{-3} for households • 1000 Bqm^{-3} for workplaces EU[47]: • 300 Bqm^{-3} workplaces and dwellings IAEA[48]: • 300 Bqm^{-3} for homes • 1000 Bqm^{-3} for workplaces	100 Bq m^{-3}, but not more than 300 Bq m^{-3} for areas with high soil emissions. [49]	• 100 Bqm^{-3}	No current recommendation

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[43] https://www.ncbi.nlm.nih.gov/books/NBK138711/

[44] https://www.ncbi.nlm.nih.gov/books/NBK138711/

[45] https://journals.sagepub.com/doi/10.1016/j.icrp.2011.08.011

[46] https://www.arpansa.gov.au/research-and-expertise/australian-radon-action-plan

[47] https://eur-lex.europa.eu/eli/dir/2013/59/oj

[48] International Atomic Energy Agency https://www.iaea.org/sites/default/files/20/11/rasa-radon.pdf https://www-pub.iaea.org/MTCD/publications/PDF/Pub1651Web-62473672.pdf https://www.iaea.org/file/document/2018/module2radonpptx

[49] https://www.who.int/news-room/fact-sheets/detail/radon-and-health

Trichloroethylene	No current recommendation	No safe limit[24] - 2.3 µg/m^3	• 2.3 µg/m^3 (1 year averaging time)	54 mg/m^3 TWA (8 hours) 216 mg/m^3 STEL (15 minutes)
Tetrachloroethylene	No current recommendation	No safe limit[24] – 0.25 mg/m^3	• 0.25 mg/m^{-3}	340 mg/m^3 TWA (8 hours) 1020 mg/m^3 STEL (15 minutes)
Bioaerosols	• Pollen • Fungi • Bacteria		In cooling tower water Legionella count must be <1000 cfu/mL and the heterotropic colony count <5,000,000 cfu/mL[50]	

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[50] https://www.health.nsw.gov.au/environment/legionellacontrol/Pages/legionella-taskforce.aspx