INDOOR AIR QUALITY

Ensuring high-quality indoor air in non-industrial buildings

CSIRO

Improving indoor air quality benefits the health, well-being and productivity of building occupants and has become a key issue in sustainable building design. This Building Technology Resource describes the factors contributing to indoor air quality and identifies good practices that assist in preventing problems. Although this resource focuses on indoor air quality in non-industrial buildings, such as dwellings, offices, schools and hospitals, much of the content is relevant to all buildings.

WHAT IS INDOOR AIR QUALITY?

Indoor air quality (IAQ) can mean a range of things to different people, but a good definition is 'the attributes of indoor air that affect the health and well-being of occupants'. Such attributes could include:

- how occupants perceive air quality (e.g. if a space feels 'stuffy')
- the degree of ventilation and air distribution
- the presence and persistence of odours
- concentrations of air contaminants (and how they interact)
- sources of air contaminants
- physical factors (such as air temperature and humidity) that influence the impacts of contaminants.

Poor IAQ in any building may be caused by one or more of these attributes in any combination, which can make it difficult to identify the source of a problem.

IAQ primarily concerns the general population, which includes people who spend most of their time indoors and people who are not in the workforce (such as the very young, the very old, and people with impaired health). Building standards for ensuring adequate IAQ should not be confused with standards for limiting exposure to airborne contaminants in the workplace.

FACTORS INFLUENCING IAQ

Three major factors influence IAQ:

- the quality of outdoor air: the air used to ventilate any building must come from outside, so any outdoor air contaminants will become part of the building air inhaled by occupants
- the quantity of outdoor air introduced to ventilate the indoor space and remove indoor contaminants
- the quantities and sources of indoor air contaminants.

Outdoor air quality in Australia is generally expected to be good, due to strict environmental regulations. There will sometimes be locations (e.g. near busy roads) and episodes (e.g. bushfires, industrial accidents) when outdoor air quality is poor and people are encouraged to restrict building ventilation rates. However, this is only a short-term solution, because outdoor pollutants will eventually reach the indoor space (unless the outdoor air is cleaned as it enters the building).

In Australia, most residential buildings use natural rather than mechanical ventilation to remove indoor air contaminants. The National Construction Code (NCC) specifies the size of openable windows and doors that are necessary to allow sufficient air into residences. Even when windows and doors are closed, indoor spaces are still ventilated by air infiltration through gaps and cracks in the building's facade. While buildings are thought to be constructed more 'tightly' today than in the past, the average air infiltration rate of closed housing in Australia is likely to be ~0.5–1 air changes per hour (older housing, which included permanently open wall and trickle vents, can have as much as 3–5 air changes per hour), which should be adequate for occupied spaces in the absence of significant sources of indoor air contaminants.

Building materials, building contents and the occupants themselves are also sources of air contaminants. It is not uncommon for many pollutants to occur at indoor concentrations much higher than those found outdoors (Figure 1).

VENTILATION OF BUILDINGS

The NCC specifies that a space used by occupants must be provided with means of ventilation with outdoor air which will maintain adequate IAQ. A building is deemed to satisfy the NCC's performance requirements when a room occupied by a person for any purpose has either:

- natural ventilation to outdoor spaces, through permanent openings such as windows and doors that have an openable size of at least 5% of the room's floor area
- a mechanical ventilation or air-conditioning system that complies with relevant Australian Standards.

These practical requirements were originally based on the need to control odours generated by occupants. In recent years, however, the increased indoor use of synthetic materials and particular appliances and equipment has been shown to have negative impacts on IAQ. Consideration of the meaning of adequate IAQ has led to more specific definitions that take into account health risks as well as occupant comfort. For example, the International Organization for Standardization (ISO) now defines 'acceptable IAQ' as 'air in an occupied space toward which a substantial majority of occupants express no dissatisfaction and that is not likely to contain contaminants leading to exposures that pose a significant health risk'.

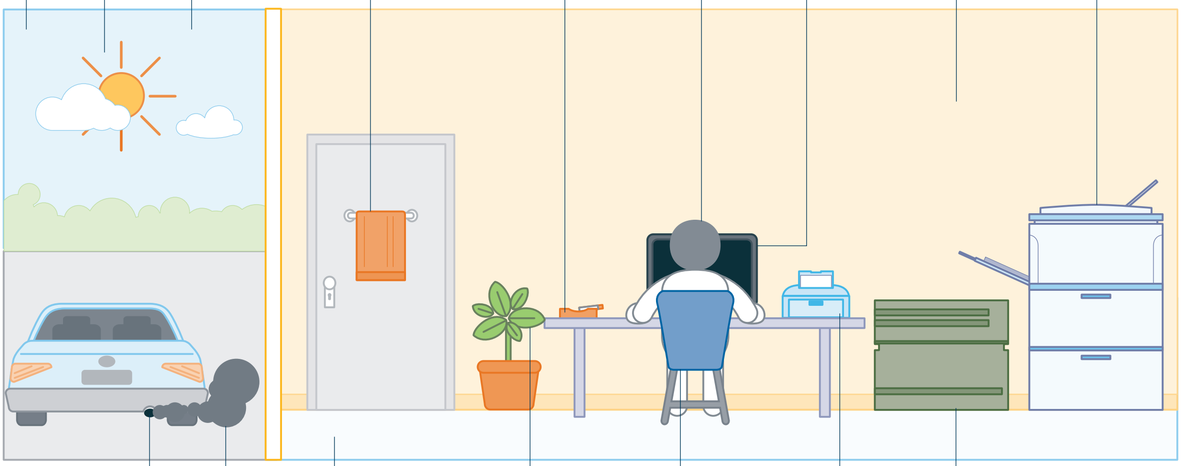

FIGURE 1 Primary sources of indoor air pollutants.

The NCC includes 'verification methods' for ensuring suitable IAQ, which list a range of indoor air pollutants and maximum limits on their concentration (Table 1). These verification methods are not mandatory, but are intended to be useful in demonstrating compliance with the NCC's performance requirements.

INDOOR CONTAMINANTS

Various common appliances, materials, processes and activities can produce pollutants that diminish IAQ.

APPLIANCES

Gas-fired space heaters that exhaust all combustion products into the same room may emit dangerous nitrogen dioxide and – if not correctly installed and maintained – deadly carbon monoxide fumes (Figure 2). The combustion products also include substantial amounts of water vapour, which may exacerbate condensation problems. Some heaters may also emit formaldehyde.

TABLE 1. INDOOR AIR POLLUTANTS AND MAXIMUM LIMITS IN INDOOR AIR CONCENTRATIONS.
AUSTRALIAN BUILDING CODES BOARD 2016.

Air contaminant	Maximum limit		Comment
	Concentration	Averaging period	
Carbon dioxide	850 ppm	8 h	Indicates acceptable ventilation of body odours in the absence of combustion sources
Carbon monoxide	90 ppm 50 ppm 25 ppm 10 ppm	15 min 30 min 60 min 1 h	Different limits are provided for carparks
Nitrogen dioxide	40 µg/m^3 200 µg/m^3	1 year 1 h	Dominant sources: unflued gas heating and cooking
Ozone	100 µg/m^3	8 h	May arise from copiers/printers, but also ozone generators
Total volatile organic compounds	500 µg/m^3	1 h	May arise from a myriad of materials: construction, furnishings, equipment, especially in new buildings
Formaldehyde	100 µg/m^3	30 min	Dominant sources: wood-based panels (particleboard, MDF, plywood)
Particulate matter $PM_{2.5}$	10 µg/m^3 25 µg/m^3	1 year 24 h	Combustion processes (cooking, heating, smoking, ingress of polluted outdoor air)
Particulate matter PM_{10}	20 µg/m^3 50 µg/m^3	1 year 24 h	Combustion processes (cooking, heating, smoking, ingress of polluted outdoor air)

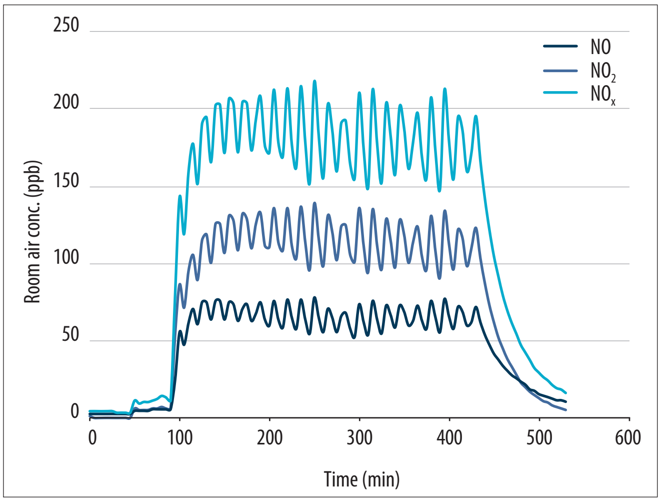

FIGURE 2 Unflued gas heaters can produce high concentrations of nitrogen dioxide within minutes of start-up (note: 200 µg/m^3 of NO_2 (Table 1) is approximately 110 ppb).

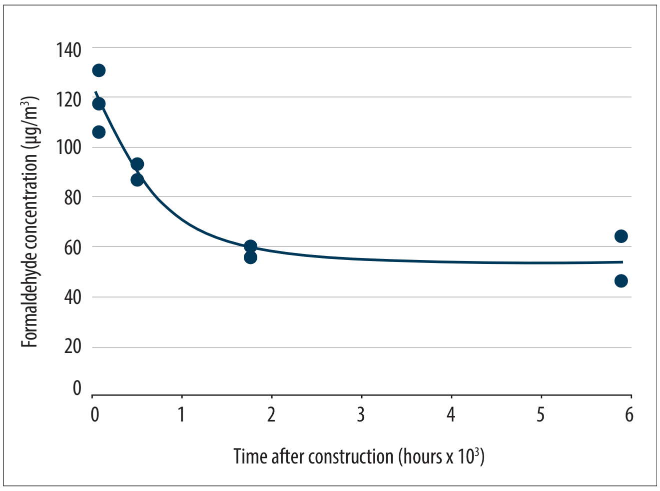

FIGURE 4 The concentration of formaldehyde in a house is usually highest at the time of construction.

Cooking on stoves generates steam, smoke and combustion products (Figure 3). Ideally, these products are captured by an extraction system and vented outdoors, but low capture efficiencies or poor installation may allow them to vent back into the room (e.g. hidden behind cupboards).

NEW BUILDING PRODUCTS

Building materials, furnishings and contents may emit significant volumes of formaldehyde and volatile organic compounds (VOCs) when first installed (Figure 4). Although the emissions decrease over time, it may take 6–12 months after construction for the total VOCs to drop below the maximum limit. In many countries, voluntary, semi-regulatory or regulatory emission criteria for new products ensure that the maximum limits on indoor air contaminants are met at the point of construction. Australian emission classification schemes are less well developed, but consumers may find some guidance from product manufacturers or organisations offering green building certification.

MOULD

Large quantities of moisture are generated by occupants' respiration and perspiration; by activities such as showering, washing and drying clothes, and cooking; and by appliances such as evaporative coolers and unflued gas heaters. If ventilation rates are low, moisture can condense on cool surfaces, leading to mould growth and spores indoors (Figure 5). The Building Technology Resource on Condensation provides specific information on the sources and management of condensation.

FIGURE 5 Mould growth from persistent indoor condensation near a window. (Ivelin/Shutterstock.com)

HOUSE DUST MITES

House dust mites live in carpets, bedding and soft furnishings and generate allergens that can become airborne (Figure 6). When inhaled by building occupants, these allergens can lead to asthma and eczema. Buildings on Australia's coasts have some of the highest levels of dust mite allergen in the world, because the mites thrive in our temperate coastal climates. Countries with freezing winters or desert areas have sustained periods of very low humidity in which house dust mites cannot survive.

PLANNING FOR ADEQUATE IAQ

Managing IAQ essentially involves understanding how the processes of ventilation and contamination interact and can be

FIGURE 3 Cooking on a stove generates pollutants that should be extracted by an efficient rangehood. (RazoomGames/iStock)

FIGURE 6 Depiction of house dust mites, which can be less than 0.5 mm long, in furnishing material. (Dabarti CGI/Shutterstock.com)

balanced. When designing and using buildings, several steps can be taken to increase IAQ.

BUILDING DESIGN

Where possible, use low-emission building products. Ensure that areas prone to condensation, such as bathrooms and laundries, are exhausted to outdoors. In buildings that are challenging to ventilate naturally, such as apartments, incorporate localised exhaust systems in areas prone to generating pollutants, such as kitchens, laundries and home offices. When choosing appliances, opt for flued rather than unflued gas heating, as well as rangehoods with the highest capture efficiency (and ventilation to outdoors).

VENTILATION

Enforce the NCC's guidelines on ventilation at the point of construction, and monitor ventilation regularly thereafter. Consider increasing building ventilation rates in the first year after construction to account for higher levels of VOCs, but be aware that (depending on a building's contents) the achievable increases may not be sufficient to reduce indoor air contaminants to the recommended maximum limits.

INTERIOR DESIGN

Reduce the use of new soft furnishings inside the building. Consider using indoor plants, as some species have been shown to remove formaldehyde and other contaminants from indoor air under laboratory conditions. The real-world impact of plants is less clear, as their air-filtration abilities are likely to be equivalent to a ventilation rate increase of no more than 0.03 air changes per hour, which would have little influence on air contamination levels.

CLEANING

Use high-efficiency vacuum cleaners or ducted systems to limit the production of airborne allergens. Consider using room air-cleaning devices, although keep in mind that manufacturers' claims about their performance are probably based on laboratory testing rather than real-world results. To make a substantial impact on the IAQ of a room in which contaminants are continually generated and circulated, an air-cleaning device must be able to demonstrate that it can efficiently remove specific contaminants and treat a substantial volume of air (at least 4 room volumes per hour). Even then, the reduction in overall concentration would be limited to ~30–40%.

MANAGING IAQ PROBLEMS

Ideally, a building should be designed, operated and maintained to prevent IAQ problems. In reality, problems may still occur. If they do, the building should be inspected by a technically competent person to ensure there are no obvious causes, such as:

- too many occupants (overcrowding)
- lack of ventilation (e.g. non-openable windows, poorly maintained or inoperative mechanical ventilation)
- poorly stored materials (e.g. solvent-based products in attached garages or other locations)
- issues with cooking and heating appliances (e.g. a stove rangehood not flued to outdoors, unflued gas heaters, leaky wood heaters or chimneys)
- large loadings of new building materials (i.e. quantities per volume of building space), particularly if they are not low-emission
- office equipment (e.g. printers, copiers) exhausting into occupied spaces
- high usage of odorous consumer products (e.g. cleaning products, personal care products)
- inadequate cleaning and maintenance (including mechanical ventilation systems).

Another way to characterise problems with IAQ is to survey the building's occupants. Their feedback about the extent, location and duration of problems can inform decisions on next steps, which might include sampling indoor air for the pollutants that are considered possible causes. Sampling should be the last resort when dealing with IAQ problems, as it can be expensive and difficult to perform accurately.

The cause of poor IAQ is unlikely to be a single issue and may be multifaceted in nature. As diagnosing and managing problems can be costly and time-consuming, it is best to use adequate planning and design, where possible, to avoid them in the first place.

MORE INFORMATION

Additional information can be found in the following resources. Please check your local authorities for specific legislation, codes and guidelines, as they can vary between states and territories.

Australian Building Codes Board (2016) National construction code. Canberra: Australian Building Codes Board

Australian Building Codes Board (2018) Indoor air quality. 2nd ed. Canberra: Australian Building Codes Board

Department of Health and Ageing (2002) Healthy homes: A guide to indoor air quality in the home for buyers, builders and renovators. Canberra: Commonwealth of Australia

Department of Health and Ageing (2007) The health effects of unflued gas heater use in Australia. Canberra: Commonwealth of Australia

Department of the Environment and Heritage (2004) Unflued gas appliances and air quality in Australian Homes. Technical report No. 9. Canberra: Commonwealth of Australia

International Standard ISO 16814:2008 Building environment design – Indoor air quality – Methods of expressing the quality of indoor air for human occupancy